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GUIDELINES FOR PERFORMANCE OF NEW ZEALAND MARKINGS

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1. Introduction

The visibility of roadmarkings is dependent on the visual abilities of drivers, the reflective properties of the markings themselves and the reflective properties of the adjacent road. These reflective properties are in turn influenced by lighting conditions, and weather conditions such as dry weather, falling rain or wet after rain.

To assist safe driving in all conditions, roading authorities require quantifiable performance levels for markings, for each weather and lighting condition, and suitable methods of test. Identifying the gap between current and required performance would enable roading authorities to assess the impact of adopting the performance levels within their specifications.

There has been a substantial international effort in developing markings performance levels, test methods, and improved products.

Four previous projects have been completed as part of the effort to adapt this international work for New Zealand application.

Transfund Project No. 65 “Minimum Reflective Level” established a minimum reflective value for markings in New Zealand for dry night-time visibility. A further Transfund Project (0406) developed the test methods for measuring reflectivity in dry night-time conditions to a contract enforcement level.

Two further completed projects have examined the wider issue of visibility. These projects were “Minimum Performance Levels of Delineation” and “Visibility of Pavement Markings When Wet”. The first of these two projects identified visibility models which could be used to assess the visibility of roadmarkings, using as input measured reflectivity of the markings and road surface. These models calculate the required preview time or visibility distance. These calculated levels could then be compared to levels recognised internationally as supportive of safe and comfortable driving, usually between 2-5 seconds ahead depending on the extent of other delineation devices. The findings of this project modify the results of Transfund Project No. 65 and show that minimum values for day and night-time conditions need to increase on busier roads if a wider range of drivers, especially including the older age group, are to be adequately catered for. Using the visibility models it is possible to identify a range of reflectivity levels for different road types so that drivers are provided with a consistent level of visibility.

The second project “Visibility of Markings When Wet” established that there are now test methods available which can be used to quantify marking performance when wet and in falling rain. Measurements of a small sample of New Zealand markings using these methods, coupled with visibility modelling indicated a reasonable level of wet visibility for conventional paints over chipseal but also indicated that thermoplastic markings, previously thought of as high performance markings, may, on asphalt, have poor visibility when wet. Informal drive-over tests in the Wellington region support these modelled results and also show that markings with good dry night time visibility may actually appear discoloured in day-time or be barely visible in wet conditions.

Day-time visibility of marking has usually not been a problem as markings were repainted frequently. However now that longer-life markings are used, they can be in place for several years, and accumulate dirt and tyre black so as to be less visible in day-time even though night-time visibility may be good.

Until several years ago, reflectivity of markings was specified in most countries (if at all) by a number of ad hoc test methods.

European Standard EN 1436 is the first international effort to establish consistent performance measures for markings and for a range of driving conditions. It specifies performance classifications (usually four for each condition) rather than a single performance level and envisages that a roading authority will select particular criteria relevant to their use.

These include:

- Reflectivity in diffuse lighting (daylight, street lighting) (Qd)
- Reflectivity in dry night-time (R)
- Reflectivity when the road is wet (R W)
- Reflectivity in rain conditions (R R)

Appropriate test methods for measuring performance of the marking under each reflectivity condition are also set out. Criteria for the skid resistance of markings as measured by the British Pendulum Tester are also included in EN 1436.

The performance requirements of EN 1436 would be useful in the performance specified environment such as is being increasingly operated by Transit New Zealand and local New Zealand authorities. However, there are several difficulties. With the exception of reflectivity in dry conditions these difficulties are:

- The test methods have had no or little previous use in New Zealand
- Current performance of the range of existing markings is not known.

There is a need to also take a perspective even wider than that taken by EN 1436 to take account of specialised markings which function other than by visual means. Audio tactile markings rely on noise and vibration for some of their effectiveness. At present performance of tactile markings is only controlled by specifying dimensions for the new marking. These dimensions have been identified from the materials available rather than by a study of requirements and no end-of-life minimum dimensions are specified. Drive-over tests in an instrumented vehicle supplemented by modelling can readily establish their effect on noise and vibration. For these markings performance criteria needs to be established.

The issues resolved by this project included:

- An increased use of long-life markings is resulting in situations where markings are becoming discoloured by accumulated dirt and tyre black. This can result in poor day-time visibility, even though night-time visibility is still excellent (day-time and night-time visibility are affected by different physical processes). Methods to define day-time visibility are required.
- Many markings on busy roads and urban streets have very poor visibility in the wet. Even some long-life markings, such as thermoplastic, which give improved safety through slower deterioration rates, have poor wet visibility. There are products that offer improved visibility in the wet but they will be more expensive. Roading authorities need established test methods and performance criteria so as to ensure cost effective provision of road safety.
- Audio tactile markings are at present specified only by their dimensions at the time of installation, not by their performance.

- Most roading authorities are progressing to a more performance-orientated environment. Performance levels for markings both visual and audio tactile type and for the different weather conditions are needed for this performance-specified environment.

This project trials the test methods of EN 1436 in the New Zealand setting; establishes the performance of current materials and of New Zealand road surfaces. The project also includes consideration of materials not in EN 1436, such as profiled markings. The project makes use of tools such as visibility models to establish needed levels of reflectivity for a range of conditions.

2. Aims and objectives

- To establish that available test methods (as outlined in EN 1436) for assessing the reflectivity of markings in wet conditions and under diffuse lighting are appropriate for New Zealand
- To determine current levels of performance of a range of markings used in New Zealand across various conditions of the adjacent road surface, including in the wet, in rain at night-time, and under diffuse lighting.
- To establish reflective performance criteria for markings when wet, in the rain at night-time
- To establish reflective performance criteria for roadmarkings in diffuse lighting (day-light and street-light) conditions
- To establish noise/vibration criteria for audio tactile markings on New Zealand roads

3. Methodology

3.1. Overview

Reflectometers, specifically suited to measuring retroreflectivity in the rain, and reflectivity under diffuse lighting were used to first trial the EN1436 test methods, then used to establish current performance of 'typical' and 'best' New Zealand markings and the reflective properties of the adjacent surface. Measured values were compared with performance levels set out in EN1436.

Modelling of the visibility of markings used parameters of New Zealand roads, such as marking position type and size, vehicle type and street lighting, to identify minimum reflectivity levels that would provide required visibility levels, expressed as seeing distance ahead or preview time recognised internationally as desirable for safe and comfortable driving. Comparison of these calculated levels with current levels identifies the extent of gaps between New Zealand markings and best practice.

Performance levels for New Zealand markings were then identified.

Concurrently, acoustic properties of audio tactile lines were identified and performance criteria established.

The specific tasks undertaken through the project included:

1. A trial of the test methods of EN1436 on a small sample of New Zealand markings to ensure that the tests are practical for New Zealand road surfaces, and the generated results are consistent.
2. Establishing the current performance of typical New Zealand markings by measuring the retroreflectivity in wet and in rain, and under diffuse lighting. The adjacent road surface was also measured.
3. Establishing the extent of improvement available from 'best' available products by undertaking a parametric study of the parameters shown in Table 1. (Not all of the 160 parameter combinations will be measured.)

Table 1 Parameters for study

Road Surface	Marking Type	Conditions	
		Retroreflectivity	Diffuse reflectivity
Large chipseal	Paint unbeaded	Dry	Dry
Small chipseal	Paint Bead Standard Beads	Wet	Wet
Asphalt	Paint Visibeads	Rain	
Open graded porous asphalt (OGPA)	Thermoplastic Standard Beads Thermoplastic Visibeads Profiled Markings – Large (vibraline) – Medium (rainline) – Small "Plastiroute"		

4. Using the measurements from Task 2 as input into a visibility model, such as 'Visibility', and model some characteristic situations, determining the visibility distance and preview time,

and comparing these with recommended practice in other countries, i.e. a preview time of at least two seconds if RRPM's or EPM's are used.

5. Refining an available test which will measure the in-car effects of noise and vibration from profiled markings.
6. Measuring a sample of profiled markings both new and worn. Analysis of these measurements and identifying suitable performance measures and levels that can be proposed for profiled markings.
7. Preparation of a report which identifies performance levels for the visual performance levels of New Zealand markings in dry and wet conditions at night-time and in daytime. The report should address marking types as described in the Manual of Traffic Signs and Markings and RTS for rural marking.

4. What does delineation provide to the driving task?

Driving is a self-paced task. Drivers adopt a speed broadly within the legal speed limit at which they can manage all the required tasks. When driving is easy they will add extra tasks so that they keep to a similar level of risk, by making the driving task more difficult, by, for example, following closely. When the driving conditions change rapidly, the driver must discard the additional tasks and it is a measure of their skill that they discard both the appropriate additional tasks and that they do this quickly. There may be a short period where the driver is exceeding the level of risk they have set themselves.

Delineation has two main functions:

- To help show the route ahead; and
- To partition the carriageway.

The first function is particularly useful on rural roads at night-time. Here, the delineation can provide long range (3-10 seconds) preview of the route ahead which, research shows, is necessary for comfortable driving, and can also provide the short range (1-3 seconds) preview needed for placing the vehicle correctly on the road and in the appropriate lane.

The second function of delineation is important on major rural roads and particularly important in urban environments. In urban settings, street lights usually provide the long-range information and it is definition of the correct lane and the short range information on placement that is important. Within New Zealand there is a mixed delineation system. Edge Marker Posts (EMPs) are providing the long range delineation, and ‘painted’ pavement markings provide the shorter range with Reflectorised Raised Pavement Markers (RRPMs) providing the visible range in between.

Delineation is not needed for driving to be possible. A single car on either a rural road or urban street can usually be easily driven at or beyond the legal speed limit when neither delineation nor signs are present. The “Do Minimum” level of service would be to provide no delineation or signs, as drivers could presumably adjust their behaviour and still be able to drive in all conditions although risk of crashes and driving strain may greatly increase.

Increasing the service provided by delineation will make the task easier, especially as traffic volumes increase.

Two scenarios, one of rural driving, the other of urban driving, help to illustrate the benefits of providing delineation above the ‘Do Minimum’ option.

4.1. Rural driving

Even at night-time there is usually sufficient definition of the roadway from the surrounding surface, vegetation etc. for a single vehicle to be driven at or above the legal speed limit. Driving is still possible, even on narrow and winding roads, but usually a reduction in speed is necessary.

As traffic increases, driving becomes more difficult for two reasons. Firstly, headlights need to be dipped for oncoming vehicles. This usually reduces effective forward illuminations to about 70-80 metres, which is about three seconds preview at 100km/h. In addition, glare from the oncoming vehicles’ lights makes it more difficult to pick the clear path between the road edge and the oncoming vehicle. By slowing, the driver can compensate for the reduced visibility, although the evidence is that drivers do not slow sufficiently so as to be driving at the same level of risk. Additional other traffic also offers some compensating effects. Traffic ahead helps to define the route ahead and lights from a vehicle in front greatly increase the long distance view of the following car. However the net effect of high volumes of other traffic is to make driving more difficult.

At low traffic volumes, other vehicles cause periodic interruptions in an otherwise steady speed. At high volumes these slowing periods should eventually overlap resulting in a general reduction in speed. The extent of speed reduction that occurs if no delineation was provided has not been assessed experimentally as roads with suitably high volumes, say 20,000 vehicles per day, without any delineation or signs do not exist (other than at reseal time).

Therefore as traffic volume increases providing the “Do Minimum” (no delineation) option results in:

- Increased travel times from slower driving as a result of reduced visibility;
- Increased VOC (vehicle operating costs) from acceleration/deceleration;
- Increased crashes from reduced visibility not adequately compensated for by speed reductions;
- Increased driver fatigue from driving at higher levels of risk;
- Decreased driver comfort and decreased driver satisfaction.

Providing delineation should have the inverse benefits of the above effects.

4.2. Urban driving

The second scenario is of urban driving. Here distance visibility is a much lesser factor. Delineation marks the lanes, especially at intersections for the optimum turning manoeuvre, and provides the short range visibility information needed for correct vehicle placement. A single car could easily travel at the legal speed, and execute any turning manoeuvre without interruption.

However for the example of an urban arterial there would normally be four lanes, flush medians, possibly six lanes at intersections with markings and signs, so the “Do Minimum” of no markings or signs is likely to cause:

- Reduced capacity of the road as drivers may not regularly form up into multiple lanes;
- Slower travel resulting from less certainty as to lane width;
- Increased travel times from blocking of traffic flows resulting from vehicles being in the wrong place, e.g. the wrong part of an intersection to execute a turn;
- Increased crashes from unexpected manoeuvres or uncertainty in position.

As was stated for the rural situation, providing effective delineation on urban roads will have the inverse benefits of the above effects.

5. Measurement instruments and test methods

Measurements of night-time retroreflectivity were measured with a MX30 brand retroreflectometer. This instrument uses a thirty metre geometry. That is, the dimensions of the instrument with respect to the angle at which light is shone out from the instrument onto the marking and which the reflected light is received back at the instrument simulates a car driver looking at a marking thirty metres ahead. Figure 1 shows the instrument.

Figure 1 MX30 Retroreflectometer

The MX30 instrument has an external beam. That is, the light (of a known wavelength) shines out of the instrument housing and onto the roadway away from the instrument. Then the light is reflected off the marking back to the instrument. Other instruments are covered beam instruments which follow similar principles but the housing is designed such that it covers the section of roadway to be measured so as to exclude external light from entering the instrument.

The external beam instruments are useful for the measurement of the wet condition. Here the road is wetted, one minute allowed for the water to drain and then the reflectivity of the still wet marking is measured. With an external beam instrument it is easier to keep the instrument safely clear of the water, to avoid damage to the measurement device. The external beam instrument is essential for measuring retroreflectivity in the falling rain condition. Here a spray of water is directed over the subject section of road during measurement and this is only practicably possible with an open beam retroreflectometer.

In this project, diffuse retroreflectivity was measured with the QD30 instrument from DELTA.

Figure 2 shows the instrument. The hemisphere is used to create a diffuse lighting environment which is then reflected off the road at a low angle equivalent to the 30 degree receiver geometry to be recorded by the instrument. This instrument is a closed beam reflectometer. It was used to assess the markings in the dry condition. The QD30 instrument is not suitable for measuring diffuse reflectance (illuminance) readings in wet conditions.

Figure 2 QD30 instrument

6. Current performance of New Zealand road markings

6.1. Retroreflectivity: Dry conditions

The MX30 was used to measure the retroreflectivity of a range of marking types in wet and rain conditions using the methods specified in EN1436. The following graphs show the measured retroreflectivity on four surface types of large chip, (grades 2, 3 and 4), small chip (grades 5 and 6) asphalt, and open graded porous asphalt (OGPA). Performance is compared with EN1436 classes for dry conditions, R1 to R5.

In the following figures, (Figure 3 to Figure 6,) the annotations ‘good’, ‘average’ and ‘poor’ refer to the visual appearance of the line in day-time and as such is primarily based on the amount of wear (or intact paint) shown by the marking. A subjective assessment of the condition of the line and implication of the amount of trafficking was needed so as to select samples for measurement. This qualitative assessment would match that exercised in general practice where the need for remarking is often determined by a similar day-time qualitative assessment of marking condition.

Figure 3 to Figure 6 are primarily useful in showing the retroreflectivity of markings in the dry condition, and how the New Zealand markings compare with the net performance levels of EN 1436. Figure 3 to Figure 6 also show the wet condition values relative to the dry condition values but Figure 7 to Figure 10 show the wet condition in more detail and in relation to the EN1436 wet condition performance levels.

The values shown in the figures are the averages for each line type, condition and surface type measured. For the beaded and unbeaded painted markings, each sample is usually of three or four specimens. For the thermoplastics, Vibraline, and Rainline markings, which are specialised markings, often only one and sometimes two samples of that type were available for measurement.

