MÖRKERTRAFIK
NIGHT TRAFFIC
REPORT NO. 6 1983

REFLECTION PROPERTIES OF ROAD MARKINGS IN HEADLIGHT ILLUMINATION

Dependence on measuring geometry

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THE ROAD DIRECTORATE · DENMARK
ROADS AND WATERWAYS ADMINISTRATION · FINLAND
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trykt på genbrugspapir

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Stougaard Jensen/København

PREFACE

The investigation is a part of the research plan outlined in Night Traffic Report No. 3 concerning optical and visual conditions on roads without fixed lighting.

The investigation gives, on the basis of measurements supported by model considerations, an account of the influence of the measuring geometry on the specific luminance of road markings. The measuring geometries are representative of the situation of illumination by the drivers own headlights.

This investigation is linked with a similar study for road surfaces, which is already reported in Night Traffic Report No. 4.

Together the two reports give a background for the choice of a standard measuring geometry for portable instruments, for the estimation of the reflection in other geometries and for the general understanding of the reflection mechanisms.

On this background a proposal for a standard measuring geometry and for other aspects of application purposes with be formulated.

The investigation is carried out by the National Swedish Road and Traffic Research Institute (VTI), and the Danish Illuminating Engineering Laboratory (LTL) and the Danish Road Laboratory within the Nordic Research Cooperation for Night Traffic.

In this cooperation participates:
- The Danish Illuminating Engineering Laboratory (LTL) - Denmark
- The Road Directorate (VD-DK) - Denmark
- Road and Waterways Administration (VVS) - Finland

- The Norwegian Road Administration (VD-N) - Norway
- The Norwegian Research Institute for Electricity Supply (EFI) - Norway
- The National Swedish Road and Traffic Research Institute (VTI) - Sweden
- The Swedish National Road Administration (VV) - Sweden

The activities are coordinated by a group (coordination group), presently composed by:

- Kai Sørensen (LTL)
- Jørgen Haugaard (VD-DK)
- Pentti Hautala (VVS)
- Hans-Henrik Bjørset (EFI)
- Torkild Thurmann-Moe (VD-N)
- Kåre Rumar (VTI)
- Karl-Olov Hedman (VV)

This investigation has been organized by a project group with the participation of Sven-Olof Lundkvist (VTI), Gabriel Helmers (VTI), Kai Sørensen (LTL), Peder Øbro (LTL), Erik Randrup Hansen (LTL) and Axel Bohn as a consultant for the Danish Road Laboratory.

The coordination group has studied and approved the contents of the report.

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ABSTRACT

Title: Reflection properties of road markings in headlight illumination - dependence on measuring geometry.

Publisher: Nordic Research Cooperation for Night Traffic. Report No. 6, 1983. (The report can be obtained from the Danish Illuminating Engineering Laboratory, Building 325, Lundtoftevej 100, 2800 Lyngby, Denmark).

The specific luminance of road markings in headlight illumination is studied both by measurement and by model considerations.

For road markings without glass beads the dependence on the geometry is shown to be as for road surfaces. For road markings with glass beads the variations are of the same nature, but enhanced and overlaid with larger individual variations.

On this basis the choice of a standard measuring geometry common to road surfaces and road markings is discussed. It is proposed that in both cases the estimation of the specific luminance for other geometries is done by means of the expressions derived for road surfaces.

RESUME

Titel: Refleksionsegenskaber af kørebaneafmærkning i billygtebelysning - målegeometriens indflydelse.

Udgivere: Nordisk forskningssamarbejde vedrørende synsbetingelser i mørketrafik. Rapport nr. 6, 1983. (Rapporten kan bestilles hos Lysteknisk Laboratorium, Bygning 325, Lundtoftevej 100, 2800 Lyngby, Danmark).

Den specifikke luminans af kørebaneafmærkning i billygtebelysning undersøges ved målinger og ved modelbetragtninger.

For afmærkning uden glasperler vises afhængigheden af de geometriske forhold at være som for vejbelægninger. For afmærkning med glasperler findes variationer af samme natur, som dog er kraftigere og overlejret med større individuelle variationer.

På denne baggrund diskuteres et valg af en standard målegeometri, som er fælles for vejbelægningers og afmærkningen på kørebanen. Det foreslås desuden, at vurdering af den specifikke luminans for andre geometrier sker ved brug af de udtryk, der er udledt for vejbelægninger.

1. INTRODUCTION

By Kai Sørensen, LTL

There is hardly any doubt concerning the importance of reflection properties of road markings. On one hand, road markings are an important tool for the regulation and guidance of traffic, and they are laid and maintained at considerable expenses. On the other hand, the reflection properties determine whether or not the road markings are visible, so as to fulfil their purpose.

The most difficult conditions of illumination are clearly found by night driving on unlit roads, where the markings should be visible at a sufficient distance in the illumination of the headlights of the vehicle.

In this situation the reflection of conventional road markings is believed to be critically low, and this is often taken as one of the explainations for a substantial increase in accidents of the type, where the vehicle leaves the road, see for instance Night Traffic Report No. 3.

The widespread use of glass beads in road markings on unlit roads (and even on roads with road lighting) can perhaps be taken to indicate the acceptance of the importance of the reflection properties of road markings.

Glass beads embedded in the surface of a marking show some retroreflection, thereby potentially enhancing the reflection in the critical situation at night. The glass beads are added to the surface of the newly laid marking (drop-on) and sometimes also to the material before the laying (premix), so as to become liberated during wear.

In a dry, newly laid road marking the retroreflective action of the glass beads is mostly high.

This is obvious from e.g. measurements reported in VTI report No. 189A (VTI 1980) or just from visual inspection.

The use of glass beads is not, however, generally considered to represent the solution of all problems of visibility of road markings in vehicle headlight illumination. Thus there is doubt on the actual effect of glass beads for worn road markings and in particular for worn and wet road markings. Measuring results for such road markings are found for instance in internal report No. 899 of the Norwegian Road Laboratory (1978).

Probably the use of glass beads is a valuable mean of improving the reflection of road markings, but with the actual effect depending on the amount and quality of the beads, the type of road markings, wear, humidity and more factors.

Glass beads are further not the only mean to improve the reflection of road markings in headlight illumination. In some countries markings with an improved surface texture are being studied or even have some application. One such marking is a surface treatment with white stones used in Denmark.

The surface texture is considered to be important for the wet condition, and perhaps also for the skid resistance of the road marking.

On this background the need for definitions, measuring methods and criteria for the reflection properties of road markings is obvious. From this need has resulted a strong activity in recent years for drafting recommendations, designing portable instruments etc.

A survey of this activity would be a lengthly one and is not attempted. For some information see Night Traffic Report No. 3.

It has to be stated, however, that much of this activity is premature, as applications do necessitate a sound basis of research, and as research has been neglected to a large degree.

The research presently carried out in the Nordic Research Cooperation for visual conditions in night traffic, on the basis of Night Traffic Report No. 3, does aim at providing the above-mentioned basis for applications.

This report concerns the variation of the reflection of road markings with the geometrical conditions. The account of this variation is meant to serve as a background for the choice of a standard geometry for in situ measurement, and thereby for the choice of a reflection parameter to be used in specifications for the reflection of road markings.

The present study is strongly linked to a similar study for road surfaces, see Night Traffic Report No. 4 .

A proposal for a standard geometry will be based on both studies, as there are considerable, practical advantages in having methods that are common to road surfaces and road markings.

In both studies the specific luminance, SL of the road surface or the road marking is used as the reflection parameter. The geometrical situation is described by means of an angular coordinate system, which is derived from an angular system used for reflection properties of road surfaces in road lighting, see for instance CIE Report No. 30/2.

These definitions and notations, which are summarized in chapter 2, are not necessarily the final choice in the Nordic countries. The definitions are rather used as sensible ones in a situation lacking more universal agreement. The results are of course valid even after conversions to other sets of definitions and notations.

The measuring equipment and the measuring procedures are introduced shortly in chapter 2 also, as a more detailed account is given in Night Traffic Report No. 4.

As it is the case in the study for road surfaces, the specific luminance of road markings is discussed both in terms of model considerations and in terms of measuring results.

The purpose of the model considerations is to give an understanding of the magnitude and the variation of the reflection, and thereby to facilitate the discussion of the measuring results. Further, to the degree that the model considerations and the measurements agree, the conclusions are taken to be well supported.

The model considerations for the specific luminance of road markings is found in Appendix A. This appendix is separated essentially into two parts concerning respectively the specific luminance of the surface and of glass beads in the surface.

The first part is mainly a summary of the model considerations for road surfaces, as these apply equally well to the surface of a road marking.

The second part introduces concepts for the specific luminance of glass beads, which are either idendical or very similar to those for the surface. This similarity is due to the nature of the model considerations, which are primarily accounts of luminous flux based on definitions and simple laws.

In spite of the formal similarity of the model considerations it is stressed, however, that the specific luminance of glass beads varies more strongly, and is less predictable, than the specific luminance of the surface.

The measuring data and their analyses are found in Appendix D and in Appendix S for road marking samples taken respectively in Denmark and Sweden.

The measuring data confirm essentially the predictions of the model considerations.

For road marking samples without glass beads, the reflection varies with the geometry in the same manner as found for road surfaces.

For road marking samples with glass beads, an increase in the reflection as caused by the glass beads is observed. The contribution from the glass beads, on the other hand, leads to an enhancement of the variation with the geometry.

The consequences for application purposes are discussed in Chapter 3. As for road surfaces a single measuring geometry can be applied to describe the reflection in a range of geometries to a certain accuracy. Due to the larger variations for road markings with glass beads the range is, however, smaller.

Thus for road markings it is even more important than for road surfaces that a standard measuring geometry is chosen with care. More specifically the standard measuring geometry should correspond to a distance on the road, which is within the range of distances considered to be most relevant to the driver.

A summary of the report is given in Chapter 4 and a similar summary in Danish in Chapter 5.

2. DEFINITIONS, MEASURING EQUIPMENT AND MEASURING PROCEDURES

By Kai Sørensen, LTL

2.1 Definitions

The specific luminance, SL (cd/m²/lux) of a surface is defined as the ratio between the luminance, L (cd/m²) of the surface at a point, P in proportion to the illuminance at the point on a plane perpendicular to the direction of illumination, $E_\perp$ (lux):

$$SL = \frac{L}{E_\perp} \ (cd/m^2/lux)$$

Thus a SL-value applies to one direction of illumination and, as the luminance, L varies with the direction of observation, in fact to one geometry of illumination and observation.

This again implies that for a situation with illumination from more than one light source (for instance two headlights on a vehicle) different SL's apply to the different light sources. The solution to this complication is of course that the luminance is given by the sum of the contributions from each light source, as it is the case in all calculations of luminance and illuminance. For this reason reflection properties can in general be discussed in terms of illumination from one light source only.

The geometrical situation is given by the angle of illumination, ε, the angle of observation, α and the azimuthal angle, β (or the supplemental azimuthal angle, β'). See fig. 2.1.

Fig. 2.1 also introduces a complete description of the geometry by means of the illumination distance, D_h, the observation distance, D_o, the illumination height (headlight mounting height), H_h the observation height (observer eye height), H_o and the transverse displacement of the headlight, D_t.

