# AN INSTRUMENT FOR THE MEASUREMENT OF ROAD SURFACE REFLECTION PROPERTIES

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## Abstract

Road surface reflection data in the form of standard r-tables serve as input for design calculations of road lighting installations on traffic roads. However, in several countries the use of the standard r-tables has not been verified by measurement in a long period of time, while the types of road surfaces in use have changed - for instance to road surface types with less noise from wheel passages.

Because of this, a co-operation between the road administrations of the Nordic countries (abbreviated NMF) decided to construct a portable instrument to be used on selections of traffic roads within these countries in order to provide updated knowledge. This article describes the principles behind this instrument.

*Keywords**: Photometry, Road surfaces, Road markings, Reflection properties

## 1 Introduction

After an introduction to conventions for road surface reflection properties in section 2, it is demonstrated in section 3 that two specific reflection values, called $r_1$ and $r_2$, are sufficient to provide the characteristics of a road surface. These are the average reflection measured by either the average luminance coefficient Q0 or the luminance coefficient in diffuse illumination Qd, and the specular factor S1. Once Q0/Qd and S1 have been determined, a suitable standard r-table can be selected to represent the road surface.

Accordingly, any instrument that measures these two reflection values may be called a basic instrument. A particular version of such an instrument is described in section 4.

This instrument uses fairly long paths of light in order to keep angular apertures sufficiently low, but folds them by means of two mirrors in order to reduce the dimensions of the instrument.

The instrument uses a commercially available luminance camera as the detector instead of a built-in luminance meter. This requires some handling of the camera images to derive the measured values, but has these advantages:

- stability of measurement can be achieved by means of an in-built wedge,
- calibration can be carried out by means of an additional wedge,
- observations angles of 1°, 1,5° and 2,29° are provided

Measurements already carried out are presented in section 5.

It has been the goal to verify the validity of results obtained with the instrument by comparison to results obtained with other equipment. This has been carried out with some success, but there is a need for more inter comparison measurements.

However, the principles of the instrument are sound and measurements in the Nordic countries are ongoing – having already been carried out in Denmark.

It is inconvenient that the traditional observation angles are 1° for road surfaces and 2,29° for road markings. As measurements show that the choice of observation angle has little effect on the measured values, it should be possible introduce a single choice, preferably 2,29°.

## 2 Conventions for road surface reflection properties

Conventions for road surface reflection properties are supplied in CIE 144:2001 “Road surface and road marking reflection characteristics”. However, a short summary is given below.

Ordinary reflection is in principle described by means of values of the luminance coefficient q with a unit of $cd \cdot m^{-2} \cdot lx^{-1}$. A value of q depends on the geometry of measurement and illumination, which is defined by the angles shown in figure 1 where $\alpha$ is the angle of measurement, $\beta$ is the azimuth angle and $\gamma$ is the entrance angle.

It is a tradition not to supply values of the luminance coefficient q directly, but instead to represent them by values of the reduced luminance coefficient r given by $r = 10.000 \times q \times \cos^3(\gamma)$. This leads to convenient numerical values and some practical advantages for the calculation of road surface luminance in road lighting.

