TECHNICAL PAPER

REFLECTION PROPERTIES OF NEW ZEALAND ROAD SURFACES FOR ROAD LIGHTING DESIGN

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ABSTRACT:

This study, carried out as an NZTA research project, reports on a New Zealand-wide evaluation of road surfaces for reflection properties in road lighting design. The sections of road surveyed were chosen from the national Road Assessment and Maintenance Management database (RAMM) and the measurement device was the portable reflectometer known as 'Memphis'.

The study measured the standard road lighting parameters Qo and S1 at 140 sites, from Auckland to Christchurch, over a 6-week period from October to December 2008.

The reflection values found in the study (Qo = 0.050 and S1 = 0.57) are significantly lower than the values being used in design today (Qo = 0.090 and S1 = 0.58 and 1.61).

The low Qo value (44% below the current design value) means that New Zealand lighting designs will be darker and produce higher levels of glare than expected.

Were new design tables to be produced based on these results, it would be likely that the capital and operating costs of new traffic route lighting would increase by around 50%. This figure could reduce in time as luminaire optics better align with the new findings.

The work is described in more detail in Jackett and Frith (2009).

BACKGROUND:

In New Zealand road lighting design follows a performance based methodology. The joint New Zealand Australian road lighting standard (AS/NZS1158) defines how brightly and uniformly lit each road should be together with the maximum glare. Whether the standard is met or not is determined by computer calculation using the light output tables of the chosen luminaires and the known reflection properties of New Zealand road surfaces.

If there are significant errors in either the luminaire tables or the reflection properties of the road surface these will be manifest in the road lighting failing to achieve the desired level. However as very few lighting designs are ever measured in the field (it is a complex and time consuming task) it is likely that neither the designer nor the client will be aware of any over or under lighting that occurs.

The lack of any field measurement places heavy reliance on the accuracy of the input parameters.

The luminaire output tables (I tables) are provided by accredited photometric laboratories at the request of luminaire manufacturers. The reflection properties of New Zealand road surfaces are contained in the AS/NZS 1158 standard as r-tables NZR2 and NZN4. These tables are based on the international CIE surfaces R2 and N4 but, prior to this work, had not been checked or measured in New Zealand since 1982 (Nicholas, 1982a).

The work described in this paper investigates the ongoing validity of the New Zealand r-tables using a modern portable reflectometer developed in Europe.

It was expected the results of this study would either:

- Confirm that the present New Zealand reference tables for road surface reflectance remain appropriate for use; or
- Indicate that changes are needed to better match the road surface properties used in road lighting design with current road surfaces.

Previous Research, 1980-82:

The current NZ standard surfaces (NZR2 and NZN4) derived from research undertaken between 1980 and 1982 by the then DSIR. The research involved two studies. One used a purpose built light box (see Figure 1) which could be transported from site to site to measure road reflectance (Nicholas 1982a). The other study was a detailed road luminance measurement made at a single site in Lower Hutt (Nicholas 1982b). The final recommendation combined the results of both studies and led to the selection of:

NZR2: A table based on the international R2 surface but with the values scaled up to give a Qo value of 0.09. R2 is a relatively diffuse surface typical of a recently laid chip or AC surface without significant polishing.

NZN4: A table based on the international N4 surface but with the values scaled up to give a Qo value of 0.09. This is a highly specular surface typical of a worn asphaltic concrete surface or a chip seal surface under stress.

The standard requires that both surfaces be used in design and in this way ensured that all lighting designs would comply no matter what the condition of the road surface beneath them.

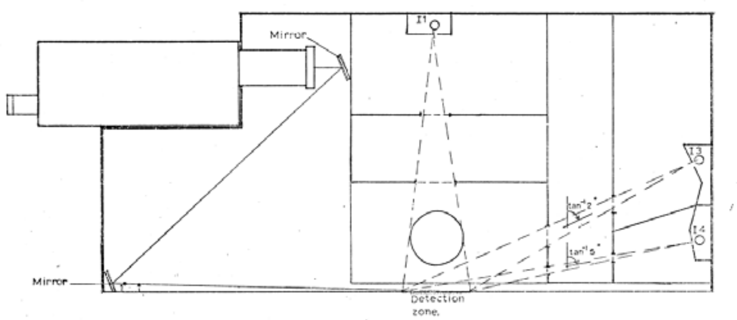

Figure 1: A cross section of the device used in the 1980s to measure the reflection properties of NZ road surfaces.