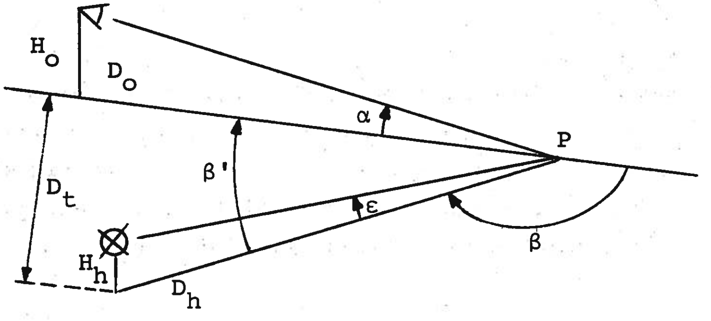

Fig. 2.1 Geometry of illumination and observation.

ε : illumination angle

α : observation angle

β : azimuthal angle

β': supplemental azimuthal angle ($=180^{o}-\beta$)

H_h: illumination height (headlight mounting height)

H_o: observation height (observer eye height)

D_h: illumination distance

D_o: observation distance

D_t: distance of light source from vertical plane of observation (transverse displacement of the headlight)

Belysnings- og observationsgeometri.

ε : belysningsvinkel

α : observationsvinkel

β : azimutvinkel

β': azimutvinklens supplementvinkel ($=180^{o}-\beta$)

H_h: belysningshøjde (lygtens monteringshøjde)

H_o: observationshøjde (observatørens øjenhøjde)

D_h: belysningsafstand

D_o: observationsafstand

D_t: sideforskydning af lygten

The geometry is preferably described by the distances and heights in the following, as a geometry is comprehended more easily this way. The measuring geometries, are, however, set by means of the angles, and the results does naturally apply not only to the given distances and heights, but to all geometries covered by the ranges of angles considered.

This means that the distances and heights are rather to be understood as illustrations of the geometries, and, therefore, these are based on some simplifications. Thus the headlight mounting height is always taken to be 0.65 m, and distances of illumination and observation are taken to be equal and are, therefore, called just the distance, $D(D=D_h=D_o)$.

The distances and heights are easily convented into angles and vice versa, when assuming a headlight mounting height.

2.2 Measuring equipment

The measuring equipment is a laboratory goniometer. originally developed and recently modified for measurements on samples of the type discussed here.

The sample is placed in the center of the goniometer on a sample holder, which allows longitudinal and transverse movements for the scanning of a total measuring field of appr. 100 cm^2.

The illumination system is a projector, while the luminance meter is a Pritchard photometer model 1980. The illumination system and the luminance meter is placed on arms with means of setting the angles ε and α respectively. The illumination further occurs through a mirror arrangement, which allows an easy setting of 5 discrete values of the angle β'.

The illumination system and luminance meter are both focussed on the sample, with the measuring field on the sample determined by a rectangular diaphragm of the size 3.3'x21'. At the measuring distance of 3.6 m this leads to a measuring field on the sample of a width 2.2 cm and a length varying with the observation angle, α.

The rather large width of the measuring field (21') does not enter directly as an aperture of measurement, as the lenses of the luminance meter and the illumination system are placed at equal distances from the sample. For this reason, the angle β does not shift with the transverse location of a point in the measuring field.

The measuring apertures are, therefore, determined mainly by the field apertures of the lenses of the luminance meter and the illumination system. These apertures were restricted to the sufficiently small values of 8'-10' (diameter) by means of iris diaphragms in front of the lenses.

For further information regarding the equipment, see Night Traffic Report No. 4.

2.3 Measuring geometries and measuring procedures

With one modification, the measuring geometries used for road surface samples were used also in this study of road markings. The modification is a dismissal of a simplification in the measuring program, where a combination ($\alpha=0.76^{\circ}$, $\varepsilon=0.37^{\circ}$) was used instead of ($\alpha=0.86^{\circ}$, $\varepsilon=0.37^{\circ}$).

The measuring geometries, therefore, are as given in table 2.1. As this modification was introduced in the couse of the measuring program, some of the reflection tables of Appendix D are, however, in the format used previously.

ε	β' \ α	0.57°	0.69°	0.76°	0.86°	0.92°	1.15°	1.37°	1.72°	1.91°	2.29°	2.86°	3.81°	4.57°	5.71°	6.84°	8.53°
0.37°	0°	x	x		x												
	1°	x	x		x												
0.50°	0°			x		x	x										
	1°			x		x	x										
0.74°	0°						x	x	x								
	1°						x	x	x								
	2°						x	x	x								
1.24°	0°									x	x	x					
	1°									x	x	x					
	2°									x	x	x					
	3.5°									x	x	x					
2.48°	0°												x	x	x		
	2°												x	x	x		
	5°												x	x	x		
3.72°	0°														x	x	x
	2°														x	x	x
	5°														x	x	x

Table 2.1 Format of reflection table containing 51 positions.

Format af refleksionstabel, som indeholder 51 værdier.

The geometries simulate for a headlight mounting height, H_h of 0.65 m distances on the road, D of 10 m, 15 m, 30 m, 50 m, 75 m and 100 m for each of the observer eye heights, H_o of 1 m, 1.2 m and 1.5 m.

For each of these geometries the table further contains positions of 2-4 different values of the angle β'. For practical reasons these values are taken out of a fixed set of 5 values (5 mirrors in the mirror arrangement) and do not correspond to fixed values of the transverse displacement of the headlight, D_t. The data does, however, permit SL-values to be determined for D_t values up to appr. 1 m by interpolation at all distances. By using extrapolation for some distances, SL-values for D_t up to 1.5 m can be derived also.

In the measuring program for a sample, the sample is placed in the equipment and aligned. All the geometries of the reflection table are then set one by one and the total measuring field is scanned by movements of the sampleholder for each geometry.

This measuring program is carried out both for the dry condition of the sample and for a humid condition. The humid condition is created initially and then restablished before each measurement in a simple procedure: First the sample is wettened with ordinary water containing detergent (to reduce surface tension), and then it is wiped off twice with a sponge.

This procedure is the one used also for road surface samples. In an initial experiment it was shown that the humid condition is sufficiently stable and reproducible, although not quite as stable as for road surface samples.

The measuring program results in a papertape punched by the measuring equipment. The measuring data is then printed in a computer run in form of one reflection table for the dry condition and one for the humid condition. Further computer runs allows the drawing of diagrams or the printing of uncertainty tables such as used in the analyses.

3. APPLICATION

By Peder Øbro, LTL

3.1 Introductory discussion

In Night Traffic Report No. 4 it is explained that for application purposes is needed a description of the reflection properties, consisting of a selected standard geometry and a method for the estimation of SL for other geometries.

The main objective in the selection of a standard geometry should be to obtain a reasonable accuracy of the estimation of SL for those geometries, i.e. those distances, which are vital to the driver. Such distances probably include distances of 30 m to 75 m, where the illumination from the headlights is low. On the other hand, it should be considered that the longer the distance, the more difficult is the construction of a portable measuring equipment.

On this basis, standard geoemtries corresponding to distances of 10 m, 30 m and 50 m were tried out. It was concluded that the distance of 10 m does not lead to an acceptable accuracy of description for longer distances, the distance of 30 m is perhaps acceptable, while the distance of 50 m is perhaps the best choice.

These conclusions must of course be based on specific methods for the prediction of the SL for other geometries, than the standard geometry.

In one method it was assumed that the SL-value varies with the geometry in the same manner for all road surfaces. In the other, more practicable method it was assumed that the variation with the geometry is precisely as given by a set of equations.

In any case, the setting up of a description for the SL of road surfaces is greatly facilitated by the type of the variation as discussed below.

Thus there is little variation with the distance on the road (with ε for a fixed ratio ε/α). The variation with the observer eye height is reasonable well accounted for by the factor of geometry ($f_{geometry} \cong \varepsilon/\alpha$). Further the variation with the transverse displacement of the headlight is not very large. Most of this variation can be accounted for by the expression derived from the measuring data for the factor of visible, illuminated facets ($f_{visible}$).

Road markings without glass beads seem to behave in the same manner as road surfaces and as summarized above. It is, therefore, obvious to repeat the abovementioned tests for such road marking samples. This is done in section 3.2.

Road markings with glass beads have, on the other hand, a stronger variation of the SL with the geometry. This variation is due partly to a variation of the luminous intensity of retroreflected light (the factor f_{retro}) and partly to variations of the fraction of the incident luminous flux falling on glass beads (f_{beads}).

This stronger variation is first of all seen as a variation with the distance on the road. The SL can increase or decrease with the distance. In earlier measurements is even seen an initial increase and then a decrease, see VTI report No. 189A. These variations are believed to express a competition between the two factors, f_{retro} and f_{beads}.

The stronger variation of the SL of road markings with glass beads shows up also in the influence of the observer eye height and the transverse displacement of the headlight. This is seen, however, not as a new type of variation, but rather as stronger variations of types already seen for road surfaces and road markings without glass beads.

It is, therefore, obvious to study the description of the influence of these parameters and the influence of the distance separately. This is done in section 3.3 and in section 3.4.

3.2 Road marking samples without glass beads

The road marking samples without glass beads are a subset, five in number, of the Danish set of samples. One of them is a paint, the others are thermoplastics.

Table 3.1 shows the potential accuracies of using geometries corresponding to distances of 10 m, 30 m and 50 m for standard geometries. The variations among the SL's of the different samples are computed using the implication of the model considerations (see Appendix A) that the SL's of different samples change in the same manner with the geometry, but at different scales.

The variations shown in table 3.1 are smaller than those reported for road surface samples. Thus assuming a permissible variation of 15 %, the 10 m, 30 m and 50 m geometries cover ranges of respectively 10 m to 30 m, 10 m to 100 m and 20 m to 100 m.

The reason for the smaller variations of the road marking samples is probably the uniform colour and, therefore, the absence of variations in the average luminance coefficient of illuminated facets, $\bar{q}$.

When basing the calculation of the variations on the precise method of conversion among geometries, which was introduced for road surfaces, the figures increase somewhat, but still remain smaller than for road surfaces.

The increase in variations (tables not shown) is mainly due to an inaccuracy in the prediction of the effect of a transverse displacement of the headlight ($\beta' \neq 0^o$). The decrease in SL is mostly smaller than predicted, the reason probably being a less pronounced surface texture for the road marking samples.

Taking into account that markings with a strong surface texture are used, although samples are not included here, it is chosen not to set up a special conversion method for road markings without glass beads.

Table 3.1 Variations (percent) among the SL-values of the five road markings without glass beads after rescalings of SL at the geometries indicated to unity. Variations are given as ranges for the groups of geometries at each simulated distance on the road, i.e. all geometries are included. The variations are for the dry condition.

Variationer (procent) blandt SL-værdierne for de 5 afmærkningsprøver uden glasperler efter omskaleringer, så SL for de angivne geometrier er én. Variationerne er givet som intervaller for de grupper af geometrier, der svarer til hver af de simulerede afstande på vejen, d.v.s. at alle geometrier er medtaget. Variationerne gælder for den tørre tilstand.

