# Portable retroreflectometers and structured pavement markings

## Introduction

This paper addresses the question: "can portable retroreflectometers be used to measure the retroreflection of structured pavement markings?"

By retroreflection is meant the coefficient of retroreflected luminance RL and it is assumed that the retroreflectometers use the 30 m geometry as defined in ASTM E 1710 and EN 1436.

By structured marking is meant any marking with a significant structure regardless of how it is created - preformed, during application or by a structure in the pavement surface. Section 1 provides an introduction to the most common types of structured markings.

The reason the question is raised is probably because 1) the measured value may vary with the position of the retroreflectometer along the marking, and 2) the surface does not form a plane on which the base of the retroreflectometer can be placed with confidence.

Section 2 provides a partial answer to the question. The essential characteristic is the average retroreflection along the marking and therefore a retroreflectometer should be used to obtain this average. In principle this means averaging the readings for a sufficient number of positions of the retroreflectometer along the road.

However, there is more to it than that. The driver of a vehicle at night does benefit from the light from the headlamps, even if it has to cross over gaps in the structure either to the bottom or to ribs or profiles at the end of gaps. A retroreflectometer, on the other hand, depending on its optical arrangements and the particular structure, may or may not provide a full reading.

In fact, the retroreflectometer must have a sufficient height tolerance. This property is introduced in section 3, where it is shown how to determine the height tolerance value in a simple manner and it is explained how to evaluate the height tolerance needed for the measurement of structured markings.

Even when the retroreflectometer has a sufficient height tolerance, it must be used in the right manner and so that - for practical reasons - the average retroreflection is obtained from a limited number of readings.

This is the theme of section 4. The retroreflectometer is shifted along the structured pavement marking in uniform steps with the feet of the retroreflectometer in a reference plane defined by the top of the structure. Methods are provided for determining the number and the length of the steps.

By reference to the other sections, section 5 summarises the planning needed before measuring the retroreflection of structured markings. In some cases this will be simple and little or no planning is needed, while in other cases it will be necessary to prepare a plan before taking the measurements.

In all cases the answer to the question is affirmative, if the instrument has sufficient height tolerance and the measurements are done according to chapter 5.

## 1. Types of structured pavement markings

Figure 1 shows some types of structured pavement markings.

Types I, II and III leave gaps of uncovered pavement surface in between covered parts. However, due to the thickness of application, the pavement surface in gaps of a limited length is not visible at normal sight distances for drivers of 100 ft. (30 m) or more.

Type II lines have typical lengths of covered areas and gaps of 4 in. (10 cm.) Dimensions of lines of the other types can be judged by means of figure 1, which shows typical relative proportions.

The material used for type I lines is either cold plastic or thermoplastic, while the material used for lines types II and III

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is generally thermoplastic. The application thickness is typically 120 mil (3 mm).

Lines of these types have been used in the Nordic countries for a number of years, mostly as edge lines on roads in rural areas. Type I is the oldest of the three; it was first produced in cold plastic under the trade name of 'Spotflex', but it does exist in other versions. Types II and III are more frequently used with the generic trade mark names of respectively 'Longflex' and 'Kamflex'.

Type III is generally considered as being composed of two parts side by side, a normal non-structured marking and a structured marking. The properties of these two markings are measured separately, and requirements are specific for the two markings. The structured part is the one of interest in this context.

Type IV is produced in thermoplastic, into which a pattern is rolled during application. It is marketed in several countries under the trade name 'Rainline'.

Type V is a tape with a wafer pattern produced by 3M. At least one other producer offers a tape with a similar pattern.

Type VI has a base and profiles, where the two are sometimes applied in different materials. The spacing of profiles ranges from approximately 4 in. (10 cm) up to 40 in. (100 cm) and the height from 120 mil (3 mm) to 500 mil (13 mm). Lines of this type are used in some European countries with the main purpose to produce a rumble effect when subjected to vehicle traffic.

Type VII is a line applied in liquid form on top of milled rumble strips in the pavement surface. This type has fairly wide acceptance in the USA and is being tried on an experimental basis in some European countries. Lines can also be applied on top of rumble strips that have been formed into the pavement surface while the paving material is still pliable.  This type marking is often referred to as 'Rumble stripe'.