Current Research, 2008-2009:

This research project used a portable road reflectance gonio-reflectometer developed in four years of research conducted by the Schreder group of companies and the University of Liege in Belgium.

The end product of the research has been an instrument (known as “Memphis”) that is sufficiently small to fit in the boot of a car, and yet capable of assessing reflection properties over a wide range of incident and reflection angles (see Figure 2). Two test plates provide a calibration check.

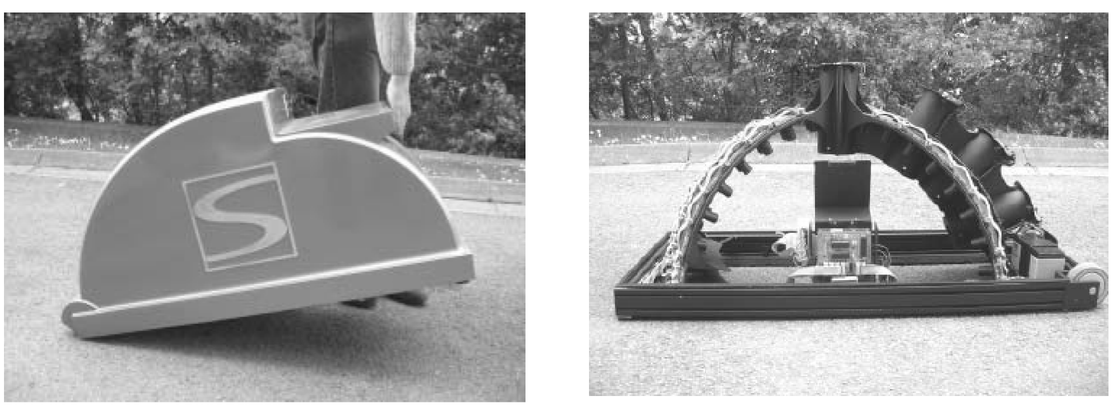

Figure 2 ‘Memphis’ a portable road reflectance gonio-reflectometer with its outer covering and with the covering removed.

Rather than attempt to gather all the reflection data necessary to fully classify a surface, it gathers just sufficient data to link the surface to a much more comprehensive database of surfaces that have been photometrically measured in the laboratory.

Memphis is equipped with 4 light sources at preset incident angles of γ = 0, 30, 50 and 70 degrees to the normal of the road surface. Each light illuminates the same 110mm diameter circular area of road (see Figure 3). The output from the 4 light sources is continuously monitored by small sensors placed in each lamp chamber.

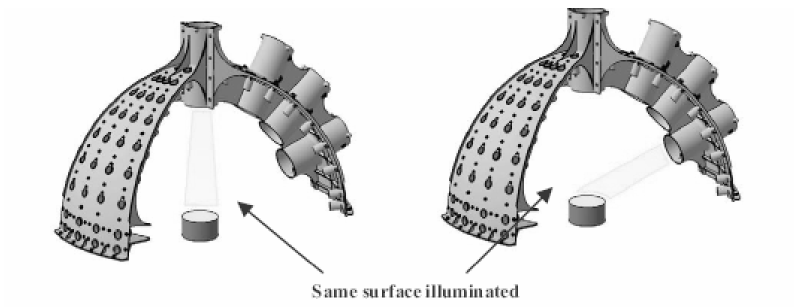

Figure 3 Memphis schematic showing the illuminated area

There are also 9 luminance meters set at α = 5, 10, 20, 30, 40, 50, 60, 70 and 80 degrees to measure the reflected light from the surface. Note that these angles are a proxy for the true angles used in road lighting. In the road lighting situation, the driver to the road-observation angle, α, is by definition 1 degree. The purpose of the multiple observation angles is to build a mathematical understanding of the surface, which can then be compared with a series of stored databases.

Memphis also makes measurements of 5 separate β angles (the horizontal angle between the direction of illumination and the direction of observation) viz β = 0, 10, 20, 30, and 150 degrees. The total number of measurements for each observation is therefore:

4 incident light angles x 9 reflection angles x 5 offset angles = 180 measurements.

All measurements (and calibrations) are made automatically under the control of a laptop computer that forms an integral part of the device. A whole set of 180 measurements is completed within just 12 seconds, allowing Memphis to be quickly moved on to the next sample point. Data is stored on the hard drive of the laptop computer for later retrieval.