Scaling according to SL-value at	Variations of geometries of distance of 10 m	15 m	30 m	50 m	75 m	100 m
10 m ($\varepsilon = 3.72^o$, $\alpha = 6.84^o$, $\beta' = 0^o$)	0-10%	5-9 %	11-13%	12-16%	11-19%	11-18%
30 m ($\varepsilon = 1.24^o$, $\alpha = 2.29^o$, $\beta' = 0^o$)	11-15%	6-9 %	0-5 %	2-6 %	1-10%	7-11%
50 m ($\varepsilon = 0.74^o$, $\alpha = 1.37^o$, $\beta' = 0^o$)	14-19%	9-13%	4-6 %	0-5 %	4-10%	6-13%

For the humid condition the variations are somewhat larger than for the dry condition (tables not shown), but conclusions are otherwise very similar to those given above for the dry condition.

It seems reasonable, therefore, to use the description method introduced for road surfaces also for road markings. The exact formulas of this method are shown in section 3.5 together with some examples of the use, i.e. transformations to other geometries than the standard geometry.

When emphasis it put on the accuracy for medium and large distances, the standard geometry should correspond to a 30 m or a 50 m geometry. The 10 m geometry is less acceptable.

3.3 Danish road marking samples with glass beads

The subset of Danish samples with glass beads consist of different types of road markings as an attempt to cover the range of reflection properties of commonly used materials.

The types of road markings are paints with drop-on glass beads and thermoplastics with premix and drop-on glass beads.

For road markings with glass beads it is perhaps possible to set up a method for a reasonably accurate estimation of SL for a geometry, when using as a starting point the SL for a geometry of the same distance (the same ε).

This means that it is perhaps possible to account for the influence of the observer eye height (of α) and of the transverse displacement of the headlight (of β').

This statement is based on a calculation of the variation of the SL's among the samples for the geometries of one distance, after a scaling of the SL's, so that SL for $H_o = 1.2$ m and $D_t = 0$ m is unity.

These variations are in the range of 0-10 % for all distances and thus so small as to support the statement given above. For the humid condition the variations are of course larger, but still not very large, appr. 0-20 %.

It is, however, obvious that the prediction method for road surfaces and road markings without glass beads cannot be used to accurately account for the influence of the above-mentioned parameters (α and β').

The reasons for this is mainly that the influence of these parameters is stronger for road markings samples with glass beads, than for samples without glass beads. Thus when variations are calculated, using the prediction methods, variations from the predicted SL's in the range of 0-40 % are found.

For the influence of these parameters (α and β') a special prediction method would, therefore, have to be set up for road markings with glass beads. This, on the other hand, has the inherent difficulty that one in practise would have to decide, if a road marking has or has not glass beads.

The criterium should be of course, whether the surface or the beads contributes most to the specific luminance. This is not an easy criterium to apply, and cases of almost equal contribution will certainly be met.

Therefore, it is not attempted to set up such a description method. Instead it should, after all, be considered to use the prediction method for road surfaces and markings without glass beads, but in certain limited ranges for road markings with glass beads. This is done in section 3.5.

The other problem is to account for the influence of the distance (of ε).

Table 3.2 shows to this purpose the variations among the SL's of the samples as found after rescalings, so that the SL's for each of the geometries of 10 m, 30 m and 50 m distance are unity. The variations are based on only those geometries of H_o = 1.2 m and D_t = 0 m, so as to extract clearly the influence of the distance.

Table 3.2 Variations (percent) among the SL-values of six road markings with glass beads after rescalings of the SL at the geometries indicated to unity. Only geometries for H_o=1.2 m and D_t=0 m are considered. The variations are for the dry condition.

Variationer (procent) blandt SL-værdierne for seks afmærkningsprøver med glasperler efter omskaleringer, så SL for de angivne geometrier er én. Kun geometrier svarende til H_o=1,2 m og D_t=0 m er taget i betragtning. Variationerne gælder for den tørre tilstand.

Scaling according to SL-value at	Variations at geometries of distances of					
	10 m	15 m	30 m	50 m	75 m	100 m
10 m (ε=3.72°, α=6.84°)	0 %	7 %	21 %	31 %	37 %	40 %
30 m (ε=1.24°, α=2.29°)	24 %	17 %	0 %	13 %	22 %	23 %
50 m (ε=0.74°, α=1.37°)	40 %	32 %	15 %	0 %	12 %	14 %

Assuming again a permissible variation of 15 %, the 10 m geometry accounts for the range of distances of 10-15 m only. Similarly the 30 m geometry accounts for distances of 30-50 m, while the 50 m geometry accounts for distances in the larger range of 30-100 m. Outside these ranges the variations are quite large.

The variations of table 3.2 are with respect to a "mean curve" for the influence of the distance. It is doubtful whether such a mean curve with a universal validity can be established, and therefore variations from the exact value of the standard geometry should be considered also.

Such variations are of course larger than shown in table 3.2 (table not shown). Assuming again a permissible variation of 15 %, the 10 m and the 30 m geometry does not account for any of the neighbouring distances, while the 50 m geometry still accounts for a range of distances of 30-75 m.

For the humid condition similar conclusions are reached, when permitting a slightly higher variation (tables not shown).

For road marking samples with glass beads it is concluded, therefore, that the 50 m geometry is strongly preferably to geometries of shorter distances for the use as a standard geometry. In the description it can be assumed that the specific luminance varies only little in the range of 30 m to 75 m.

For the influence of the observer eye height and of the transverse displacement of the headlight the prediction method for road surfaces and road markings without glass beads should be used in limited ranges of these parameters, like shown in section 3.5.

3.4 Swedish road marking samples with glass beads

The Swedish set of samples consists of only one type of road markings, namely thermoplastics with premix and drop-on glass beads to cover the range of reflection properties caused by differences of recipe, climate, manufacturer and chance.

Since these markings are all of the same type, the dependence of SL on the measuring geometry is more uniform than found for the Danish road markings with glass beads.

Calculations of variations of SL among the samples, like done for the Danish samples, all confirm this.

As an example of this more uniform influence of the parameters is calculated the variation among the samples with respect to influence of the distance, D (of ε).

Table 3.3 shows (like table 3.2 for the Danish samples) the variations among the SL's of the Swedish samples as found after rescalings, so that the SL's for each of the geometries 10 m, 30 m and 50 m distance are unity. Again, only geometries with $H_o = 1.2$ m and $D_t = 0$ m are used, so as to extract clearly the influence of the distance.

These variations which are with respect to a "mean curve" for the influence of the distance are really somewhat smaller than found for the Danish road markings with glass beads.

In fact the Swedish road marking samples are in this respect intermediate to the two subsets of Danish samples, those with and those without glass beads. This is the case also in other respects, the level of the SL and the absolute variations. The reason is as stated in Appendix S that the glass beads of the Swedish samples have a rather small effect.

For these reasons the Swedish samples confirm the conclusions of sections 3.2 and 3.3.

This statement applies as well for the humid condition, however, the variations are somewhat higher.

Table 3.3 Variations (percent) among the SL-values of the 12 Swedish road markings with glass beads after rescalings of SL at the geometries indicated to unity. Only geometries for $H_o = 1.2$ m and $D_t = 0$ m are considered. The variations are for the dry condition.

Variationer (procent) blandt SL-værdierne for 12 svenske vejafmærkninger med glasperler efter omskalering, så SL for de angivne geometrier er én. Kun geometrier svarende til $H_o = 1,2$ m og $D_t = 0$ m er taget i betragtning. Variationerne gælder for den tørre tilstand.

Scaling according to SL-value at	Variations at geometries of distances of					
	10 m	15 m	30 m	50 m	75 m	100 m
10 m ($\varepsilon = 3.72^o$, $\alpha = 6.84^o$)	0%	3%	8%	15%	21%	27%
30 m ($\varepsilon = 1.24^o$ $\alpha = 2.29^o$)	8%	6%	0%	10%	18%	23%
50 m ($\varepsilon = 0.74^o$ $\alpha = 1.37^o$)	15%	15%	10%	0%	9%	17%

3.5 The standard geometry and the transformation to other geometries

The results of the sections 3.2, 3.3 and 3.4 together imply that the 50 m geometry as a standard geometry is the most useful for road markings with or without glass beads. For a headlight mounting height, H_h of 0.65 m it covers the range of distances of 20 m-100 m, corresponding to the range of ε of 1.86^o-0.37^o for road markings without glass beads, while it covers the range of distances of 30 m-75 m, corresponding to the range of ε of 1.24^o-0.50^o, for road markings with glass beads.

The SL value of the standard geometry, SL' is assumed to be determined in a measurement by a suitable instrument on the road.

The SL for other geometries can then according to Appendix A.2 and section 3.2 be estimated by the following set of formulas.

$$SL(\varepsilon,\alpha,\beta') = \frac{f_{geometry}}{f'_{geometry}} \cdot f_{visible} \cdot SL'$$

where SL' is the SL for the standard geometry (it is assumed that $\beta' = 0^{o}$ for this geometry)

$f'_{geometry}$ is the factor of geometry for the standard geometry

$$f_{geometry} = \sin\varepsilon/\sin\alpha \cong \varepsilon/\alpha$$

and $f_{visible} = 1 - F_1(p_1) \cdot F_2(p_2)$

where $p_1 = \beta'/(\alpha-\varepsilon)$

$$F_1 = \begin{cases} \frac{1}{3}p_1 & \text{for } p_1 \leqq 3 \\ 1 & \text{for } p_1 > 3 \end{cases}$$

$$p_2 = \alpha-\varepsilon \text{ (radians)}$$

$$F_2 = \begin{cases} 0.1 & \text{for } p_2 \geqq 0.01 \\ 0.1 + 0.5(1 - \frac{p_2}{0.01}) & \text{for } p_1 < 0.01 \end{cases}$$

The luminance of the road marking as seen by the driver of a vehicle can be calculated using the SL for the geometry of each headlight and the driver together with the illumination, $E_{\perp}$ from each headlight.

Example of transformation

For a geometry of ($\varepsilon = 0.74^{o}$, $\alpha = 1.37^{o}$, $\beta' = 0^{o}$) SL' has been measured for a certain road marking to 60 mcd/m²/lux. Referring to the method of estimating SL above the factor of geometry, $f'_{geometry}$ is $0.74^{o}/1.37^{o} = 0.54$.

For this road marking is desired an estimation of the SL for both headlights at a distance

$D = D_h = D_o = 80$ m for a low car with a headlight mounting height, $H_h = 0.6$ m and a drivers eye height of $H_o = 1$ m.

The factor of geometry, $f_{geometry}$ for this vehicle is 0.6 m/1 m = 0.6. Hence a correction factor of 0.60/0.54 = 1.11 applies for this vehicle.

For the headlight in the steering side the transverse displacement, D_t is approximately 0, and hence $f_{visible} = 1$ and:

SL (headlight in steering side) = 1.11×60 mcd/m²/lux
= 66.7 mcd/m²/lux

For the other headlight $D_t = 1.3$ m and a smaller value of $f_{visible}$ applies.