Figure 3 Markings on large chip: Retroreflectivity, compared to the EN1436 'dry condition' requirement

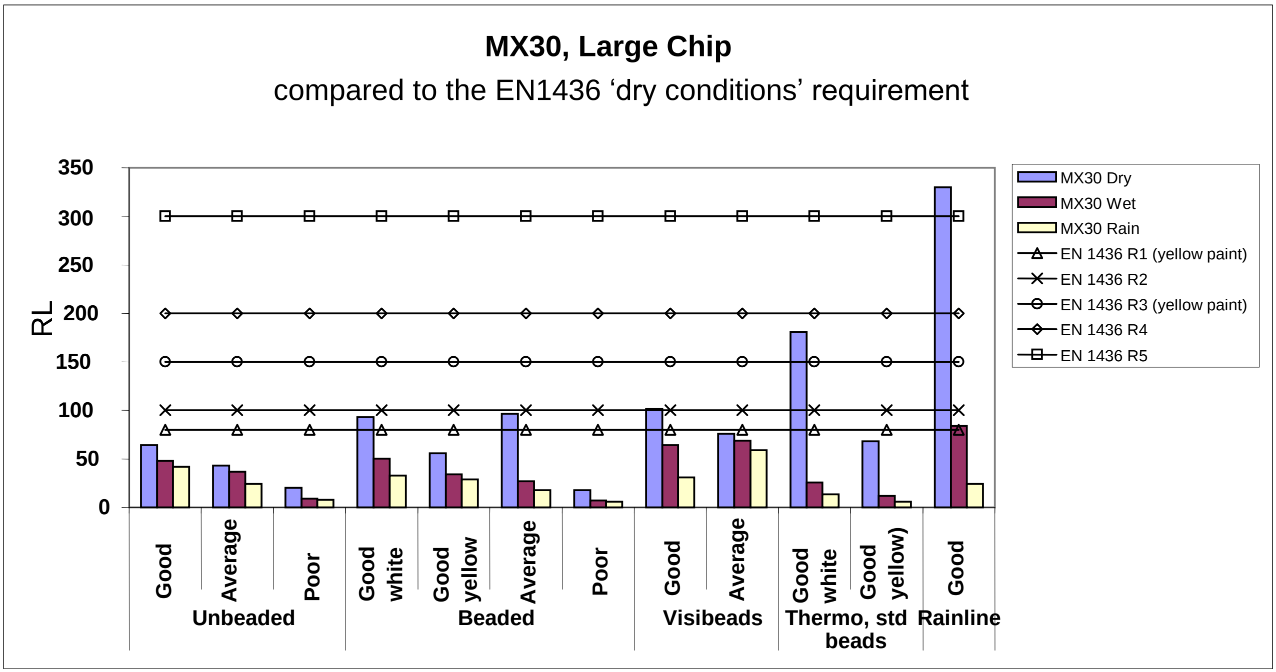


Figure 4 Markings on small chip: Retroreflectivity, compared to the EN1436 'dry condition' requirement

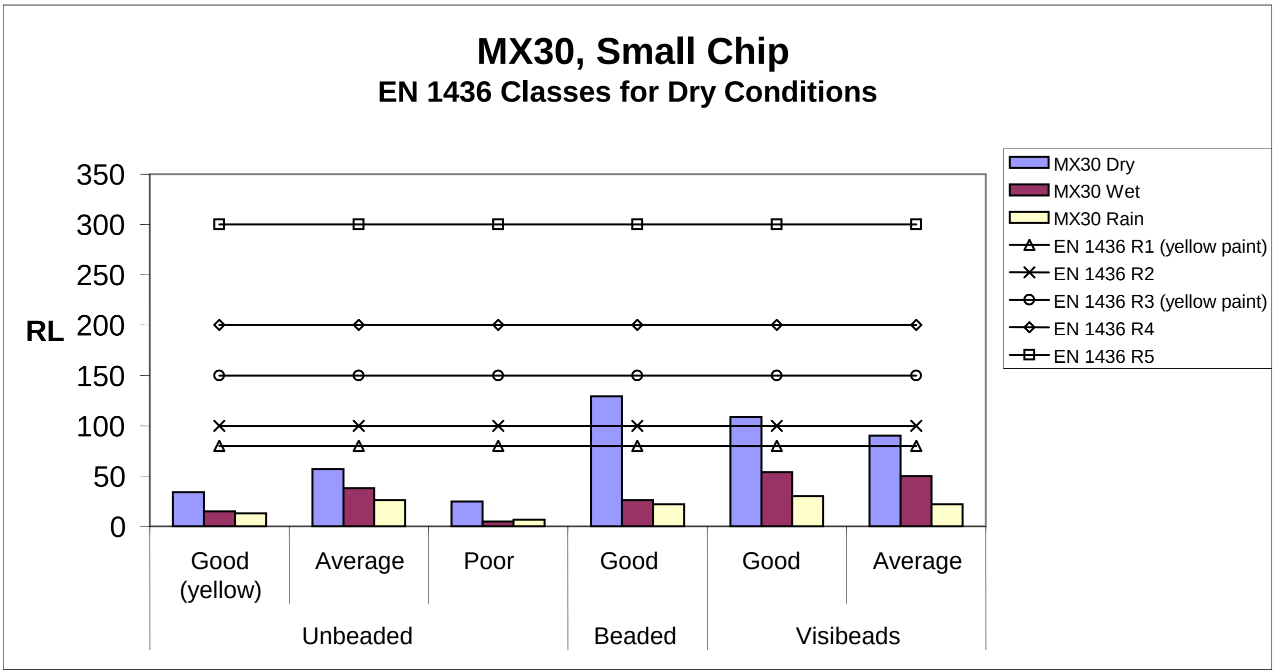


Figure 5 Markings on OGPA: Retroreflectivity, compared to the EN1436 'dry condition' requirement

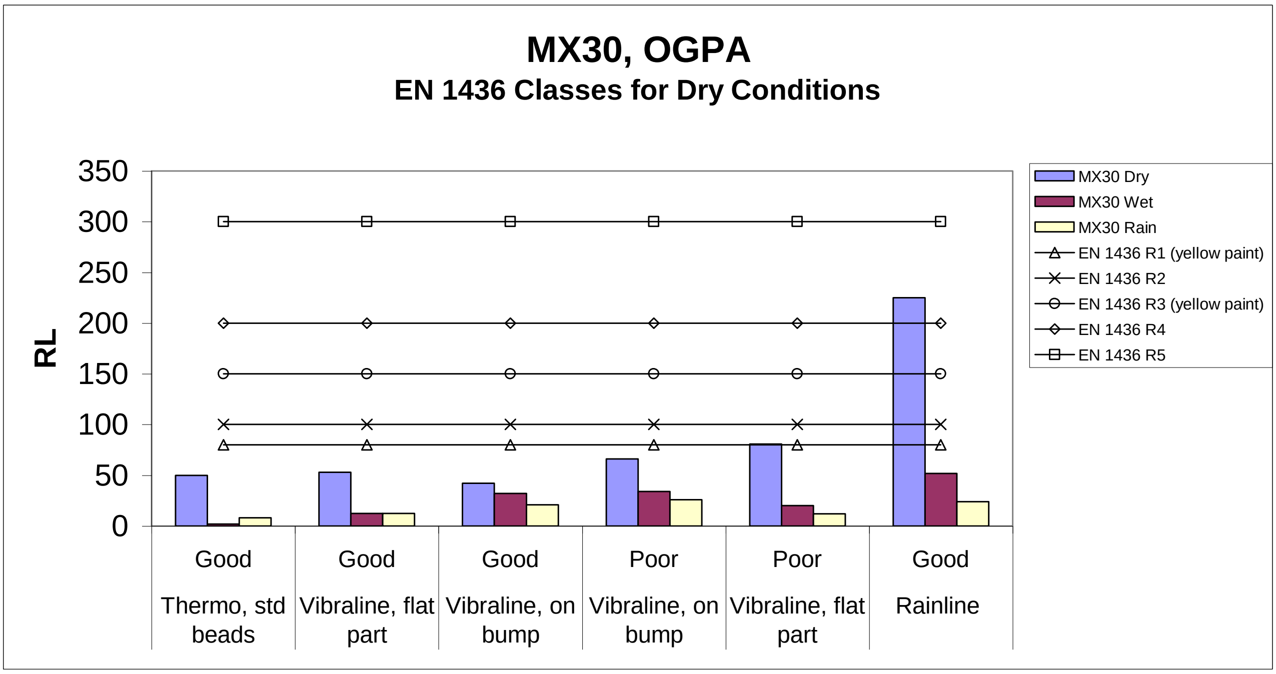


Figure 6 Markings on asphalt: Retroreflectivity, compared to the EN1436 'dry condition' requirement

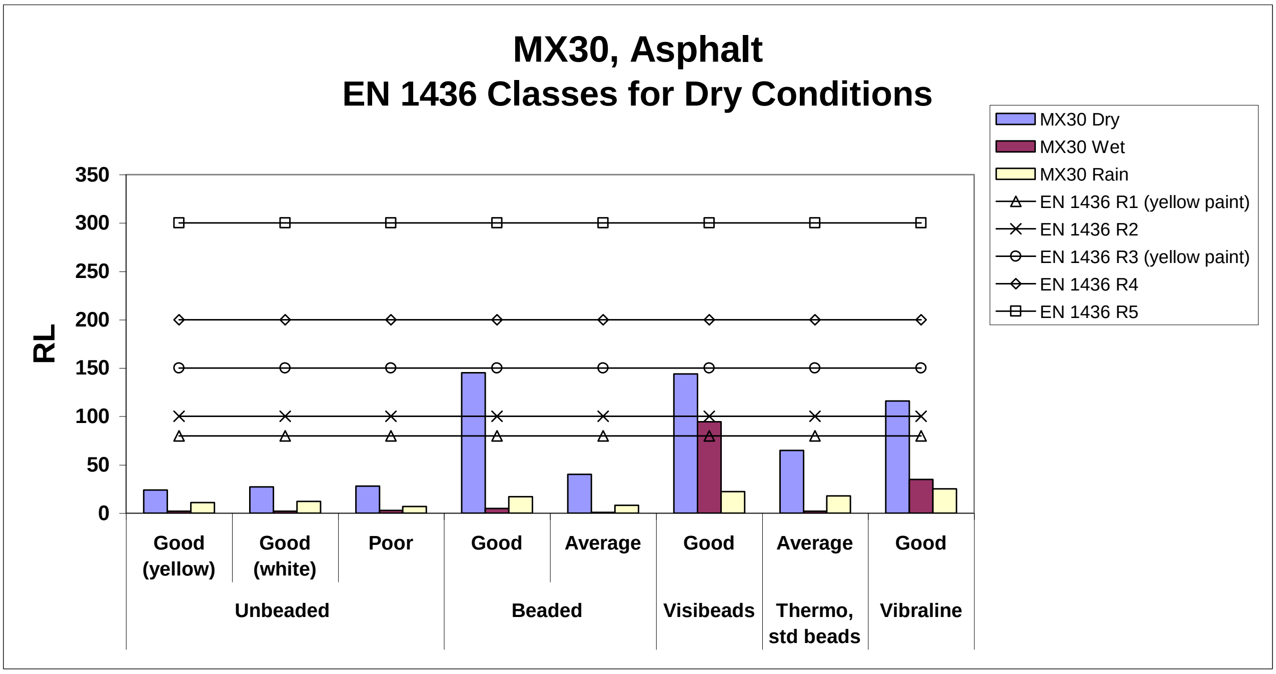


Figure 3 to Figure 6 show that, aside from specialised markings, in the dry condition most New Zealand markings are equal to, or less than, the first EN1436 classification for white markings of R2. Figure 3 to Figure 6 show that road texture has a significant effect on the retroreflectivity of common painted markings. The texture of large chips in a chipseal enables even unbeaded markings to achieve moderate levels of retroreflectivity. As the chips forming the chipseal decrease in size, the retroreflectivity of unbeaded lines also decreases. With asphaltic surfaces, ordinary unbeaded painted markings have a very low level of retroreflectivity.

The beaded lines are, as expected, much less dependent on the road surface type to provide retroreflectivity, with all samples achieving good levels of about R2. This is even more pronounced for the high-build profiled line types of Vibraline and Rainline.

Figure 3 to Figure 6 also show the retroreflectivity results in the wet condition. These are often much lower than for the dry condition. The effect of texture on retroreflectivity for the common marking paints is even more pronounced than was noted under dry conditions, with the markings on asphalt generating close to a zero reading.

Visibeads are a large bead for increasing the reflectorisation of pavement markings in wet conditions. These particular beads counteract the texture-related trend, as shown in Figure 6. The unbeaded lines shown in Figure 3 and Figure 6 are of interest. On the large chip, retroreflectivity values in wet conditions are close to the dry values whereas on asphalt the retroreflectivity value is near zero. This may explain why New Zealand has lagged behind other countries in developing and installing high performance markings. The past has seen a common use of large chips and unbeaded lines which have delivered modest levels of retroreflectivity in both the dry and the wet. Now, however, as more asphalt and OGPA surfaces are used and with higher traffic densities, markings with higher retroreflectivity performance are needed.

6.2. Retroreflectivity : Wet conditions and during rain

The MX30 was used to measure the retroreflectivity of a range of marking types in wet and rain conditions as specified in EN1436. The methods for measurement of wet retroreflectivity and retroreflectivity in the rain followed those set out in EN1436. The following graphs (Figure 7 to Figure 10) show the measured retroreflectivity on four surface types. Performance is compared with EN1436 classes for wet conditions, RW1 to RW33. Retroreflectivity levels for conditions of rain, RR1 to RR3, correspond with the wet classes. That is, RR1 and RW1 are 25 $mcd.m^{-2}.lux^{-1}$, RR2 and RW2 are 35 $mcd.m^{-2}.lux^{-1}$ and RR3 and RW3 are 50 $mcd.m^{-2}.lux^{-1}$.