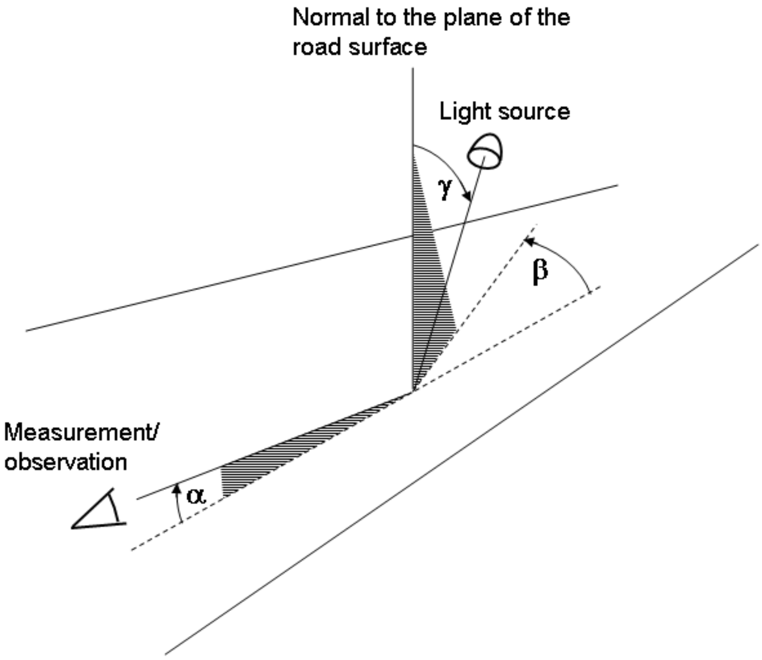


**Figure 1: The angles α, β and γ.**

The value of $\alpha$ is traditionally 1° corresponding to distances of 60 to 90 m for a driver of a passenger car. Because of this, the reflection properties of a road surface can be described by a table of r values with $\beta$ and $\gamma$ as parameters. Such a table in a standard format is called an r-table.

The format of r-tables is accounted for in CIE 144:2001. The table has values of $\beta$ from 0° to 180° only, as symmetry about the plane 0°/180° is assumed. It uses $\tan(\gamma)$ as a parameter instead of $\gamma$.

An r-table shows reflection of a diffuse nature overlaid with specular reflection with both types of reflection distorted in the texture of the road surface. Accordingly, an r-table can be characterized by a measure for the average reflection and a degree of specular reflection.

The average reflection can be indicated by the average luminance coefficient Q0 or the luminance coefficient in diffuse illumination Qd. Both have the unit of $cd \cdot m^{-2} \cdot lx^{-1}$. Both of these can be determined by means of weighted summation of the r-values of an r-table as described in CIE 144:2001. The weights are so that the summation of Q0 is with more emphasis on specular reflection than the summation of Qd. For this reason, the value of Q0 is larger than the value of Qd.

The degree of specular reflection is indicated by the specular factor S1, which is determined by S1 = $r_2/r_1$ where $r_1$ and $r_2$ are the r values at respectively ($\tan\gamma=0$; $\beta=0°$) and ($\tan\gamma=2$; $\beta=0°$).

Accordingly, Q0/Qd and S1 serve to characterize the reflection properties of a road surface and their values can be derived from the r-table that represents the road surface.

Alternatively, if Q0/Qd and S1 are measured directly on a particular road surface, the values can be used to select a suitable r-table to represent the road surface in road lighting calculations. The method is to choose an r-table with an S1 value close to the measured S1 value and then rescale it so that it obtains the measured value of either Q0 or Qd.

The choice can be among the standard r-tables accounted for and provided in CIE 144:2001, or it can be among a larger collection of measured r-tables.

## 3 Principles of a basic instrument

It is reasonable to assume that the average reflection measured by either Q0 of Qd can be estimated from the two r-values introduced in section 1, $r_1$ and $r_2$. To test that assumption, a collection of 285 r-tables provided in LTL report No. 10, Road surface reflection data, the Danish lighting laboratory 1975 has been used. It is noted that these r-tables are considered to be of a good quality and have been used for several purposes over the years – including the construction of the N- and C-series of standard r-tables.

Linear regression in these data 10 shows that the best possible linear estimates of Q0 and Qd are:

Q0 estimated = $(0{,}957 \times r_1 + 0{,}746 \times r_2 + 104{,}5)/10.000$ (1)

Qd estimated = $(0{,}981 \times r_1 + 0{,}323 \times r_2 + 86{,}1)/10.000$ (2)

For the total of the 285 r-tables, the correlations between true and estimated Q0 and Qd values are shown in figure 2.

