Work on reflection properties at DELTA

Work on reflection properties of road surfaces, road markings and road signs at DELTA.

Introduction

The Danish Illuminating Engineering Laboratory was founded in 1964. Work regarding design criteria for road lighting, involving reflection properties of road surfaces, started almost at once. Work on the reflection properties of road markings and road signs started somewhat later, during the seventies.

At the beginning, this work was of a pioneering nature, as the technical development brought new techniques concerning road equipment (mirror optics for road lighting luminaries, glass beads for road markings, and retro-reflective sheeting materials for road signs). The work was both with a national aim, to provide the basis for national road standards, and with an international aim of participation in the work of CIE. A Nordic Research Co-operation in this field was established in 1973. The work included research sponsored by in particular the Danish Road Directorate, and it included work on a commercial basis.

The work has been carried on with of course a gradual change of circumstances. Close connections to the Danish Road Directorate still exist, Danish road standards are complete, but need revision at intervals, standardisation regarding road equipment in the CEN has been a fairly large activity for some years, there is still participation in the work of CIE, the Nordic Research Co-operation is still active etc. On the organisation side, the Danish Illuminating Engineering Laboratory was a part of a merger in 1990 resulting in 'Light & Optics', which is now a division of DELTA Danish Electronics, Light & Acoustics.

This work has led to accumulation of knowledge in the field of road equipment, of which a spin-off is successful design of measuring instruments. The paper accounts for some steps in this accumulation of knowledge and for some features of the measuring instruments.

Road lighting and the reflection properties of road surfaces and road markings

General considerations

The use of the luminance of the carriageway as design criteria for road lighting for traffic roads emerged as an idea in the mid sixties and was developed in a period of about 10 years.

The basis of this 'luminance concept' is that a driver sees the road surface by means of its luminance (and not its illuminance), which must be sufficiently high and uniform. The road surface obtains its luminance by the process of illumination and reflection and therefore the road surface becomes a 'component' of the road lighting system.

A road surface has 'mixed reflection', which to some simplification is composed of 'diffuse reflection' and 'specular reflection'. The 'whiteness' of the aggregates in the road surface adds to the diffuse reflection, while the texture of the surface determines the specular reflection - less texture leads to more specular reflection.

The reflection parameter used to describe this type of reflection is the luminance coefficient q, which is the ratio of the luminance L of the road surface to the illuminance on the plane of the surface E. As luminance is measured in $cd \cdot m^{-2}$ and illuminance in lx, the unit is $cd \cdot m^{-2}\ lx^{-1}$.

Drivers need to see the road surface at some distance. The angles relative to the road surface do of course vary with the actual distance and the transverse location of the observed location, but the value of q depends little on this variation as long as the distance is fairly large. Therefore, the observation direction has been fixed to form a certain

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small angle relative to the plane of the road surface and to point in the direction of traffic.

The value of q, on the other hand, depends fairly strongly on the direction of illumination. Accordingly, a table of q values is needed to characterise the reflection of a particular road surface.

NOTE: A somewhat different reflection parameter, which is derived from q and called the 'reduced luminance coefficient' r, is used in the table for practical reasons.

The general features of a table are characterised by two parameters, one relating to the average or total reflection value and one relating to the balance between specular and diffuse reflection. The final step in making the concept practical was to set up classes of typical reflection properties.

Contribution by DELTA

The introduction of the road surface into the design of road lighting installations led to experimentation with light coloured aggregates and different types of road surfaces in Denmark, and in some other countries.

Some of the contribution by DELTA was to measure the reflection tables of a large number of samples of road surfaces, to contribute to the characterisation and classification of reflection properties and to complete the design method for road lighting installations. It was understood that road surfaces are wet or damp for more than half of the dark hours in Denmark, and therefore the work included wet conditions.