Figure 7 Markings on large chip: Retroreflectivity, compared to the EN1436 'wet condition' requirement

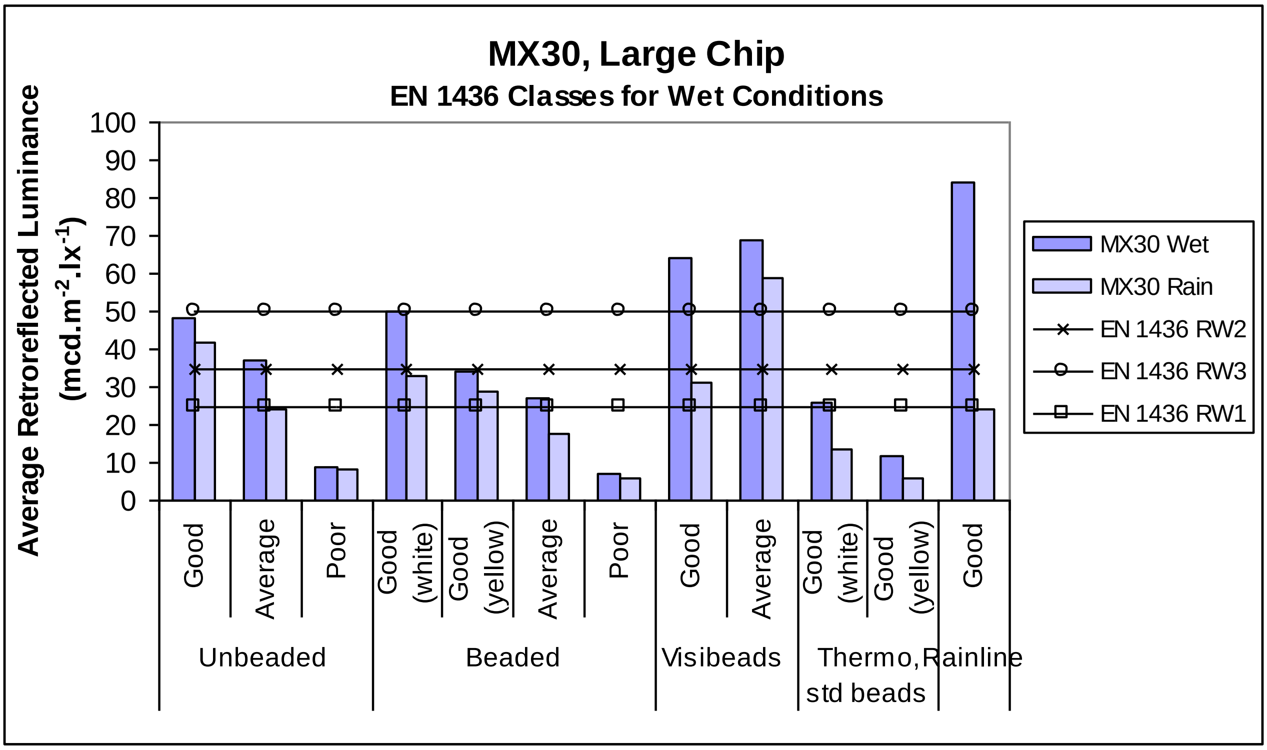


Figure 8 Markings on small chip: Retroreflectivity, compared to the EN1436 'wet condition' requirement

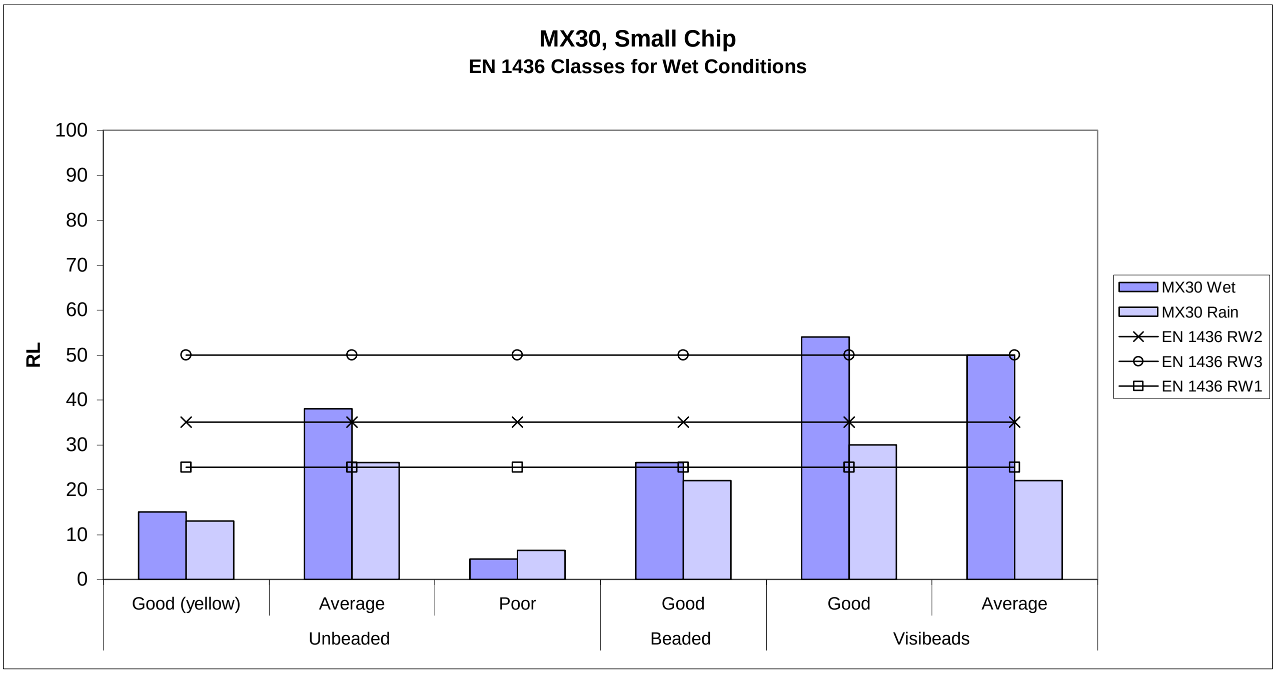


Figure 9 Markings on asphalt: Retroreflectivity, compared to the EN1436 'wet condition' requirement

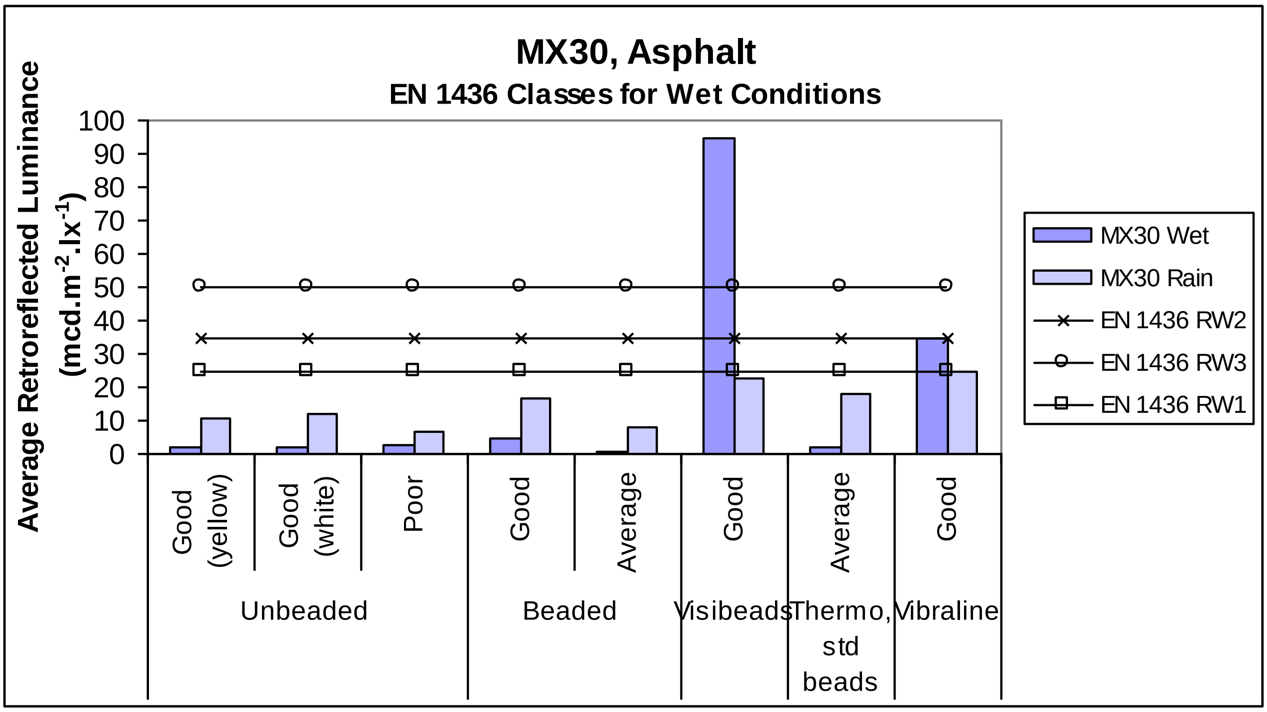


Figure 10 Markings on OGPA: Retroreflectivity, compared to the EN1436 'wet condition' requirement

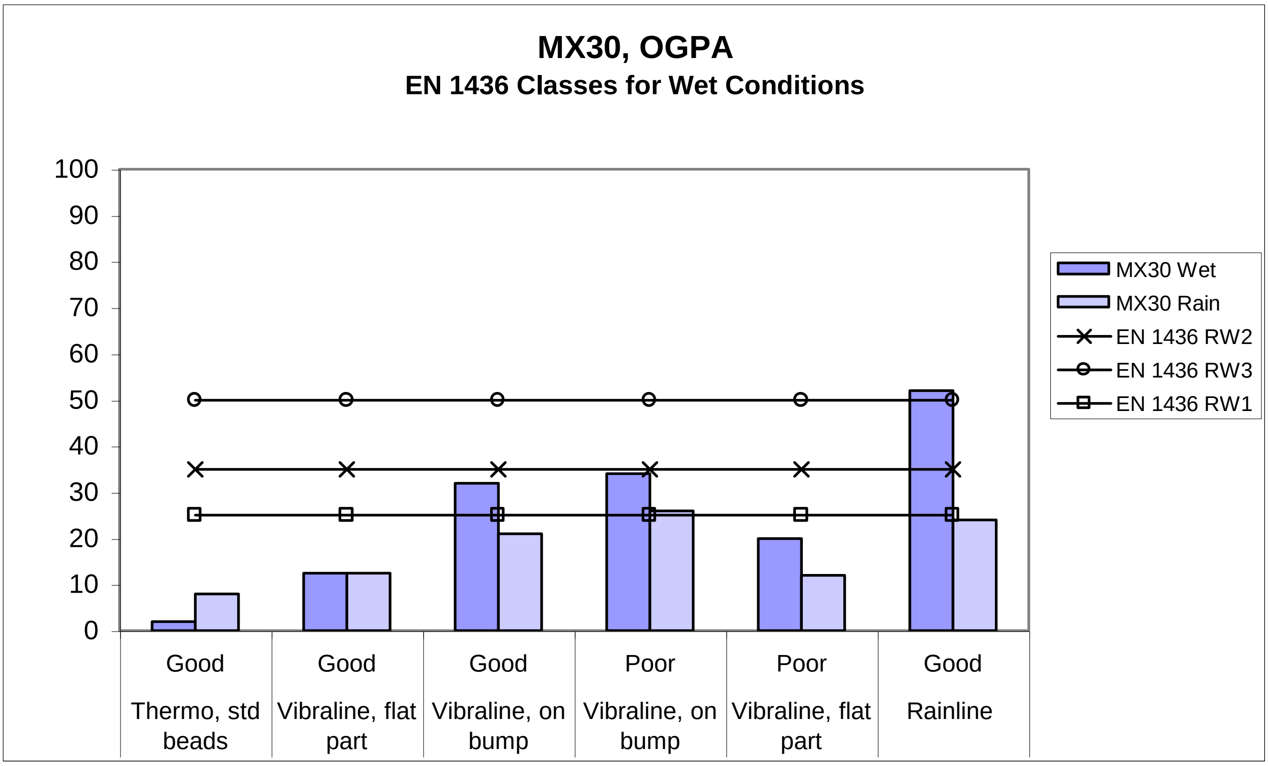
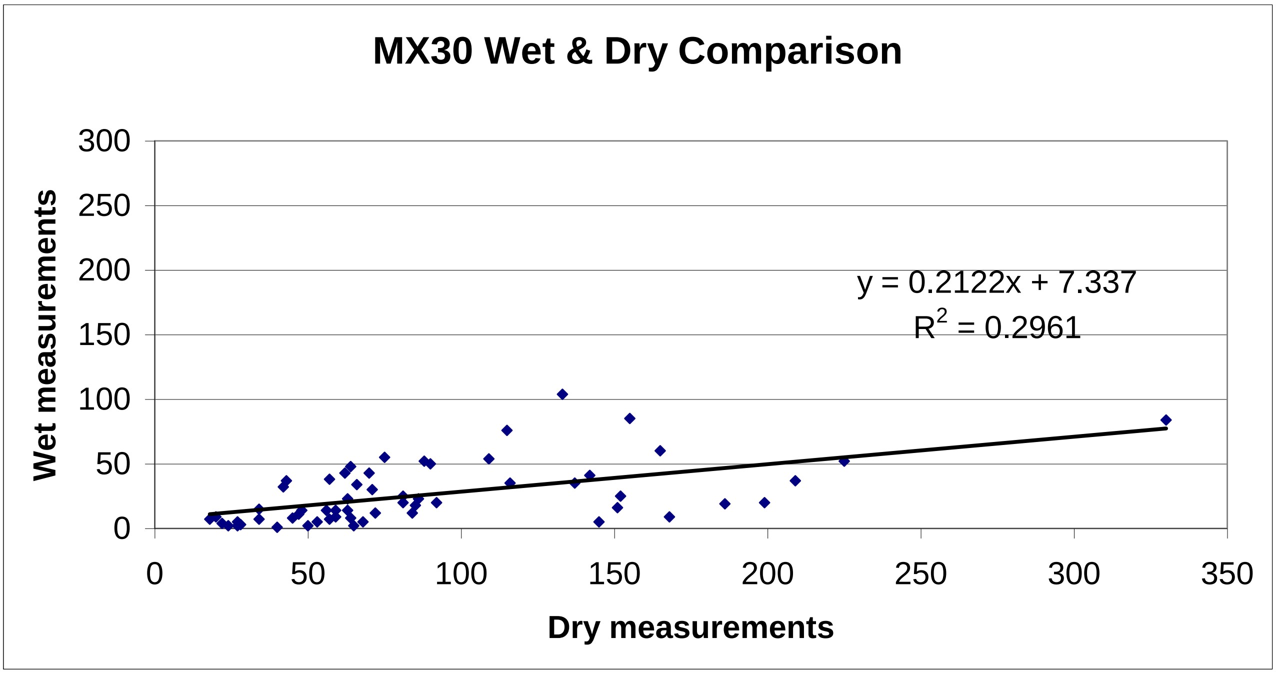


Figure 9 and Figure 10 are of interest. On asphalt surfaces, only the large beads (Visibeads) are excellent in the wet (Vibraline is satisfactory) but conventional markings are very poor. In contrast, markings over the large chip, the conventional markings meet the RW2 and RR1 classification and are only a bit below Visibeads in performance.

Figure 11 presents a plot of the retroreflectivity values obtained in dry conditions versus the retroreflectivity values obtained in wet conditions, for each of the road surface and marking types measured by the MX30. A line of best fit has been approximated. The calculated R^2 value identifies the extent of correlation, where one is perfect correlation and zero is purely random. The R^2 value of 0.2961 indicates poor statistical correlation between wet measurements and dry measurements. Practically, this implies that the dry condition measurement cannot be used as a proxy or to infer the wet condition measurement.

Figure 11 Comparison of retroreflectivity under dry conditions and wet conditions



6.3. Diffuse Lighting: Dry

The diffuse lighting reflectivity was measured with the Delta diffuse reflectometer following the methods of EN1436.

Figure 12 to Figure 15 show Qd results. These are measurements taken using a diffuse open beam reflectometer. EN1436 classes for dry conditions are shown. Measurements were taken on four different road surface types and there is one graph for each type of surface.