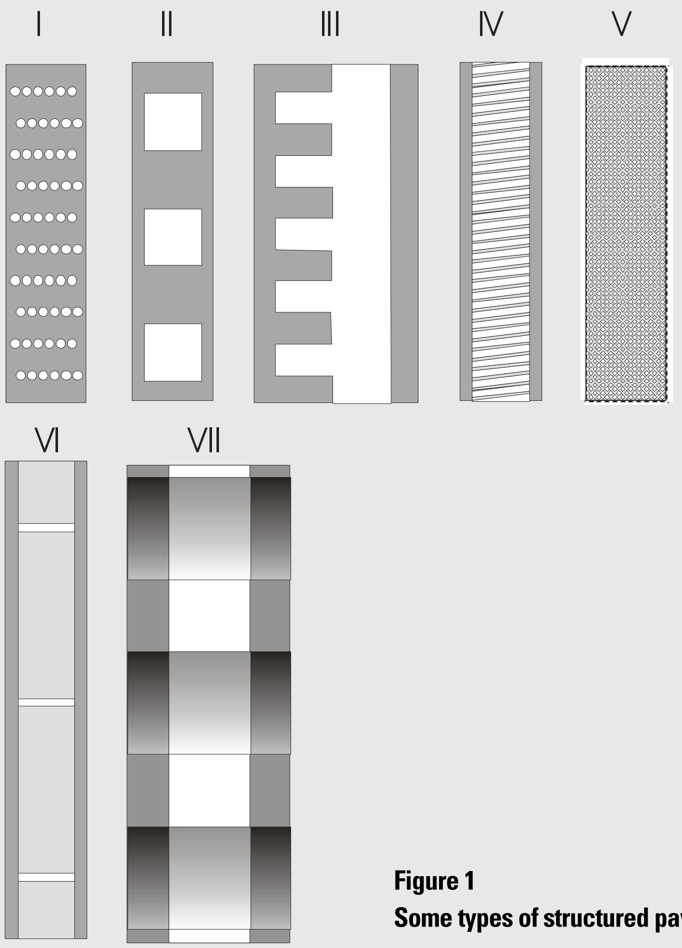



**Figure 1**
**Some types of structured pavement markings.**

## 2. Retroreflection and visibility of structured pavements markings

Figure 2 shows illumination and observation of a structured marking, exemplified by a marking over a milled rumble strip. The figure assumes the '30 m geometry' of ASTM E 1710 and EN 1436, in which illumination and observation are in directions forming angles of respectively 1,24° and 2,29° to the pavement surface. The figure shows one spacing of the structure consisting of one milled depression in the surface and also the following plane part of the surface until the next milled depression. By spacing is meant the smallest length by which the structure repeats itself.

At the small angle of illumination, some parts of the surface are illuminated, while other parts are in the shadow of the illuminated parts. At the larger angle of observation, all of the illuminated parts and some of the non-illuminated (shadowed) parts are visible.

The illuminated parts will have some luminance, and these may generally be different for the different parts (the plane part and the sloping part at the end of the depression). The shadowed parts will show virtually no luminance. Accordingly, there is a variation of the luminance along the pavement marking corresponding to the repeated pattern of the structure.

For a rumble stripe, each spacing has three sections with different luminance values.  One section has a very low luminance.  For other types of structured markings, the variation may be different, but variation in itself is a general feature of a structured marking.

The question is how such variations might affect the visibility of the marking when viewed by the driver of a vehicle.

According to COST Action 331, visibility conditions when driving at night are close to the simple limiting case where Ricco's law applies. This means that the stimulus for visibility of an object is the illuminance on the eye of the observer created by light reflected off the object. This again leads to some interesting observations, among else that the width of the marking is almost as important as the retroreflectivity value. For a full account, reference is made to the report of COST Action 331, and to the demonstration computer program 'Visibility' developed as a part of the action.

For the purpose of answering the question stated above it is sufficient to note that the average luminance of the marking is the essential matter, while the variation of the luminance has no consequence. This, on the other hand, implies that the meaningful measure of the retroreflectivity is the average value along the marking.