There are numerous publications from this period. Some of these are LTL reports No. 9[1]) and 10[2]), CIE publication 30[5]), CIE publication 47[6]), CIE publication 66[8]) and the first national road lighting standard. LTL report No. 9 is a sort of textbook based on the knowledge in that point in time (1974), LTL report No. 10 provides a large amount of data on road surfaces, CIE publication 30 provides design methods including two computer programs of widespread use (1976 revised in 1982), the national road lighting standard introduces the concept in a mature form (drafted in 1975 but not published until 1979), CIE publication 47 extends the methods to include wet conditions and CIE publications 66 explains the reflection properties of road surfaces in more detail.

There was an early effort by DELTA to design a portable instrument LTL200 for in situ measurement. A few of these instruments exist, but the cost of the instrument and the complexity of use prevented widespread application. A more recent contribution by DELTA is the development of a basis and the design of equipment for integral measurement the 'lightness' of road surfaces. The work was partly carried out by the Nordic Research Co-operation.

The parameter for 'lightness' is the luminance coefficient under diffuse illumination Qd, which was proved to be relevant for as well road lighting as daylight conditions. An advantage from a measurement point of view is that diffuse illumination is relatively easy to establish by indirect illumination from a photometric sphere. The unit of Qd is the same as for q, but the one thousand times smaller unit of $mcd \cdot m^{-2} \cdot lx^{-1}$ is used in order to obtain convenient numerical figures.

Some publications with major contributions by DELTA is a report by CIE committee 4-25[10]) and EN 1436[12]). The report of CIE committee 4-25 is a sort of textbook on the subject of reflection properties of road surfaces and road markings; it includes conditions of road lighting and daylight, and also vehicle headlamps. EN 1436 is the basic European standard for the performance of road markings, it defines parameters, classes of performance and measuring methods for reflection, colour and skid resistance.

Use of collimated optics for laboratory measurement

Measurements of reflected light have generally to be carried out in a particular geometrical condition fixed by the values of certain angles. The convention for road surfaces in road lighting conditions is that the measuring direction forms a small fixed angle relative to the plane of the road surface and points in the direction of traffic.

The conventional method is to mount a sample of the road surface and a detector at some distance from each other in such a way that the direction from the centre of the sample to the centre of the sensitive area of the detector forms the desired measuring direction. Refer to figure 1.

There is obviously some spread of the actual measuring directions about the central direction, because the sample has some size, and because the detector has a sensitive area of some size. This spread depends on the measuring distance and may be reduced by increasing the distance.

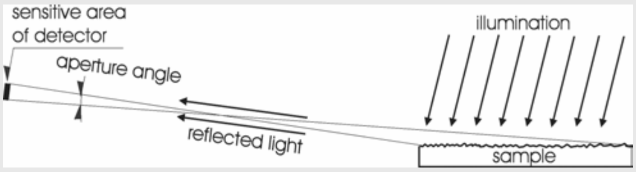

Figure 1: Conventional method for measuring reflected light using a detector placed at some distance from a sample. The aperture angle depends on the dimensions of the sample and the sensitive area of the detector, and on the distance.

On one hand, it is desirable that the measuring distance is large, so that the measuring geometry is well-defined. On the other hand, the measuring signal decreases sharply with distance, and cannot be very large. Therefore, some spread of the measuring direction has to be permitted.

The spread of directions is measured by aperture angles, normally with different values in the vertical and the horizontal plane. For the above-mentioned reasons, conventions for measurement include maximum values of the aperture angles.

The alternative to the above-mentioned method is to use collimated optics, meaning that the detector is placed behind a lens with its sensitive area in the focal plane of the lens, and that the lens is placed close to the measured area. Refer to figure 2.