Figure 12 Markings on large chip: Diffuse reflectivity, compared to the EN1436 'dry condition' requirement

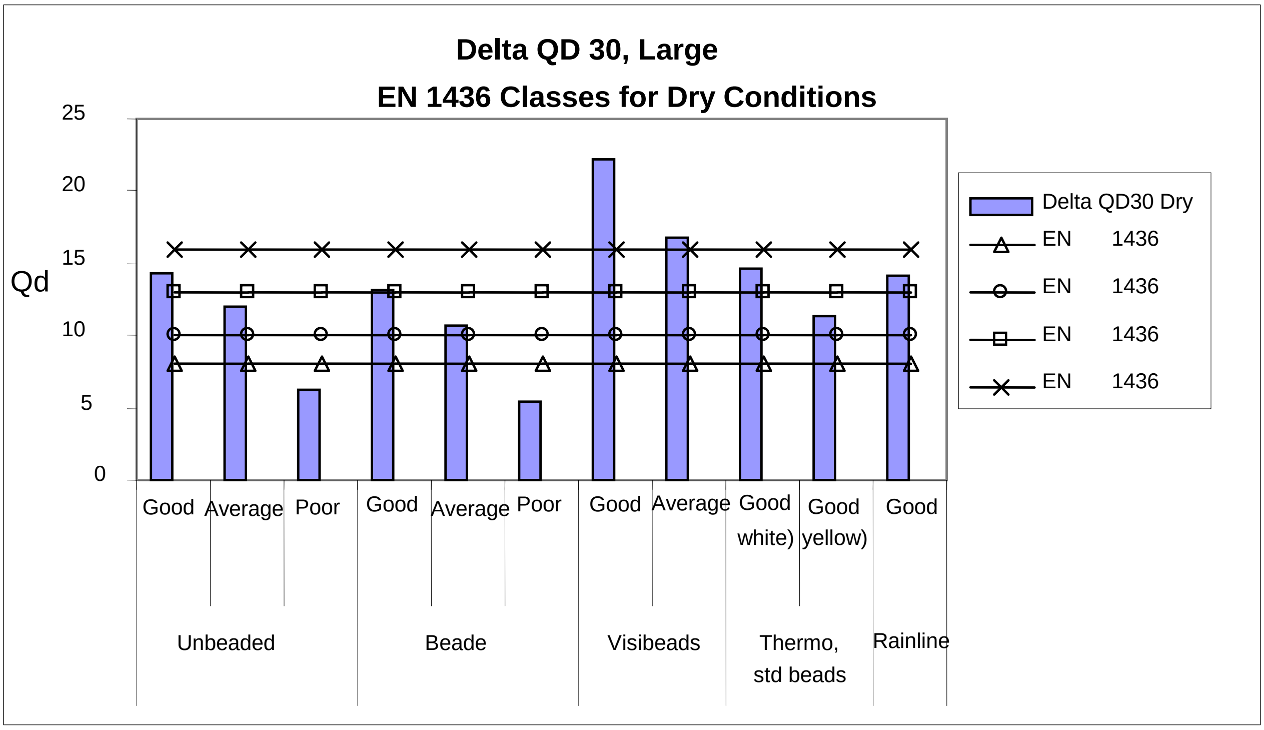


Figure 13 Markings on small chip: Diffuse reflectivity, compared to the EN1436 'dry condition' requirement

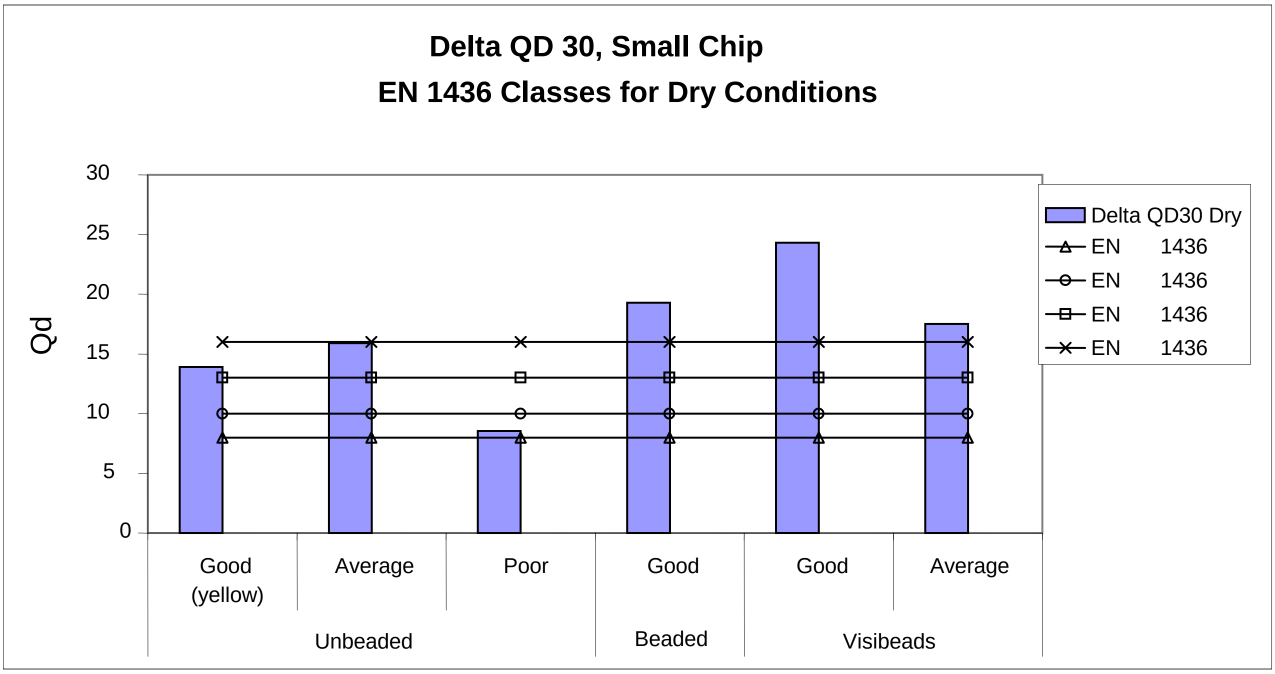


Figure 14 Markings on asphalt: Diffuse reflectivity, compared to the EN1436 'dry condition' requirement

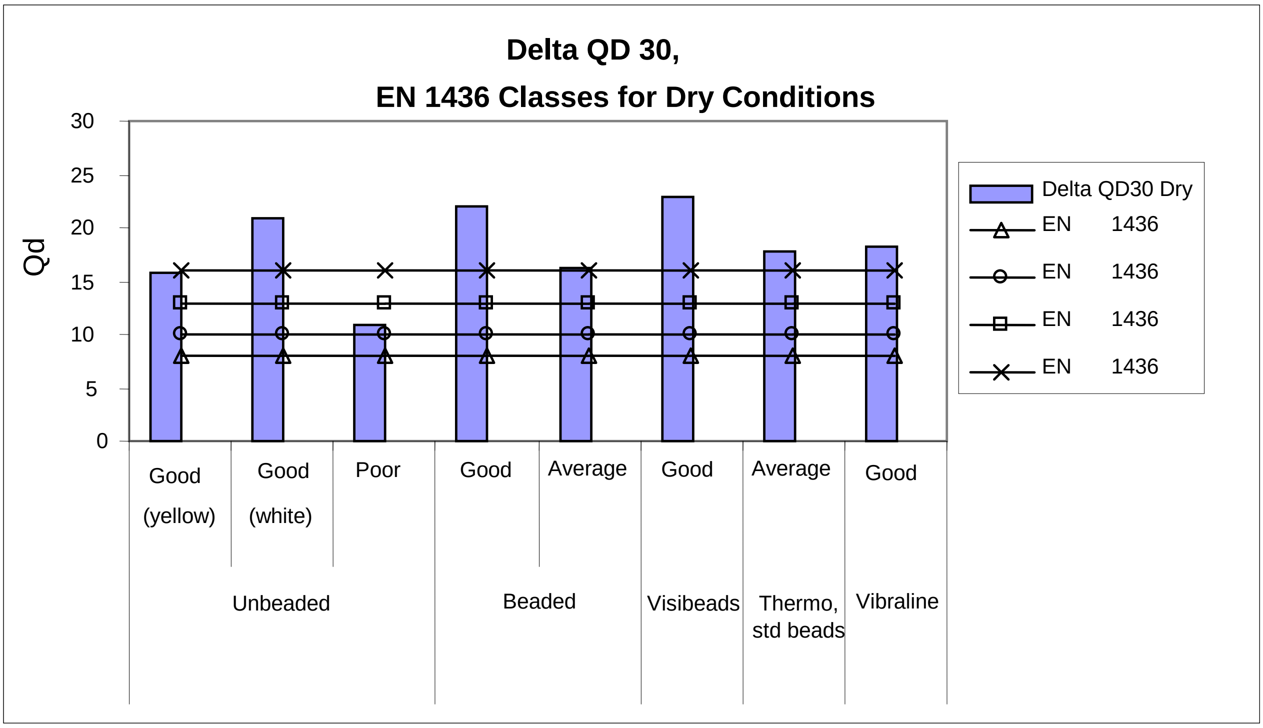


Figure 15 Markings on OGPA: Diffuse reflectivity, compared to the EN1436 'dry condition' requirement

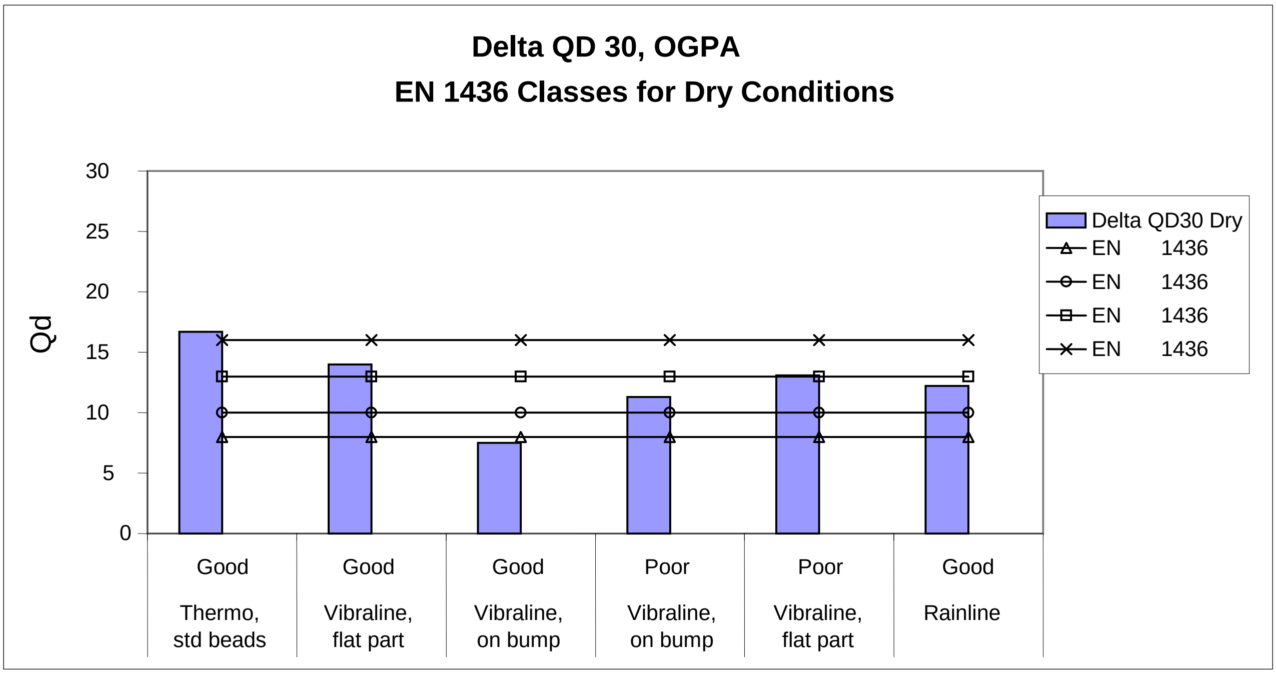


Figure 12 to Figure 15 show that the New Zealand markings generally have good diffuse reflectivity, around the EN1436 classification of Q3 or better.

6.4. Road surfaces

The retroreflectivity (RL) and diffuse reflectivity (Qd) of the road surface are used as inputs into the visibility modelling. These provide information about the background relative to the markings (the contrast ratio). Typical results for the four road surface types used in this study are shown in Table 2. The table shows that retroreflection decreases on all surface types when wet compared with dry conditions.

Table 2 Typical reflectivity levels of New Zealand road surfaces

	QD30 (Diffuse reflectivity)		MX30 (Retroreflectivity)	
Surface Type	Dry		Dry	Wet
Large chipseal	40		9	3
Small chipseal	47		14	3
Asphalt	47		11	1
Open Graded Asphalt (OGPA)	43		12	2

The diffuse reflectivity and retroreflectivity provided by a chipseal road surface are affected by the aggregate used within their construction. Table 3 shows the properties of a sample of aggregates from a range of sources around New Zealand.

Table 3 Diffuse reflectivity and retroreflectivity of New Zealand aggregate types

		Qd30 (Diffuse reflectivity)		**MX30 (Retroreflectivity)**	
Gravels from a range of quarries		Dry		Dry	Wet
Wellington greywacke	Grade 3	47		29	5
Dunedin	Grade 3	60		29	1
Matamata	Grade 3	33		20	5
Nelson	Grade 3	57		35	10
Wellington greywacke	Grade 3	66		35	7
New Plymouth	Grade 4	47		26	5
Taupo	Grade 3	33		37	7
Southland Aparima River	Grade 3	54		29	5
Gore River Terraces	Grade 3	75		36	8
Paki Paki	Grade 3	58		35	5
Pukewawa	Grade 3	36		17	1
Otaika	Grade 3	51		22	5
Brown Greywacke	small	26		32	8

7. Converting reflectivity measurements into assessed visibility

A driver's experience of the visibility of delineation is a function of its size, its position on the road, the illumination provided by daylight, street light or vehicle lights, the driver's vehicle type and the driver's visual capabilities. It is possible to use information on these items to calculate the distance ahead that a driver, in a particular set of circumstances, will easily see delineation. By including speed in the calculation, the available preview time can be determined.

Studies have shown that easy, comfortable driving requires a preview time of five to ten seconds of the general route ahead. Research from Europe has established two seconds as an absolute minimum for preview of the lane immediately in front to allow for appropriate vehicle placement.

7.1. Calculating Preview Times

Calculating preview times from first principles requires knowledge of marking size and position and reflective properties, vehicle type and position, geometry of the road and features such as lane width, illumination whether by daylight, streetlight or vehicle, and drivers' visual capabilities. Computer models have been developed which encompass these features and can be used for calculating preview times. Their development is at a point where they are a useful tool, although they do not yet fully address the driver's visual performance. Examples of such models are CARVE, OCARD, TARVIP (all from USA) and VISIBILITY (from Denmark).

Figure 16, Figure 17 and Figure 18 show the use of one of these models, VISIBILITY, to determine preview times.

Figure 16 Preview times of edgelines typically used in New Zealand (100km/h, headlights at full beam)

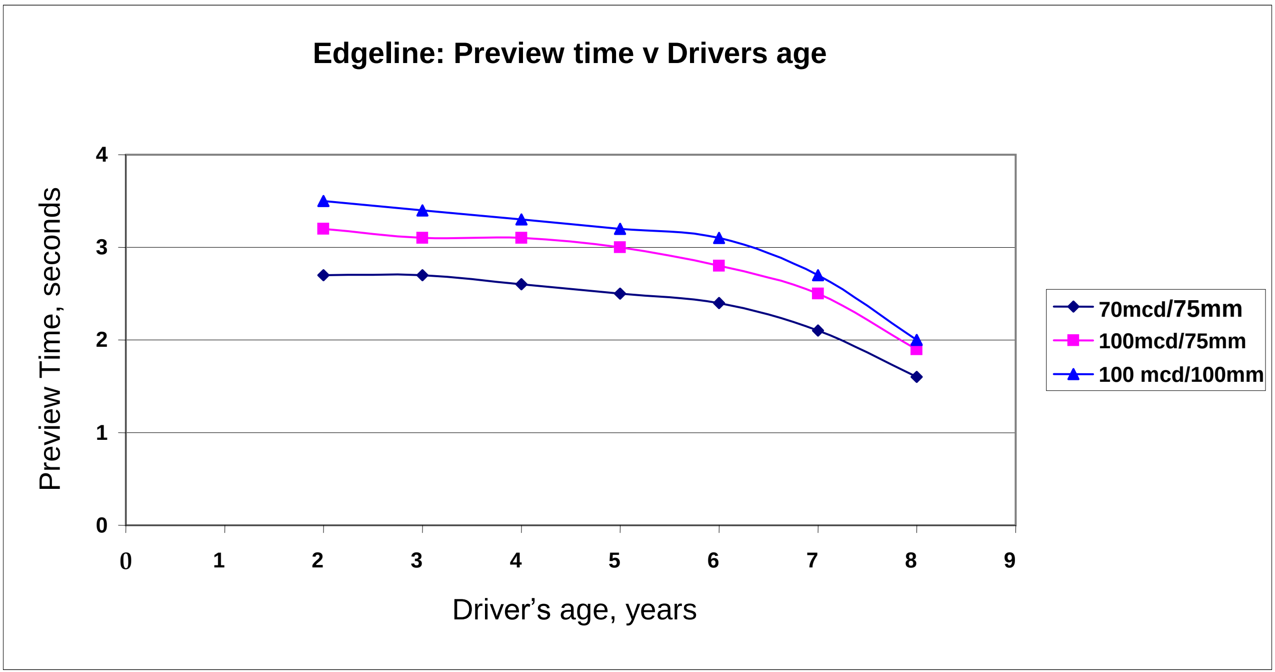


Figure 16 shows how the visibility distance of edgelines is affected by driver age. The line representing an edgeline width of 75mm, seen as the bottom line on the figure, corresponds to the as-new dimensions of most edgelines in New Zealand. The middle line represents beaded edgelines in good condition. The top line illustrates how a wider line (of 100mm) is more visible than a standard line (of 75mm).