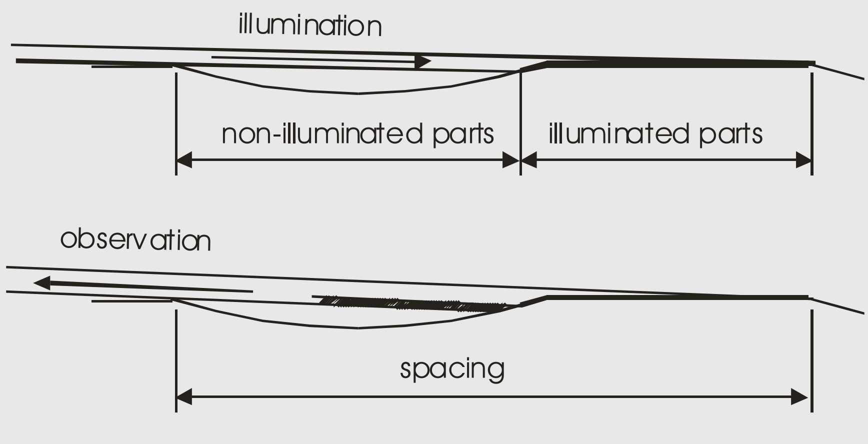



**Figure 2**
**Illumination and observation of a marking over a milled rumble strip.**

## 3. Height tolerance of portable retroreflectometers

### 3.1 Height tolerance

According to the previous section the relevant measure of retroreflectivity of a structured pavement marking is the average value along the marking.

It seems pretty obvious then to use a portable retroreflectometer in a procedure, in which readings are taken in positions in a number of steps along the structured pavement marking followed by forming the average of the readings.

However, in some positions the measuring beams of the retroreflectometer have to cross a gap in the structure to reach some other part of the structure. This may be the bottom of the structure or it may be some other part of the structure at the end of the gap.

Some portable retroreflectometers are able to do that without loss of signal, and some are not - depending on the depths and lengths of the particular structure.

### 3.2 Height tolerance test (depth ability)

ASTM E 1710 defines the depth ability of portable retroreflectometers with fixed aim.

The capability is expressed as height tolerance, which is the height to which the retroreflectometer can be lifted without change of signal (measurement) of more than 10%. A practical method to determine this tolerance is to use a pavement marking panel on which the retroreflectometer is first placed directly and then lifted 1 mm, 2 mm etc.

Lifting the retroreflectometer causes the measured area to move forward relative to the retroreflectometer. Therefore, in order to avoid influence of variations along the panel, the panel is to be moved forwards (or the retroreflectometer backwards) a certain amount in each step so as to maintain the same location of the measured area on the panel.

For retroreflectometers that complies with the 30 m geometry defined in ASTM 1710 and EN 1436, the movement of the panel is by 25 mm per mm lift for retroreflectometers with arrangement A and 46 mm for each mm lift for retroreflectometers with arrangement B. In arrangement A the detected area is enclosed within the illuminated area, while in arrangement B the illuminated area is enclosed within the detected area. The first-mentioned area defines the measurement area, which is the detected area or the illuminated area in arrangements A or B respectively.

NOTE- DELTA retroreflectometers use arrangement B. This has the advantage - compared to arrangement A - that readings are less sensitive to small tilts caused by dirt or texture, when placing a retroreflectometer on a real pavement surface.

The test is quite simple to perform and can be carried out by the user of a portable retroreflectometer by placing small objects - for instance coins - under the feet of the retroreflectometer. If a panel is not available, the test can be carried out in the field on an actual plane and level pavement marking. See figure 3.

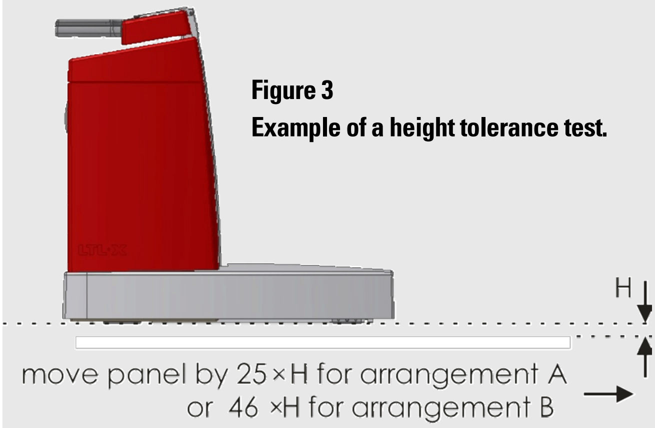
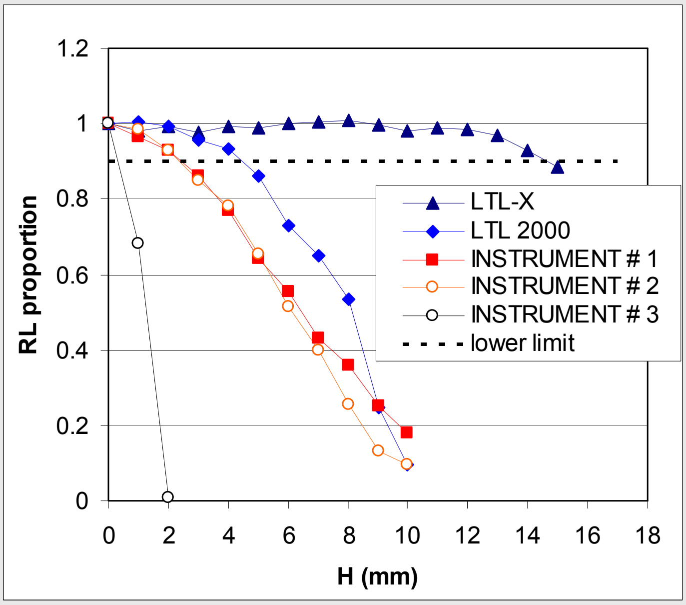



