A box for for the measurement of road surface reflection properties - version 21 February 2017

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Background

Road surface reflection properties are input to dimensioning calculations of road lighting on traffic roads and are in practise represented by standard assumptions that are old and have not been verified by measurements since the early 1980's.

There were some portable instruments for in situ measurement of road reflection properties in use during the 1970's and 1980's, but they were, with one exception, basicly unreliable. The exception was the LTL 200, which was developed at the Danish lighting laboratory at about 1980 and produced in a small number. These were a bit complex in use and expensive to produce, and none of them are probably in practical use to-day. A later type of instruments, Memphis®, may well have had virtues, but worked in an indirect manner and is no longer in use.

This situation gave cause to an idea of a simple instrument for the measurement of road surface reflection properties, which emerged on an NMF meeting in the Autumn of 2015. At this meeting, the author was given the job describe principles of such an instrument and, at further NMF meetings during 2016, this job was extended to include first a description of the optics and next to actually build a prototype.

This instrument is a box like construction that contains a mirror, two lighting systems, an in-built calibrator and a mount for a luminance camera. It is referred to as a measuring box or just a box in the following.

Note: NMF stands for Nordic Meeting For improved road equipment.

1. Introduction

In annex A it is explained that two values of the reduced luminance coefficient, called r_1 and r_2 in the following, of a road surface can lead to both of the characteristic values for the reflection properties of road surfaces. These are the specular factor S1 and the average reflection - measured by either the average luminance coefficient Q0 or the luminance coefficient under diffuse illumination Qd.

S1 is the ratio r_2/r_1, while Q0 and Qd are derived by means of these linear expressions in r_1 and r_2:
$Q0 = (0{,}957 \times r_1 + 0{,}746 \times r_2 + 104{,}5)/10.000$,
$Qd = (0{,}981 \times r_1 + 0{,}323 \times r_2 + 86{,}1)/10.000$.

It is recommended that Qd is used as the measure of average reflection for these reasons:

- the Qd value is determined with a smaller uncertainty than the Q0 value,
- reference values of Qd of samples can be determined by diffuse illumination provided in a photometric sphere, while it is very difficult to obtain reference Q0 values of samples,
- Qd is probably a better measure of the average reflection of road surfaces in road lighting conditions than Q0, in particular for road lighting with cut-off luminaires.

The reduced luminance coefficient is defined by:
$r = q \times \cos^3(\gamma) \times 10.000$,
where q is the luminance coefficient,
and γ is the entrance angle.

The multiplications with 10.000 and $\cos^3(\gamma)$ are conventional and serve to provide convenient numerical values.

As also accounted for in annex A, r_1 is defined by illumination perpendicular to the road surface, while r_2 is defined by illumination from the front at an entrance angle γ of 63,4° ($\tan\gamma = 2$). The value of r_1 can be measured with fairly large angular spreads of illumination, while the value of r_2 must be measured with angular spreads of a few degrees only.

Values of the reduced luminance coefficient are conventionally measured at an observation angle of 1,0°, which is measured between the central direction of measurement and the road surface. Therefore, the characteristic values are in principle also defined for an observation angle of 1,0°.

In contrast to this, Qd values of road markings are measured at an observation angle of 2,29° corresponding to the 30 m measuring geometry defined in EN 1436 "Road marking materials – Road marking performance for road users and test methods".

Because of this, the box hax been equipped to measure at both the above-mentioned observation angles – and also an observation angle in between the two of 1,5°. The observation angle, 1,0°; 1,5° or 2,29°, is set by the position of the camera on top of the box.

The measured field and the measuring system are introduced in section 2, the illuminations systems in section 3, calibration and stability of measurements in section 4, handling images from the camera in section 5, the cabinet in section 6 and use of the box in section 7.

2. The measured field and the measuring system

The box has three feet that define a plane containing a measured field, whose size and position is defined by the measuring system. The feet and the measuring system need to be held firmly into position relative to each other in order to maintain the size and the position of the measured field. This applies also for the illumination systems introduced in the next section.

In some portable instruments, for instance retroreflectometers for road markings such as the LTL-X produced by DELTA Light & Optics, the measuring system is a collimating luminance meter with a mirror at the bottom close to the road surface.

It is a characteristic of a collimating luminance meter that it is placed close to the measured field, so that dimensions of the instrument can be relatively small. It is another characteristic that the lens of the luminance meter must be larger that the width of the measured field.

However, the measuring system of the box uses a luminance camera - the LMK mobile advanced from TechnoTeam. This camera cannot be used as a collimating luminance meter, as the lens – rather the entrance pupil of the lens – is not sufficiently large. The camera must therefore be placed at a sufficient optical distance from the measured field in order to keep the angular spreads of measurement within acceptable limits. This has necessitated that the box has a "tower" on which the camera is placed.

The may be seen as a disadvantage, but the use of a camera also brings some advantages. One is that it is easy to set the observation angle by setting the position of the camera. Another advantage is that the measured field on the road surface is defined by a field in the camera image, which can be inspected and adjusted – for instance to fit fairly small samples.

The camera is also used with a mirror, which is a hard coated front mirror with a width of 72 mm and a height of 42 mm. It has been supplied by DELTA Light & Optics. The mirror is placed close to the road surface and has an inclination of approximately 45°.

The camera is placed above the mirror and aims at the road surface through the mirror. The total optical length from the camera lens to the centre of the measured field is 175 cm.

The camera is used with these settings:

a. full zoom corresponding to a focal width of 50 mm, so that there is a high resolution of the road surface,
b. manual focus on the road surface at a distance of a bit less than 2 m so as to obtain a good sharpness of the image at the road surface,
c. the maximum aperture number of 22, so that the entrance pupil of the camera lens is small and leads to a good depth sharpness of the image,
d. manual mode with a setting of the exposure time to 1/8 second in order to obtain a proper exposure of the image,

e. an exposure delay of 2 seconds to avoid that the image is shaken.

Settings a. and b. are to be checked for each exposure as handling the camera easily leads to changes.

Note 1: The camera is used for other purposes with an additional setting to full dynamic range, which leads to the exposure of three images with respectively 0,25, 1,00 and 4,00 times the requested exposure time. These images are later turned into a single image with a dynamic range that is 16 times the dynamic range of a single image. However, the dynamic range obtained in a single image of approximately 1:2000 is sufficient for this purpose.

Note 2: For reasons explained later, the camera does not have to be calibrated. This explains that it can be used with an aperture number of 22 for which the calibration is not valid.

The camera has 4.525.752 pixels placed in 1738 rows and 2604 columns. At full zoom with a focal width of 50 mm, the angular spacing between the pixels is 0,01028°. In total, the rows cover an angular range of approximately ±8,5°, while the columns cover an angular range of approximately ±13°

When measuring an unbroken surface or a sufficiently large sample, the small field in the camera image is set to produce a measuring field of a width of 4,4 cm and a length of 20 cm.

A width of the measured field of 4,4 cm is achieved by a width of 140 pixels of the small field in the camera image. The side angle within this width varies by ±0,72°

When the camera position is set to an observation angle of 1,0°, the length of the measured field of 20 cm is achieved by a height of only 11 pixels of the small field in the camera image. The observation angle then varies from 1,06° at the front end down to 0,95° at the back end.

This is actually the basis for a determination of the camera position for the observation angle of 1,0°. The box is placed on a panel with a white area of a length of 20 cm. The camera position in the longitudinal direction is adjusted until the image of the white area has a height of 11 pixels. This needs to be done only in illumination from the r_1 lighting system (vertical illumination), which gives the best promotion of a white area.