The parameter, p_1 is computed to $D_t/(H_o - H_h) = 3.25$. which is greater than 3 and therefore the value of 1 is taken for F_1.

The parameter, p_2 is $(H_o - H_h)/D = 0.005$, which is smaller than 0.01, and therefore, F_2 is calculated by:

$$F_2 = 0.1 + 0.5(1 - \frac{p_2}{0.01}) = 0.1 + 0.5(1 - 0.5) = 0.35$$

This gives an $f_{visible}$ of $1 - F_1 \cdot F_2 = 1 - 0.35 = 0.65$ and:

SL(other headlight) = $0.65 \times 1.11 \times 60$ mcd/m²/lux
= 43.3 mcd/m²/lux

Errors introduced by the transformation

The results of section 3.2 show that for road markings <u>without</u> glass beads errors of the order below 15 % (RMS) can be expected when the transformation is used in the range of distances (of ε) covered by the standard geometry and for all values of observer eye height (of α) and lateral displacement (of β') of the measuring table, table 2.1.

For road markings <u>with</u> glass beads the errors generelly are higher, but they might after all be acceptable for some practical applications.

Table 3.4 shows some examples of the errors introduced when the transformation is done on some actual road markings. In these examples are used models of three types of vehicles, a sports car, a normal car and a small truck (or a motorvan). For practical reasons the headlight mounting height have been chosen to be the same for all the vehicles, namely H_h = 0.65 m.

The road markings selected are No. CR1 of Appendix S and Nos. 7 and 12 of Appendix D. All of them show a rather high variation of SL dependent on the geometry. For No. CR1 and No. 12 this variation is among the highest while for No. 7 it is more normal.

For the two longest distances the errors are almost in all cases below 15 %. Errors higher 15 % is mainly connected to the shortest distance of 30 m. This can be accepted because the visual conditions on shorter distances are less critical than on longer distances.

The error of a calculation of the luminance of the road marking as seen by the driver will be a weighted mean value of the errors of SL for the two headlights; weighting according to the illumination from each headlight. If the two headlight give equal illumination on the road marking the error will be the average of the two error values.

Table 3.4 Examples of the errors introduced when the transformation method is used on road markings with glass beads.
The deviation in percent between calculated and measured values.
The SL of the standard geometry, SL ($\varepsilon = 0.74^o$, $\alpha = 1.37^o$, $\beta' = 0^o$) has been transformed into the SL's of the two headlights of 3 different cars at 3 different distances.
The vehicles all have the headlight mounting height of $H_h = 0.65$ m and the same lateral displacement of the headlight in the steering side of $D_{ts} = 0$.
The lateral displacement of the headlight in the other side, D_{to} and the drivers eye hight, H_o are different for the 3 vehicles as shown.

Eksempler på fejl, som opstår, når omregningsmetoden bruges på vejmarkeringerne med glasperler.
Afvigelse i procent mellem beregnede og målte værdier.
SL for standard geometrien, SL($\varepsilon = 0{,}74^o$, $\alpha = 1{,}37^o$, $\beta' = 0^o$) er omregnet til SL for de to lygter på 3 forskellige køretøjer ved 3 forskellige afstande. Køretøjerne har alle lygtehøjden $H_h = 0{,}65$ m og antages ikke at have sideforskydning for lygten i førersiden, $D_{ts} = 0$.
Sideforskydningen af lygten i den anden side, D_{to} samt førerens øjenhøjde, H_o er forskellig for de 3 køretøjer.

Distance	"Sports car" $H_o = 1$ m		"Normal car" $H_o = 1.2$ m		"Small truck" $H_o = 1.5$ m	
	$D_{ts} = 0$	$D_{to} = 1$	$D_{ts} = 0$	$D_{to} = 1.2$	$D_{ts} = 0$	$D_{to} = 1.5$
Errors in percent for road marking No. CR1						
30 m	+20 %	+ 9 %	+19 %	+26 %	+25 %	+22 %
50 m	- 1 %	-11 %	0 %	+ 3 %	+ 1 %	+ 4 %
75 m	- 7 %	- 8 %	-13 %	-10 %	-19 %	-17 %
Errors in percent for road marking No. 7						
30 m	+ 1 %	- 4 %	+ 4 %	+33 %	+19 %	+12 %
50 m	- 4 %	+ 3 %	0 %	+11 %	+ 8 %	+21 %
75 m	+ 6 %	+ 5 %	- 3 %	+10 %	- 4 %	+11 %
Errors in percent for road marking No. 12						
30 m	+14 %	+ 5 %	+28 %	+35 %	+35 %	+47 %
50 m	- 9 %	- 6 %	0 %	+10 %	+ 9 %	+13 %
75 m	- 3 %	- 9 %	-12 %	- 8 %	- 7 %	- 4 %

Thus, for the road marking No. 7 which might be a typical thermoplastic with glass beads, the average of the errors applying for the two headlights are equal to or below 15 % for all distances.

It is concluded, therefore, that transformation using the method shown above in most practical situations can be done also for road markings with glass beads without introducing serious errors.

4. SUMMARY

By Kai Sørensen, LTL

This study concerns the dependence of the reflection of road markings in vehicle headlight illumination on the geometrical conditions. The geometries considered are representative for illumination by the drivers own headlights.

The study is a part of a research program for optical and visual conditions on roads without fixed lighting. This research program is carried out within the Nordic Research Co-operation for Night Traffic. The plans are given in Night Traffic Report No. 3 (1980).

This study in particular is linked with a similar study for road surfaces, which has already been carried out and is described in Night Traffic Report No. 4 (1982).

Both of the studies are carried out in the classical manner, where model considerations on the reflection are set up and tested against a set of measurements.

For the reflection parameter is used the specific luminance, SL as defined in section 2.1. The unit of SL is cd per m^2 per lux. However, in most diagrams is used the unit of mcd per m^2 per lux in order to have convenient numbers.

The geometries are expressed either in an angular coordinate system, or by means of dimensions as shown in fig. 2.1.

The angular coordinate system has been derived from an angular coordinate system used in road lighting. It employs the following three angles,

the illumination angle ε, the observation angle α and the azimuthal angle β'.

The dimensions are the observation height H_o, the illumination height H_h, the transverse displacement between the observer and the headlight D_t and finally the distance D to the point on the road marking.

The geometries considered are,for an assumed illumination height (headlight mounting height) of 0.65 m,given by observation heights of 1 to 1.5 m, transverse displacements of 0 to 1.5 m and distances of 10 to 100 m. In total there are 51 geometries, which together form a reflection table as shown in table 2.1. The measurements are carried out by means of the equipment, which was used for road surfaces also. The equipment, which is described in section 2.2, is found at the National Road and Traffic Institute, Linköping, Sweden.

The road marking samples to be measured were selected and taken from roads in Denmark and Sweden. For each of these samples a complete reflection table was measured both for the dry and a humid condition.

The Danish road marking samples and their measuring data are given in Appendix D. The samples are described both in table D.1 and by means of photographs in fig. D.1, D.2 and D.3. The measuring data are discussed by means of a number of diagrams, which are to reveal the influence of the geometry, and the influence of humidity. Further, the complete measuring data are given in the form af reflection tables in section D.4.

A similar survey of Swedish road marking samples and their measuring data are given in Appendix S. In particular the samples are described in table S.1 and fig. S.1 and S.2. The Danish samples, 11 in total, include paints and thermoplastics both with and without glass beads. The Swedish samples, 11 in total, all are thermoplastics and all with glass beads. They fall in two categories, one of a standard composition used in the south and middle parts of Sweden, and one of a soft composition used in the north.

The diagrams for the influence of the geometry are all set up to test various aspects of the model considerations, which are given in Appendix A.

The specific luminance, SL is considered to be the sum of the SL for the surface of the road marking, and of the SL of the retroreflective glass beads as found in most road markings. Thus two sets of model considerations are given in Appendix A.

For the contribution from the surface, the model, which was derived and tested for road surfaces, is considered to apply equally well to road markings. The model for road surfaces is expressed by the product of four factors:

$$SL(\text{surface}) = \bar{q} \cdot f_{\text{geometry}} \cdot f_{\text{texture}} \cdot f_{\text{visible}}$$

The factor, $\bar{q}$ is the average luminance coefficient of illuminated facets in the texture. For a white road marking a value of 200 mcd per lux should be feasible.

The factor of geometry, f_{geometry} is given simply as the ratio ε/α, i.e. the ratio between angles of illumination and observation. One can note that a large observation height as for a truck driver, leads to a small SL.

The factor of texture, $f_{texture}$ is the fraction of the incident luminous flux, that falls on facets of a large inclination towards the vehicle. From this can be read, that facets of a large inclination are the active agents of reflection. Further, a good texture of the road marking can lead to a significant value of $f_{texture}$. It is judged that in practise values up to 0.5 say are feasible.

The factor of visible illuminated facets, $f_{visible}$ gives the fraction of illuminated facets, that are also visible. This factor is unity, when the observer is right above the headlight. The value decreases with increasing transverse displacement of the headlight in a rather complicated manner. The formulas derived for road surfaces are given in section A.2.

Thus for the surface, the level of reflection is given by the two factors $\bar{q}$ and $f_{texture}$, and the variation with the geometry by the two factors $f_{geometry}$ and $f_{visible}$. Values of 50 to 100 mcd per m^2 per lux should be feasible. The variation with the geometry is expected to be roughly the same for all surfaces.

The model for the reflection of glass beads, which is derived in section A.3, turns out to be very similar to the surface model. This is perhaps less surprising, when it is stated, that the models are essentially accounts of luminous flux and based on simple laws and definitions.

The glass bead model predicts a specific luminance as given by four factors also:

$$SL(\text{glass beads}) = f_{retro} \cdot f_{geometry} \cdot f_{beads} \cdot f_{visible\ beads}$$

These factors have a one to one correspondance to the factors of the surface model. The differences of definitions and behaviour are all to be understood by the difference in reflection agents, being respectively glass beads and facets of a large inclination.

The factor f_{retro} is a sort of luminance coefficient for glass beads. The retroreflection of glass beads are considered in figs. A.1 to A.3. It is shown that a width of the retroreflected beam of appr. $\pm 10^{o}$ is expected, and that the depth of which the beads are fixed in the matrix is important. On this basis a value of f_{beads} of 1000 mcd per m^2 per lux should be typical.

In fig. A.4 the two reflection agents of the two models are compared. It is indicated that a consequence of the high value of f_{retro} is a higher dependence of the geometry. The factor must decrease, whenever the angular separation between directions of illuminatiom and observation increases. Thus one must expect, that variations as seen for the surface are enhanced by the glass beads,and also that there will be a tendency of an increase with the distance on the road.

The factor of geometry, $f_{geometry}$ is identical for the two models. However,two different interpretations apply as shown in fig. A.5.

The factor of illuminated beads, f_{beads} is the fraction of incident luminous flux that falls on glass beads. In a worn road surface marking one can imagine that active glass beads are mostly found in protected positions deep in the texture. For this reason f_{beads} might sometimes decrease with the distance on the road, and thus more or less counteract the increase in f_{retro}. The value of f_{beads} is expected to be lower than the value of the corresponding factor $f_{texture}$.