**Figure 3**
**Example of a height tolerance test.**



## 3.3 Interpretation of height tolerance (depth ability)

Figure 4 shows that the illuminated and detected areas move when a retroreflectometer with arrangement B is lifted in steps. The retroreflectometer uses collimating optics, which provides virtually infinite optical distance. For this reason the areas are uniform except for un-sharp edges.

With such optics, the signal is roughly constant as long as the illuminated area stays fully within the fully effective part of the detected area. This is the case for all the stepwise lifts shown in figure 4, where the lift resulting in a signal below 90% of the original signal is defining the height tolerance, H.

NOTE- DELTA retroreflectometers use collimating optics. Non-collimating retroreflectometers are likely to show small height tolerances H as the movement of the areas is not insignificant compared to the inherent measuring distance.

Accordingly a retroreflectometer with arrangement B provides a full reading when the illuminated area is fully within the fully effective part of the detected area. This principle has been explained for a non-structured marking in connection with figure 4, but holds also for structured markings. An analysis provided in annex A leads to the following conclusion:

A retroreflectometer with a height tolerance H and arrangement B is capable to measure a structured marking if:

- The height differences of the marking are no bigger than H
- and/or the gaps in the marking are no longer than 46xH.

Those two conditions do not have to be complied with both of them simultaneously; compliance with only one of the conditions is sufficient.

This conclusion has been derived for retroreflectometers with arrangement B. It can be applied also for retroreflectometers with arrangement A, but with a unique characteristic that the variation from position to position can be strong. This is undesirable from a practical point of view.

The interested reader is referred to annex A for a more full explanation.

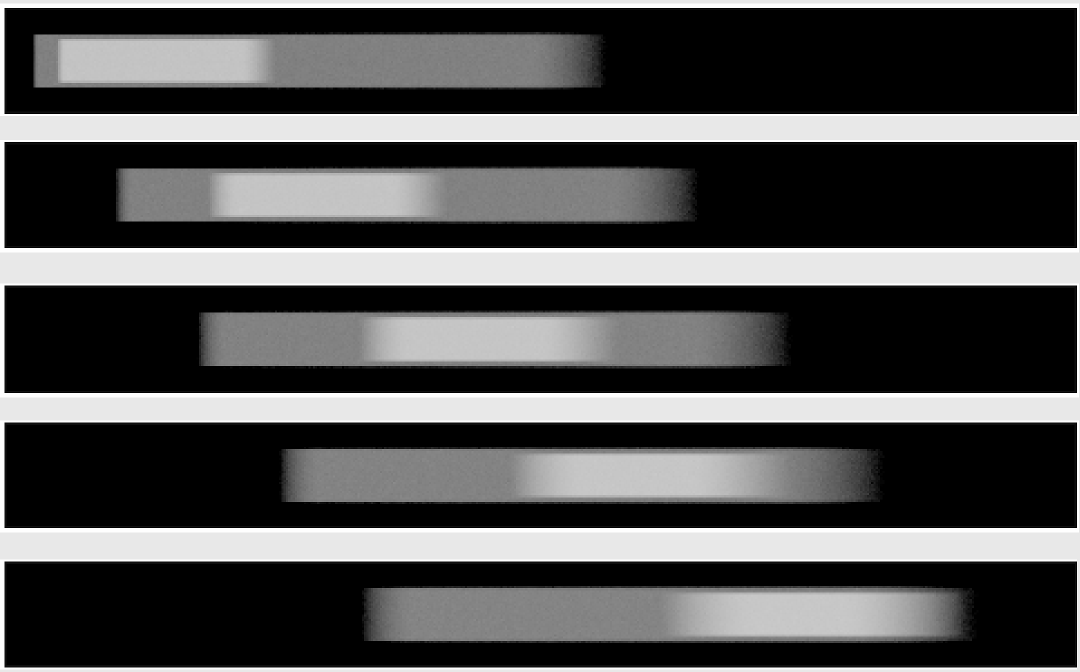


**Figure 4**
**Movements of the illuminated and the detected areas in arrangement B with increasing height of the retroreflectometer.**