Figure 1 shows a camera image of a such a panel overlaid by a main field of a height of 11 pixels. It is seen that the height of the white area does match the height of the main field. The additional field is explained in section 4.

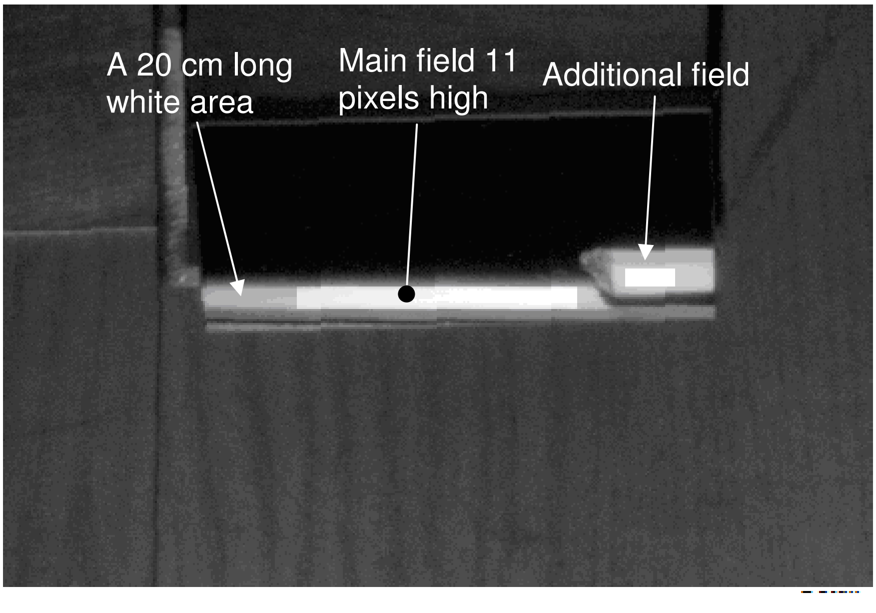


Figure 1: A panel with a white field.

The camera positions for the other observation angles of 1,5° and 2,29° can be determined the same way with, however, heights of the white area of respectively 17 and 25. These are also the heights of the main field that should be used when measuring at these observation angles.

However, it is more easy to calculate the camera locations relative to the location for 1° observation angle. At the optical distance of 175 cm, the camera position at the observation angle of 1,5° is found by moving the camera backwards by 175×tan(1,5°-1,0°) = 1,53 cm. For the observation angle of 2,29°, the camera is moved backwards by 3,94 cm.

3. The illumination systems

There are individual illumination systems for the two r-values, r_1 and r_2.

Both illumination systems use halogen low voltage reflector lamps of the type 12V/20W/GU 5.3 from Philips. These are probably the standard lamps with the most narrow beam on the market and have the advantages that they are driven by an ordinary 12 V sealed lead battery, and that the spectral composition is close to the standard illuminant A that is prescribed for measurements of road reflection properties.

The use of these lamps was supposed to be intermediate until suitable LED panels could be obtained. However, it seems to be difficult to find suitable LED panels, and the halogen lamps are used in a manner - as described in the following - that can serve as a permanent solution.

The illumination system for r_1 has five lamps aimed vertical downwards in a longitudinal row directly above the centre line of the measured field at a height of 50,2 cm above the road surface (measured to the fronts of the lamps). The spacing between the lamps is 98 mm and the position is so that the middle lamp is placed at a small distance of 3,6 cm in front of the centre of the measured field.

As the nominal beam width is 8°, it was thought that the lamps would provide an illumination of the measured field with an acceptable uniformity.

However, the illumination pattern did actually show isolated spots from each of the lamp. Additional non-uniformity is caused by differences in the aims of the lamps, as the aims are not firmly fixed by the sockets.

Both of these problems are solved in the way shown in figure 2. The fronts of the lamps are brought into contact with a glass that introduces a spread of the light of approximately ±5°. The contact dictates the aim, and the spread of light softens the illumination pattern. The glass does cause a raise of the beam width, but there is sufficient tolerance for this, when measuring r_1.

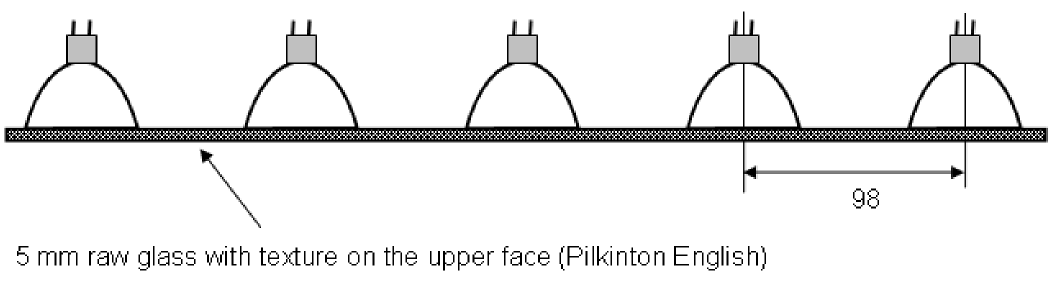


Figure 2: Illumination system for the measurement of r_1.

The illumination system for he measurement of r_2 is shown in figure 3.

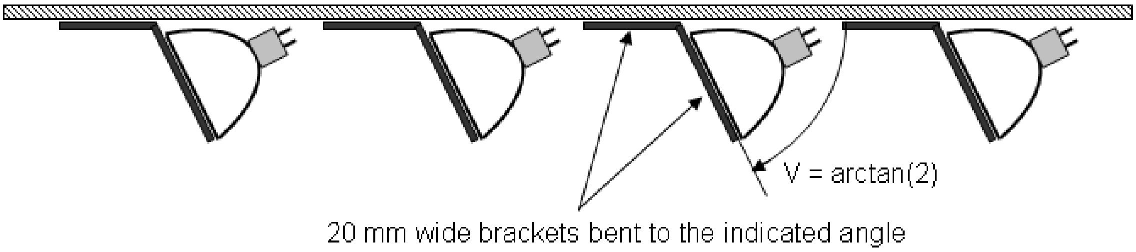


Figure 3: Illumination system for the measurement of r_2.

This illumination system has four lamps aimed at the proper angle in a row at a height of 53 cm above the road surface (measured to the centre of the fronts of the lamps). The spacing of the lamps is 11,2 cm.

The aim of the lamps is secured by contact with brackets. These brackets hide a substantial part of the fronts of the lamps and, thereby, reduces the luminous output. This on the other hand, causes a strong reduction of the beam width in the vertical plane, actually from the nominal ±8° down to ±2° or ±3°. This makes the illumination suitable for the measurement of r_2.

The lamps in the illumination system for r_2 illuminate the measured field by means of a mirror that sits at the front of the box and is rotated by 5° about a vertical axis. This mirror is an ordinary mirror; it has a height of 30 cm and a width of 10 cm. Its centre is 24 cm above the road surface and 45,7 cm in front of the centre of the measured field.

Because of the rotation of the mirror, the lamps are placed in a line that is turned 10° relative to the direction of measurement.

Accordingly, the lamps do lie in the vertical plane through the direction of measurement when viewed through the mirror. The optical distances from the centre of the measured field are respectively 93,2; 104,4; 115,6 and 126,8 cm. This can be compared to the above-mentioned distance to the mirror of 45,7 cm and shows that the mirror allows a reduction of the length of the box by more than 80 cm.