Figure 17 Combinations of line width and retroreflective level which provide equivalent levels of visibility for younger drivers (driver of 20 years old)

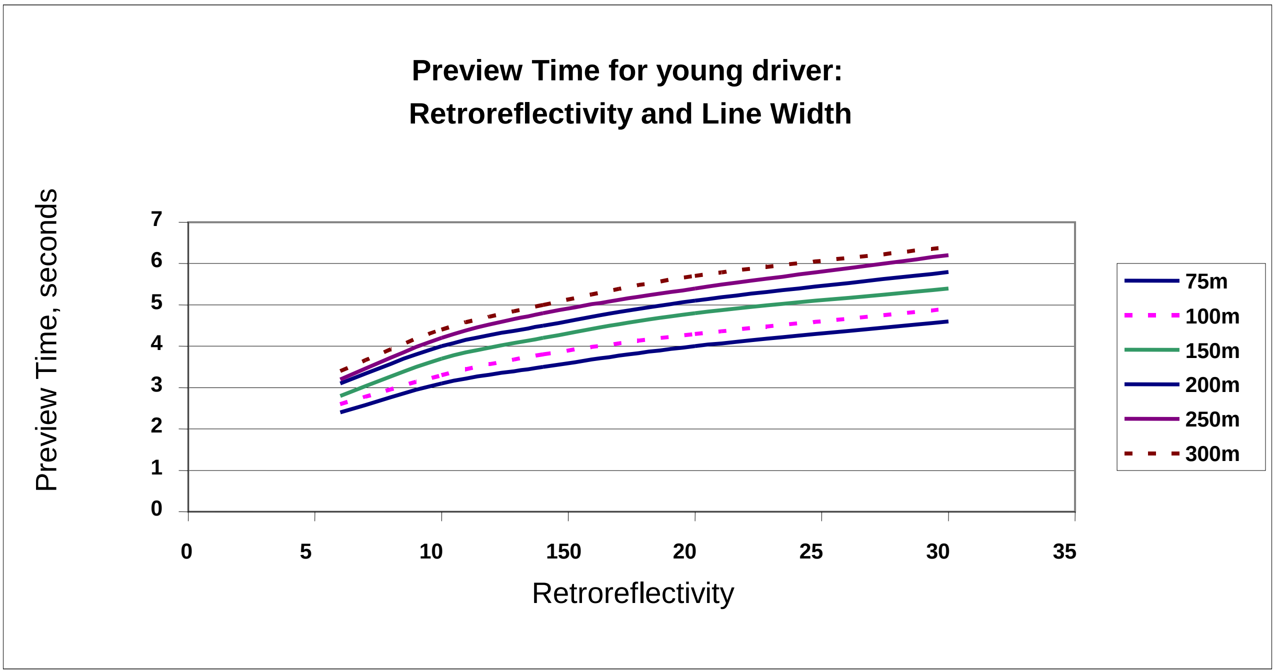


Figure 18 Combinations of line width and retroreflectivity level which provide equivalent levels of visibility for older drivers (driver of 70 years old)

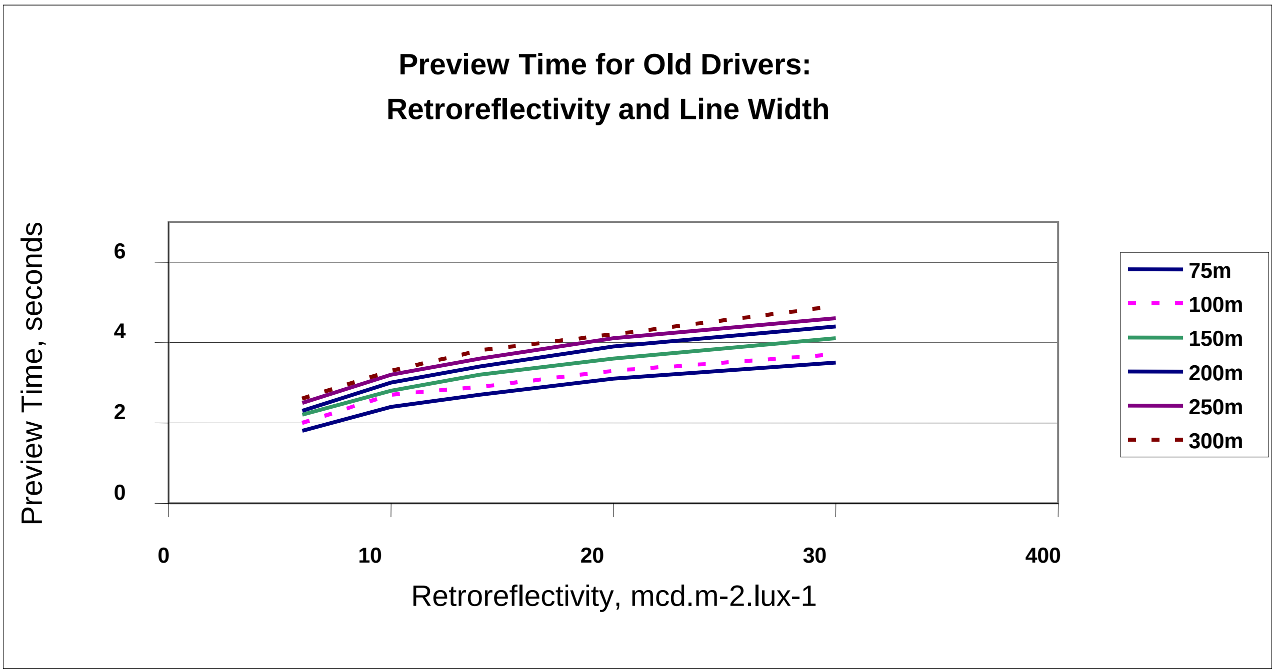


Figure 17 and Figure 18 show how a preview time could be achieved from a range of combinations of line widths and retroreflectivities. Current New Zealand practice requires edgeline delineation in the bottom left-hand of this family of curves, both with respect to width (75 to100mm) and reflectivity (50 to 150 mcd.m^{-2}.lux^{-1}).

8. Setting performance levels

Visibility levels expressed as preview times can be used in setting performance levels for the delineation elements.

The function of road markings is to provide short range delineation. Two seconds is a minimum figure identified by research as adequate for comfortable and safe driving if RRPM and/or edge marker posts are also being used.

The visibility modelling shows that lighting conditions (that is street lights, headlights dipped or on full beam, and light provided by other vehicles) and driver age are two very significant factors in establishing the visibility level. Therefore the *lighting situation* and *proportion of the driving population* to be provided with a level of visibility needs to be defined.

A common sense approach would be to meet the needs of most drivers at the time when they are most likely to need markings. The first hour of winter darkness is a time when many drivers have to drive, either returning from work, or completing travel. Even older drivers who may normally avoid driving in the dark are likely on occasions to be driving at this time. This time period, about 5:00pm to 6:00pm, also coincides with the evening peak traffic volumes.

8.1. Traffic flow will influence the lighting situation

The lighting situation provided for a driver is affected by the number of vehicles sharing the road environment. Thus, traffic flow is an input into visibility models.

It is known that traffic flows are not uniformly spread over time. About 25-30% of daily traffic flow will occur within the hours of winter darkness, being about 5:30pm to 7:30am. Approximately 8% of daily traffic flow will occur in the first hour of winter evening darkness, centred on 6:00pm. As noted above, this is deemed the critical hour for consideration

8.2. Driver age will influence the visibility required

If the design requirements for 70 year old drivers are met, the provided markings will be adequate for almost all of the driving population as well as providing a large improvement for younger drivers. Table 4 illustrates a process to use in assessing the lighting condition and the likelihood of older drivers being present. The process assesses:

- The number of drivers in the busiest hour;
- The likelihood of older drivers (from license statistics);
- The proportion of driving time on dipped beam;
- The number of oncoming cars at any one time.

To assess the last two factors, it was considered that the flows are unlikely to be directionally even, so they have been divided in a 3:2 ratio. Those drivers travelling in the minor direction will therefore face more opposing traffic. The likelihood of platooning of vehicles, given the hourly flow, has also been considered as this will affect the number of oncoming vehicles and therefore visibility. Assessment of the proportion of time that drivers will be on dipped headlights, assumes a 30 second approach time although this will obviously depend on the geometry of the road.

Table 4 Assessed flows in hours of darkness and time driving with headlights on low beam

Vehicles Per Day	Vehicles in first hour of darkness (8% VPD)	Opposing Flows (60:40)		Likelihood of older drivers	Likelihood of platoons of vehicles	% of time per hour requiring low beam
100	8	5	3	×	×	4%
250	20	12	8	×	×	10%
500	40	24	15	Several	Groups of only 2 or 3 vehicles	15%
750	60	36	24	Several	Groups of only 2 or 3 vehicles	20%
1,000	80	50	30	✓	Groups of only 2 or 3 vehicles	30%
2,000	160	96	64	✓	✓ Groups of 5 or more vehicles	35%
5,000	400	240	160	✓✓	✓✓ Groups of 5 or more vehicles	100%

In assessing the required performance level of the marking, it has been assumed that drivers can adjust their behaviour to allow for a lower standard of markings so long as it is infrequent and associated with clearly defined specific events, e.g. oncoming car, dipped lights, slow down a bit.

To support this analysis, a set of graphs were prepared of marking visibility around parameters of whether the subject driver's vehicle's headlights are on full beam or dipped beam.

Figure 19 and Figure 20 show the visibility distance for edgelines under full beam and dipped beam with oncoming vehicles. These figures show the visibility distance on straight roads. An allowance of about 20% extra distance should be made to allow for the required visibility distance on gentle curves.

50 $mcd.m^{-2}.Lux^{-1}$ corresponds to a unbeaded line mid-life. 70 $mcd.m^{-2}.Lux^{-1}$ is the minimum required by Transit New Zealand in its performance specifications. 100 $mcd.m^{-2}.Lux^{-1}$ is equivalent to current conventional beaded lines about mid-life; while 150 $mcd.m^{-2}.Lux^{-1}$ would be equivalent to these beaded lines when near-new.

Figure 19 shows that on full beam at 100 km/h (28 m/sec), then drivers 70 and younger will have two seconds preview time. Table 4 shows that below 250 vehicles per day an older driver would not be expected, and even if they were, they could drive on full beam 90% of the time and could modify their behaviour e.g. slow down for the 10% of the time on dip.

Table 4 shows that for the traffic volumes centred on 500 through to 1,000 vehicles per day, it becomes increasingly certain that a number of older drivers will be present in the first hour of winter darkness. The oncoming vehicles will increasingly be encountered in small platoons of 2 to 3 vehicles, with the number of platoons increasing as traffic volumes rise. Some platoons may form with more vehicles and this would reduce the overall numbers of platoons, but this will be infrequent. The time a driver spends with headlights on dipped beam will range from 15% to 35% of the driving time. Figure 20 shows that the current TNZ P/20 standard of 70 $mcd.m^{-2}.Lux^{-1}$ is sufficient for older drivers on most occasions but will be less than required on the few occasions where four to five cars are approaching together.

For traffic volumes around 2,000 vehicles per hour the assessment in Table 4 shows that a number of older drivers is certain to be present and cars will now be tending to group up into platoons of 4 or 5 cars or more. Figure 20 shows that in these circumstances a 100 mm wide line of 100 $mcd.m^{-2}.Lux^{-1}$ is needed. At traffic volumes of 5,000 vehicles per day, drivers in the first hour of winter darkness will be confronted with a continuous stream of traffic, vehicles will often be clustered at 5 or more and drivers will be almost continuously on dipped beam. Figure 20 shows that an even brighter line is needed. If the EN1436 standards were used this would be the equivalent to the R3 classification of 150 $mcd.m^{-2}.Lux^{-1}$, although in EN1436 this is a classification for yellow lines

Table 5 summarises the retroreflectivity (dry conditions) assessed as being required.

Table 5 Required retroreflectivities

Traffic Volume AADT	<250	250-1,500	1,500 – 5,000	5,000+
Minimum Retroreflectivity Classification	50	70 Current P/20	100 R2	150 Equivalent R3

As is indicated by Figure 18, an equivalent level of visibility could be provided by a wider edgeline 150mm of a lower reflectivity.

Figure 19 Visibility distance under full beam of two current edgeline marking moderate to good and a third very good marking