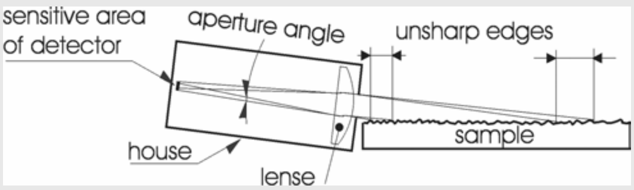

Figure 2: Collimated optics for measuring reflected light using a detector placed behind a lens in the focal plane of the lens. The aperture angle depends on the dimensions of the sensitive area of the detector in proportion to the focal width of the lens. The measured area is defined by an aperture in front of the lens, but has unsharp edges.

The method of collimated optics has some peculiar features compared to the conventional method.

One feature is that collimated optics take up less space than the conventional method. For the measurement of road reflection tables, where some values are obtained with the light source placed at a large distance in front of the sample, it is valuable to save space behind the sample. For the measurement of Qd values, the collimated optics can conveniently be placed within the photometric sphere, which provides the diffuse illumination.

Another feature is that the aperture angles are defined by the dimensions of the sensitive area of the detector in proportion to the focal width of the lens. The sample surface is virtually at the infinite as seen from the detector, and does not contribute to the aperture angles. Therefore, the sensitive area of the detector can be as large as permitted by maximum aperture angle values, this leading to a stronger signal. The sensitive area would normally be defined by a stop in front of the detector.

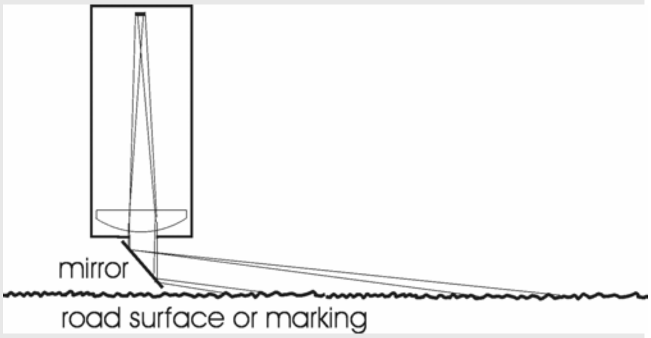

Figure 3: Collimated optics can be used for in situ measurement, when a mirror (or a mirror prism) is introduced just above the surface.

Yet another feature is that the measured area is defined by the lens, or by a stop in front of the lens. This may normally be considered an advantage. It should be noted that the measured field has unsharp edges as shown in figure 2. The lens is placed close to the surface in order to keep the unsharp edges relatively small.

The method of collimated optics was described in among else CIE publication 303), and has been copied by other laboratories.

Use of collimated optics for in situ measurement

The obvious feature of collimated optics is that it requires fairly little space. This feature may not be absolutely essential for laboratory measurement, but it is crucial for in situ measurement by portable equipment. As the lens cannot easily be brought close to the measured surface, a mirror (or a mirror prism) is introduced just above the road surface. Refer to figure 3.

This type of equipment was used in a portable equipment with the fairly ambitious aim to measure enough reflection parameters to allow reproduction of the full reflection table. The equipment works, but was expensive to produce and complex to use. A few copies, called LTL200, exist.

This type of optics is presently used in a more simple equipment named Qd30, which is used to measure the coefficient under diffuse illumination Qd of road markings and to some degree road surfaces as well. The diffuse illumination is produced by indirect illumination from an aperture in a photometric sphere. Refer to figures 4 and 5.

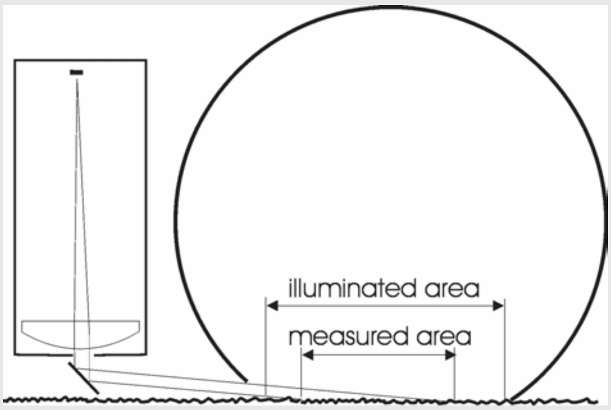

Figure 4: Collimated optics and photometric sphere used in Qd30 to measure the coefficient under diffuse reflection Qd.