MEASUREMENTS:

Sample selection:

The objective of road lighting design is to present a uniform and bright road surface to drivers so that objects can be easily identified through silhouette vision. The design width used in road lighting may include all of the following areas and some may have slightly different reflection characteristics:

- Shoulder / parking or cycle lane – little or no traffic polishing
- Wheel tracks – heavy traffic polishing
- Between wheel tracks – minor traffic polishing, some oil splashes
- Between directions of traffic – minor traffic polishing

For this survey 5 measurement points were taken in the shoulder and 5 along the LHS wheel track. The shoulder and wheel track generally represent the extremes of traffic polishing and wear found in the road. The average of all 10 measurements was taken to best represent the road surface reflection properties for the site as a whole. See Figure 3.

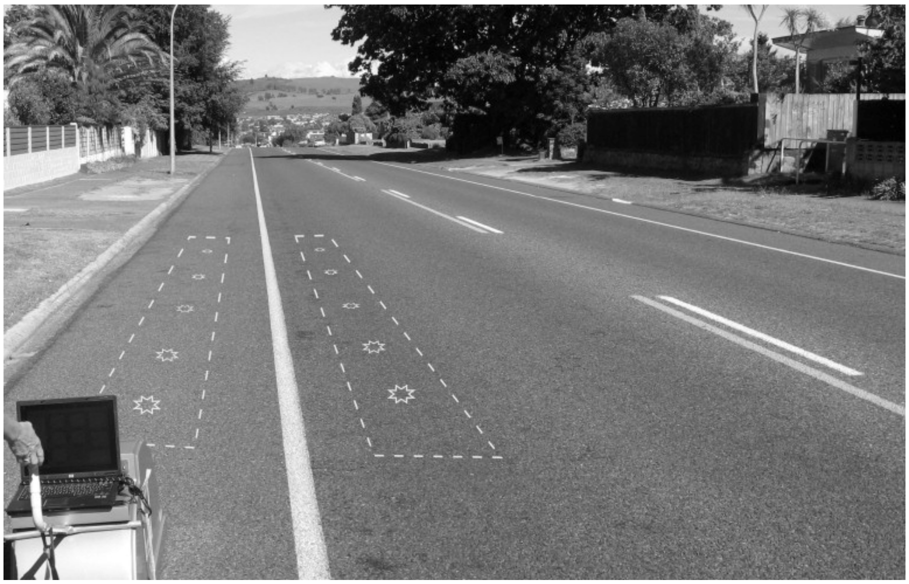

Figure 3: Typical roadway showing Memphis with measurement areas superimposed on the road shoulder and in the LHS wheel track. The stars represent the five measurement positions on the shoulder and wheel track.

At each site the following data was collected;

- Location (GPS and street name / house number)
- Road surfacing material
- Photographs (site, shoulder and LH wheel track)
- A set of 10 road surface reflection measurements using Memphis as shown in Figure 3

Field data as above was collected from 140 sites, within 9 Road Controlling Authorities (RCAs) located from Auckland in the north to Christchurch in the south.

Memphis Output:

Memphis provides output in the form of two CIE standard parameters Qo and S1. These parameters characterise the reflection properties of road surfaces and provide the information necessary to select an appropriate CIE r-table

Qo is a measure which indicates how efficiently a surface will reflect light at the incident and reflection angles appropriate to road lighting. In general light coloured surfaces have high Qo values and dark coloured surfaces have low Qo but that rather superficial alignment should not be taken too far. Variations in Qo cannot be explained by surface colour alone.

A surface with a high Qo will needs less light in order to meet the luminance requirements of the AS/NZS1158 standard. Surfaces with high Qo values are generally more desirable in road lighting terms than those with low Qo

S1 is a measure of how specular or “shiny” the road surface is. Road surfaces tend to become more specular as traffic polishes the road surface material.

Surfaces with high specularity (S1) produce both very bright and very dark areas under street lighting. Surfaces with high S1 will require closer luminaire spacing or higher mounting heights to overcome the irregular light patterns produced.

While there is no single, “ideal” road surface in road lighting in general a surface with a high Qo and low S1 will be the most economical to light. (ie. Less light is required and greater luminaire spacing is possible)

RESULTS:

Overall:

The Qo value (0.050) found in this study is 44% lower than the present value used in AS/NZS1158 r-tables. This difference is substantial and suggests that New Zealand roads have road lighting luminance levels approximately 40% lower than the designs indicate.

The S1 value (0.570) found in this study is almost identical to that of the current NZR2 surface but substantially less than that of the NZN4 surface. This suggests that our road surfaces are not as specular as had been anticipated and our road lighting more uniform than designs indicate. There may be potential for some compensatory savings here.