The aims of the lamps, as seen though the mirror, meet the centre line of the measured field at -12,8; -14; 10,0 and 21,3 cm relative to the centre (minus means to the back and plus to the front of the centre). The average of these values is 4,3 cm. Accordingly, both of the two lighting systems provide illumination that is not symmetrical about the centre, but shifted a bit in the forward direction.

This is on purpose, as the illumination must have some reserve in the longitudinal direction for the reason that curve and texture of the road surface, and small particles on the road, tend to cause lifts and tilts of the box. As an example, a lift of box of 1 mm would make the measured field move 5,7 cm forwards.

The r_1 illumination system provides illumination of more that 10.000 lx, while the r_2 illumination system provides approximately 2.000 lx.

4. Calibration and stability of measurement

An r value, either r_1 or r_2, can in principle be obtained by:

$r = C \times L_{field}$

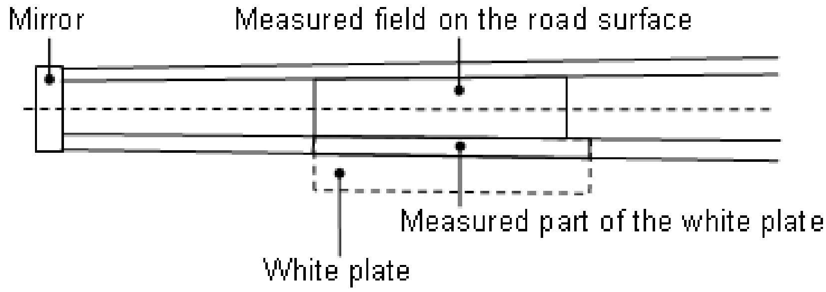
where C is a calibration constant,

and L_{field} is the luminance of the measured field as determined in the main field of the camera image.

However, this assumes that the levels of illumination by the two illumination systems remain constant – and this is not the case in view of changes in the voltage of the battery that feeds the lamps.

It is to compensate for this that the additional field in the camera image is introduced as already mentioned in section 2. This additional field is directed towards a white plate that is placed next to the measured field and therefore also illuminated. See figure 4.

Figure 4: Location of a white plate next to the measured field.



Accordingly, an r value, either r_1 or r_2, is obtained by:
$r = C \times L_{field}/L_{additional\ field}$
where C is a calibration constant,
L_{field} is the luminance of the measured field as determined in the main field of the camera image,
$L_{additional\ field}$ is the luminance of the white plate.

If a panel with a known value of r is available, the calibration constant can be determined by:
$C = r \times L_{additional\ field}/L_{field}$

Calibration has to be carried out for both r_1 and r_2 leading to two calibration constants C_1 and C_2.

The only problem is to obtain a panel with known values of r_1 and r_2. It is preferable that the values do not depend on the observation angle, so that offset in this angle does not introduce offset in the calibration constant. Additionally, the panel should be sturdy and the values should stay constant over time.

One attempt to establish such a panel has been to apply paint of the type used for the interior of photometric spheres in several layers on an aluminium substrate. The purpose is to achieve a panel with ideal diffuse reflection to the degree that the luminance coefficient is independent of the directions of illumination and measurement.

However, at small values of the observation angle, the luminance does decrease gradually with the actual value of the observation angle. This shows that the panel does not have the desired property of ideal diffuse reflection.

Note 1: The reflectance of the above-mentioned panel in the 45/0 geometry is 0,88, so that diffuse reflection would result in a value of r_1 of $0{,}88 \times 10.000/\pi = 2801$ and a value of r_2 of $r_1 \times \cos^3(\arctan(2)) = r_1 \times 0{,}0894 = 251$ and a value of S1 of 0,089.

However, the actual values are lower and corresponds to diffuse reflection with a reflectance of only 0,65.

The reason for this loss is probably that the measuring beam is partly reflected below the lamps in a kind of specular reflection. This in itself is a deviation from diffuse reflection, which makes the measured values depend on the observation angle.

Instead of a white panel, a wedge formed by a white steel plate and an opal plate as shown in figure 5 has been introduced. The sides of the wedge are closed by white walls as also shown in figure 5.

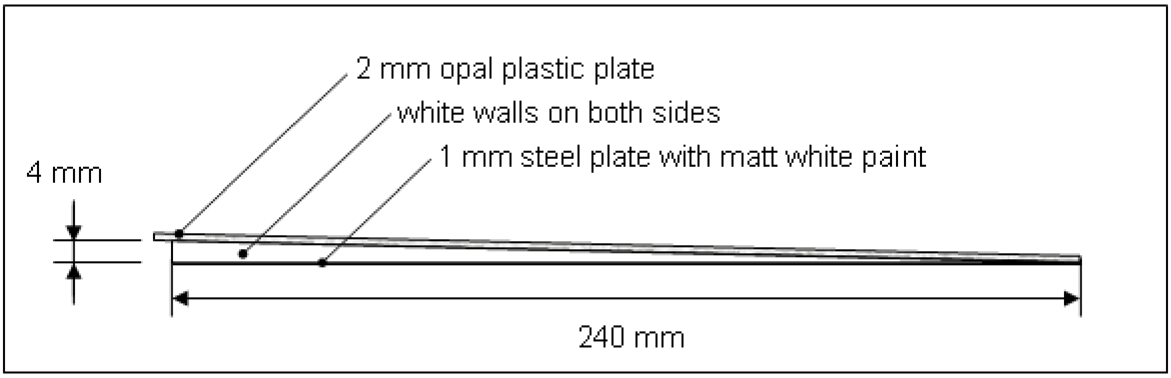


Figure 5: Wedge formed by a white steel plate and an opal plate.

This wedge has the advantage that the bottom plate plate - as seen through the opening of the wedge - shows a luminance with a high degree of uniformity and with little or no variation with the actual observation angle.

The luminance of the bottom plate can, therefore, be measured with a luminance meter to a good accuracy at a convenient observation angle of for instance 2° or 3°. Additionally, the horizontal illuminance at the location of the bottom plate is measured with a luxmeter.

The ratio between the luminance and the illuminance is the luminance coefficient of the wedge. This luminance coefficent has been determined to be 0,248 for the illumination direction of r_1. Accordingly, the wedge has an r_1 value of $r_1 = 0{,}248 \times 10.000 = 2480$.

Note 2: The above-mentioned luminance coefficient corresponds to a reflectance of a bit less than 0,8. This may seem to be a high value as about 60 % of the light falling on the opal plate is reflected and only about 40 % enters the wedge. However, interreflection between the white surface and the opal plate raises the reflectance considerably.

Because of the advantage obtained by the use of a wedge, instead of just a white panel, the white plate shown in figure 4 is also a wedge with, however, a smaller width and height. This wedge is fixed to the right hand side of the cabinet by means of two right angle brackets each held by two machine screws. It can be dismounted by removing these screws.

Both of the wedges and their fields are shown in the camera image in figure 6.

Figure 6: A camera image with the two wedges and their fields.