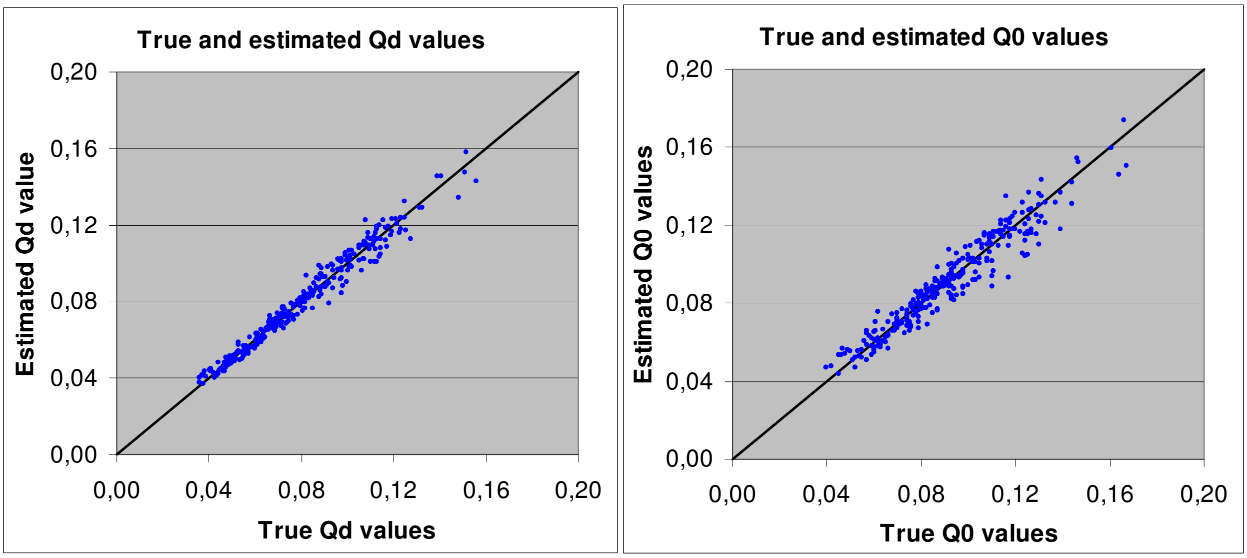


**Figure 2 - Correlations between true and estimated values of Q0 (left) and Qd (right).**

Figure 2 shows that the correlations are high for both Q0 and Qd, but highest for Qd. The reason for this is that Qd has the least weight to specular reflection – which is the type of reflection that is the most difficult to reproduce.

The actual standard deviations are 7,4 % for Q0 and 5,0 % for Qd. This means that the deviations in 5 % of the cases can be 14,5 % or higher for Q0 and 9,8 % for Qd. However, these figures are probably affected by fluctuations in the measured values of $r_1$ and $r_2$, so that the deviations in practice can be expected to be somewhat lower.

In view of this, a basic instrument can measure $r_1$ and $r_2$ only. Q0/Qd values are derived by means of the above-mentioned linear expressions. S1 is calculated as the ratio $r_2/r_1$.

## 4 Description of a particular instrument

### 4.1 Optics of the instrument

The optics includes illumination systems 1 and 2 for the measurement of respectively $r_1$ and $r_2$ and a luminance camera for the determination of the average luminance of the measured field. Refer to figure 3.