The magnitude of change can perhaps be seen more clearly in Figure 4 which is a plot of S1 verses Qo. The “no change from 1980-82” expectation was that the majority of points from this study would fall into the vertical egg shaped design envelope surrounding NZN4 and NZR2. In fact not a single data point fell into this area. Rather the data points are clustered around a horizontal egg shaped design envelope with a substantially lower Qo.

Table 1: Summary of the Qo and S1 values for the two standard New Zealand r-tables (NZR2 and NZN4) and for the results found in this study.

	Qo	S1
NZR2	**0.090**	**0.58**
NZN4	**0.090**	**1.61**
Study Results		
Mean All	**0.050**	**0.57**
Mean Chip seal	0.045	0.55
Mean AC	0.055	0.59
Min All	0.028	0.23
Max All	0.084	1.31
Sample size	140	140

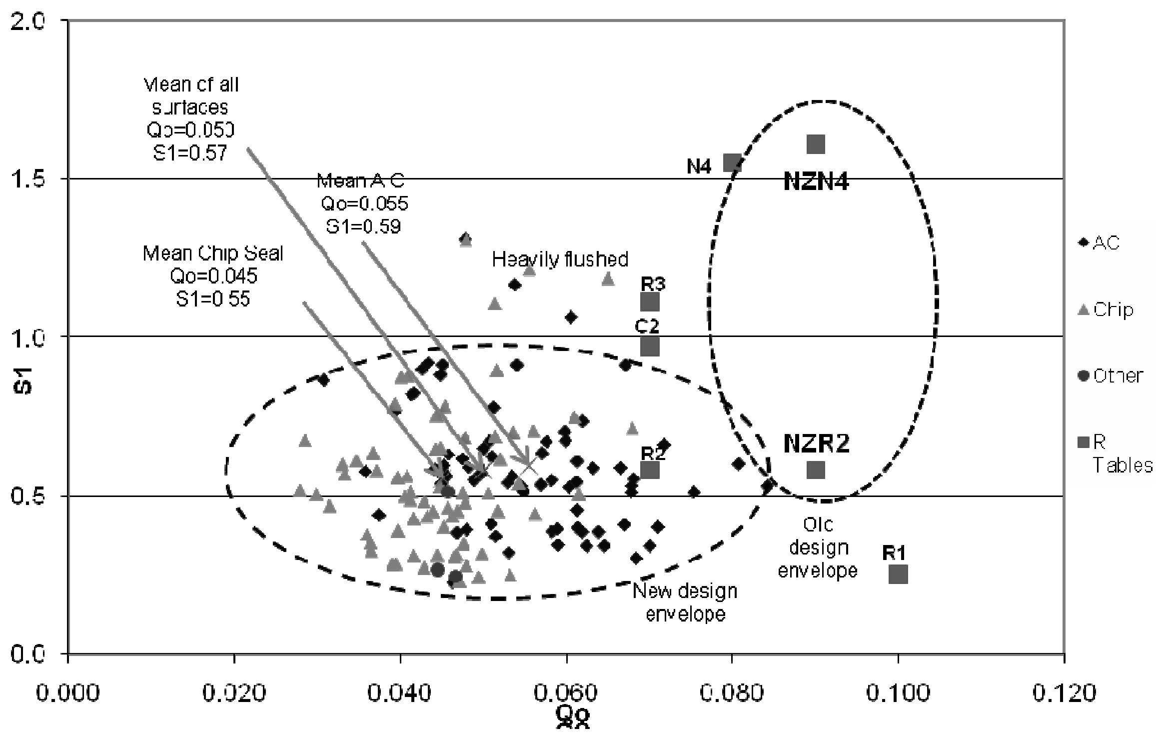

Figure 4: S1 vs Qo for all 140 data points in the field study. The current design envelope surrounding NZR2 and NZN4 is shown as enclosing no data points. A second envelope illustrates a possible new design envelope.

Chip Seal and Asphaltic Concrete:

The average Qo value from chip seal surfaces (0.045) was some 18% lower than that found on asphaltic concrete surfaces (0.055) [This difference is statistically significant at the 95% level]. Figure 4 demonstrates how the chip seal surfaces tend to cluster at lower values of a S1 vs Qo graph.

The reason for this is not immediately clear but is probably related to the physical size of the surface elements and the fact that the binder plays little or no part in the reflection characteristics of chip seal surfaces (it is not seen at low observation angles) but does play a part in the reflection properties of asphaltic concrete surfaces.