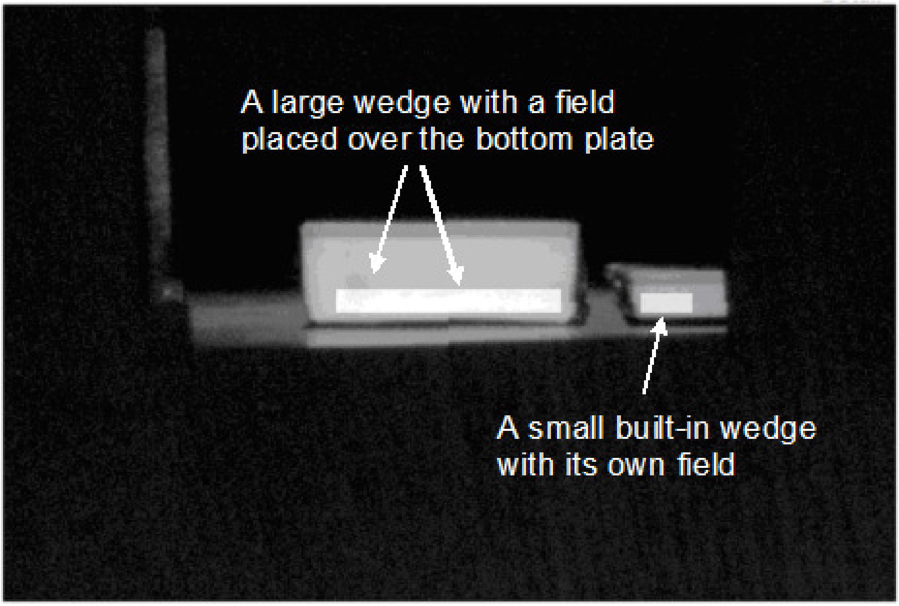


Figure 7 shows the luminance values in r_1 illumination of the two wedges for each of the three observation angles that the box can be used with.

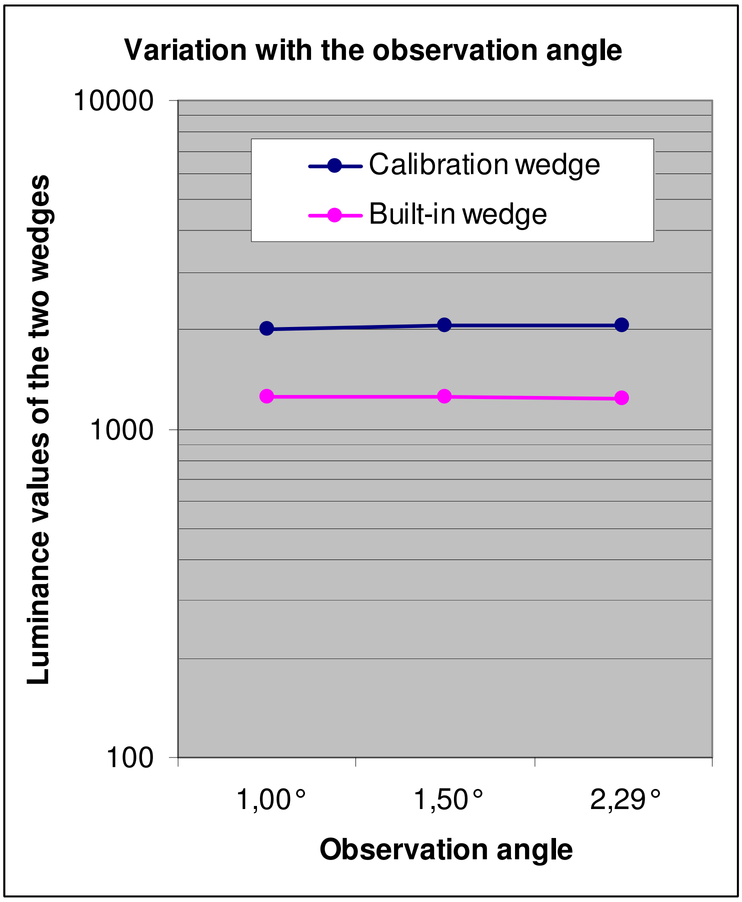


Figure 7: Luminance values of the two wedges for each of the three observation angles that the box can be used with.

In this case, measurements were done in a quick succession, so that both of wedges show close to constant luminance values. The most important matter is, however, that the ratio between the luminance values of the two wedges stays constant with 1 or 2 %. This shows that it is sufficient to calibrate at only one of the observation angles.

In the above, it was stated that the r_1 value of the luminance coefficient of the large wedge used for calibration is 0,248 for the illumination direction of r_1. This value of the luminance coefficient cannot be expected to apply for the illumination direction of r_2, as the reflectance of an opal plate increases with the angle of incidence.

Therefore, the luminance coefficient of the wedge would have to be measured for the r_2 illumination as well. Instead, the average illuminance values of the measured field for both illumination systems box have been determined in the box, and used to determine the luminance coefficient for the illumination direction of r_2. It becomes 0,235 corresponding to a value of r_2 of 210.

Note 3:

Some details are as follows. The two q values are given by:
$q_1 = L_1/E_1$
$q_2 = L_2/E_2$

where q_1 and q_2 are the luminance coefficients of the wedge in the two illuminations,
L_1 and L_2 are the luminance values of the opening of the wedge in the two illuminations,
and E_1 and E_2 are the average illuminance values in the two illuminations.

The ratio between the two equations is:
$q_2/q_1 = (L_2/L_1)\times(E_1/E_2)$

Which leads to:
$q_2 = q_1\times(L_2/L_1)\times(E_1/E_2)$

In this equation, q_1 is known.

The values of L_1 and L_2 appear in the camera images. It is best to determine these values twice, first in the sequence L_1 - L_2 and then in the sequence L_2 – L_1 and use the average values of each. The advantage of this procedure is that compensates for a gradual loss of voltage from the battery.

The ratio E_1/E_2 has also to be determined.

To do that, a number of locations within the measured field are selected. The luxmeter is held at the first location, the r_1 illumination is turned on, the illuminance is measured, the r_1 illumination is turned off, the r_2 illumination is turned on, the illuminance is measured, and the r_2 illumination is turned off.

This is done for all the locations, and the E_1 value is determined as the average of the illuminance values for r_1 illumination, while the E_2 value is determined as the average of the illuminance values for r_2 illumination.

The advantage of this procedure is that E_1 and E_2 values are determined shortly after each other, so that the ratio is not much influenced by gradual loss of voltage from the battery. In practice, the number of locations can be small.

5. Handling images from the camera

Images are converted to tables of pixels values as described in ”Bilag A: Optagelse af billeder med et digitalt luminanskamera og fremstilling af en måletabel” in the note ”Et regneark til beregning af luminans, blænding og lysstyrke”, Kai Sørensen, 9. februar 2016 (in Danish, available on nmfv.dk). The table can then be inserted into an excel file and analyzed as also described in the note.

The above-mentioned note concerns an excel file that can be used in combination with the camera to provide values of luminance, glare and luminous intensity in road scenarios. This excel file has been modified for this purpose in the sense that matters relating to glare, luminous intensity and some aspects of luminance have been deleted, while a second field has been introduced in addition to the main field as accounted for in section 4.

The main page of this excel file is shown in figure 8.

Zoom: (1 for f=50 mm, 2 for f=17 mm) :		1			
Greyscale: Level for black and step to white		10,0	5000		
Detail: move up/right	(pixels):	147	70	Average luminance of field 1 (cd/m2):	1105
rotation	(degrees):	271,0		Average luminance of field 2 (cd/m2):	2668
Field 1: width/height	(pixels):	140	11		
Field 2: move up	(pixels):	-8		r1 value	1025
Calibration factor for r1		2475			

Overview

Detail

Figure 8: Main page of the excel file.

The page has two images, one for overview and one for detail. The image for detail has the full pixel resolution and is the one to pay interest to.