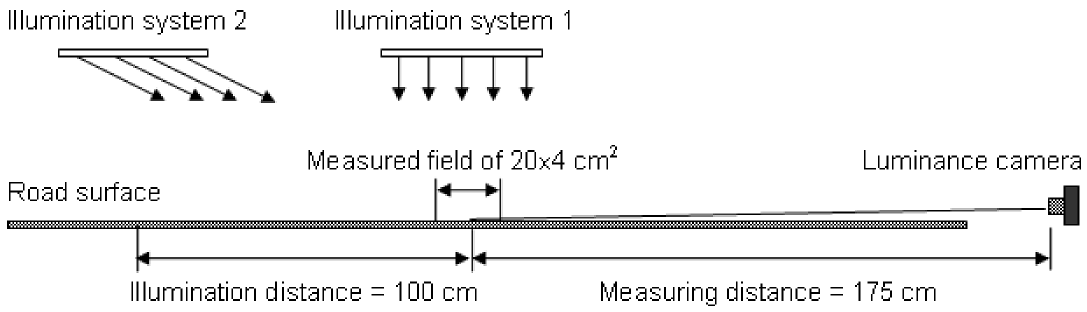


**Figure 3 - Optical principles of the instrument.**

The dimensions reflect the concern that $r_2$ must be measured with a small spread in the side angle $\beta$ of at most $\pm 2°$ for the reason that $r_2$ is a measure of specular reflection which is narrow of nature. With the indicated dimensions, the total spread in $\beta$ meets this requirement. Simultaneously, the measuring angle $\alpha$ varies no more than $\pm 6$ % along the measured field.

It is stated at once that the dimensions of figure 3 would lead to an instrument of an undesirable length of more than 2 m. additionally, the camera would get into conflict with the road surface. These problems are solved by the introduction of two mirrors as shown in figure 4. The back mirror is a front coated mirror placed with a tilt of about 45°. The front mirror is an ordinary mirror that is turned 5° about a vertical axis. Thereby, the illumination system 2 is placed in a line turned 10° to the side and out of conflict with illumination system 1.

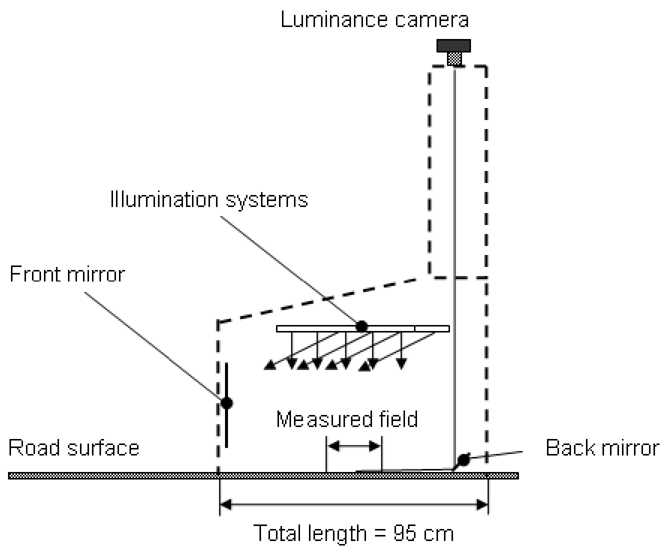


**Figure 4 - Use of two mirrors.**

Both of the illumination systems must provide uniform illumination over a field that covers the measured field with some reserve.

For the illumination system 1 the beam can be fairly wide, like ±10°, which also leads to a uniform illumination. This is achieved by mounting lamps of the same type against a raw glass causing some spread of light. The lamps are Philips halogen reflector lamps of the type 12V/20W/GU 5.3. Refer to figure 5.

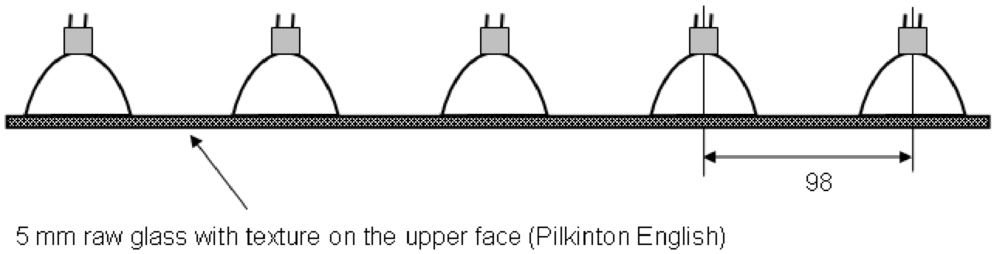


**Figure 5 - Illumination system for the measurement of $r_1$.**

For the illumination system 2, this raises the particular concern that the lamps must have very narrow beams. This is achieved by the use of lamps of the same type in the way shown in figure 6.