The factor of visible illuminated beads, $f_{visible\ beads}$, can be expected to change with the geometry in the same manner as $f_{visible}$ for the surface model. Both factors account for the "shadowing" of the reflection agents, when the headlight is displaced in the transverse direction.

The Danish road marking samples without glass beads comply very well with the surface model. In fig. D.5 one sees the expected variation with the observation height, in fig. D.7 the independence of the distance and in fig. D.9 the expected variation with the transverse displacement.

The specific luminance ranges from 30 mcd per m^2 per lux for a smooth paint to 78 mcd per m^2 per lux for a thermoplastic with a good texture.

The SL's of Danish road markings samples with or without glass are compared in fig. D.4. For markings with glass beads the SL's are in the range of appr. 100 to 200 mcd per m^2 per lux. The highest values are for paints, probably because the beads are deposited in depths favourable for retroreflection. The paints seem, on the other hand, to be sensitive to wear.

The SL's of thermoplastics with glass beads are in the range of 100 mcd per m^2 per lux.

For the markings with glass beads the reflection must significantly or even predominantly by caused by the glass beads. The expected tendency of enhanced variations are thus also seen in the diagrams of fig. D.4, D.6, D.8 and D.10.

The Swedish road markings seem to be in a state of heavier wear than the Danish, this probably caused by the widespread use of studded tyres in Sweden in winter. The result is lower values of the SL, which are to a higher degree to be attributed to the surface. Thus the variations with the geometry are somewhere in between those shown by Danish road markings with and without glass beads.

For the humid conditions the assumption used for road surfaces seem to apply equally well to road markings. This assumption is that the SL for the humid condition is a certain fraction of the SL for the dry condition. The value of the fraction changes from sample to sample, but only to a smaller degree with the geometry. Thus the reflection tables for the humid condition are supposed to be downscaled version of the reflection tables for the dry condition.

This assumption is tested by log-log diagrams of SL(dry) versus SL(humid). The points lie along lines of a 45^{o} inclination and thus confirming the assumption. See for instance fig. D.14. The loss in SL in the humid condition can be judged by tables D.2 and S.2.

The consequences for application purposes are discussed in chapter 3.

Road markings without glass beads can be treated like road surfaces. This means that a single measurement in a standard geometry corresponding to a certain distance on the road covers reflection properties in a certain range of geometries to a certain accuracy, see table 3.1.

A choice of a standard geometry corresponding of a distance of 50 m is adequate for both road surfaces and road markings for covering a large range of distances to an accuracy of 15%. The SL's of geometries other than the standard geometry are estimated by the conversion formulas as given in section 3.5 and as based on the surface model.

For road markings with glass beads the larger individual variations lead to a reduction of the range covered by a standard geometry. Thus the choice of a standard geometry is more critical and must be based on a careful consideration of what geometries are most relevant in driving situations.

A choice of a standard measuring geometry again corresponding to 50 m seems reasonable, as it covers distances of appr. 30 m to 100 m, see tables 3.2 and 3.3.

It is to be remarked, that the longer the distance of a standard measuring geometry, the more difficult is the design of a portable equipment. Thus the choice of a standard measuring geometry must consider also practical aspects of instrumentation.

However, the use of appr. 10 m simulated distance, as in some commercially available equipments is not satisfactory. This is evident from this study and in particular from fig. D.4. This figure shows that a ranking of the samples with glass beads, done at 10 m, does not at all hold at larger distances.

In fact the sample of the highest SL at 10 m is the one of the smallest SL at 50 m.

Thus it is necessary to increase the simulated distance of a standard measuring geometry above 10 m and it is desirable to go as high as 50 m.

Again due to the individual variations of the SL of road markings with glass beads, it is not attempted to set up a method of conversion among geometries. However, some examples given in section 3.5 show that in practise the conversion formulas for the surface can be used to a reasonable accuracy for those road markings also.

5. SAMMENFATNING

af A.O. Bohn, for Statens Vejlaboratorium

Vejstriber, som påføres vejen i form af måling eller som termoplastiske markeringsmasser, og hvis synlighed i forhold til den omgivende vejbelægning kan fremhæves ved iblanding eller pådrypning af glasperler har stor trafiksikkerhedsmæssig betydning ved at lede trafikken specielt ved kørsel om natten på ubelyste veje.

LTL (Lysteknisk Laboratorium) og VTI (Statens Väg- och Trafikinstitut) har, med yderligere deltagelse af Statens Vejlaboratorium, foretaget en undersøgelse af vejstribers refleksionsegenskaber. Undersøgelsen er et led i det nordiske forskningssamarbejde og er foretaget i tilslutning til en lignende undersøgelse af vejbelægninger.

Den for trafikanten vigtigste lystekniske størrelse ved kørsel på veje uden faste belysningsanlæg er den specifikke luminans, SL (tidligere kaldet retrorefleksionen), som her måles i millicandela pr. m^2 pr. lux. Den kan siges at være et mål for, hvor stor en del af trafikantens billys, der rammer et betragtet punkt af vejen, som reflekteres i retning af trafikantens øje - nøjagtigere defineres det i afsnit 2.1. Lysheden - luminansen - i punktet fås ved at gange SL med den af billyset frembragte belysningsstyrke på en plan gennem punktet vinkelret på belysningsretningen.

På fig. 2.1 er der gjort rede for, hvorledes observationsafstanden til punktet P, observationshøjde, lygtehøjden og sideforskydningen mellem observatør og lygte (en størrelse, som kun er 0 for motorcykelsituationen) er knyttet sammen med geometrien, d.v.s. med de karakteristiske vinkler α, β' og ε. α er observationsvinklen og ε belysningsvinklen.

Ved målingen af SL har man benyttet et på VTI (Statens Väg- och Trafikinstitut) i Linköping værende måleapparat, der var forsynet med belysningsanordning og luminansmeter, og hvor man ved passende valg af målegeometrien, d.v.s. variationsområdet for de 3 nævnte vinkler, kunne finde de værdier af SL af vejstribeprøverne, som måtte anses for at være aktuelle. Det betød vinkler, som svarede til lygtehøjder på 0,65 m, afstande til observationspunktet på 10-100 m, observationshøjde fra 1-1,5 m og sideforskydninger fra 0-ca. 1,5 m.

Tabel 2.1 viser vinkelkombinationerne, desuden er der ved krydser angivet, ved hvilke kombinationer det er formålstjenligt at måle.

I afsnit D.4 og S.4 er vist måleresultaterne for henholdsvis de danske og de svenske vejstriber i såvel tør som våd tilstand. Tabel D.1 giver en kort oversigt over de danske vejstriber og på fig. D.1-D.3 er der vist fotografier af striberne. I tabel S.1 og Fig. S.1 og S.2 bringes de tilsvarende oplysninger for svenske vejstriber. Blandt de svenske prøver findes der i modsætning til de danske ingen malede striber, kun termoplastiske markeringsmasser.

I kapitel 3 omtales, at de afstande, der er vigtigst for trafikanten, er området fra 30 til 75 m. Et transportabelt måleapparat til brug på vejen bør derfor måle ved en geometri, der tillader at bedømme dette område korrekt, selv om det vil betyde en for apparatkonstruktionen noget ubekvem lille værdi af belysningsvinklen ε. For vejstriber uden perler (og for vejbelægninger) er problemet mindre end for vejstriber med perler.

Der er tidligere udviklet en modellov for vejbelægningers SL, der tillader at omregne SL målt ved en geometri til en anden. Modelloven, som udførligere omtales i Appendix A antages at gælde for vejstriber uden perler. I afsnit 3.5 omtales, at man ved en sådan omregning skal gange med forholdet mellem faktorerne $f_{geometry}$ (som er sinε/sinα) for de to geometrisituationer og gange med $f_{visible}$, som er en størrelse, der kun afhænger på den der viste måde af vinklerne α, β' og ε. $f_{visible}$ er et tal for hvor mange belyste facetter, der er synlige. For striber med perler er der ikke fundet en generel anvendelig modellov, men en række eksempler viser i afsnit 3.5, at den førnævnte modellov dog kan anvendes i nogle almindelige praktiske situationer.

Tabel 3.1's tre linier viser for striber uden glasperler hvilke variationer man får for forskellige observationsafstande mellem målte SL tal og beregnede SL tal, idet beregningerne er foretaget ved i hver linie at gange de målte tal med faktorer, der ville bevirke, at alle målte tal for ε svarende til henholdsvis afstandene 10, 30 og 50 m (og observationssideforskydning 0 og observationshøjde 1,2 m) var lig med de beregnede. Måles ved vinkelsæt svarende til 10 m observationsafstand viser tabellens øverste talrække, at hvis man tillader 15 % variation, dækker denne geometri afstandene fra 10-30 m. Målinger med vinkelsæt svarende til 30 og 50 m observationsafstand er fordelagtigere, her dækker 15 % variation områderne 10-100 m og 20-100 m.

Tabel 3.2 viser for de danske prøver med glasperler, at her er det på grund af perlernes meget retningsbestemte refleksion langt vigtigere til målingerne at vælge en geometri, der svarer til 50 m observationsafstand. Vælges 10 m, viser øverste linie, at to striber med perler, der afviger fra hinanden med en bestemt faktor ved 10 m observationsafstand godt ved 100 m kan afvige med en faktor, der er 40 % forskellig fra faktoren ved 10 m. Der er her kun medtaget målinger svarende til observationshøjden 1,2 m.

Tabel 3.3 svarer til tabel 3.2, men gælder de svenske prøver, og viser at disse prøvers SL-værdier har en mere ensartet afhængighed af geometrien end de danske. Desuden varierer SL-værdien i det hele taget mindre ved ændringer i geometrien for svenske end for de danske prøver.

Det konkluderes for vejmarkeringer med glasperler, at standardgeometrien svarende til 50 m observationsafstand er stærkt af foretrække, og at SL-værdien for denne geometri kan antages for afstande fra 30 m til 75 m.

I afsnit 3.5 er vist de formeludtryk, som svarer til den ovennævnte modellov. Formlerne, som er uddybet i Appendix A, kan anvendes ved omregning af SL-værdier fra én geometri til en anden, og et eksempel på en omregning er vist. For vejmarkeringer uden glasperler er unøjagtigheden ved omregning af SL fra 50 m standardgeometrien til andre geometrier ca. 15 % (standardafvigelse, RMS). For vejmarkeringer med glasperler er fejlen i det generelle tilfælde højere, men tabel 3.4 viser, at den i en række praktisk relevante tilfælde alligevel ikke er større end, at det kan accepteres.

Til eksemplerne i tabel 3.4 er anvendt 3 vejmarkeringer, nr. CR1 fra Appendix S og nr. 7 og nr. 12 fra Appendix D. For nr. CR1 og nr. 12 varierer SL temmelig meget med geometrien, mens nr. 7 er mere "normal". For disse vejmarkeringer er der beregnet den fejl i %, som opstår, når SL for standardgeometrien omregnes til geometrier for tre forskellige køretøjer, en sportsvogn, en normal personvogn og en lille lastvogn.