These measurements indicate that on average an asphaltic concrete surface requires 18% less light than a chip seal surface to achieve the same level of brightness.

Geographic Differences:

The field surveys included 10 RCAs in 4 Regions. The highest average Qo was found in Wellington City (0.060) and the lowest in Hamilton City (0.041). However the survey was not designed to test for geographic variation and it is possible these differences are due to chance alone.

The basalt stone in the Auckland area appeared darker than typical greywacke stone and this may have had some influence on the low average Qo value found in Auckland. However other factors which have not been investigated such as temperature, traffic polishing, presence of transferred binder on the surface etc. may also have played a role.

Table 2: The range of Qo and S1 values by RCA. (Sorted in decreasing order of Qo)

RCA	Average Qo	Average S1	Sample size
Wellington CC	0.060	0.45	12
Porirua CC	0.054	0.48	9
Taupo DC	0.052	0.65	10
Lower Hutt CC	0.052	0.53	19
Christchurch CC	0.052	0.54	17
SH (Wgtn)	0.052	0.77	6
Kapiti Coast DC	0.050	0.47	20
Upper Hutt CC	0.049	0.45	9
Auckland CC	0.046	0.67	22
Hamilton CC	0.041	0.72	16
All sites	0.050	0.57	140

Traffic Polishing:

The wisdom arising from the current r-tables is that as road surfaces polish and wear S1 increases (ie the surface becomes more specular) but Qo remains constant. The current r-tables (NZR2 and NZN4) have identical Qo values but very different S1 values.

This study provided an opportunity to test the effect of traffic polishing. The road shoulder measurements were made on a section pavement that had typically seen little traffic polishing. In most cases the reflection properties on the shoulder would have remained much the same over the life of the pavement. In contrast the wheel track measurements were made in the area of concentrated wear from polishing of the stone and stressing of the pavement. The difference shows the changes in reflection properties due to the influence of vehicle tyres.

Figure 5 illustrates that both Qo and S1 increase with traffic wear (the broad arrow in Figure 5 points towards the upper right of the graph). This increase in Qo as a surfaces polish may be of some material assistance as it implies surfaces can become helpfully more reflective with some traffic polishing. [Note: Although not shown in this paper the graph for AC surfaces has similar shape.]

A small number of extreme wheel track values were found especially in chip seal surfaces where the surface had completely flushed and the wheel track measurement was largely made on the binder (see top right points in Figures 4 & 5). They were relatively few in number and as aberrant road conditions probably do not justify special treatment in road lighting design.