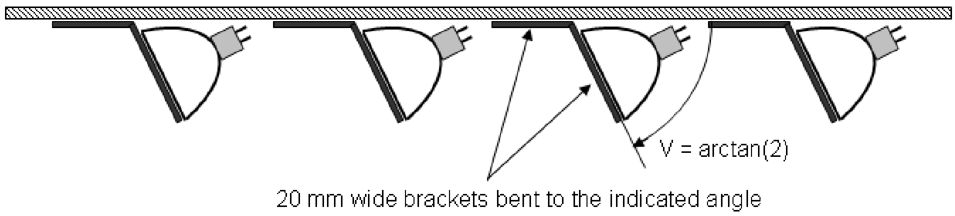


**Figure 6 - Illumination system for the measurement of $r_2$.**

The lamps are pressed against brackets as indicated in figure 6. This secures the proper alignment and, simultaneously, eliminates the broad part of the beam from the centre part of the lamps. The remaining part of the beam has a width of around ±2°.

The lamps of both illumination systems are placed with their openings approximately 50 cm above the road surface. The illumination system 1 provides illumination of more that 10.000 lx, while the illumination system 2 provides approximately 2.000 lx.

The luminance camera is an LMK mobile advanced from the German company TechnoTeam. Other types of luminance cameras of similar quality can be used.

## 4.2 Stability of measurement and calibration

The two illumination systems are supplied directly from a battery which will not provide constant light output from the lamps. Therefore, a particular device has been placed next to the measuring field and its luminance is determined from the camera images together with the luminance of the measured field.

The device is a wedge as shown in figure 7. The luminance of the device is the luminance of the opening of the wedge facing the measuring direction.

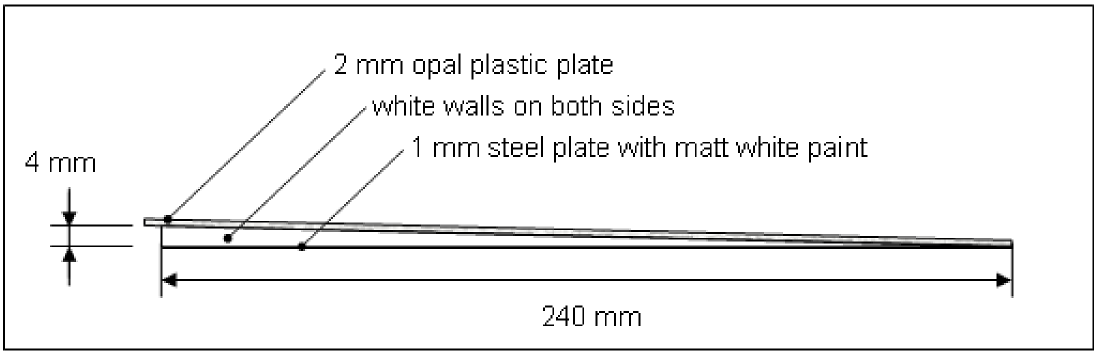


**Figure 7 - Wedge formed by a white steel plate and an opal plate.**

Accordingly, the measured value M is not directly the luminance of the measured field, but the ratio of this luminance $L_{field}$ and the luminance of the wedge $L_{wedge}$. Accordingly:

$$M = L_{field}/L_{wedge} \quad (3)$$

The r value, either $r_1$ or $r_2$, is obtained by:

$$r = C\times M \quad (4)$$

Where C is a calibration factor.