## 3.4 Need for height tolerance (depth ability)

ASTM E 1710 requires that a fixed aim retroreflectometer has a height tolerance for the heights of -1, 0, 1 and 2 mm. This height tolerance is called 'normal' in the following and is intended to cover offsets and lifts of portable retroreflectometers in practical situations caused by texture and curvature of the pavement marking, and grains lying on the surface.

Table 1 shows dimensions of the structured markings described in section 1. The table is probably not exhaustive regarding types of structured markings in use, and the dimensions are intended to be typical or representative only.

Table 1 also indicates the need for the height tolerance H. Sometimes the gap is the more demanding dimension, and sometimes it is the height/depth of the structure.

It is seen that some structured markings require only normal height tolerance, while some require larger height tolerance. The more demanding are rumble lines of large profile heights and long gaps in between, and milled rumble stripes of broad milled depressions.

In principle the height tolerance should be evaluated for each structured marking. This is not too difficult according to this procedure:

a. measure the largest height/depth of the structure
b. measure the largest gap of the structure and divide by 46
c. take the smallest of the values derived in a and b.

| Structured marking | Elements in a spacing | | Height/depth | Needed H |
|---|---|---|---|---|
| I: 'Spotflex' | Gap with two rows of 'dots' 2) | Gap of 100 mm | 3 mm | 3 mm |
| II: 'Longflex' | Profile and gap 2) | Each 100 mm | 3 mm | 3 mm |
| III: 'Kamflex' 4) | Profile and gap 2) | Each 55 mm | 3 mm | normal 1) |
| IV: 'Rainline' | Profile and gap 3) | Spacing 20 mm | 1-2 mm | normal 1) |
| V: tape | Profile and gap 3) | Spacing 15 mm | 2 mm | normal 1) |
| VI: rumble line | Profile and gap 3) | 100 to 1000 mm | 3 to 10 mm | 3 to 10 mm |
| VII: milled 'Rumble Stripe' | Plane and depression | Plane 175 mm<br>depression 300 mm | 13 mm | 7 mm |

1) by normal is meant -1, 0, 1 and 2 mm according to ASTM E 1710
2) the bottom of the gap is the pavement surface
3) the bottom of the gap is closed by pavement marking material
4) the structured part of this type only

**Table 1**
**Typical dimensions of structured pavement markings.**

## 4. Principles of a measurement procedure

### 4.1 Introduction to the procedure

The aim of the procedure is to provide the average retroreflection along a structured pavement marking. The basis of the procedure is to shift the retroreflectometer in steps with a constant increment along the marking, take readings at each step and average the readings. See figure 5.

The steps must be chosen in such a way that each equivalent location along the structure has been given a constant weight to the average of the readings. This is the case, when the number of steps and the increment are chosen according to the criteria established in the next section and the feet (base) of the retroreflectometer remains in a reference plane defined by the top of the structure.

If the feet cannot span over the gaps in the structure, the retroreflectometer needs to be supported. When necessary, this can be done by attaching rails designed for this purpose, or by placing objects of the right height under the feet (base).

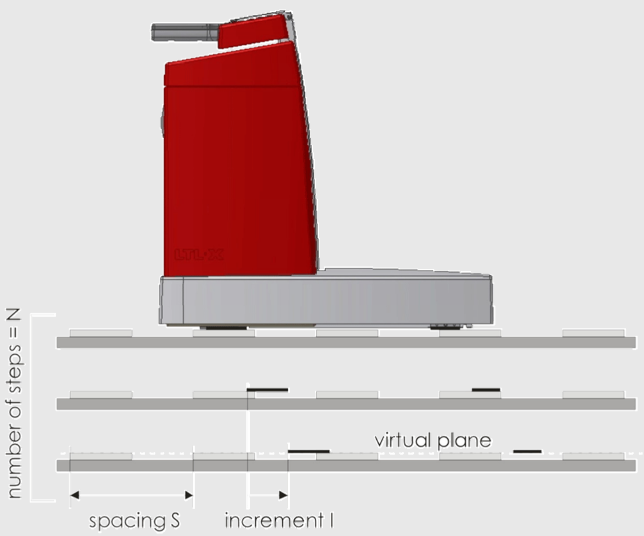



**Figure 5**
**Shifting a retroreflectometer in uniform steps with the feet in a reference plane.**

### 4.2 Criteria for choosing the number of steps and the increment

The obvious criterion is to select a number of steps N with an increment I equal to the length of the measurement area of the retroreflectometer L so that the total measured length fits at least approximately to one or a few spacings S of the structure of the marking.