The sphere of the Qd30 is relatively large and one can raise the question why not use a smaller and more convenient sphere? The answer to that question illustrates an important principle of portable equipment.

An instrument is designed to provide a certain measured area, which must be sufficiently long to represent actual road surfaces or markings. As some surfaces, for instance profiled road markings, have a considerable texture the nominal length should be for instance 200 mm.

Figure 5: Photo of Qd30.

However, the measured area will in practice be longer than the nominal length, because of the unsharp edges of the measuring field, and because of the grazing angle in combination with texture of the surface. Refer to figure 6. An angle of 2,29° according to EN 1436[12]) in combination with a depth of the texture of for instance 1 mm results in an elongation of 36 mm.

Further, a portable instrument may not be placed at the absolutely right height relative to the surface to be measured depending on unevenness of the surface and sometimes dirt. This leads to shifts of the measured field, refer again to figure 6. A portable instrument may also be slightly tilted relative to the surface, causing further changes of the measured field.

The illuminated area must cover the measured area uniformly with reserves for elongation and shift in order to measure correctly. This is a sufficient requirement, as Qd is not sensitive to small changes of the actual measuring angle.

It is a quality of an instrument that reserves are sufficient for the surfaces that occur in practice. A sphere with an aperture of 300 mm length allows measurement of all surfaces excepting profiled road markings with a spacing of more than 300 mm between profiles. The sphere cannot be smaller than say 450 mm diameter.

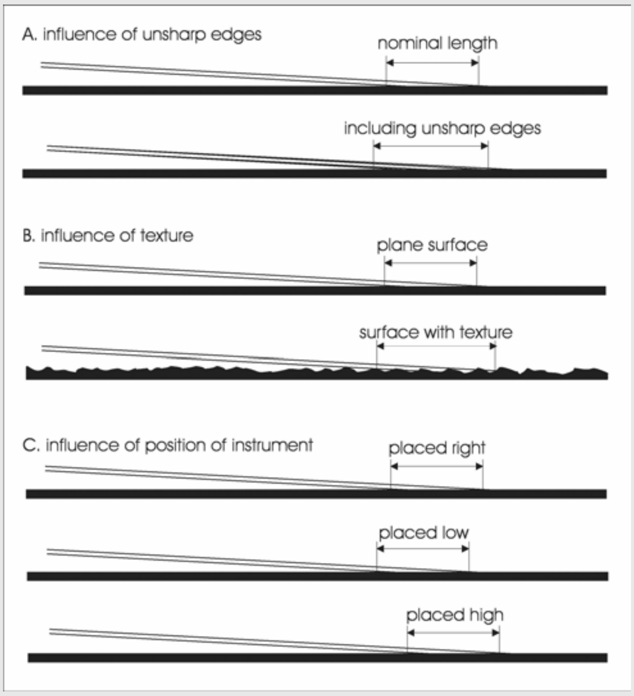

Figure 6: Examples on how the length and the position of the measured area are affected in practical in situ measurement.

It would be tempting to use a shorter illuminated area produced by a smaller sphere, and make the measured area be the longest with the necessary reserves compared to the illuminated area. However, with such an arrangement of the areas, the instrument does not measure the luminance of the illuminated area, which is independent of the measuring angle. Instead it measures the total intensity of reflected light, which is in proportion to the actual measuring angle (because the projected area of the illuminated area is in proportion to the measuring angle).

Therefore, the arrangement of a measured area that includes the illuminated area introduces some undesirable variation of the measured value. This was the case with the above-mentioned LTL200, in which this arrangement had to be used for other reasons.