Calibration is performed by means of a similar wedge, serving as a calibration standard, whose r value $r_{standard}$ has been determined independently of the instrument. This standard is placed in the instrument, the value of M is measured and the value of C is determined by:

$$C = r_{standard}/M \quad (5)$$

The calibration has to be performed for both $r_1$ and $r_2$ measurement, for which different values of $r_{standard}$ and C apply.

The advantage of the wedges is that their luminance coefficients are robust to changes in the directionality of the lighting, and to the actual measuring angle.

**Figure 8 - The instrument on a road.**

## 4.3 The instrument itself and its use

The instrument in actual use is shown in figure 8.

The cabinet is built in 9 mm plywood of a good quality. There is one foot at the back on which the back mirror is mounted, and two additional feet at the sides. The front mirror is mounted on the inside of the front, which has the above-mentioned 5° turn. The top is a hinged lid with handles and a buckle bracket. It serves as a door to the battery and a panel with the illumination systems on the lower face and electrical wires on the top face. There are two switches on the right side of the cabinet to turn on/off the two illumination systems.

The camera is fixed in a mount placed on the top of a “tower”. There are locations corresponding to observations angles of 1,0°, 1,5° and 2,29°. The value of 1,0° is the standard value for road surfaces, while 2,29° is the standard value for road markings. The value of 1,5° has been added at an intermediate value. The calibrations are valid for each of the observation angles.

The high levels of illumination provided by the illumination systems ensure that any intrusion of daylight into the system is negligible. To prevent internal reflected illumination all interior surfaces has been painted black. A black horizontal panel is placed under the front mirror as an additional precaution.

The total dimensions of the instrument are L: 950 mm, W: 420 mm, H: 1400 mm, two wheels mounted at the back of the tower makes it easy to move between measurement areas.

After mounting the camera, and giving it the proper settings, the instrument is placed on the road. The measuring location can be inspected when opening the lid (it is next to the wedge). After closing the lid, measurements are done in a quick sequence, turn on illumination system 1, expose an image, turn illumination system 1 off and turn illumination system 2 on, expose an image, and turn illumination system 2 off.

The instrument can also be used to measure samples of road markings as the size of the measured field can be set in the software mentioned in the next section.

## 4.4 Handling images from the camera

A luminance table is generated from each of the two exposures by the camera for either $r_1$ or $r_2$ measurement. A table is inserted into a particular excel file, which shows an image containing the measurement field (field 1) and a field placed in the opening of the wedge (field 2). Refer to figure 9.

The fields are moved to the correct locations and the r value, either $r_1$ or $r_2$, is provided. Once both r values are available, a separate excel file is used to generate values of Q0 and/or Qd and S1 in accordance with section 3.

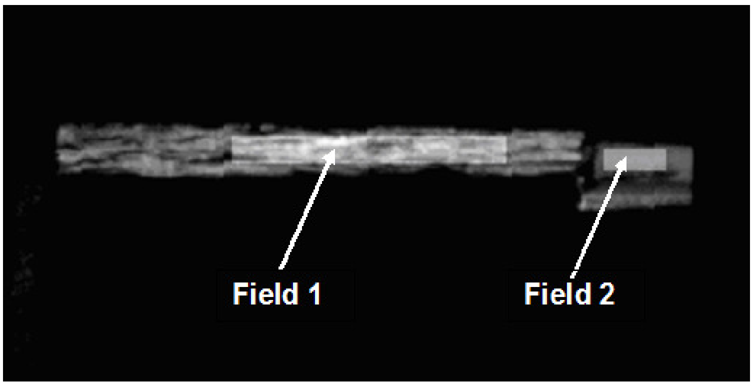


**Figure 9 – Image of the excel file.**

## 5 Measurements that have been carried out

It has been the goal (and still is) to verify the validity of results obtained with the instrument by comparison to results obtained with other equipment.