NOTE 1 – The length of the measurement area in DELTA retroreflectometers is 20 cm.

If the fit is perfect, each equivalent location along the structure is included the same number of times (equal to the number of spacings) within the measurement area and therefore given constant weight. Even if the fit is not perfect, only a small part of the total measured length is measured once too few or too many. The variation of the RL value with the location relative to the structure is therefore eliminated or strongly reduced.

The number of steps will depend on both the spacing of the structure and on the total measured length considered to be necessary to reduce the variation of the RL value caused by other phenomena like non-uniform distributions of glass beads or non-uniform traffic wear of the surface.

A large number of steps N means that the procedure is more time-consuming and tends to become unpractical - depending on the retroreflectometer and the circumstances. If the retroreflectometer has an auto-average of a pre-selected number of readings it is tolerable to do more readings. It is also tolerable to do more readings, if the retroreflectometer feet can stay at the top of the structure without needing support.

NOTE 2 – The DELTA retroreflectometer LTL-X has an auto-average of a pre-selected number of readings and also optional rails, which form a long base.

If it is uncertain if the number of steps can be for instance 5 or should be for instance 10, an initial test can be carried out using the higher number. If the individual readings do not vary strongly from reading to reading, it can be decided to use the lower number for further measurement.

Measurements the retroreflection of structured markings often involve measurements for the dry condition and a condition during wetness or rain such as produced according to EN 1436, ASTM E 2176 or E2177. In conditions during wetness or rain, individual readings tend to vary more strongly than in the dry condition. An initial test should therefore reflect the conditions involved in the measurements.

The types IV and V of structured markings introduced in section 1 will normally have spacings that are much shorter than the measurement area of the retroreflectometer.

For such structured markings, a single placement of the retroreflectometer covers several spacings of the structured marking and therefore one or a few steps may be sufficient. Simultaneously, the base of the instrument will be at the top of the structure so that there is no need to support the retroreflectometer. These structured markings do in fact not require particular considerations compared to non-structured markings

The types IV and V of structured markings introduced in section 1 have spacings that are comparable to the measurement area of the retroreflectometer.

The number of steps can mostly be relatively small. Assume as an example that the spacing is 15 cm and the length of the measurement area is 20 cm. If the number of steps is 3 then each equivalent position in 4 spacings is measured 3x20 cm/4x15 cm equal to once.

Another option for such structured markings is to select a number of steps together with an increment that will cover one spacing of the structure. This option is sometimes used to determine the variation of the $R_L$ value caused by the structure. If the average reading is to represent the average $R_L$ value of the marking, the increment should also be a simple fraction of the length of the measured area. If in the abovementioned example the number of steps is 3 and the increment is 5 cm, all equivalent positions are measured the same number of times equal to 20 cm/5 cm = 4 times.

The types VI and VII of structured markings introduced in section 1 will normally have spacings that are much longer than the measurement area of the retroreflectometer. The number of steps may therefore become relatively high.

## 5. Planning of measurements of structured pavement markings

### 5.1 Decision if the retroreflectometer can be used

The first step in planning measurements of structured pavement is to decide if the retroreflectometer, which is available for the purpose, is applicable for the structured pavement marking to be measured.

It is assumed that the retroreflectometer is a fixed-aim retroreflectometer using collimating optics as defined in ASTM E 1710, and that its measurement geometry complies with ASTM E 1710 and EN 1436.

The additional information needed for the retroreflectometer is the height tolerance H

The producer of the retroreflectometer should be asked to supply this information - if it is not already included in technical data sheets for the retroreflectometer. If the height tolerance figure H cannot be supplied, the user of the retroreflectometer can determine this figure himself using the rather simple test described in section 3.1.

The information needed for the structured pavement marking includes the type of structure and the dimensions of the structure see the examples in figure 1 and table 1. This information is used to derive the requirement for height tolerance according to section 3.3.