This arrangement is, on the other hand, used in an instrument LTL2000 to be discussed later, where the effect is the opposite, namely to eliminate variation with the actual measuring angle.

Vehicle headlamps and the reflection properties of road markings and road surfaces

General considerations

With increasing volume and complexity of traffic, road markings find increasing use, new types of road markings are being developed, performance criteria and test methods have been developed and are being applied.

When driving on dark roads, road markings need to be visible at a sufficient distance in the illumination by the drivers own headlamps. The relevant type of reflection is backwards towards the vehicle. The parameter used to describe this type of reflection is the coefficient of retroreflected luminance RL, which is the ratio of the luminance L of the road marking to the illuminance at the road marking measured on a plane perpendicular to the illumination direction E⊥. As luminance is measured in $cd \cdot m^{-2}$ and illuminance in lx, the unit of R_L is $cd \cdot m^{-2} \cdot lx^{-1}$. However, in order to obtain convenient numerical figures, the one thousand times smaller unit of $mcd \cdot m^{-2} \cdot lx^{-1}$ is used.

Interest in practical measurement of R_L started in the sixties and grew during the seventies, probably as it became common to use glass beads to improve the reflection of road markings. Glass beads were first used as drop-on beads in paints, and later as both drop-on and pre-mix beads in the more durable thermoplastic and cold plastic marking materials.

Interest focussed on portable measurement, as the R_L of road markings depends heavily on the abrasion by traffic and on weather. Drop-on glass beads may provide fairly high R_L values, but may last a few months only depending on traffic. Pre-mix glass beads provide less high R_L values, also depending on traffic. Wet weather makes the R_L drop sharply, sometimes to virtually naught. Wet weather occurs during rain and after rain, and even as a sort of general wetness in long periods during winter.

The measuring task is not easy as the R_L value depends on the actual measuring geometry and as the signal is small. Some early measuring instruments were either inconvenient or showed lack of understanding the problems and lack of standardisation. An equipment used by the Belgian road authorities was 15 m long. Other types of instruments were difficult to calibrate, not having a well-defined measuring geometry, and gave different results.

Contribution by DELTA

An early contribution by DELTA, within the Nordic Research Co-operation, was to clarify the nature of the reflection and to expose a fairly simple influence of the angles. This was done in two studies, on for road surfaces and one for road markings, which were published in reports No. 4[3]) and 6[4]) by the Nordic Research Co-operation. Some of the results are included in CIE report 73[9]) and later in the draft report by CIE TC 4-25[10]).

Based on these results, an instrument LTL800 using a '50 m geometry' was developed in the early eighties. A number of countries, among else the Nordic countries, based their first national road standards with performance requirements for road markings on the LTL800. In Denmark, DELTA took part in the drafting of national road standards, and assisted the Danish Road Directorate by carrying out road trials of road marking materials - the first in 1986 - and by carrying out other studies.

DELTA was therefore well-equipped to assist the Danish Road Directorate in the CEN work on European standards initiated on the background of the Construction Products Directive, starting in 1990. DELTA had chairmanship of two groups, which developed the concepts behind EN 1436[12]) and drafted the standard. As a part of this work, a compromise was made that R_L is to be measured in a '30 m geometry'. This geometry has later been adopted by the American Society for Testing and Materials with some assistance by DELTA, refer to ASTM E 1710[14]), and has in fact become accepted word-wide.

The LTL800 was modified to use the 30 m geometry, and was later replaced by LTL2000. These instruments have won international reputation for reliability and range of application.

DELTA was also well-equipped to assist the Danish Road Directorate in the COST Action 331 'Requirements for horizontal road marking'11). Some experiments on drivers needs were carried out by the Nordic Research Co-operation leading to essential parts of the final report of the action. Another contribution by DELTA within the action is a computer program 'Visibility', which predicts the visibility distance to road markings taking account of a large range of circumstances such as driver age, glare, road marking geometry and reflection, vehicle geometry, daylight/road lighting or headlamp illumination etc. Refer to figure 7. This work was sponsored by the Danish Road Directorate except for an extension with typical US and European headlamps. The program has a wide circulation and is suitable for educational purposes and for the development of national road marking policies.