One successful comparison has been on the 11 samples shown in figure 12, which have been measured in a laboratory with suitable accreditation. Values of $r_1$ and $r_2$ are compared in figure 10. It is seen that correlations are good, but not perfect.

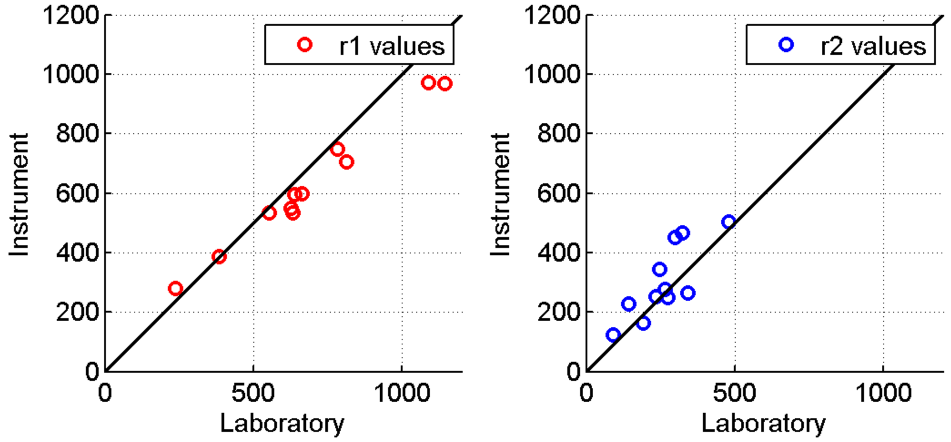


**Figure 10 - Comparison between $r_1$ and $r_2$ values measured on samples**

The reason for the deviations could be that the samples are critically small, in particular the ten circular samples which have a diameter of 15 cm. In all measurements, it is necessary to avoid some length at both ends – because of texture – so that the useful length becomes quite short.

It is the hope that there will be other opportunities for inter comparison. In the meantime the instrument is already being used in the Nordic countries. Measurements have been carried out on selected road in Denmark, and measurements on selected roads in Finland are being carried out this summer.

It is a peculiar case in Denmark that requirements for road surfaces include both the size and the average reflection of the stone material, so that class N2 can be expected in most cases. This involves a Qd value of approximately 0,078 and an S1 value in the range from 0,28 to 0,60. Figure 11 shows that these expectations were fulfilled.

In many cases, the measurements were performed not only with the observation angle of 1° traditionally used for road surfaces, but also with the observation angle of 2,29° used for road markings and the observation angle of 1,5° in between.

The general observation is that the values change little when changing the observation angle. This might be the basis for an attempt to introduce the same observation angle for road surfaces and road markings – preferably the larger of the two as a larger observation angle makes measurements easier.