If the height tolerance of the retroreflectometer exceeds the requirement, it can be used - else not. If measurements are to be carried out for conditions during continuous wetting according to EN 1436 or ASTM E 2176, the retroreflectometer needs to be an open beam retroreflectometer.

### 5.2 Planning of the measurement procedure

The additional information needed for the retroreflectometer is the length of the measurement area L. It is also relevant to know if the retroreflectometer uses arrangement A or B. The producer of the retroreflectometer should be asked to supply this information - if it is not already included in technical data sheets for the retroreflectometer.

For the structured marking, the reference plane in the top of the structure has to be identified, and the spacing of the structure S has to be determined.

The number of steps N in which to shift the retroreflectometer along the structured marking and the increment is determined by means of principles and methods supplied in section 4.

### 5.3 Test of the measurement procedure

A test of the measurement procedure will reveal if the number of steps N seems adequate and does not cause undue inconvenience. It is an advantage if the measurement area is not short. It is also an advantage if the retroreflectometer uses arrangement B, which leads to the smallest variation of readings from step to step, refer to section 3.2.

The test will also reveal if support is needed for the feet of the retroreflectometer, so that small plates of the correct thickness can be provided for this purpose. In some cases such a measure can be avoided by placing the steps so that the structure supports the feet at all steps.

## Literature


EN 1436:1997 Road marking materials - Road marking performance for road users

ASTM E 1710-05 'Standard test method for measurement of retroreflective pavement marking materials with CEN-prescribed geometry using a portable retroreflectometer'

ASTM E 2176-01 Standard Test Method for Measuring the Coefficient of Retroreflected Luminance (RL) of Pavement Markings in a Standard Condition of Continuous Wetting

ASTM E 2177-01 Standard Test Method for Measuring the Coefficient of Retroreflected Luminance (RL) of Pavement Markings in a Standard Condition of Wetness

COST 331 Requirements for Horizontal Road Marking, Final Report of the Action, 1999.

## Annex A:
## Conditions that a retroreflectometer provides full signal for a structured marking

A retroreflectometer with a height tolerance H and arrangement B is capable to measure a structured marking if:

- The height differences of the marking are no bigger than H
- and/or the gaps in the marking are no longer than 46xH.

The first-mentioned condition is assumed to be obvious, because the height tolerance in itself ensures that the illuminated area stays fully within the fully effective part of the detected area.

The second condition may be less obvious and is therefore illustrated for a simple profiled marking with thin profiles shown in figure A1. It is assumed that the height of the profiles exceeds H and that the gaps between profiles have a length of 46xH. This means that the first-mentioned condition is not complied with while the second condition is just complied with as a limiting case.

Figure A2 shows the placements of the illuminated and detected areas on the profile sides for two different locations of the retroreflectometer. For both locations, all of the illuminated area is included within the full part of the detected area. Therefore, the signal has its full value for both locations. This is true for all locations of the retroreflectometer, which is therefore able to reach across gaps of this size.

This conclusion has been derived for retroreflectometers with arrangement B. It can be applied also for retroreflectometers with arrangement A, but with a unique characteristic.

The unique characteristic is illustrated in figure A3, which is similar to figure A2, but modified to illustrate a retroreflectometer with arrangement A instead of arrangement B. The height tolerance H has not been changed.

In one position there is no overlap at all of the areas of illumination and detection, and the reading is in principle zero. In the other position, the illuminated area is fully included within the detected area, and the reading is maximum.

The average reading for several sufficiently close positions will be sin1.24°/sin2.29° = 0.542 times the maximum reading. While the validity of this ratio can be proved, it goes beyond this paper to do so.

The unique characteristic of arrangement A is that the variation from position to position can be strong, which is undesirable from a practical point of view.