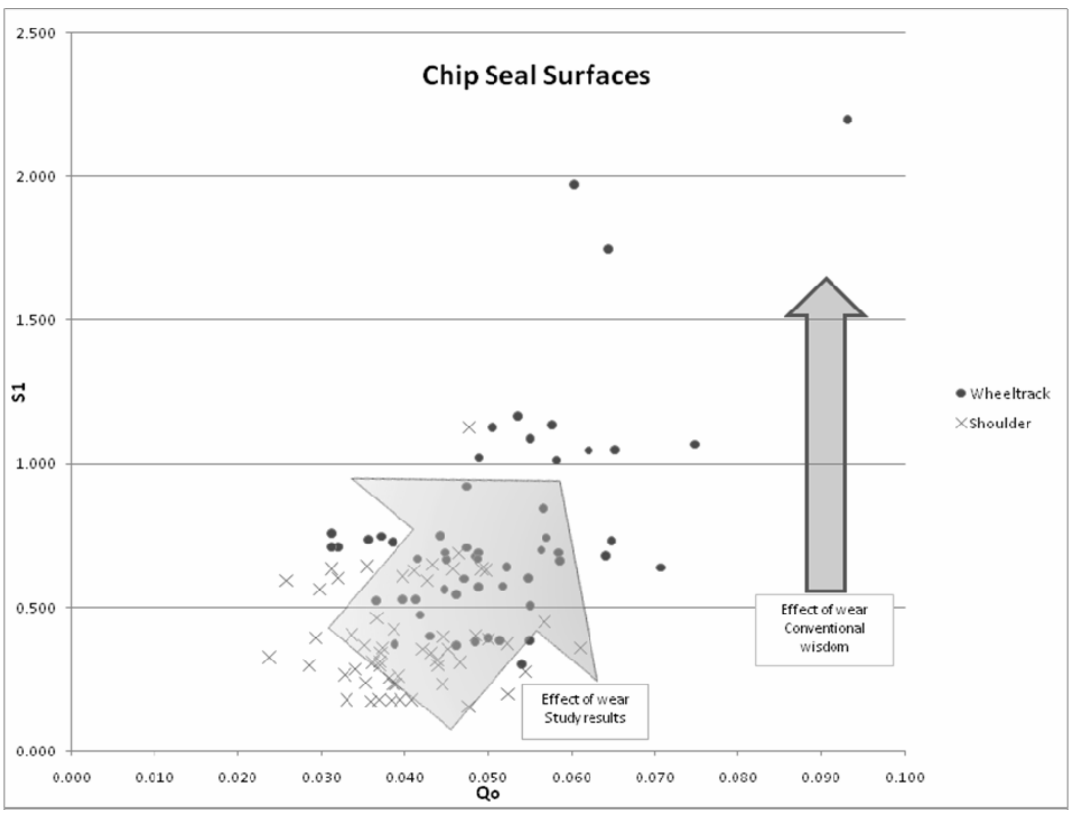

Figure 5: Effect of traffic wear / polishing on chip seal surfaces. The broad arrow shows the direction of change in reflection properties S1 and Qo from the road shoulder to the wheel track. ie moving to a traffic polished region increases both Qo and S1. The narrow arrow shows the previous wisdom (NZR2/NZN4) where traffic polishing led to an increase in S1 but not Qo.

Laboratory Results:

Figure 6 summarises the results of some laboratory measurements on trays filled with loose road surfacing chip of material that was not otherwise available in the field. Due to the lack of wear or soiling these tests do not exactly mirror field conditions but do provide some evidence that higher Qo values may be possible using light coloured supplementary material such as quartzite and marble.

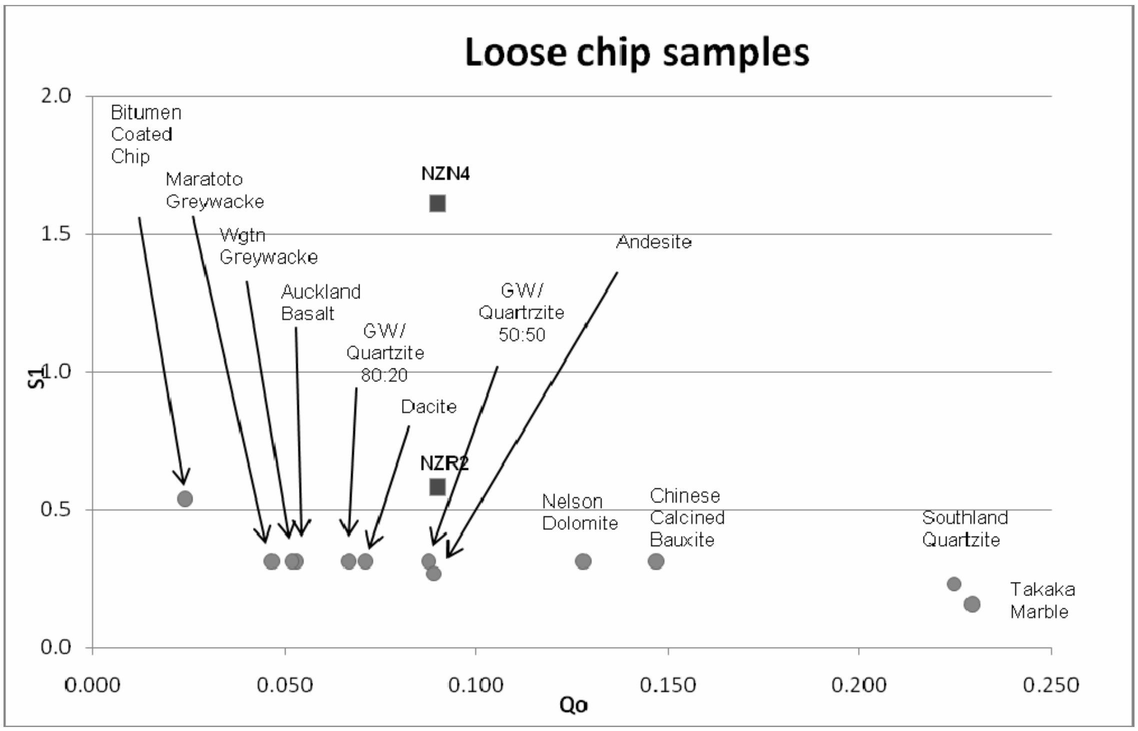

Figure 6: Results of untrafficked, loose chip samples measured in the laboratory. Note that very high Qo values (above 0.1) are unlikely to be fully realised in the field due to surface contamination from dirt and rubber.