This image shows two fields that are being promoted by having a higher luminance. The wide field is the main field (field 1) that defines the measured field, while the smaller field is an additional field (field 2) intended to be placed on the bottom plate of the in-built small wedge.

Additionally, a number of values can be set:

a. The value for zoom should generally be 1, meaning that the camera is used at full zoom (a focal width of 50 mm).
b. The values for grey scale do not have any influence of the results, but can be modified in order promote various aspects of the images.
c. Changes of the values for “move up/right” cause the detail image to move relative to the two fields. The value of “move up” should be selected so that the main field (field 1) clearly lies in the illuminated field on the measured surface, while “move right” should be selected so that the secondary field (field 2) lies in the left part of the opening of the in-built wedge.
d. The values for “width/height” decide the dimensions of the main field (field 1). The values should normally be 140 and either 11, 17 or 25 depending on the observation angle . However, the value for the height needs to be reduced, when measuring samples of lengths less than 20 to 25 cm.
e. The value for “move up” of the additional field (field 2) determines the up/down location of this field relative to the main field (field 1). The value should be selected, so that the field lies rather low in the opening of the in-built wedge.
f. The normal value for “rotation” is 270°, but can be changed a bit if this makes the image fit better to the pattern of the fields.

The dimensions of the additional field (field 2) cannot be changed and it cannot be moved sidewise relative to the centre of the main field, as this should not normally be necessary. However, changes can be set in a different page.

It is practical to open and work in two excel files, one for r_1 and the other for r_2, so as to ensure that the fields are placed in the same manner in both excel files.

For this reason, the excel file exists in two versions, for r_1 and r_2. Each of these has the relevant calibration factor and supplies the relevant value of r_1 or r_2 in addition to the average values of the two fields. The output values are given with a red font.

6. The cabinet of the measuring box

The cabinet is built in 9 mm plywood of a good quality. It is a box with the modifications mentioned below.

The front is turned 5° about a vertical axis, so that the mirror in the illumination system for r_2 can be mounted directly on the inside.

The top has some slope so as to provide space at the back for the 12 V sealed lead battery that feed the lamps. The top is a hinged lid with a handle and a buckle bracket. It serves as an entry to the battery and a horizontal panel just below the lid with the illumination systems on lower face and electrical wires on the top face.

The battery has a capacity of 3 Ah, while the illuminations systems for r_1 and r_2 use respectively 8,3 and 6,7 A. This does not leave much time with the light on, but is sufficient as a measurement takes a few seconds only. The battery should be fully charged before a series of measurement.

The back part of the box has a “tower”, on which the camera is mounted in a well defined position. The “tower” serves only to provide enough optical distance for the camera and is not needed if the camera is replaced by a collimated luminance meter in a final version of the box.

The feet of box are strong right angle brackets in stainless steel that are mounted with bolts and stick approximately 1 mm down under the cabinet. One is at the back, and serves also as a mount for the mirror in the measuring system. The other two are at the sides, approximately at the front end of the measured field.

There are two switches on the right side of the cabinet to turn on/off the two illumination systems.

There are no particular measures to prevent intrusion of daylight into the box. However, this is not a problem, because the cabinet leaves a gap of only 1 mm above the surface, and because the illumination systems provide illumination measured in thousands of lux.

The r_1 illumination system places by far the most of its light on the road surface at about the measured field and on the white wedge just above the road surface. Some of this light will be reflected onto the black interior surfaces and a bit of this light with be reflected again to add some illumination on the measured field and the white strip. This reflected light has a different directionality than the direct illumination, but can be ignored, being less than 1 % of the direct illumination.

The r_2 illumination system places most of its light in the same way through reflection in the mirror at the front surface. However, some light is placed at the front surface under the mirror and could – to the degree that it is reflected - raise the luminance of the measured field by specular reflection in the road surface. This, however, is avoided by means of black horizontal panel placed under the mirror over the width of the box.

The overall dimensions are a length of 95 cm, a width of 42 cm and a height of the sloping surface from 53 cm to 68 cm. The “tower” reaches op to a height of 140 cm.

All inside parts are painted black with a matt finish. Outside surfaces are painted grey with a matt finish.

The box is not heavy, but a bit akward to handle because of its size and shape. It can be carried in balance by means of the handle on the top lid, and it can be moved like a hand truck by means of two wheels mounted low at the back and another handle mounted high.
There is a protective bottom that can be fixed to the box by means two buckle brackets at each of the two sides.

Figure 9 shows the box with a camera mount placed on the top of the “tower”. The mount can be placed in the locations corresponding to the observations angles 1,0°, 1,5° and 2,29°.

Figure 9: The measuring box with the camera mount at the top.

7. Use of the measuring box

The protective bottom should be fixed to the box during transport and the camera should be placed in its box. It is most easy to mount/demount the protective bottom, when the box is lying on its back surface.

Before use, it should be verified that the optical components are clean:

- the camera lens,
- the two mirrors,
- the wedge next to the measured field.

It is best to place the box on a side or the back, when inspecting the two mirrors and the wedge.

The camera lens and the 45 mirror at the bottom are sensitive and should be cleaned with care and suitable agents. The mirror at the front, on the other hand, is an ordinary mirror and durable.

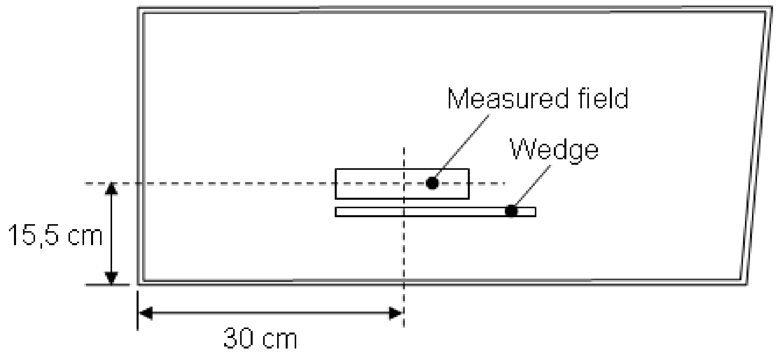
Further, the battery should be charged by using a 12 V battery charger (that comes with the box). This may take hours.

The camera is to be mounted in the holder and to be given the settings that are listed in section 2.

The box is to be placed on the road surface to be measured so that the measured field is at the desired location.

As accounted for in section 2, the measured field has the dimensions of 4,4 times 20 cm, when using a field in the camera image of 140 times 11 pixels. Additionally, the centre of the measured field is located as shown in figure 10.

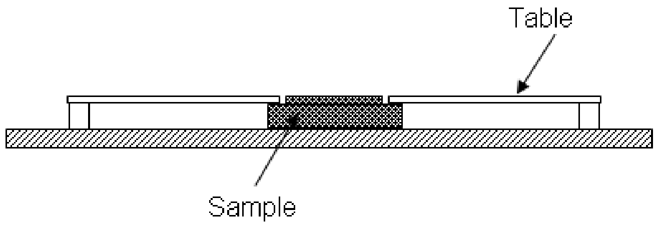
Figure 10: The location of the measured field.



Due to the relatively small area of the measured field, the measured values of r_1 and r_2 may be subject to random variations. This would in particular apply for road surfaces with large stones. Therefore, it should be considered to measure at two or three nearby positions, and let the average values of r_1 and r_2 for these positions represent the road surface.