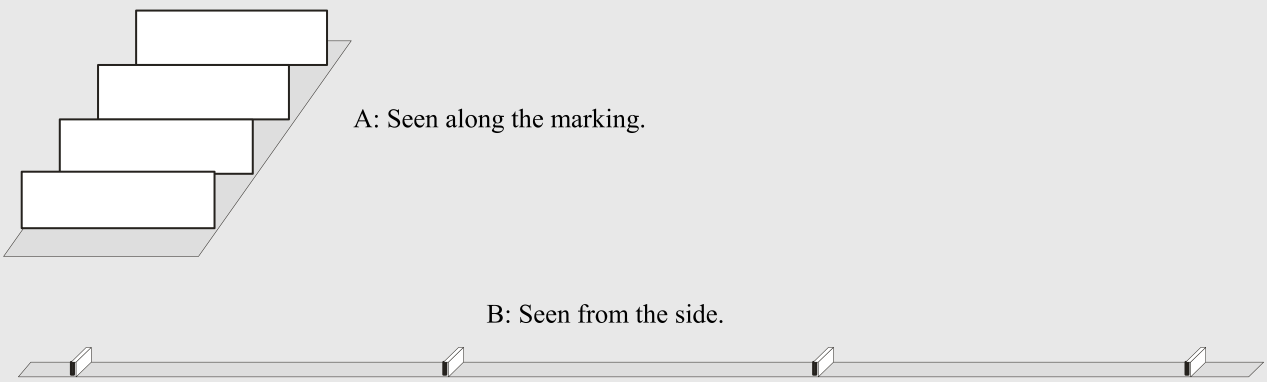
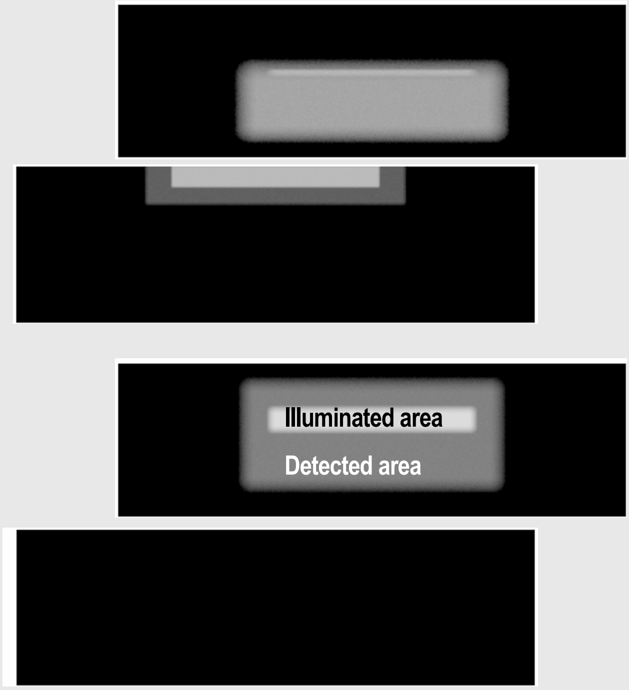


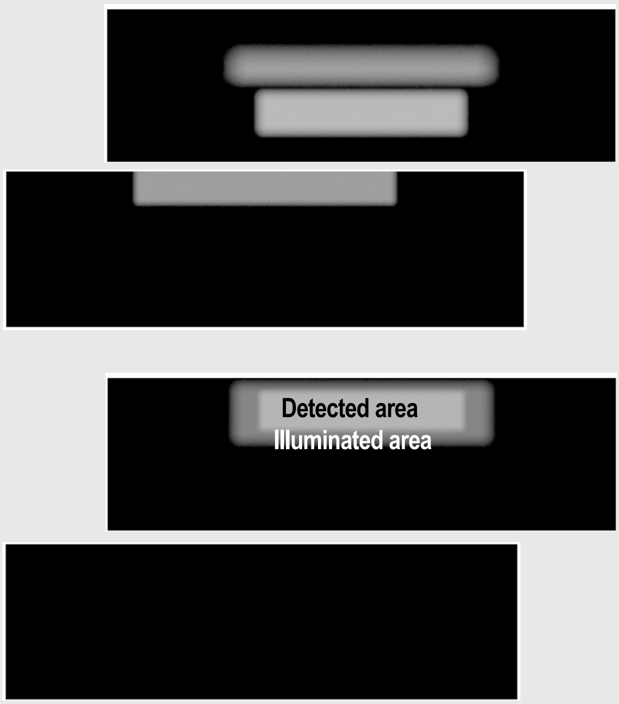

**Figure A1**
**A simple profiled pavement marking with thin profiles.**




**A:** A critical position, where some light just slips over a profile to fall on the next profile

**B:** Another position, where both areas fall on one profile side

**Figure A2**
**Placement of the illuminated and the detected area in arrangement B on profile sides for two positions of the retroreflectometer.**




**A:** A critical position, where the detected area just slips over a profile to fall on the next profile, causing a reading of zero

**B:** Another position, where both areas fall on one profile side, causing a maximum reading

**Figure A3**
**Placement of the illuminated and the detected area in arrangement A on profile sides for two positions of the retroreflectometer.**