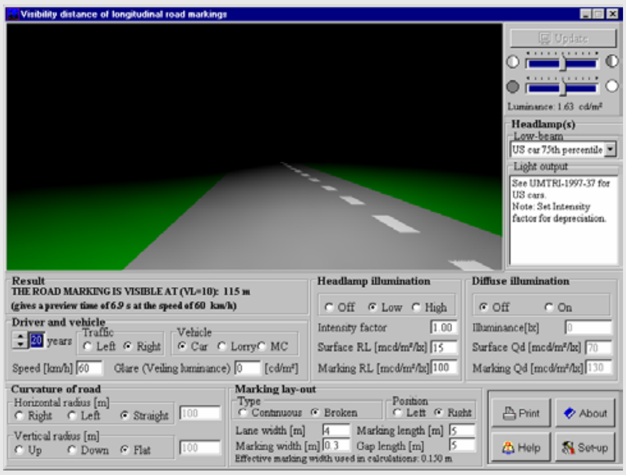

Figure 7: The 'Visibility' program.

Activities are still going on. The CEN work has not yet been completed, EN 1436 is being revised, Danish road standards have been revised, road trials are still being carried out, and there is still activity within the ASTM etc.

Use of collimated optics

The laboratory equipment with collimated optics for measurement mentioned in section 2.2 had some additional collimated optics for illumination in an R_L geometry. To avoid physical conflict of two sets of collimated optics placed near the sample, the illumination and the measuring and illumination beams were mixed in a semitransparent mirror.

This is the same type of optics used in LTL800 and later in LTL2000, LTL2000S and SQ and LTL-X. The latter is shown in figure 8.

The use of collimated optics lead to well-defined measuring angles and aperture angles. The LTL800 was the first instrument of this type to show this feature. The good reputation of these instruments is due to this feature and a number of other features.

Figure 8: Photo of LTL2000.

One of these features is the mutual arrangement of the measured and illuminated field.

The obvious arrangement is to let the illuminated field be the larger of the two, enclosing the measured field, so that the R_L value is measured directly. However, this would introduce variability of the results for the following reason. The R_L value is in proportion to the ratio of the angles of illumination and measurement (measured from the directions to the plane of the road surface). The ratio can be set accurately in an instrument relative to the plane defined by its feet, but the instrument will in practice have small tilts, when placed on the road, this affecting the actual value of the ratio.

Therefore, the opposite arrangement is used, where the illuminated field is the smaller of the two and enclosed in the measured field. The measured value is then the reflected intensity of light, which to a first approximation is independent of the above-mentioned ratio.

Another feature is that the measured field has large reserves compared to the illuminated field. This is necessary because both fields changes length and position by the mechanisms shown in figure 6. The criterion for correct overlapping of the fields is that a tilted reflection standard must provide a nearly constant reading at a certain range of positions.

Yet other features are use of high quality components, suppression of reflected light, good shielding from daylight and automatic compensation, automatic internal checks, a tilted ceramic reflection standard with traceable calibration etc.

Road signs and the reflection properties of retro-reflective sheeting materials

General Considerations

As with other road equipment, road signs are being used to an increasing extent. The technique of improving the reflection in headlamp illumination was invented early, first by applying glass beads in paint on the sign face, and later by applying retro-reflective sheeting materials to the sign face.

The ‘encapsulated lens’ material was the first to be developed. It has a fairly strong retro-reflection at relatively short distances and is still being used for road signs to be read at low driving speeds. Later, from about 1970, the ‘encapsulated lens’ material offered sufficient retro-reflection at somewhat longer distances, it is being used for road signs to be read at higher driving speeds. Micro-prismatic materials are more recent developments, mostly designed for sufficient retro-reflection at large distances, and of increasing use for motorway signs.