In case a sample is to be measured, it is practical to mount the sample in a table as shown in figure 11. The table is to be placed on a plane surface, and the sample is to be aligned so that its upper surface lies in the plane of the top surface of the table. Measurements are done with the box placed on the table. In case the sample is shorter than 20 cm, the height of the small field in the camera image must be reduced and perhaps moved a bit, so that it fits within the surface of the sample.

Figure 11: A table to be used for the measurement of samples.



The camera in its holder should not be mounted on the top of the box until it is placed at the measuring location, either on a road surface or on top of a table. Check before each exposure that the focus (a bit less than 2 m) and the zoom (maximum zoom of f equal to 50 mm) has not been changed by handling.

The camera is then turned on and the following sequence is carried out:
illumination system 1 is turned on,
an image is exposed,
illumination system 1 is turned off,
illumination system 2 is turned on,
an image is exposed
illumination system 2 is turned off.

The sequence takes only about 15 seconds.

Before or after a series of measurements, the calibration wedge may be measured. The box is placed on a plane surface and the calibration wedge is placed next to the in-built wedge, so that it covers the measured field.

After a series of measurements, the images are handled like described in section 6. Each pair of images for r_1 and r_2 may take about 5 minutes.

Annex A: Some principles for in situ measurement of road surface reflection properties

A.1 Introduction

Road surface reflection properties are introduced in A.2.

Among else, it is stated that a road surface can be characterized by its average reflection and a measure of its degree of specular reflection. The average reflection can be indicated by the average luminance coefficient Q0 or the luminance coefficient in diffuse illumination Qd. The degree of specular reflection, on the other hand, is indicated by the specular factor S1, which is the ratio between two individual reflection values called r_1 and r_2.

In A.3 it is shown that Q0 and Qd can be estimated on the basis of r_1 and r_2. This provides the possibility of basing in situ measurement of road surface reflection properties on the measurement of those two reflection values only.

The principles of a measuring box for in situ measurement are discussed in A.4. It is shown that it is permissible to use illumination with rather large angular spreads for the measurement of r_1, while the angular spreads of illumination must be small, when measuring r_2.

A.2 Road surface reflection properties

The reflection of a road surface can in principle be described by means of values of the luminance coefficient q, which is given by:

Q = L/E

where L is the luminance produced by illumination,

and E is the illuminance on the plane of the road surface.

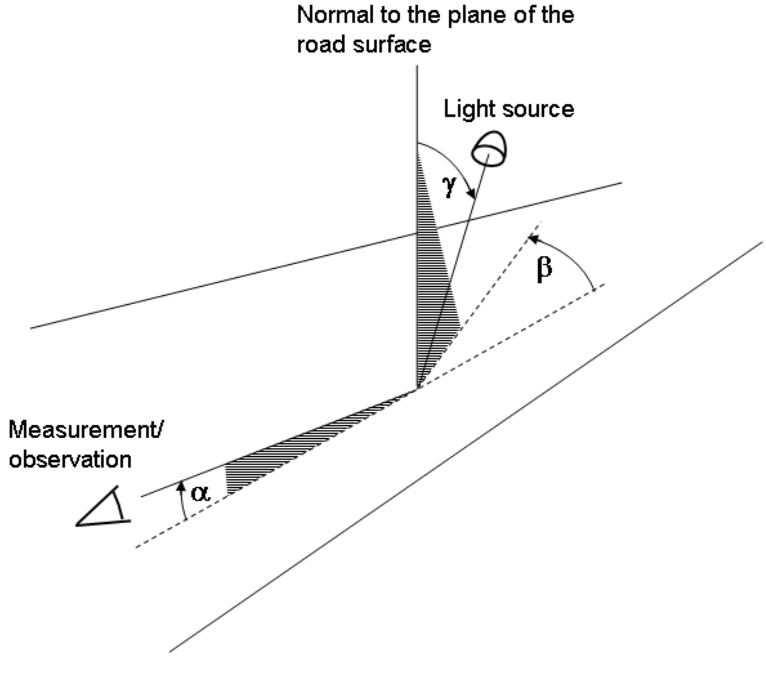
The unit for q is $cd \cdot m^{-2} \cdot lx^{-1}$.

A value of q depends on the geometry of measurement and illumination, which is defined by the angles shown in figure A.1:

- α is the angle of measurement/observation measured between the plane of the road surface and the direction of measurement observation,
- β is the side or azimuth angle measured between two half planes, both perpendicular to the plane of the road surface, and containing respectively the direction of measurement and the direction of illumination,
- γ is the entrance angle measured between the normal to the plane of the road and the direction of illumination.

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

Figure A.1: The angles α, β and γ.



The value of the angle of measurement/observation is traditionally 1° corresponding to distances of 60 to 90 m for a driver of a passenger car. Because of this, it is sufficient to supply a table of r values with β and γ as parameters to describe the reflection properties of a road surface. Such a table is called an r-table.

An r-table is presented in a standard format as shown in table A.1.

The standard format has values of β from 0° to 180° only, as a symmetry about the plane 0°/180° is assumed. The standard format does not use γ directly as a parameter, but tan(γ).

Table A.1: Example of an r-table in a standard format.

	β (degrees)																	
tan(γ)	0	2	5	10	15	20	25	30	35	40	45	60	75	90	105	120	165	180
0,00	***354***	354	354	354	354	354	354	354	354	354	354	354	354	354	354	354	354	354
0,25	391	391	390	389	388	385	381	378	373	369	365	351	338	328	319	313	304	304
0,50	406	404	403	397	390	379	366	355	343	330	318	291	268	256	247	242	240	240
0,75	405	403	399	384	365	342	319	298	278	260	244	213	192	182	176	175	177	177
1,00	396	392	384	357	322	287	254	228	207	189	175	147	133	126	124	123	129	130
1,25	383	374	360	317	269	227	193	168	149	134	123	103	93	89	87	89	95	96
1,50	360	351	328	270	215	172	141	119	105	94	86	72	66	63	63	64	71	72
1,75	335	325	294	224	165	127	102	86	75	67	61	52	47	46	47	48	54	55
2,00	***312***	298	259	182	126	94	75	63	56	50	45	38	35	35	35	37	42	43
2,50	270	250	199	120	76	53	43	35	32	28	26	23	22	21	22	23	28	28
3,00	233	206	148	78	46	31	26	21	19	18	17	15	14	14	15	16	19	20
3,50	202	171	109	51	29	20	17	14	13	12	11	10	10	10	11	11	14	15
4,00	177	142	82	35	20	13	11	10	9	8	8	7	7	7	8	8	11	11
4,50	155	118	61	24	14	10	8	7	7	6	6	5	5	6	6	6	8	9
5,00	137	100	47	18	10	7	6	6	5	5	5	4	4	5	5	5	7	7
5,50	121	84	37	13	8	6	5	5	4	3								
6,00	108	72	29	11	6	5	4	4	4									
6,50	97	62	24	8	5	4	4	3										
7,00	89	55	20	7	4	3	3	3										
7,50	81	49	17	6	4	3	3											
8,00	74	43	15	5	3	2	2											
8,50	68	38	12	4	3	2	2											
9,00	63	34	11	4	2	2												
9,50	58	31	9	3	2	2												
10,00	54	28	8	3	2	2												
10,50	51	26	7	3	2	2												
11,00	48	24	6	2	2	2												
11,50	45	22	6	2	1													
12,00	43	21	5	2	1													

The luminance coefficient q does not vary strongly at values of β of 5° or higher, corresponding to reflection of an approximately diffuse character produced by reflection in the surface material. However, because of the above-mentioned factor of $\cos^3(\gamma)$, the r-values decrease with tan(γ).