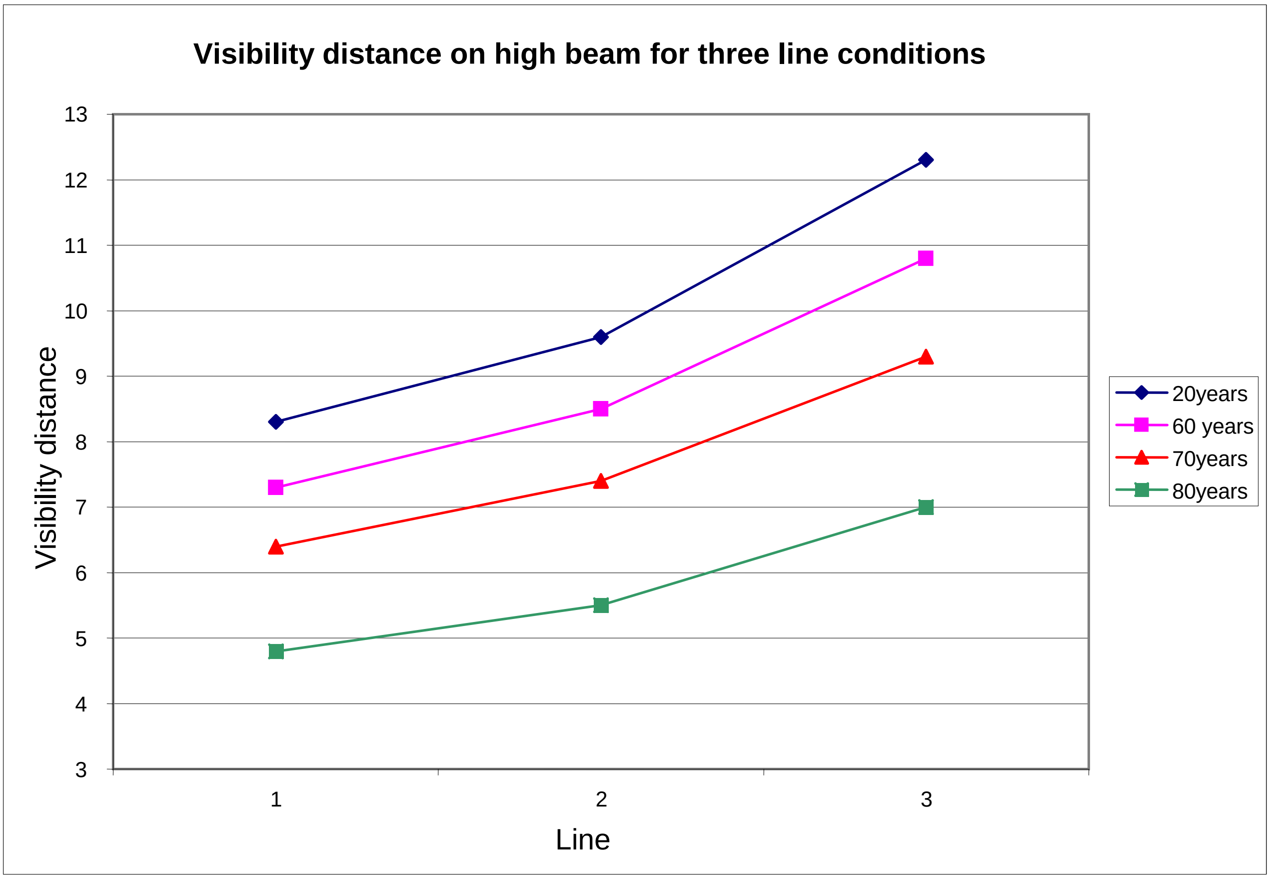
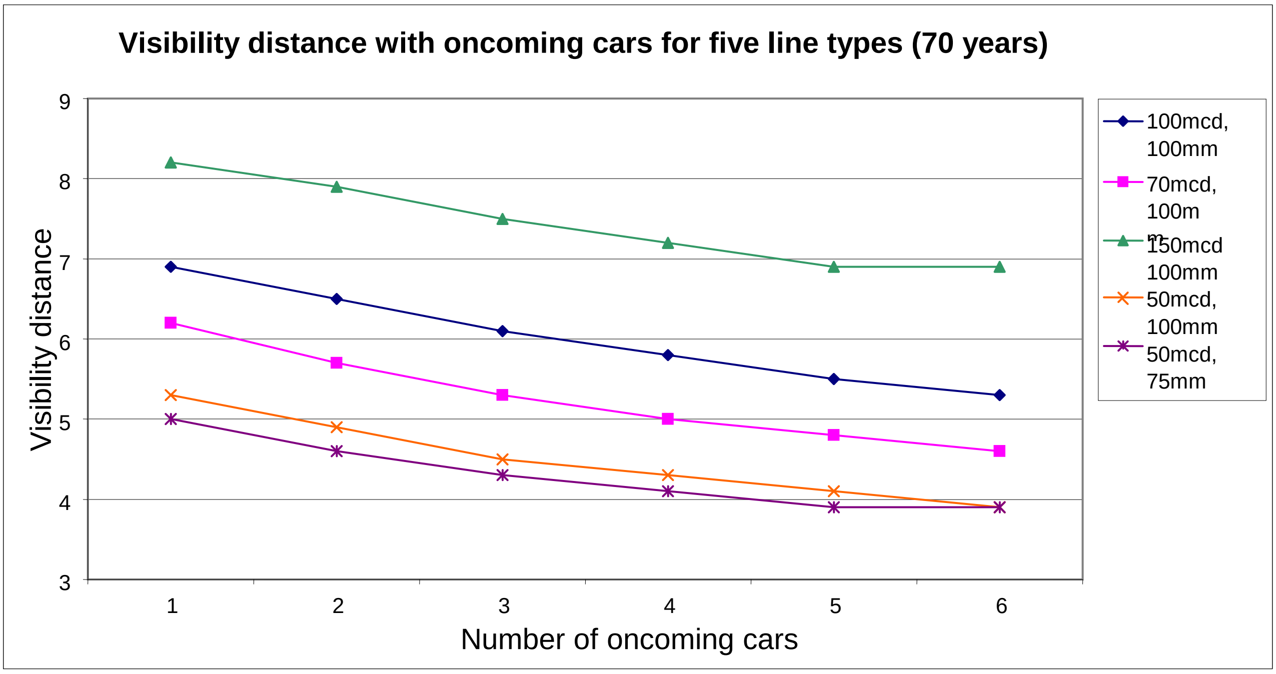


Figure 20 Visibility distance with dipped headlights of four edgelines (poor to good) and Fifth Very Good Marking



Although the required reflectivity of lines differs for each traffic volume, drivers are being provided with a constant level of visibility i.e. 2 seconds minimum.

8.3. Street lighting and twilight

An advantage of the visibility models is that they allow both the diffuse and retroreflectivity to be combined. Under street lighting retroreflectivity can become only a small contributor to total visibility as the lighting level increased. The difference between the two curves "low beam" and "no lights" shows the contribution from retroreflectivity.

Figure 21 shows how the visibility of markings is affected when there is street lighting present, or at dusk. In these conditions Qd dominates and reflection of the headlight is less important. About 15-20 Lux is motorway standard, with most street being about 2-5 Lux. Twilight is 30-100 Lux, and full sunlight about 10,000 Lux.

Figure 21 Effect of lighting level on visibility distance

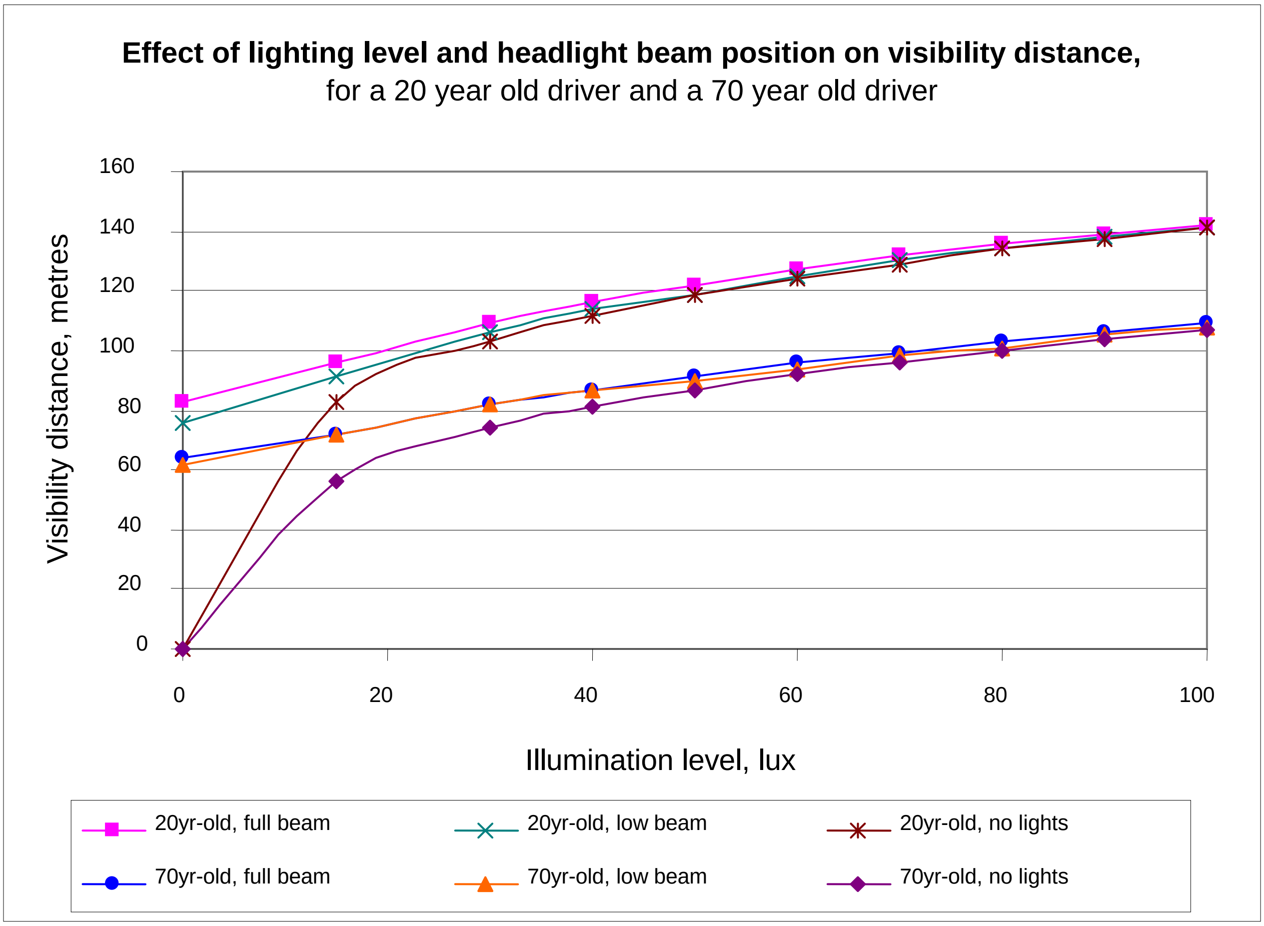
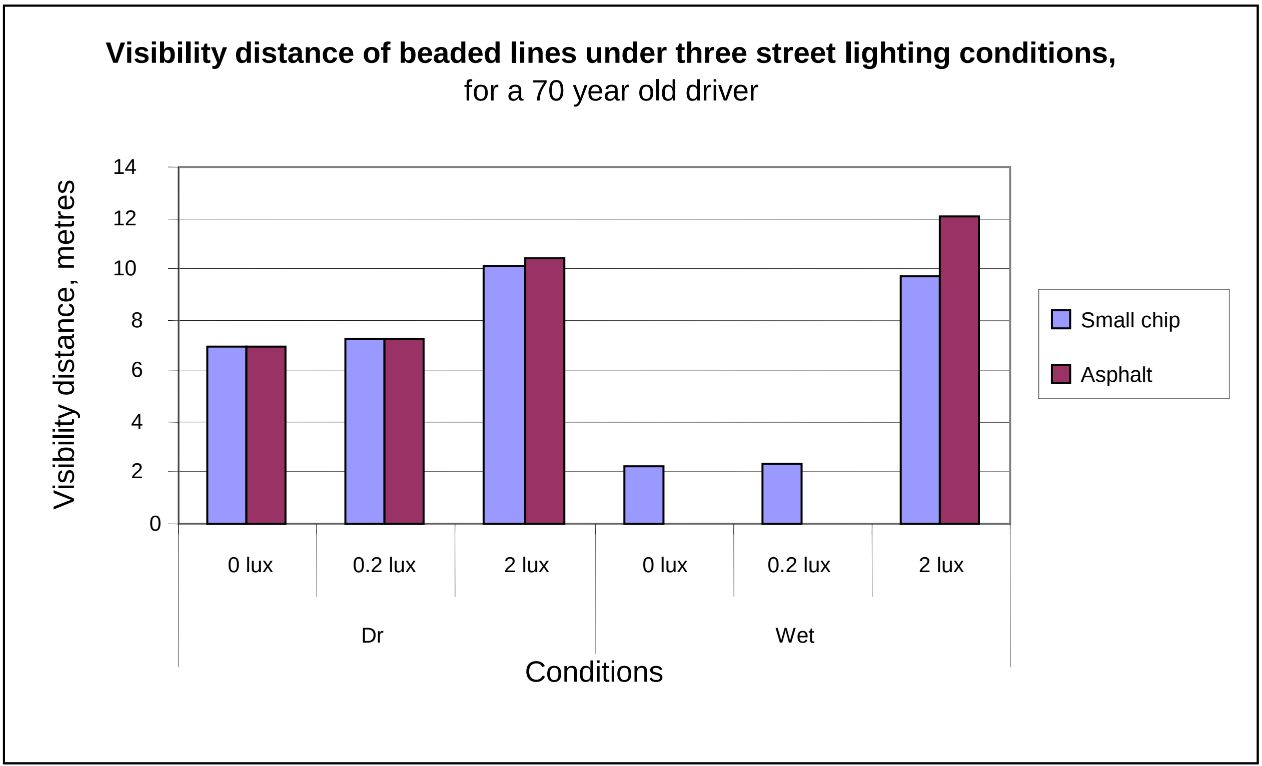


Figure 22 shows the effect of street lighting in more detail. As Qd dominates and lighting improves, even ordinary markings have good visibility

Figure 22 Visibility distance of beaded lines under various street lighting conditions


Visibility distance of beaded lines under three street lighting conditions,
for a 70 year old driver
Visibility distance, metres
14
12
10
8
6
4
2
0
0 lux
0.2 lux
2 lux
0 lux
0.2 lux
2 lux
Dr
Wet
Conditions
Small chip
Asphalt

9. Recommended reflectivities for wet conditions for road markings on open road

In developing recommended guidelines for dry conditions, a two second preview time and the needs of drivers about 70 years of age was taken as the basis. Table 4 helped define the likelihood of older drivers being present and the presence and number of oncoming vehicles.

Table 6 shows the preview time at 100km/h for markings that meet EN1436 classifications of RW1, RW1 and RW3 for a rural two lane highway, and a four lane highway with dividing median.

Table 6 Required marking preview time at 100km/h

Driver Age	Headlight angling and oncoming traffic	Two lane highway			4 Lane Highway With Median	
		RW1	RW2	RW3	No Lighting RW3	With Lighting RW3
70 year old driver	Full Beam	1.9	2.1	2.3	2.3	4.1
	Dipped beam 2 oncoming vehicles	1.5	1.7	1.9	2.2	4.0
	Dipped beam 5 oncoming vehicles	1.3	1.4	1.5	2.0	3.7
20 year old driver	Full Beam	2.5	2.8	3.1	3.1	5.7
	Dipped beam 2 oncoming vehicles	2.0	2.2	2.5	2.8	5.6
	Dipped beam 5 oncoming vehicles	1.7	1.9	2.2	2.6	5.4

Table 6 shows that markings of RW3 standard give adequate visibility in the wet for all drivers where the roadway is wide, e.g. a median or there is street lighting.

The RW1 standard is almost sufficient for driving on full beam but the RW2 does give a full 2.1 seconds to 70 year old drivers. For higher volume roads the top classification of RW3 is still not sufficient for the older driver.

In urban areas the driving speed is only 50km/h. The preview times available at 50km/h will be double those times shown in Table 6. Therefore RW1 is sufficient for all urban roads and visibility will be even better in street lighting.

Table 7 Recommended retroreflectivities (based on a 30 metre geometry) for speed limits of 100km/h

Traffic volume (AADT)	<250	250-1,500	1,500 – 5,000	5,000+
Minimum retroreflectivity under dry conditions	50	70	100	150
EN1436 classification		NOTE 1	R2	Equivalent R3
Minimum retroreflectivity under wet conditions	25	35	50	50+
EN1436 classification	RW1	RW2	RW3	RW3+

NOTE 1: Below R1 (EN1436) but equivalent to current TNZ P/20 minimum requirements.

10. Noise and vibration

10.1. Introduction

The aim of this section of the study is to establish noise/vibration criteria for audio tactile markings on New Zealand roads.

10.2. Road markings

A test vehicle was instrumented with a B&K accelerometer attached to the vehicle floor pan, and a sound level meter, both connected to a computer. This enabled the simultaneous measurement of vibration and noise levels inside the car, and the data were stored for subsequent processing for 1/3-octave band spectral analyses.

The test vehicle was a 1999 Daewoo Nubira Eurowagon SX equipped with Firestone Firehawk with tyres inflated to 30 psi.

To date the range of such markings studied is:

- Vibraline in various conditions; and
- Raised Pavement Markers.

10.3. Vibraline

Vibraline is used as an edge marking on motorways, and provides a visual, sensory and audible warning to drivers straying out of lane. It is applied using an applicator in one continuous operation. The base-line material is mechanically screeded, and a transverse rib of thermoplastic is applied at regular intervals. Reflectivity is provided by a surface application of glass beads. It is designed to enhance wet night visibility due to a greater surface area from the sloping faces of the ribs. In addition the flat tops of the ribs give vibration and an associated audible warning noise.

The Vibraline in this study was applied to both chipseal and to Open Graded Porous Asphalt (OGPA). The spacing for the raised ribs was 500mm, and each rib was nominally 8 to 10mm in height above the base-line material, and around 60mm in length across the profile. Tests were carried out on lengths of Vibraline ranging from “good” condition, to “worn” condition.