IMPACT OF RESULTS:

A representative series of road lighting designs were made to test the likely impact of the new Qo and S1 values found in this study. The purpose was to identify both the shortfall in what is being delivered now and the likely increase in cost if a more representative r-table was adopted.

Choice of r-table:

Figure 7 below shows the Qo and S1 value for each surface measured by Memphis. The closest standard CIE surface based on a sample mean for S1 of 0.57 is the CIE R2 surface (S1 = 0.58). The sample mean of the Qo values is 0.050. A single surface using the CIE R2 r-table but with a Qo value of 0.050 was therefore chosen as typical of the NZ road surfaces found in this study. This surface is subsequently referred to as the R2_05 surface.

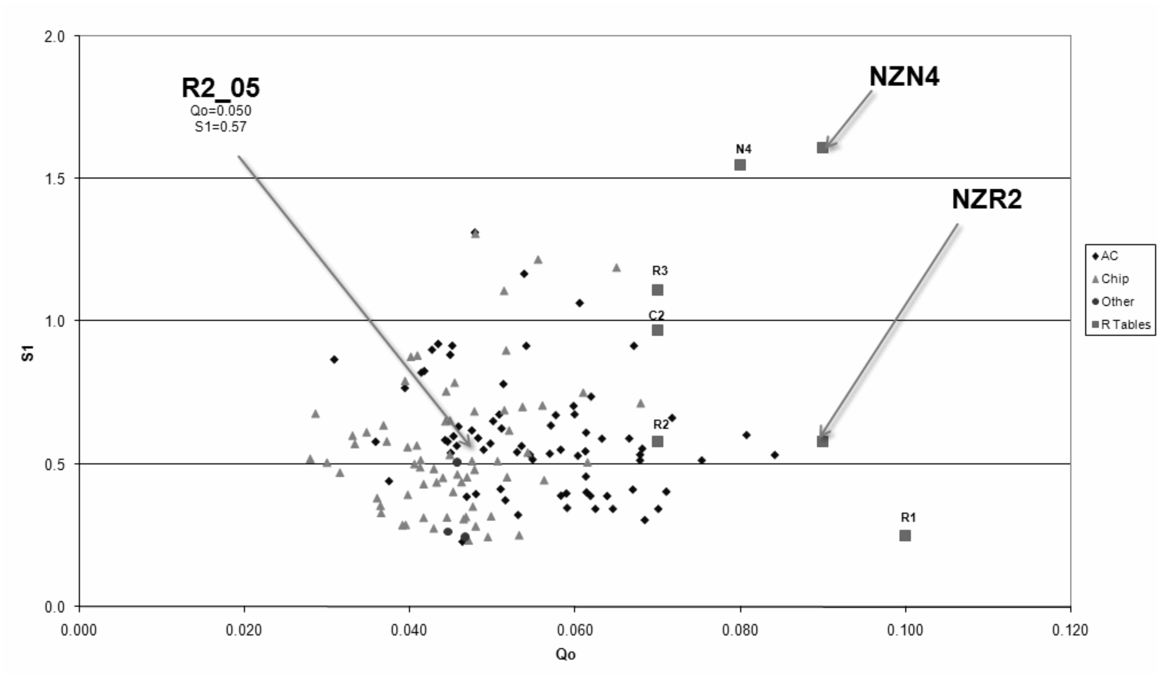

Figure 7: Qo verses S1 for all field measurements and the relative position of the R2_05 surface

Configurations Tested:

Thirty different lighting configurations were used to provide a cross section of the type of designs carried out with category V lighting in New Zealand. These used combinations of;

- 3 road cross sections (10m, 14m and 24.2m median divided)
- 3 lighting levels (V4, V3, and V2)
- 3 lighting arrangements (single sided, staggered, central)
- 2 lamp sizes (150 watt, 250 watt)
- 3 road surface r-tables (NZN4, NZR2 and R2_05)

Luminaire I-tables were chosen from the Betacom range typical of the most commonly used luminaires in New Zealand. An optimum mounting height was set for each option (10.5 - 12m) but some flexibility maintained for practical reasons.

Shortfall

To identify the status quo all 30 designs were made according to AS/NZS1158 standards using NZR2 / NZN4 r-tables. To establish what these designs were probably delivering the R2_05 r-table was substituted into the designs and the calculations rerun. The difference is the shortfall.