At small values of β, the r-values decreases more slowly with tan(γ) and reach in fact often a maximum before decreasing again. This corresponds to a steady increase of the luminance coefficient q with tan(γ) to high values. This feature is explained by specular reflections in the facets of the road surface.

In this way, an r-table can be understood as showing reflection of a diffuse nature overlaid with specular reflection. This is useful, but somewhat simplified as both types of reflection are distorted in the texture of the road surface.

An r-table is characterized by a measure for the average reflection and a degree of specular reflection expressing the balance between diffuse and 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 $cd \cdot m^{-2} \cdot lx^{-1}$.

Q0 and Qd can both be determined by means of weighted summation of the r-values of an r-table. 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 specular degree is indicated by the specular factor S1, which is the ratio between the r-values at ($\tan\gamma=2$; $\beta=0°$) and ($\tan\gamma=0$; $\beta=0°$). Those two values are promoted by fat types in table A.1 by and are designated r_1 and r_2 for the r-values at respectively ($\tan\gamma=0$; $\beta=0°$) and ($\tan\gamma=2$; $\beta=0°$) in the following.

An r-table can result from measurement on a road surface, or it can be a standard r-table. The following standard r-tables are in use:
- an N-series including N1, N2, N3 and N4,
- a C-series including C1 and C2,
- an R-series including R1, R2, R3 and R4.

These standard r-tables apply for dry road surfaces. For wet road surfaces, there is a W-series including W1, W2, W3 and W4 in use.

The values of Q0, Qd and S1 for the above-mentioned standard r-tables are shown in table A.2

Table A.2: Q0, Qd and S1 for standard r-tables.

Serie	Tabel	Q0	Qd	S1
N1-N4	N1	0,100	0,092	0,18
	N2	0,070	0,061	0,41
	N3	0,070	0,054	0,88
	N4	0,080	0,054	1,61
R1-R4	R1	0,100	0,087	0,25
	R2	0,070	0,057	0,58
	R3	0,070	0,050	1,11
	R4	0,080	0,052	1,55
C1-C2	C1	0,100	0,090	0,24
	C2	0,070	0,054	0,91

One intention behind the characterization with Q0/Qd and S1 is to make it sufficient to measure either Q0 or Qd and S1 for a given road surface, and then represent the road surface by one of the standard r-tables. This standard r-table is selected on the basis of the value of S1, and then rescaled to match the measured values of Q0 or Qd.

For the N series of r-tables, N1 is selected when $S1 \leq 0{,}50$; N2 when $0{,}50 < S1 \leq 1{,}00$; N3 when $1{,}00 < S1 \leq 1{,}50$ and N4 when $1{,}50 < S1$. There are similar criteria for the C and R series of r-tables.

If, as an example, the measured Qd value is 0,08 and the standard r-table N2 with a Qd value of 0,07 has been selected, this table is to be rescaled with a factor of 0,08/0,07 = 1,143. However, it is more practical to use N2 as it is without rescaling, and instead rescale the luminance values resulting from calculations of road lighting.

A.3 Estimation of Q0 or Qd on the basis of r_1 and r_2

LTL report No. 10, "Road surface reflection data", the Danish lighting laboratory 1975 presents among else r-tables for 285 road surfaces and their values of Q0 and S1. These data 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. The R-series of standard r-tables, on the other hand, are based on a smaller number of measured r-tables of an even older date and probably of a less good quality.

An additional use of these data has been to form the basis for a portable instrument - called the LTL 200 – for in situ measurement of road surface reflection properties. This instrument was produced in a few copies and worked well without being perfect.

However, the basis show that it is possible to construct an r-table from a few characteristic r-values, of which r_1 and r_2 are the most important. The ratio between these two r-values gives directly the value of S1 and, if Q0 and/or Qd can also be determined on the basis of the two r-values, they can lead to a complete characterization of the reflection properties of a road surface.

Linear regression in the above-mentioned data in LTL report No. 10 shows that the best possible linear representation of Q0 is given by $(0{,}957 \times r_1 + 0{,}746 \times r_2 + 104)/10.000$. As an example, the r-table shown in table A.1 has a calculated value of Q0 of 0,068, while the correct value is 0,070.

For the total of the 285 r-tables, the correlation shown in figure A.2 is established. The correlation is very good with, however, a standard deviation of 7,4 %. This means that the deviation can be 14,5 % or higher in 5 % of the cases.

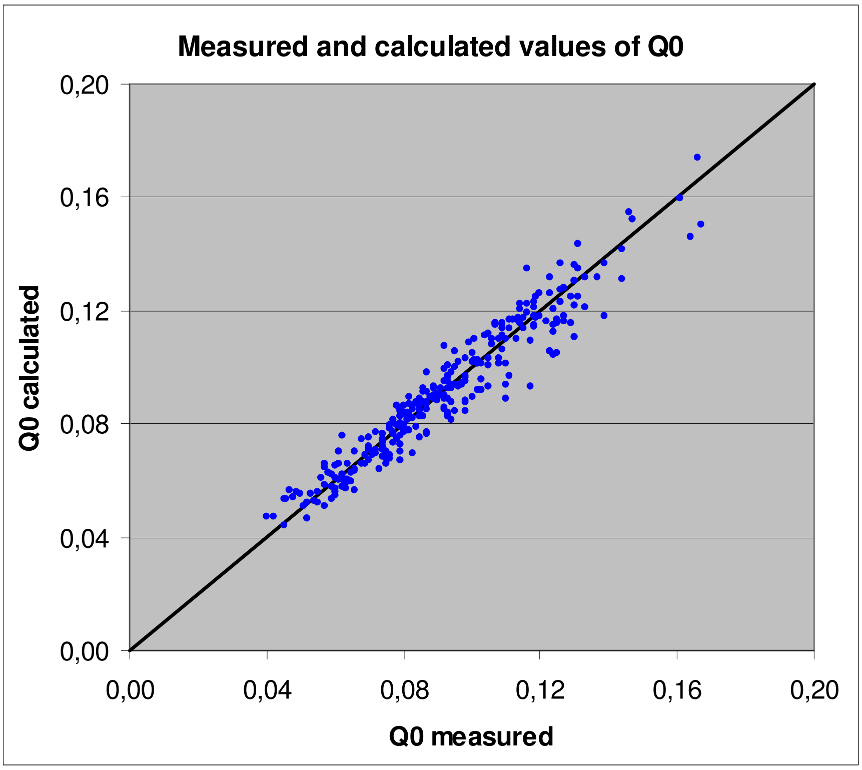
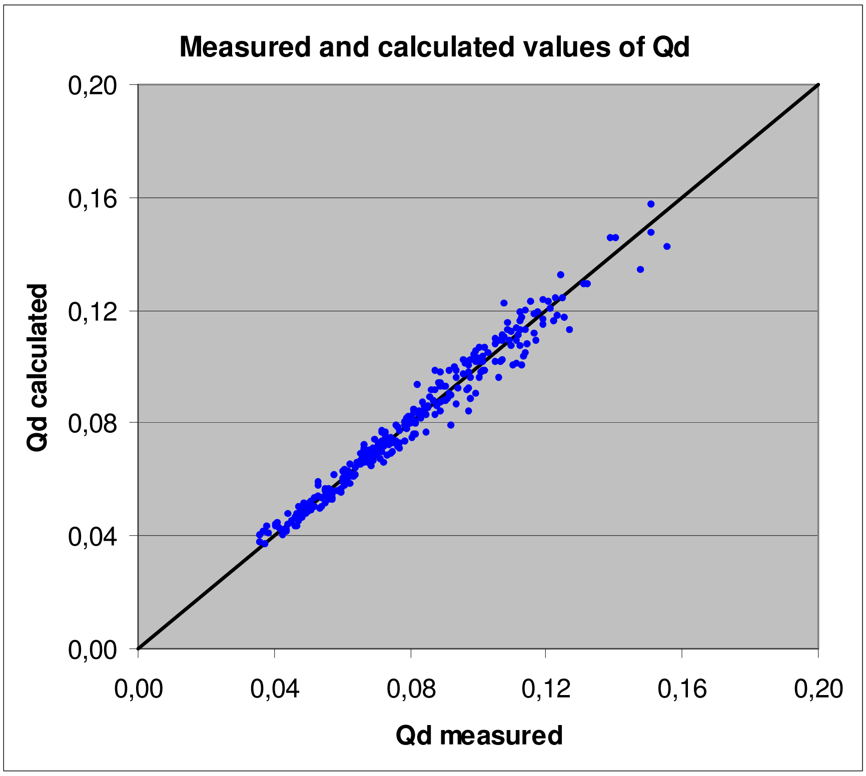