Noise

At a test vehicle speed of 100km/h, the in-car noise levels ranged from 81 dBA for Vibraline in “good” condition, to 79 dBA for Vibraline in a “worn” condition. Figure 23 shows the spectral content of the in-car noise for the test vehicle at 100 km/h on Vibraline in “good” condition, and Figure 24 shows the spectral content of the in-car noise for the test vehicle at 100 km/h on Vibraline in “worn” condition. Additionally the spectra for the in-car noise for the test vehicle at 100 km/h on both a relatively new grade 3 chipseal and OGPA have been included.

In terms of overall noise levels, there is only a 2 dBA difference for the in-car noise for the test vehicle at 100 km/h on Vibraline in “good” or “worn” condition.

Figure 23 shows that the dominant frequency of the in-car noise for the test vehicle at 100 km/h on Vibraline in “good” condition is 100 Hz, with a secondary peak at 160 Hz. Compared to a grade 3 chipseal in good condition, the in-car noise level from the Vibraline exceeds the chipseal road noise by around 5 dBA at these frequencies. Because of these tonal differences, the noise from Vibraline in “good” condition will be clearly distinguished inside the car, even though the overall noise levels are only 2 dBA higher for the Vibraline compared to the chipseal. The increase at the higher frequencies shown in Figure 23, from around 2 to 6 kHz, is possibly due to a resonance within the test vehicle interior (something rattling due to the vibrations).

Figure 23 In-car noise spectra for vehicles on 'good condition' Vibraline

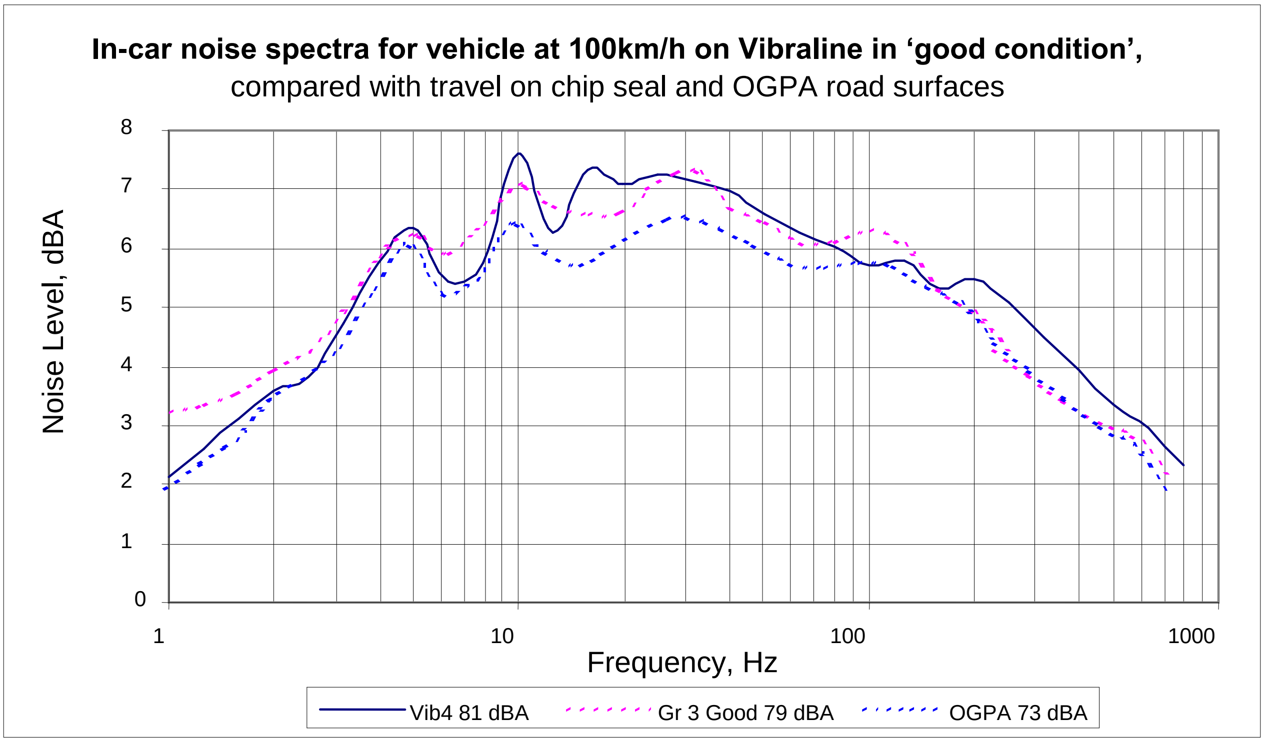
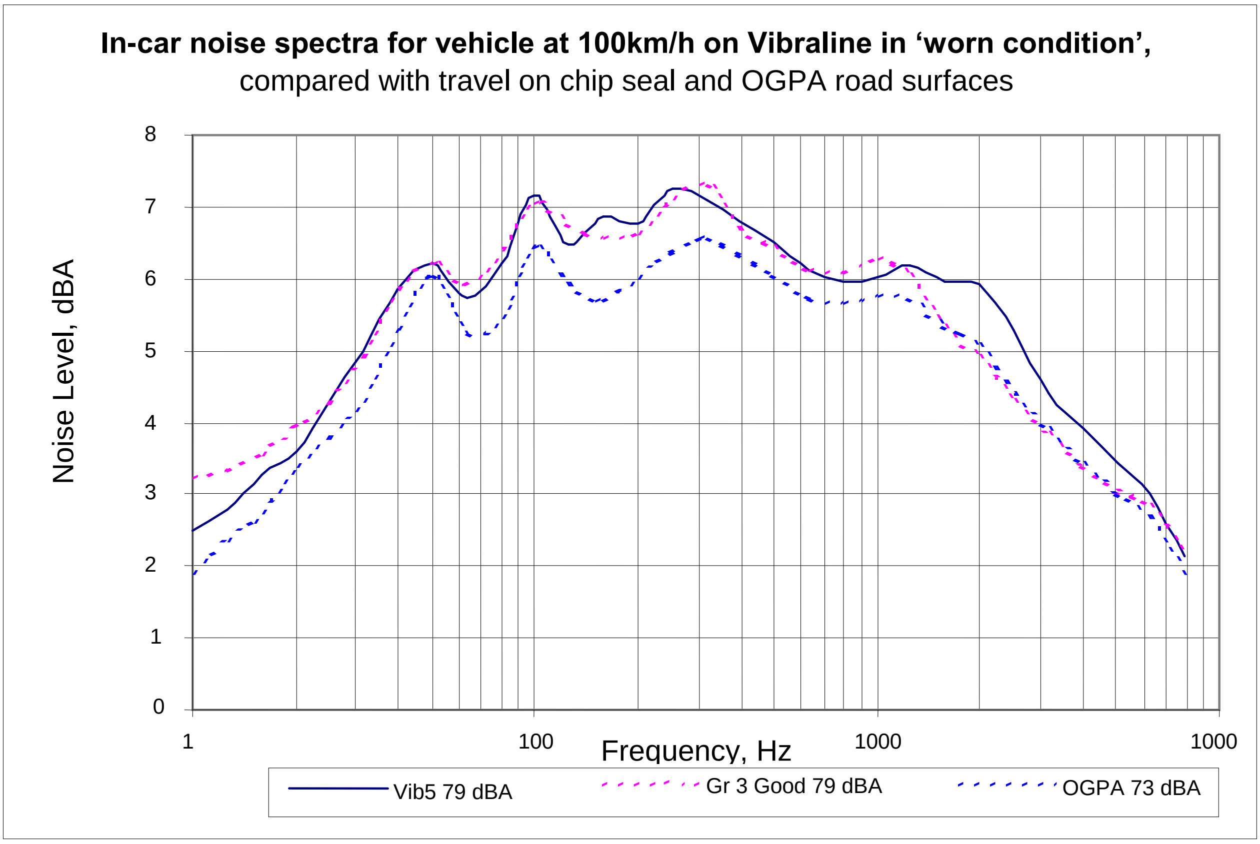


Figure 24 In-car noise spectra for vehicle on 'worn condition' Vibraline



From Figure 24 it can be seen that the noise level, and the tonal content of the in-car noise for the test vehicle at 100km/h on Vibraline in a 'worn condition' is similar to that of the in-car noise from the grade 3 chipseal. Without the associated vibration, the effect of the worn Vibraline may be difficult to detect on a road sealed with a grade 3 chip in good condition.

However, Figure 23 and Figure 24 show that compared to a road sealed with OGPA, the in-car noise for the test vehicle at 100km/h on Vibraline is 8dBA higher when the Vibraline is in 'good condition', and 6dBA higher when the Vibraline is in a 'worn condition'. In this situation, the noise from Vibraline in either condition will be clearly distinguished from the road noise inside the car.

Vibration

Calculations indicate that at a vehicle speed of 100km/h, the in-car vibration experienced due to travel on Vibraline is around 50 to 55 Hz, and that for a vehicle speed of 70km/h, the in-car vibration due to the Vibraline is around 38 to 40 Hz. Figure 25 shows 1/3 octave band analysis of the vibration data from the in-car measurements made while driving on the Vibraline at 100 km/h, and at 70 km/h, and on a grade 3 chipseal and OGPA at 100 km/h. It identifies peaks between 1 and 2 Hz, and in the 10 Hz, and 100 Hz centre frequency bands. Additionally, the measurements made on the Vibraline show a peak at 50 Hz for a vehicle speed of 100 km/h, and at 40 Hz for a vehicle speed of 70 km/h. This is in line with the calculations referred to above. That the 40 and 50 Hz peaks were representative of the in-car vibration due to the effect of the Vibraline was confirmed by comparing the in-car vibration measured in the vehicle on Vibraline, and on the grade 3 chip and OGPA road surfaces. Figure 25 shows that the 50 Hz centre band frequency at 100 km/h moves to around 40 Hz for a vehicle speed of 70 km/h, while most of the other peaks remain stable. It is further confirmed by the fact that the peaks between 1 and 2 Hz, and in the 10 and 100 Hz centre frequency bands also appear in the vibration data for the test vehicle on both the grade 3 chipseal and OGPA at 100 km/h.

Consequently, it was decided that in order to quantify the vibration effects of the Vibraline, the 50 Hz centre frequency band would be considered to be the indicator.

According to literature, the other peaks are accounted for as follows:

- Vehicle body roll: 1 to 3 Hz;
- Vehicle suspension: 10 to 13 Hz;
- Vehicle body vibration: 90 to 110 Hz

There may be a Vibraline effect in the 100 Hz region as well, due to the vehicle body vibration being affected by the vibrations from the Vibraline. However, this effect does not appear as pronounced as it does at 50 Hz, due to the masking effect of the vehicle body vibration already present.

Figure 25 In-car vibration for vehicle on Vibraline

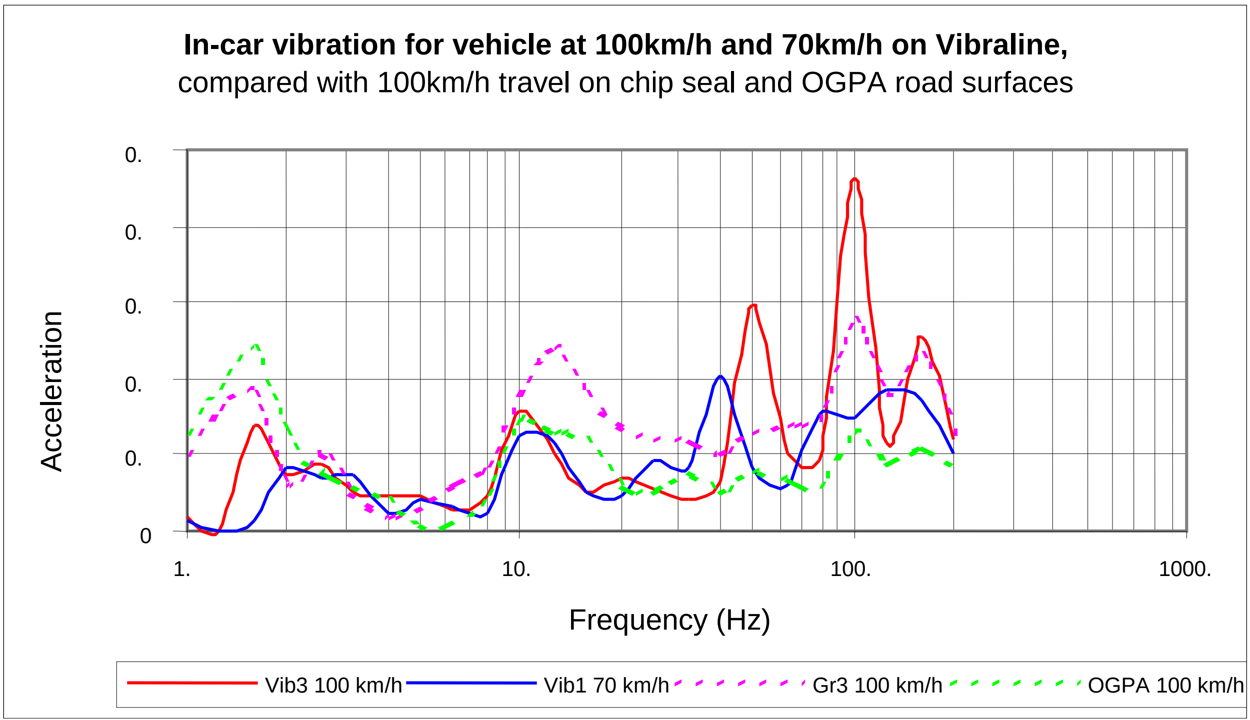
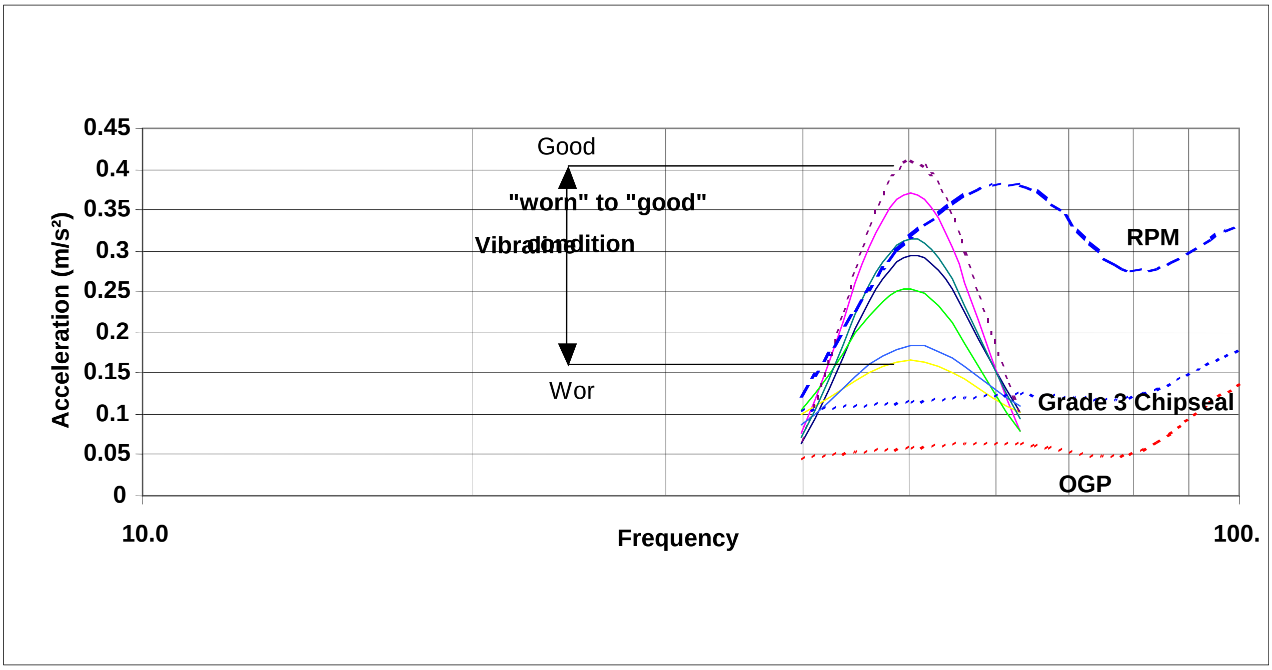


Figure 26 shows the in-car vibration resulting from the test vehicle being driven on the Vibraline at 100 km/h. From this it can be seen that the acceleration due to the vibration at 50 Hz ranges from around 0.16 m/s^2 for Vibraline in “worn” condition, to around 0.41 m/s^2 for Vibraline in “good” condition. Additionally, Figure 26 shows the in-car vibration when the test vehicle is driven on grade 3 chipseal, OGPA and ceramic raised pavement markers (RMPs).