Store fejl er i det væsentlige knyttet til de korte afstande, hvor synsforholdene normalt ikke er kritiske, mens fejlene hovedsageligt er mindre end 15 %

på de længere afstande, hvor behovet for nøjagtigt kendskab til SL, på grund af den lavere belysningsstyrke, er større.

Det konkluderes derfor, at omregning med den viste metode i de fleste praktiske situationer uden alvorlige fejl kan foretages også for vejmarkeringer med glasperler.

I Appendix A er den tidligere nævnte modelbetragtninger uddybet. De anvendes siden til fortolkningen af de i afsnit D og S viste forsøgsresultater. For striber uden perler, kan man benytte det udtryk, der i en tidligere rapport med held er brugt for vejbelægninger.

$$SL = \bar{q} \cdot f_{geometry} \cdot f_{texture} \cdot f_{visible}$$

$\bar{q}$ er den gennemsnitlige luminanskoefficient af belyste facetter og er dermed et mål for lysheden af stenene i overfladen. Den kan for lyse striber være så høj som 0,2-0,3.

$f_{geometry}$ er $\sin\varepsilon/\sin\alpha$. Det ses, at efter dette har en stor observationshøjde i forhold til lyskildehøjde en uheldig indvirkning på SL.

$f_{texture}$ er den brøkdel af billyset, der falder på facetter, der danner en gunstig stor vinkel mod bilen. Det viser betydningen af at få markeringsmaterialer med en god struktur, der ikke nedslides for meget af trafikken.

$f_{visible}$ er den brøkdel af de belyste facetter, der også er synlig. Denne faktor redegør for det fald i SL, der indtræffer, når $\beta' \neq 0$. I afsnit A.2 er der redegjort for, hvordan $f_{visible}$ afhænger af α, β' og ε.

Formlen for SL viser, at for vejstriber uden perler varierer SL med geometrien på en simple og beregnelig måde. Den relative variation med geometrien er ret ens for alle striber uden perler, men det absolutte niveau for SL afhænger af teksturen og af $\bar{q}$.

SL for en stribe med glasperler er, da perlerne ikke dækker hele overfladen, summen af SL for perlerne og SL for perlefri overflade.

Figurerne A.1-A.3 viser hvorledes lys retroreflekteres af en kugleformet glasperle, der delvis er nedsænket i et reflekterende afmærkningsmateriale. Som det fremgår af fig. A.3.C, er en glasperle mest effektiv, når den sidder med sit centrum omtrent i højde med overfladen af afmærkningsmaterialet. Glasperlerne vil aldrig være så tæt pakket som teoretisk muligt, retrorefleksionen er derfor ikke optimal.

En modellov for perlernes refleksion er foreslået i afsnit A.4. Den kan skrives

$$SL = f_{retro} \cdot f_{geometry} \cdot f_{beads} \cdot f_{visible\ beads}$$

De enkelte faktorer diskuteres i det følgende.

I afsnit A.4.2 omtales f_{retro} som en art parallel til luminanskoefficienten. Men som det fremgår af fig. A.4 er det lys, der reflekteres fra en perle, meget mere orienteret mod lysgiveren for en glasperle end for en facette i en almindelig vejbelægning. Der vises, at en realistisk værdi af f_{retro} er 1 cd/lm. f_{retro} vil antagelig altid vokse med afstanden.

I afsnit A.4.3 omtales $f_{geometri}$, der - som tilfældet var ved almindelige vejbelægninger - defineres som forholdet mellem sinus'erne til belysnings- og observationsvinkel. Det er den faktor, der varierer, når observationshøjden varierer. Som det fremgår af fig. A.5, har $f_{geometry}$ derfor forbindelse med antal af belyste perler pr. enhed tilsyneladende areal af feltet.

Afsnit A.4.4 omtaler f_{beads}, den del af lysstrømmen, der falder på perlerne. For ny udførte striber med pådryppede perler, der ligger højt i forhold til overfladen, vil f_{beads} vokse med afstanden. Det omvendte kan være tilfældet ved slidte striber, hvor perlerne ligger nedtrykket i stribemassen. SL's variation med afstanden skyldes samspillet mellem f_{beads} og f_{retro}.

Afsnit A.4.5 omtales $f_{visible\ beads}$ som et udtryk for belyste, synlige perler, d.v.s. perler, der ikke er kommet i skygge som følge af lyskildens sideforskydning. Ændringer i denne faktor er forbundet med ændringer i f_{retro}.

I afsnit A.4.6 konkluderes der, at det er vanskeligt at udnytte modelloven for glasperleholdige striber til kvantitative betragtninger; det er navnlig faktoren f_{retro}, der udviser den store vinkelafhængighed, der gør det besværligt. Derfor benyttedes den enklere modellov for perlefri striber til omregninger, og fejlen påvises at være acceptabel. Modelloven er dog nyttig til at forklare variationsårsagerne.

I afsnit D vises i en række diagrammer måleresultaterne. Af fig. D.4 fremgår det, at man for tørre, danske prøver med glasperler, som oftest får en stigning i SL med afstanden. Endvidere er SL højere for disse prøver end for prøverne uden glasperler. De højeste værdier for SL (op til 200 mcd/m^2/lux) fås for maling med pådryssede perler; perlerne fæstnes åbenbart her i en særlig fordelagtig dybde. Ved slid synker SL for de malede striber. SL for termoplastiske striber med perler er ca. 100 mcd/m^2/lux. Uden perler er SL noget lavere. Kun hvis markeringsmasserne har en grov struktur, opnår man ca. 60-80 mcd/m^2/lux. Lavest ligger en relativ jævn maling uden perler (30 mcd/m^2/lux). Fig. S.4 viser, at SL for svenske standardprøver stiger med observationsafstanden. For bløde termoplastiske svenske prøver til brug i landets kolde egne falder SL dog med afstanden, antagelig på grund af perlernes tendens til at blive trykket ned i den bløde termoplastiske matrix.

Målinger på fugtige striber giver lavere værdier - en relativ nymalet stribe var her bedst blandt de danske prøver med et SL på 135 mcd/m^2/lux; den havde bevaret sin vandafvisende overflade. Det ses af tabel D.2 og S.2, hvor SL for 50 m afstand og observationshøjden 1,2 m er anført for både tørre og våde overflader.

Fig. D.5 og D.6 samt den til D.6 svarende figur S.6 viser, at SL er relativt større for små observationshøjder end for store. For prøverne uden glasperler (fig. D.5) er der kvantitative overensstemmelse med ændringen i $f_{geometry}$. SL for prøverne med glasperler i fig. D.6 viser en større afhængighed af observationshøjden end svarende til ændringen i $f_{geometry}$. Det forklares ved ændringen i f_{retro}, som jo voksede jo tættere observationsvinklen var ved belysningsvinklen. Pigdækkørsel i Sverige er antagelig ansvarlig for at fig. S.6 viser, at observationshøjdens betydning er mindre udtalt end for de tilsvarende danske prøver.

I fig. D.7 og D.8 er der vist for henholdsvis prøver uden og med glasperler, hvorledes SL varierer med afstanden D, idet der er divideret med SL for

D = 50 m for sammenligningens skyld. Mens SL for prøverne uden glasperler kun viser ringe variation med afstanden, vil variationen i f_{retro} og f_{beads} forårsage de store variationer i SL for prøverne med glasperler. Man ser eksempler på, at SL kan vokse med afstanden, kan aftage med afstanden og kan passere gennem et maksimum. Fig. S.8 viser lignende, men knapt så store udsving for de svenske prøver.

I figurerne D.9-D.12 er vist indflydelsen på SL af sideforskydningen af lygten; de to første figurer viser forholdene for prøverne uden glasperler og de to sidste de tilsvarende for prøverne med glasperler. Fig. D.9 viser, at SL aftager ved voksende sideforskydning. Fig. D.10 viser, at ved lav observationshøjde er faldet med sideforskydningen størst. Det stemmer med tidligere målinger på vejbelægninger, og det forklares af faktoren $f_{visible}$. Fig. D.11 og D.12 viser, at disse forhold er endnu mere udprægede ved prøverne med glasperler. Ved sideforskydning D på 1,5 m kan man ved 100 m afstand få fald i SL på op til 40 % i forhold til sideforskydningen 0, viser fig. D.11. SL's afhængighed af afstanden viser her det nye, at SL passerer et maksimum, således at SL bliver særlig lille ved D = 10 m. Det skyldes et fald i f_{retro} på grund af vinklen β' (fig. 2.1), som her bliver stor. f_{retro} betragtninger forklarer ikke hele SL's afhængighed af D - det spiller også ind, at visse belyste glasperler skjules ved sideforskydningen - $f_{visible\ beads}$ ændres herved. Fig. S.11 for de svenske prøver viser lignende forhold - dog er afhængigheden af sideforskydningen af lygten her knapt så udpræget.

I tabel D.2 og S.2 omtales, at fugtige striber har en lavere SL end tørre - dog er reduktionen relativt beskeden, 30-40 % for prøver uden glasperler, mens den er 40-75 % for prøver med glasperler.

Alligevel er der nogen virkning tilbage af glasperlerne. Fig. D.13 og S.13 viser, henholdsvis for danske og svenske prøver, at SL varierer på samme karakteristiske måde med afstanden, som det sås på fig. D.8 og S.8 for den tørre situation.

I figurerne D.14-D.17 og S.15-S.17 er der fundet en bekræftelse på en formodning, at SL for våde prøver er en bestemt brøkdel uafhængig af målegeometrien for hver enkelt af prøverne. Der er her afbildet sammenhørende værdier af SL (fugtig) og SL (tør) for hver enkel vejprøve for alle de undersøgte geometrier i log-log diagrammer. Vi ser, at punkterne nogenlunde ligger på en 45° linie, her tegnet gennem punktet svarende til vinkelsituationen $\varepsilon = 0,75^{\circ}$, $\alpha = 1,37^{\circ}$ og $\beta' = 0^{\circ}$.

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APPENDIX A

MODEL CONSIDERATIONS FOR THE SPECIFIC LUMINANCE OF ROAD MARKINGS

By Kai Sørensen and Peder Øbro, LTL

Contents Page

A.1 - Introductory remarks

Whether or not the road marking contains retroreflective glass beads, the surface of the road marking will give a contribution to the specific luminance.

This contribution, i.e. the specific luminance of the surface itself, is called SL(surface) and is considered to be accounted for by the model for the specific luminance of road surfaces. The reason for this is of course that a surface of a road marking is of the same nature as the surface of a road covering, being, however, mostly lighter and sometimes of less surface texture.

The results of the model for the surface are summarized in section A.2, while for a detailed account is referred to Night Traffic Report No. 4.

The retroreflection mechanisms of glass beads are introduced in section A.3, and model considerations for the contribution to the specific luminance of the road marking are given in section A.4. This contribution is called SL(beads).