Figure A. 2: Measured and calculated values of Q0 for r-tables in LTL report No. 10.

In order to obtain a correlation for Qd it has been necessary to digitize the r-tables of LTL report No. 10 and calculate the Qd values. The correlation is shown in figure A.3.

The best possible linear representation of Qd is given by $(0{,}981 \times r_1 + 0{,}323 \times r_2 + 86{,}1)/10.000$. The correlation is shown in figure A.3 and is seen to better than for Q0. The standard deviation is 5,0 %, which means that the deviation can be 9,8 % or higher in 5 % of the cases.

Figure A.3: Measured and calculated values of Qd for r-tables in LTL report No. 10.



The reason why Qd can be reproduced with a better accuracy than Q0 is that Qd has the least weight to specular reflection – which is the type of reflection that is the most difficult to reproduce.

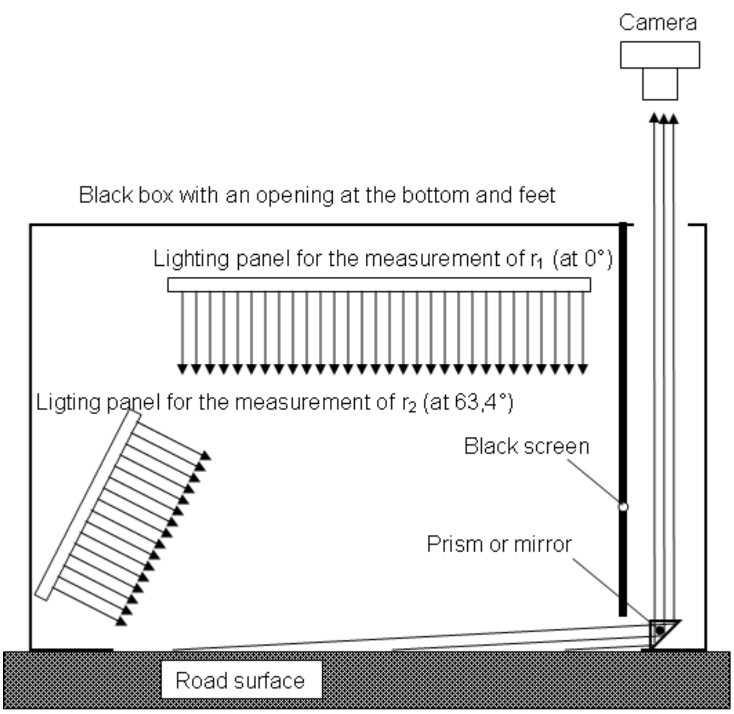
Because of this, it is an advantage to use Qd in stead of Q0 as a measures for the average reflection of a road surface..

However, this raises as old discussion of whether Qd or Q0 provides the best directional distribution of the illumination of a road surface in road lighting – and of road lighting traditions in different countries. The author thinks that Qd is also best in this connection and that LED lighting pushes in this direction.

A.4 Principles for the measurement of r_1 and r_2 with a portable measuring box

Figure 4 shows the principle for a box for the measurements of r_1 and r_2.

Figure 4: Principle for a measuring box for the measurement of r_1 and r_2.

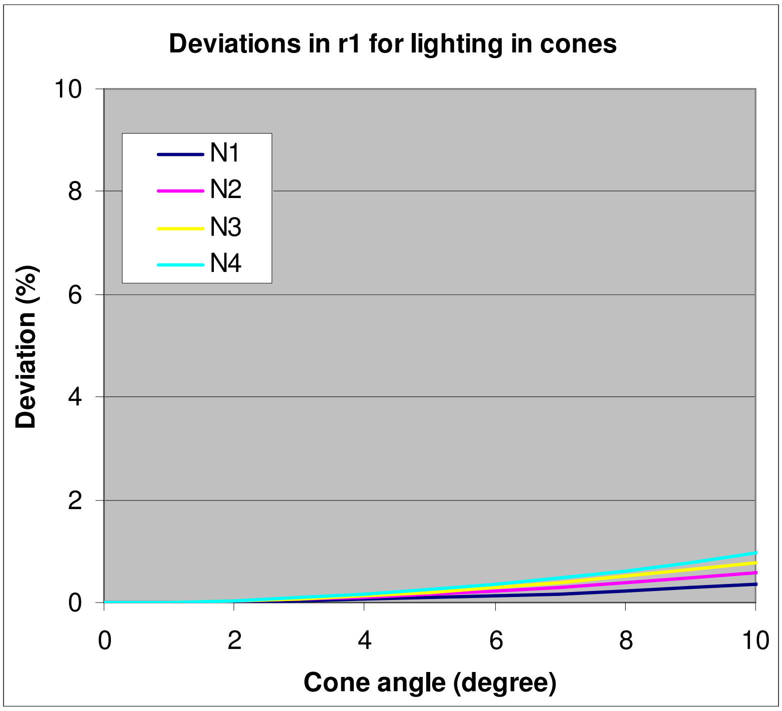


The lighting panels will in practice emit light within a certain angular range, whereby the measured value becomes an average of the luminance coefficient within that angular range. Any deviation between this average and the value measured with a small angular spread is a source error.

This deviation can be calculated for a given r-table by assuming lighting within a cone with a given cone angle.

Such deviations are shown in figure 5 for r_1 and the standard tables N1, N2, N3 and N4. The deviations are small up to even ±10°.

Figure 5: Deviations in measured values of r_1 for lighting in cones.



The deviations are shown in figure 6 for r_2 and the standard tables N1, N2, N3 and N4. These deviations can become large unless the cone angle is at most ±2°. However, a closer study shows that the spread of illumination in the longitudinal direction can be larger, as long as it does not exceed ±2° in the transverse direction.

The reason why there is little tolerance for spread in the illumination for r2 is that is that the q value is large at β = 0° due to specular reflection, bur decreases rapidly with increasing value of β. This also explains why the deviation grows in the sequence N1, N2, N3 and N4, which corresponds to an increasing degree of specular reflection.

It is to be noted that spread in the measuring direction has the same effect and needs to be kept low.

Figure 6: Deviations in measured values of r_2 for lighting in cones.