Figure 26 In-car vibration measurements for the test vehicle at 100km/h on various Vibraline surfaces, grade 3 chipseal, OGPA, and on ceramic RPMs. Only the 40 to 60 Hz component is shown for the Vibraline measurements



From Figure 26 it can be seen that the vibration acceleration for the Vibraline in worn condition is around 0.16 m/s^2 at 50 Hz, and that the vibration acceleration for the grade 3 chipseal in good condition is around 0.12 m/s^2. From this it can be deduced that the vibration effect of the worn Vibraline can be detected even on a road sealed with a grade 3 chip in good condition. Figure 26 also shows that the vibration effect of Vibraline in good condition can be easily detected on a road sealed with a grade 3 chip in good condition.

Figure 26 also shows that compared to a road sealed with OGPA, the in-car vibration for the test vehicle at 100 km/h on Vibraline is significantly greater when in either worn or good condition. In this situation, the vibration from Vibraline in either condition will be clearly distinguished from the in-car road vibration.

ISO 2631-1 contains some approximate indications of likely passenger reactions to various magnitudes of overall vibration values. According to this standard, vibrations of less than 0.315 m/s^2 do not cause discomfort, while vibrations of magnitude 0.315 to 0.63 m/s^2 cause a little discomfort. Therefore, any of the vibrations generated by the profiled lines will cause no more than minor discomfort to drivers and vehicle occupants.

10.4. Ceramic Raised Pavement Markers

Ceramic Raised Pavement Markers (RPMs) are placed in groups spaced at one metre intervals, and are used for lane delineation. They are circular and dome-shaped, of 100mm diameter and have a maximum height above the road of around 10 to 20mm. Consequently they provide a visual, sensory and audible warning to drivers straying out of lane.

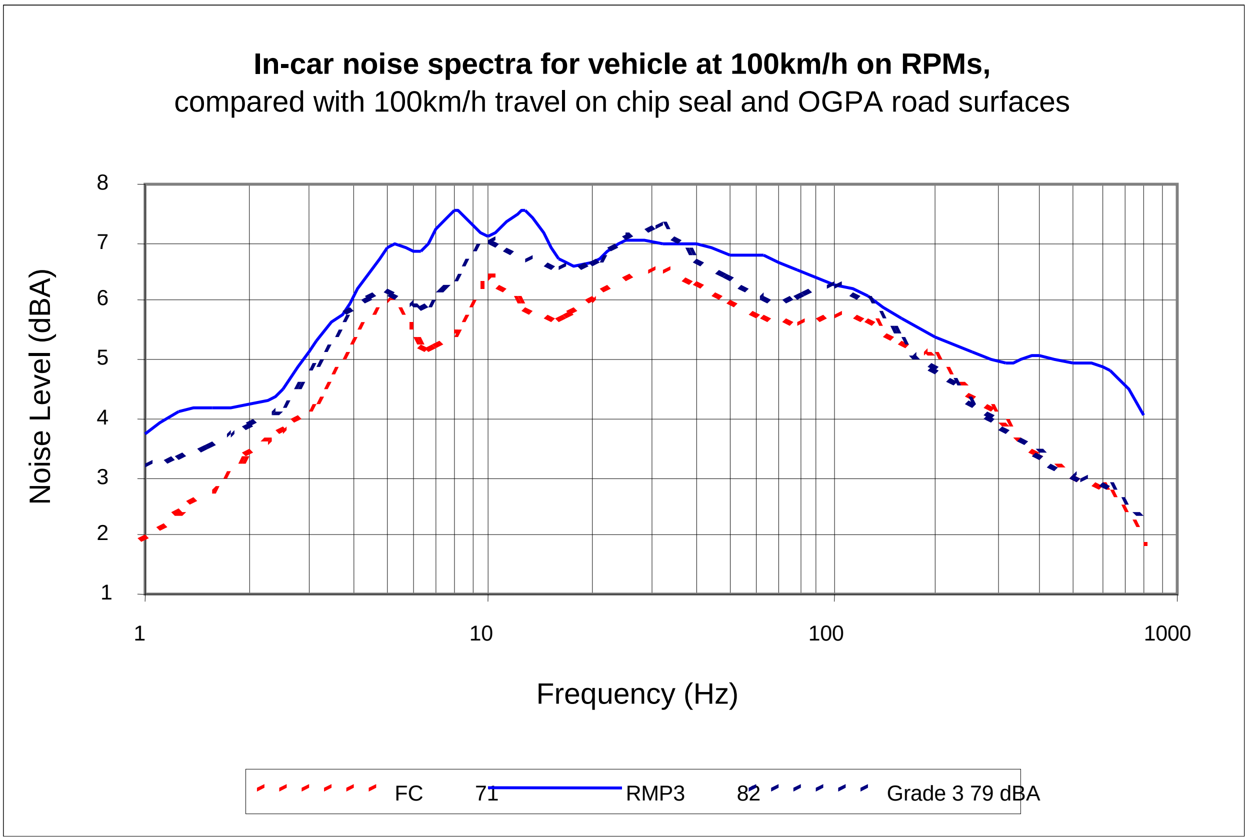
Noise

The test vehicle was driven over six different groups of RPMs at 100km/h. In-car noise levels ranged from 80 dBA to 82 dBA. Figure 27 shows the spectral content of the in-car noise for the test vehicle at 100 km/h on a group of typical RPMs. Additionally the spectra for the in-car noise for the test vehicle at 100 km/h on both a relatively new grade 3 chipseal and OGPA have been included.

Figure 27 shows that the dominant frequencies of the in-car noise for the test vehicle at 100 km/h on RPMs range between 80 and 150 Hz, but the low slope of the graph indicates that the overall in-car noise is relatively broad spectrum in character. Compared to a grade 3 chipseal in good condition, the in-car noise level from the RPMs exceeds the chipseal road noise by between 1 and 3 dBA. Although in terms of overall noise levels this is not a great difference, the RPM noise is likely to be clearly distinguished inside the car because of the significant low frequency component of the noise.

Figure 27 also shows that compared to a road sealed with OGPA, the in-car noise for the test vehicle at 100 km/h on a typical RPM is around 9 to 11 dBA higher. In this situation, the noise from the RPMs will be clearly distinguished from the road noise inside the car.

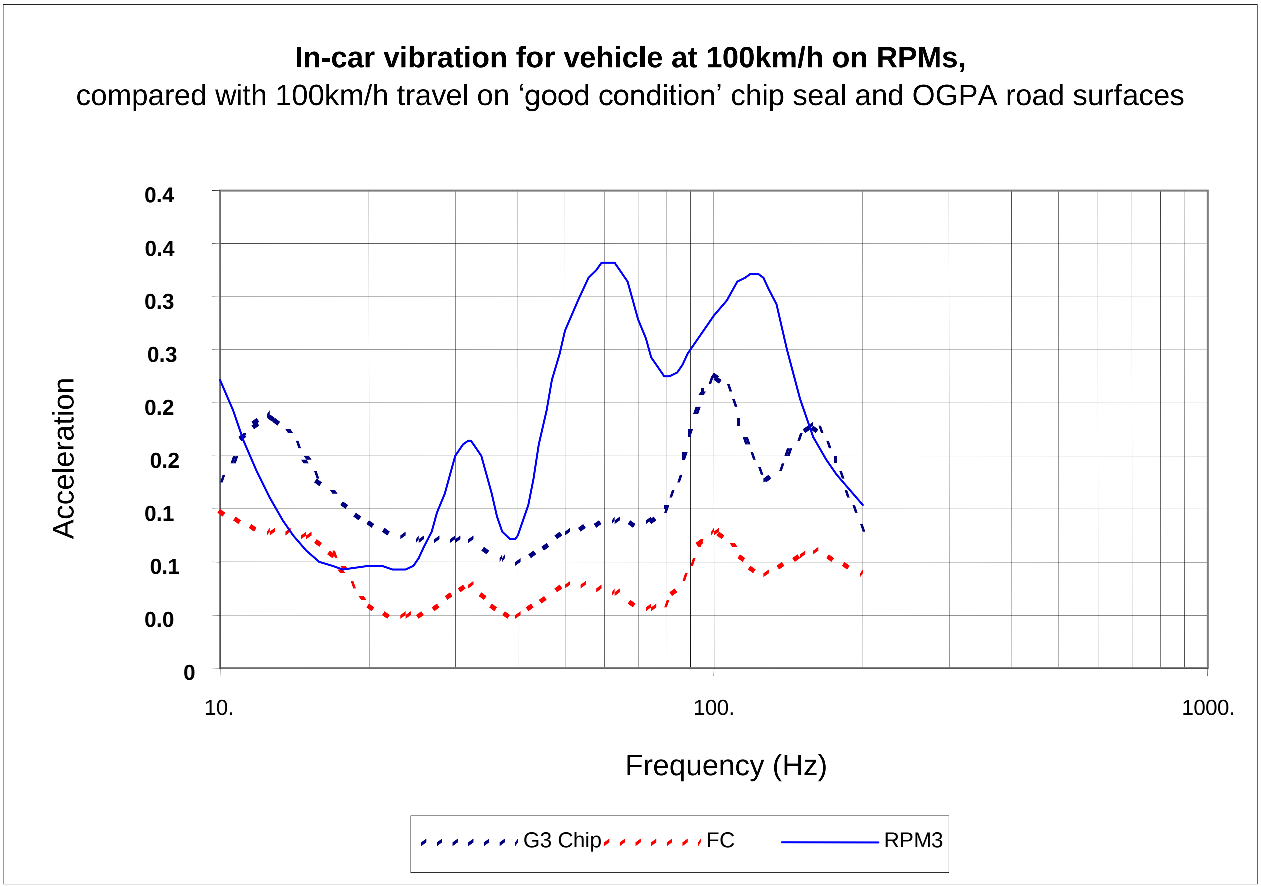
Figure 27 In-car noise spectra for vehicle on RPMs



Vibration

Figure 28 shows 1/3 octave band analysis of the vibration data from the in-car measurements made while driving on the RPMs, on a grade 3 chipseal, and OGPA at 100 km/h. For the RPMs, significant peaks in the 32, 63, and 126 Hz centre frequency bands have been identified. Figure 6 also shows that the vibration acceleration due to the RPMs is substantially higher than that of either the grade 3 chipseal or of the OGPA. Consequently it can be seen that the in-car vibration due to RPMs will be clearly distinguished from the in-car road vibration.

Figure 28 In-car vibration for vehicle on RPMs



11. Conclusions

1. The method of vibration measurement as described in this report is effective for determining the condition of audio tactile markings.
2. The in-car noise for the test vehicle at 100 km/h on Vibraline in “good” condition will be clearly distinguished from the noise of grade 3 chipseal because of tonal differences, even though the overall in-car Vibraline noise levels are only 2 dBA higher than the chipseal noise levels.
3. The in-car noise level for the test vehicle at 100 km/h on Vibraline in “worn” condition is only 2 dBA lower than the in-car noise level for Vibraline “good” condition.
4. Without the associated vibration, the effect of the “worn” Vibraline may be difficult to detect on a grade 3 chipseal.
5. For a road sealed with OGPA, the in-car noise for the test vehicle at 100 km/h on Vibraline in either “good” or “worn” condition will be clearly distinguished from the road noise.
6. In order to quantify the in-car vibration effects of the Vibraline, the 50 Hz centre frequency band is considered to be the indicator for the test vehicle at 100 km/h.
7. For the test vehicle at 100 km/h there is a wide range in the in-car 50 Hz component for Vibraline, linked to the condition of the Vibraline.
8. For the test vehicle at 100 km/h, the vibration effect of Vibraline in good condition can be easily detected on a road sealed with a grade 3 chip, while it is likely that the vibration effect of worn Vibraline can also be detected on a road sealed with a grade 3 chip.
9. Compared to a road sealed with OGPA, the in-car vibration for the test vehicle at 100 km/h on Vibraline in either the “worn” or “good” condition will be clearly distinguished from the road vibration.
10. For the test vehicle at 100 km/h, the in-car noise from RPMs will be clearly distinguished from the in-car noise due to either grade 3 chipseal or OGPA.
11. For the test vehicle at 100 km/h, the in-car vibration due to RPMs will be clearly distinguished from the in-car road vibration due to either grade 3 chipseal or OGPA.

12. Glossary: EN1436 classifications

Classes of Q_d for dry permanent road markings

Road marking colour	Road surface type	Class	Minimum luminance coefficient in diffuse illumination, Q_d (mcd.m^{-2}.lx^{-1})
White	Asphaltic	Q0	No requirement
		Q2	$Q_d \geq 100$
		Q3	$Q_d \geq 130$
	Cement concrete	Q0	No requirement
		Q3	$Q_d \geq 130$
		Q4	$Q_d \geq 160$
Yellow		Q0	No requirement
		Q1	$Q_d \geq 80$
		Q2	$Q_d \geq 100$

NOTE: The class of Q0 applies when day-time visibility is achieved through the value of the luminance factor ß

Classes of R_L for dry permanent road markings

Road marking colour	Class	Minimum coefficient of retroreflected luminance, R_L (mcd.m^{-2}.lx^{-1})
White	R0	No requirement
	R2	$R_L \geq 100$
	R4	$R_L \geq 200$
	R5	$R_L \geq 300$
Yellow	R0	No requirement
	R1	$R_L \geq 80$
	R3	$R_L \geq 150$
	R4	$R_L \geq 200$

NOTE: Class R0 is intended for conditions where the visibility of road markings is achieved without retroreflection under vehicle headlamp illumination.

Classes of R_L for permanent road markings in conditions of wetness

Conditions of wetness	Class	Minimum coefficient of retroreflected luminance, R_L (mcd.m^{-2}.lx^{-1})
As obtained one minute after flooding the surface with approximately 10 litres of water	RW0	No requirement
	RW1	$R_L \geq 25$
	RW2	$R_L \geq 35$
	RW3	$R_L \geq 50$

NOTE: Class RW0 is intended for situations where this type of retroreflection is not required for economic or technological reasons.

Classes of R_L for permanent road markings in conditions of rain

Conditions of rain	Class	Minimum coefficient of retroreflected luminance, R_L ($mcd.m^{-2}.lx^{-1}$)
As obtained after at least five minutes exposure to uniform rainfall of 20mm/h	RR0	No requirement
	RR1	$R_L \geq 25$
	RR2	$R_L \geq 35$
	RR3	$R_L \geq 50$

NOTE: Class RW0 is intended for situations where this type of retroreflection is not required for economic or technological reasons.

13. References

Some recent research publications related to this project performed by the proposed research team are:

"Road Signage and Delineation (Literature Review)", Transit New Zealand Report PR3-0123 (draft)

"Effectiveness of Edge Marker Posts", Transit New Zealand Research Report PR3-0021 (draft)

"Minimum Retroreflectivity Value", Transit New Zealand Research Report PR3-0011

"Photometric Properties of New Zealand Road Signs", Central Laboratories Report 96-527912

"Mirolux 12 Retroreflectometer Performance Assessment on Road Test Sites", Central Laboratories Report 91-27329

"Retroreflectivity – A Minimum Recommended Value", Transfund New Zealand Research Report No. 65

"Performance of Roadmarkings on New Zealand Chipseal Road Surfaces", Transit New Zealand Research Report PR3-0131 (in preparation)

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