The shortfalls identified were:

- None (0) of the designs actually achieved the intended lighting subcategory. This is hardly surprising as average luminance decreased by 43% on average. The R2_05 designs usually delivered one and a half lighting subcategories below the intended level. eg V2 designs became slightly over lit V4 designs .
- The threshold increment (glare) increased on average by 58%. This resulted in 47% (14) of the designs failing to meet the threshold increment criteria.
- The overall uniformity (Uo) increased by 15% on average and the longitudinal uniformity (Ul) by 5% on average. This suggests that designs which are currently having difficulty attaining uniformity would probably have fewer problems with a R2_05 r-table.

Cost of Change:

Designs on the R2_05 surface required an average spacing 57% shorter than required for the NZN4 and NZR2 surfaces. The cost of the installation and its maintenance would also increase by around 57%.

However with greater flexibility in the design parameters (eg. higher wattage lamps) the increase in all of life costs can be reduced to around 50%. No doubt further economies of scale could arise to reduce this figure still further.

DISCUSSION:

This study commenced with the objective of measuring the road surface reflection properties of New Zealand roads to test how well they aligned with the results of the last measurements made 28 years ago. It was expected these results would either confirm the present New Zealand r-tables or indicate that changes are needed to match them with the surfaces in use today. The results suggest that the latter is the case and that the existing r-tables poorly represent the road surfaces in use today.

The NZ standard requires that all designs comply on a highly specular surface (NZN4) – a surface that was not found in this survey. Designing for this surface is unnecessarily restrictive and the standard tables can safely be reworked to remove this surface from the design criteria.

Of greatest impact is the finding on the Qo value. The two NZ standard r-tables used today (NZN4 and NZR2) have Qo values higher than their equivalent CIE standard surfaces as a result of previous studies. A high Qo raises the calculated brightness of the road so that less light is required in road lighting designs to meet the standards. However this study found that New Zealand road surfaces have Qo values consistently lower, not higher, than standard CIE surfaces. This means our roads are being lit to a lower level than our design calculations indicate.

It could be argued that NZ traffic routes have been lit to a level which most users now accept and that radical change is not really required. New Zealand traffic route lighting is already designed at lower brightness level than would be expected in Europe and this is further confirmation that New Zealanders are accepting much lower levels of lighting than Europe.

However, this type of argument is at variance with the safe system approach to road safety, recently endorsed by the National Road Safety Committee and forming the philosophical basis behind the draft road safety strategy for 2010. Safety rather than user acceptance is the issue. The alternative argument is that it is important that New Zealand uses the correct design parameters so that light is not wasted, value for money is obtained and the requirements of a safe system are achieved. Using a poorly aligned r-table doesn't just mean that our pavements are less well lit than previously thought it also means that the wrong decisions will be made during the lighting design process. Luminaire manufacturers develop luminaires to work effectively according to the documented road reflection properties. They provide different reflector /lamp positions so the best configuration can be selected based on road geometry. It is essential to this whole process that the correct road reflectance properties are used.

A further finding from this research is that designs made using the current r-tables are likely to subject motorists to higher levels of glare than design outputs indicate. New Zealand glare levels are already high by European standards. Older drivers suffer greater impairment from glare than younger drivers and older drivers are becoming a larger proportion of the New Zealand driving population.

The findings of this study are based on results from a calibrated, internationally established reflectometer from a major lighting firm. The average Qo value of 0.05 found in this study aligns with the values now being found on UK and European surfaces. (A recent UK study (Fotios, 2005) found an average Qo of 0.05 on UK asphaltic surfaces very similar to this study.)

CONCLUSIONS:

The conclusions from this study are that;

- The Memphis reflectometer has proved a practical device capable of measuring the surface reflectivity of New Zealand asphaltic concrete and chip seal road surfaces while remaining in calibration over the six week study period.
- The findings of this study suggest the current New Zealand r-tables used in lighting design (NZN4 and NZR2) are a poor fit with actual New Zealand road surfaces. The findings suggest New Zealand lighting will have lower carriageway luminance and higher glare levels than expected from the design outputs.
- The best-fit r-table for New Zealand road surfaces would be one based on CIE R2 with a Qo value of 0.05.
- Adopting the above r-table could increase the costs of new Category V lighting schemes by around 50%. (Category P schemes would not be affected.)
- To maximise road safety and energy efficiency it may be appropriate, as better and cheaper technology becomes available, to encourage local measurement of road surface reflection properties, rather than relying solely on average values from the standard tables for design purposes.

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