The total specific luminance of a road marking with glass beads is the sum of the two above-mentioned contributions, i.e.:

SL(road marking) = SL(surface) + SL(beads)

A.2 - Summary of the model for the contribution of the surface

The contribution by the surface is expressed as:

$$SL(surface) = \bar{q} \cdot f_{geometry} \cdot f_{texture} \cdot f_{visible}$$

where $\bar{q}$ is the average luminance coefficient of illuminated facets

$f_{geometry}$ is a factor of the geometry = $\sin\varepsilon/\sin\alpha$

$f_{texture}$ is a factor of texture giving the fraction of the incident luminous flux, which falls on facets of a large inclination towards the vehicle

$f_{visible}$ is a factor of visible, illuminated facets, accounting for the fraction of illuminated facets that are visible

For road markings with a considerable amount of glass beads in the surface, a further factor should be applied to account for the fraction of the incident luminous flux falling on the surface.

For a light coloured road marking $\bar{q}$ can be expected to be quite high, perhaps 0.2 to 0.3 (for diffuse reflection the upper limit is $1/\pi = 0.32$).

The factor $f_{geometry}$ accounts for the major part of the influence of the angles ε and α. For a headlight mounting height of 0.65 m and an observer eye height of 1.2 m the value is appr. 0.54.

The factor $f_{texture}$ has a value depending on the texture of the surface. This is perhaps a critical property of many types of worn road markings, and, therefore, undertakings with the aim of improving the texture can be recommended. It should be possible to obtain values of appr. 0.5 or even higher.

The factor $f_{visible}$ has a value below unity, when $\alpha<\varepsilon$ (when the point of observation lies below the headlight) or more interesting, when $\beta' \neq 0^{o}$ (when the headlight is displaced transverse to the observer).

For road surfaces the following estimate, which perhaps applies as well to road markings, is given:

$$f_{visible} = 1-F_1(p_1) \cdot F_2(p_2)$$

where

$$F_1 = \begin{cases} \frac{1}{3}p_1 & \text{for } p_1 \leq 3 \\ 1 & \text{for } p_1 > 3 \end{cases}$$

$$p_1 = \frac{\beta'}{\alpha-\varepsilon}$$

$$F_2 = \begin{cases} 0.1 & \text{for } p_2 \geq 0.01 \\ 0.1 + 0.5(1 - \frac{p_2}{0.01}) & \text{for } p_2 < 0.01 \text{ radians} \end{cases}$$

and $p_2 = \alpha-\varepsilon$ (radians)

The result of these factors is that SL(surface) varies in a rather simple manner with the geometry, and in a manner, which is essentially the same for all surfaces. The level of SL(surface) is, however, characteristic of the surface and given by its lightness ($\bar{q}$) and its texture ($f_{texture}$).

It is to be remarked that a combination of a good lighthess and a good texture leads to a value of SL(surface), which is certainly worthwhile and contributes essentially to the visibility of the road marking. This is even more so for wet conditions, where the SL of a light coloured surface is well maintained.

A.3 - Retroreflection of glass beads

A glass bead embedded in a lightcoloured marking material acts as a retroreflector in the manner indicated in fig. A.1.

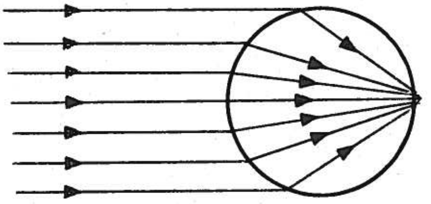
This is a retroreflection mechanism, which is used also in lens-type retroreflectors for various applications. The glass bead functions as a lens two times, before and after reflection, which takes place in a reflecting layer, or in the material in which the glass bead is embedded.

If the retroreflected light is to be emitted in a small solid angle, the reflection has to take place in the focal plane of the lens (glass bead).

This is not the case for glass beads in a road marking. The beads are manufactured of glass materials of refractive index of appr. 1.5, this leading to a position of the focal plane at a distance equal to the radius of the bead behind the bead. The reflection, however, takes place in the material just behind the bead.

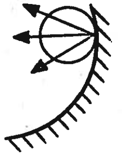
The effect is as illustrated in fig. A.2 that the retroreflected light has a spread of appr. 11° around the direction of incident light. Further spread is in practise caused by deviations of the beads from the spherical shape, by scattering in the surfaces of the beads etc.

Another circumstance, which is special for glass beads in road markings, is that the direction of incident light is close to being parallel to the plane of the reflecting material. This turns the depth of the position of the bead in the road marking material important, as it is illustrated in fig. A.3.



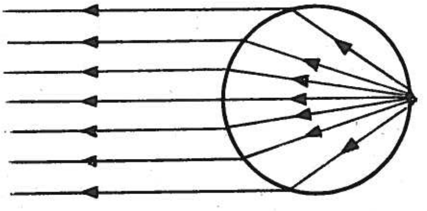
A. THE LIGHT INCIDENT IN A CERTAIN DIRECTION IS FOCUSSED BY THE GLASS BEAD ON A SMALL REGION JUST BEHIND THE GLASS BEAD.

LYS, SOM RAMMER GLASPERLEN I EN GIVEN RETNING, FOKUSERES AF GLASPERLEN PÅ ET LILLE OMRÅDE BAG DENNE.



B. THE LIGHT IS REFLECTED BY THE LIGHT-COLOURED MARKING MATERIAL, IN WHICH THE GLASS BEAD IS EMBEDDED.

LYSET REFLEKTERES AF DET LYSE AFMÆRKNINGSMATERIALE, SOM GLASPERLEN SIDDER I.

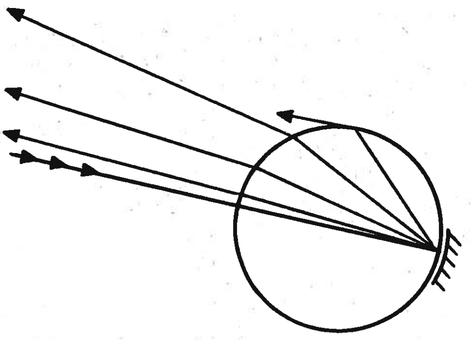


C. THE REFLECTED LIGHT IS COLLIMATED BY THE GLASS BEAD INTO DIRECTIONS CLOSE TO THE DIRECTION OF THE INCIDENT LIGHT.

DET REFLEKTEREDE LYS SAMLES AF GLASPERLEN I RETNINGER, SOM LIGGER TÆT PÅ RETNINGEN FOR DET INDFALDENDE LYS.

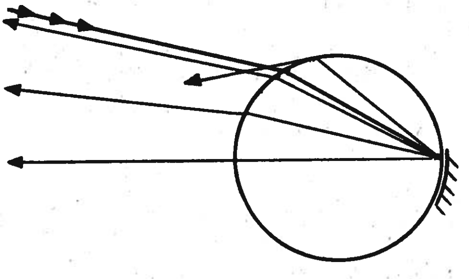
Fig. A.1 A glass bead and the marking material, in which the glass bead is embedded, acts together as a retroreflector in the way indicated in the figures.

En glasperle og det afmærkningsmateriale, i hvilket glasperlen sidder, virker tilsammen som en retroreflektor på den måde, som er vist på figuren.



A. LIGHT THAT FALLS ON THE CENTRAL PART OF A GLASS BEAD CAN BE REFLECTED INTO DIRECTIONS, WHICH LIE UP TO APPR. 11^0 ABOVE THE DIRECTION OF LIGHT INCIDENCE.

LYS, SOM RAMMER DE CENTRALE DELE AF EN GLASPERLE, KAN REFLEKTERES TILBAGE I RETNINGER, DER LIGGER INDTIL CA. 11^0 OVER RETNINGEN FOR DET INDFALDENDE LYS.

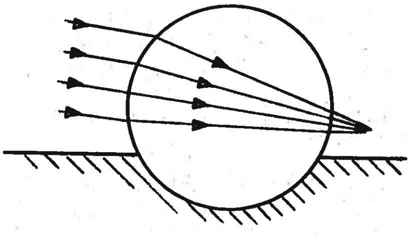


B. LIGHT THAT FALLS ON THE UPPER PART OF A GLASS BEAD IS REFLECTED INTO DIRECTIONS BELOW THE DIRECTION OF LIGHT INCIDENCE.

LYS, SOM RAMMER DE ØVRE DELE AF EN GLASPERLE, REFLEKTERES IND I RETNINGER, DER LIGGER UNDER RETNINGEN FOR DET INDFALDENDE LYS.

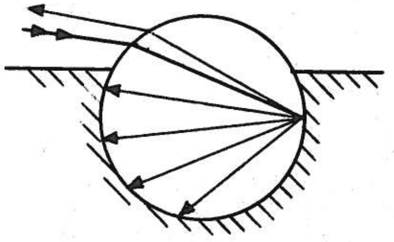
Fig. A.2 When the index of refraction of the glass is appr. 1.5 the point of focus lies somewhat behind the glass bead, this leading to a rather large spread of reflected light as shown in fig. a and b.

Når glasmaterialets brydningsindeks er ca. 1,5, ligger glasperlens brændpunkt et stykke bag glasperlen, således at lyset reflekteres i et ret stort vinkelområde, som vist på fig. a og b.



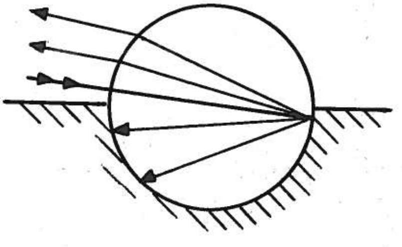
A. A GLASS BEAD, WHICH LIES HIGH IN THE MARKING MATERIAL, TRANSMITS THE INCIDENT LIGHT. HENCE RETRO-REFLECTION IS VERY WEAK.

EN GLASPERLE, SOM SIDDER HØJT I AFMÆRKNINGSMATERIALET, TRANSMITTERER DET INDFALDENDE LYS. RETROREFLEKSIONEN ER DERFOR GANSKE SVAG.



B. A GLASS BEAD, WHICH LIES DEEP IN THE MARKING MATERIAL, HAS A WEAK RETRO-REFLECTION, AS ITS FREE SURFACE IS SMALL AND AS A LARGE FRACTION OF THE INCIDENT LUMINOUS FLUX IS LOST WITHIN THE GLASS BEAD.

EN GLASPERLE, SOM SIDDER DYBT I AFMÆRKNINGSMATERIALET, HAR EN SVAG RETROREFLEKSION, DA DENS FRI OVERFLADE ER LILLE, OG DA EN STOR DEL AF DEN INDFALDENDE LYSSTRØM TABES I PERLEN.



C. A GLASS BEAD IS MOST EFFICIENT AS A RETRO-REFLECTOR, WHEN LYING WITH ITS CENTER APPR. AT THE SURFACE OF THE MARKING MATERIAL.

EN GLASPERLE ER MEST EFFEKTIV SOM RETROREFLEKTOR, NÅR DEN SIDDER MED SIT CENTRUM OMTRENT I HØJDE MED OVERFLADEN AF AFMÆRKNINGSMATERIALET.

<u>Fig. A.3</u> The position of a glass bead in the marking material is important for its retro-reflection.

En glasperles beliggenhed i afmærkningsmaterialet er vigtigt for dens retrorefleksion.

When the bead lies high in the material there will hardly be any retroreflection, except at large angles of illumination. When it lies deep in the material, on the other hand, a large part of the incident luminous flux is lost in the bead. The most efficient position is one, where the center of the bead is approximately level with the surface of the marking material, but even in this position there is some loss in the lower half of the bead.