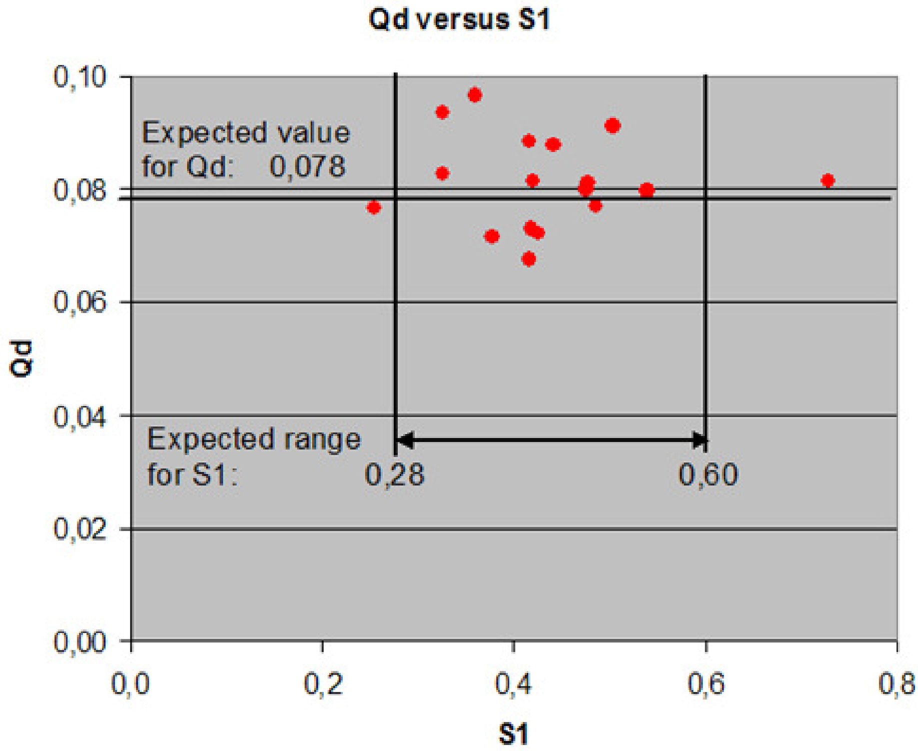


**Figure 11 - Measured values of Qd and S1 on roads in Denmark and their expected values.**

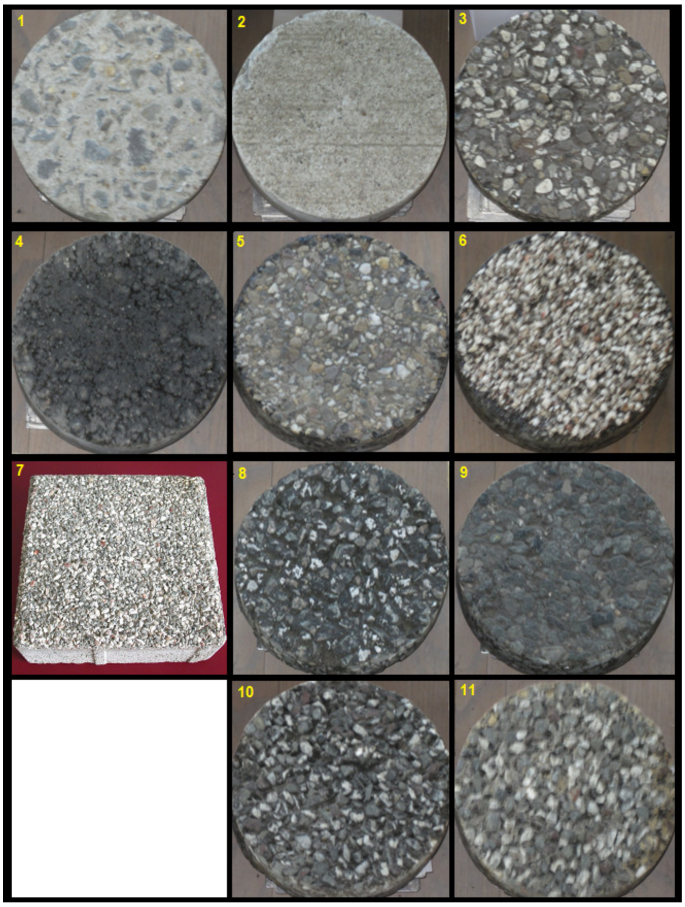


**Figure 12 – Eleven road surface samples**

## 6 Conclusion

In this paper a prototype instrument to measure the reflectance properties of road surfaces have been presented. The prototypes is based on a simple principle, to measure only two r-values of a road surface, and from these calculate the Q0, Qd and S1 values of the road surface. When these have been determined a suitable r-table can be selected. Comparison of eleven road samples measured with the instrument and a laboratory with a suitable accreditation has been carried out, it was seen that the correlation between the results are good, but not perfect. Results from measurements done in Denmark have been presented and they show that the measured values lies within what was expected for road surfaces in Denmark.

## References


CIE 2001. CIE 144:2001 Road surface and road marking reflection characteristics. Vienna: CIE.

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