Road signs were often illuminated externally or internally in the sixties and seventies. Now only few road signs are illuminated in view of saving expense and energy, and in view of the availability of more types of retro-reflective materials.

The parameter used to describe the retro-reflection of road signs is the coefficient of retro-reflection R' (the symbol R' is to be replaced by RA), which is the ratio of the intensity of reflected light to the illuminance at the road sign measured on a plane perpendicular to the illumination direction per m2 of the area of the sign face. As intensity is measured in cd and illuminance in lx, the unit of R' is $cd \cdot lx^{-1} \cdot m^{-2}$.

The full unit is used for R' and provides convenient numerical features. This is opposed to road markings, where a thousand times smaller unit is used, and illustrates that road signs have a much stronger retro-reflection than road markings. Road signs need, on the other hand, to have a strong retro-reflection as the illumination received from the low beam of headlamps is weak.

Again, as opposed to road markings, retro-reflective road signs show a strong variation of the R' value with the geometrical conditions, in particular an increase with distance. This increase compensates for the decrease in illumination with distance, so that road signs are able to provide a roughly constant luminance over a certain range of distance. The range is characteristic of the retro-reflective material.

Retro-reflective materials show another type of variation, which shows up as a decrease of the R' value with oblique view to a road sign. The micro-prismatic materials show further strong variations relating to the positions of the headlamps relative to the observer, and relating to the location of the road sign relative to the road.

The producers have had the initiative to develop requirements and test methods for particular types of retro-reflective materials and even for particular products. This has been, and still is, a competition issue between producers.

Contribution by DELTA

DELTA has had a considerable role in developing national road standards for the Danish Road Directorate. For the Danish Road Directorate, DELTA also takes part in the CEN work initiated on the background of the Construction Products Directive, starting in 1990. The goal has been to introduce requirements and test methods aiming at the needs of the drivers in different road situations. This goal has been pursued in some groups of the CEN for a number of years, but the work was eventually stopped on the initiative of one of the producers. The work was, however, carried on in a Nordic/English co-operation and resulted in a basis, which has recently been introduced in Danish road standards. The work is carried on independently in CIE TC 4-40 with participation by DELTA.

Some other activities are inspired by the CEN work. The Nordic Research Co-operation carries out a durability test of retro-reflective materials using 10 test sites placed at different locations in the Nordic countries. DELTA took part in the revision of CIE report No. 54[7]), which is the basic document on retro-reflection. DELTA also takes part in ASTM work, among in a current revision of ASTM E 1709[13]) on portable instruments.

Use of collimated optics

Although there is still no universal agreement on requirements and test methods for retro-reflective materials, some agreement has been reached on handheld instruments. Europe uses a certain geometrical configuration for road signs, USA uses another and a third is used for retro-reflective parts of safety clothes. DELTA produces a handheld instrument called RetroSign in the corresponding three versions.

Figure 9: Photo of RetroSign.

RetroSign has a single lens with apertures for both illumination and measurement placed in the focal plane of the lens. This causes a false, but constant signal by reflection in the surfaces of the lens. However, the false signal does not cause problems in view of the strong signal provided by retro-reflective sheeting materials. This is not the case for the measurement of R_L of road markings and, therefore, the previously mentioned LTL2000 has a more complex arrangement.

RetroSign has a number of strong features, and has become of widespread use. One such feature is an accurate correction of the spectral system response, which allows that coloured portions of roads signs can be measured accurately after calibrating the RetroSign with a white reflection standard

Conclusion

The early start and continued work in basic research aimed at improving the visibility aspects of traffic safety has provided the tools for implementing Nordic viewpoints in international standards as well as the basis for the production of a series of instruments for reflection measurements, which are to day used world wide and considered the instruments of reference.

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