Further, the glass beads will never in practise be packed as densily in the surface of a road marking, as retroreflective elements are packed in other retroreflectors.

For these reasons a road marking with glass beads will have a much smaller retroreflection (luminance) than most other retroreflectors. The retroreflection is further not sharp, but of a comparatively large spread. This means that there will be some retroreflection even in geometries with a rather large angular distance between directions of illumination and observation (e.g. at short distances on the road).

The final special feature of glass beads in road markings compared to other retrereflectors is that their active surfaces are exposed. In rain or moist conditions the retroreflection will be reduced by any moist around the beads obscuring their illumination or modifying the spherical shape.

A.4 - A model for the retroreflection of glass beads

A.4.1 - Basic expressions

The following expression can be derived for the contribution of the glass beads to the specific luminance of road markings:

$$SL(\text{beads}) = \frac{\sin\varepsilon}{\sin\alpha} \cdot f_{beads} \cdot \sum_{l} \cdot \left[\frac{I}{\Phi}\right]_l \cdot a'_l$$

where the summation is for beads that are illuminated and visible in a selected field (index l).

$\left[\frac{I}{\Phi}\right]_l$ is the ratio between the luminous intensity of retroreflected light and the incident luminous flux for bead No. l.

a'_l is the normalized projected area of the bead

and f_{beads} is the fraction of the incident luminoux flux that falls on beads.

The normalized, projected area of the bead, a'_l is defined by:

$$a'_l = a_l/(A \cdot \sin\varepsilon \cdot f_{beads})$$

where a_l is the area of the free surface of the bead as seen in the direction of illumination

and A is the total area of the field

The area a'_l thus expresses the fraction of the incident luminous flux on beads, which falls on bead No. l. The sum of these fractions for all illuminated beads (index j) is unity:

$$\sum_j a'_j = 1$$

The expression for SL(beads) can be rearranged to be the product of four factors:

$$SL(beads) = f_{retro} \cdot f_{geometry} \cdot f_{beads} \cdot f_{visible,beads}$$

In this expression f_{retro} could be called the factor of retroreflected luminous intensity. This factor is an average of $\frac{I}{\Phi}$ and is defined by:

$$f_{retro} \cdot \sum_{l} a'_l = \sum_{l} \left[\frac{I}{\Phi}\right]_l \cdot a'_l$$

The factor of geometry is of the definition given in section A.2 ($\sin\varepsilon/\sin\alpha$).

The factor for the fraction of the incident luminous flux falling on glass beads has already been introduced, its definition is:

$$f_{beads} = \sum_{j} a_j / (A \cdot \sin\varepsilon)$$

where the summation is for all illuminated beads (index j).

The factor for visible, illuminated beads is defined by:

$$f_{visible\ beads} = 1 - \frac{1}{f_{beads}} \cdot \sum_{m} a'_m$$

where the summation is for beads that are illuminated, but not visible (index m).

The interpretations and variations of these factors are discussed in the following sections.

A.4.2 - The factor of retroreflected luminous intensity, f_{retro}

This factor is an average of the ratios $\left[\frac{I}{\Phi}\right]_1$, which are in close family to luminance coefficients. Both parameters can be looked upon as given by a "reflectance" (ratio of reflected to incident luminous flux) in proportion to an "apparent solid angle of reflected light".

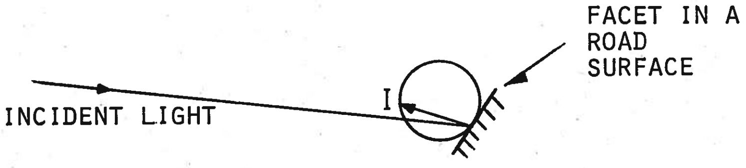
The special feature of a retroreflective element is that the solid angle of reflected light is small, and that the ratio $\left[\frac{I}{\Phi}\right]_1$ is large and strongly varying for directions within this solid angle. For other directions the value of the ratio is small. See fig. A.4.

The factor, f_{retro} has a similar variation. Because of the rather large spread of retroreflected light indicated in fig. A.2, f_{retro} can, however, be expected to show relatively large values for all geometries relevant for the illumination by the drivers own headlights.

The order of magnitude of f_{retro} can be estimated at follows.

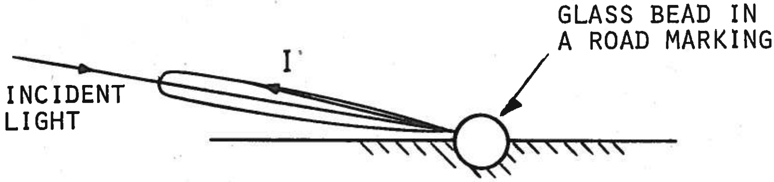
Reflection losses should be appreciable, among else beacuse of the losses indicated in fig. A.3 and considering that any scattering and transmission through the beads might be considered to contribute to the losses also. A "reflection factor for retroreflection" is, therefore, estimated to be of the order of magnitude of 0.1.

The "apparent solid angle of retroreflection" is taken to be defined by a cone of radius 10^o. The corresponding solid angle is appr. 0.1. The order of magnitude of f_{retro} is, therefore, 1 cd/lm.



A. THE LUMINOUS INTENSITY OF LIGHT, I REFLECTED BY A FACET IN A ROAD SURFACE IS RELATIVELY SMALL, BUT VARIES SLOWLY WITH THE DIRECTION.

LYSSTYRKEN, I AF LYS REFLEKTERET I EN FACET I EN VEJBELYSNING ER RELATIVT LILLE, MEN VARIERER SVAGT MED RETNINGEN.



B. THE LUMINOUS INTENSITY OF LIGHT, I REFLECTED BY A GLASS BEAD IN A ROAD MARKING IS RELATIVELY STRONG IN DIRECTIONS CLOSE TO THE DIRECTION OF INCIDENT LIGHT, BUT VARIES STRONGLY WITH THE DIRECTION.

LYSSTYRKEN, I AF LYS REFLEKTERET AF EN GLASPERLE I EN AFMÆRKNING ER RET STOR I RETNINGER TÆT PÅ BELYSNINGSRETNINGEN, MEN VARIERER KRAFTIGT MED RETNINGEN.

<u>Fig. A.4</u> Distributions of light reflected in a facet (fig. a) and a glass bead (fig. b).

Fordelinger af lys reflekteret af en facet (fig. a) og en glasperle (fig. b).

This estimate is, however, uncertain and f_{retro} can in any case be expected to vary strongly with the angles of the geometry. The largest values certainly apply, when the angular distance between directions of illumination and observation is small.

Thus, f_{retro} can be expected to show a variation with the observer eye height, which adds to the variation predicted by $f_{geometry}$ (see section A.4.3).

The factor, f_{retro} further can introduce a variation with the distance on the road. Such a variation will compete with a possible variation of f_{beads} (see section A.4.4).

Finally, f_{retro} will show a variation with β', which adds to the variation predicted by $f_{visible\ beads}$ (see section A.4.5).

A.4.3 - The factor of geometry, $f_{geometry}$

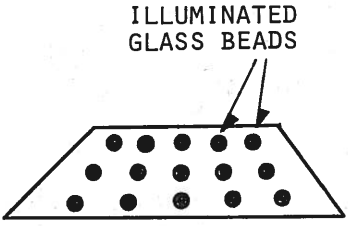
This factor appears in the same definition for both SL(surface) and SL(beads). The reason for this is that the factor has a fundamental meaning, as it gives the ratio between the apparent areas of the field available for respectively illumination and observation.

The physical interpretation why this factor enters as a factor to the SL differs, however, somewhat.

In the model considerations for road surfaces it was shown that $f_{geometry}$ can be interpreted as the fraction of the apparent area, which is filled with illuminated facets. In the case of glass beads the interpretation rather concerns the variation of the number of luminous glass beads per unit apparent area of the field. See fig. A.5.

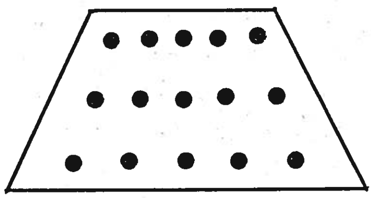
A.4.4 - The fraction of the incident luminous flux falling on glass beads, f_{beads}

In comparison to the expression for SL(surface) this factor, f_{beads} replaces the factor of texture, $f_{texture}$. Both factors represent the fraction of the incident luminous flux falling on the elements active in the kind of reflection considered. These elements are respectively glass beads and facets of a large inclination.



A. THE FIELD AS SEEN FROM A LOW OBSERVER EYE HEIGHT (SMALL α)

FELTET SET FRA EN LAV OBSERVATIONSHØJDE (LILLE α)



B. THE FIELD AS SEEN FROM A LARGER OBSERVER EYE HEIGHT (LARGER α)

FELTET SET FRA EN STØRRE OBSERVATIONSHØJDE (STØRRE α)

Fig. A.5 The number of illuminated glass beads in the field depends on the illumination angle, ε while the apparent size of the field depends on the observation angle, α. The factor, $f_{geometry}$ is then related to the number of illuminated glass beads per unit apparent area of the field.

Antallet af belyste glasperler i feltet afhænger af belysningsvinklen, ε mens feltets tilsyneladende areal afhænger af observationsvinklen, α. Faktoren, $f_{geometry}$ har derfor forbindelse med antallet af belyste glasperler pr. enhed tilsyneladende areal af feltet.

As values of SL(beads) seem to be of the order of magnitude of 0.1 cd/m^2/lux for worn road markings with glass beads, and f_{retro} as discussed above is of the order of magnitude of 1 cd/lm (= 1 cd/m^2/lux), f_{beads} must have values far below unity.

The value of SL(beads) is known from measurements to vary with the distance (with ε). One source for this variation is certainly the factor, f_{retro}. It is, therefore, not possible to estimate from measurements the possible variations of f_{beads} with ε.

One could, however, imagine sources for variations of f_{beads} with ε. Thus a new road marking with drop-on beads in the top of the surface texture could be expected to show an increase in f_{beads} with the distance. A worn road marking, on the other hand, will perhaps have active beads mainly in protected positions in the bottom of the texture. In such a case f_{bead} would decrease with distance.

It is, therefore, not possible from reasoning either to give secure statements concerning the possible variation of f_{beads}.

It is most likely that variations in SL(beads) with the distance can be explained by variations in both f_{retro} and f_{beads}. When SL(beads) decreases with the distance this can probably be taken to indicate a strong decrease in f_{beads}, since f_{retro} will probably always show an increase.

A.4.5 - The factor of visible, illuminated beads, $f_{visible\ beads}$

Compared to the expression for SL(surface) this factor replaces the factor of visible, illuminated facets, $f_{visible}$.

The two factors both expresses a hiding of the active, reflective elements, when $\beta' \neq 0$ or when $\alpha < \varepsilon$. Apart from the fact that the active, reflective elements are respectively illuminated facets of a large inclination and illuminated glass beads, the mechanisms of hiding are the same.

The factor $f_{visible\ bead}$, therefore, should vary with the angles in a manner very similar to $f_{visible}$.

Possible sources of a modification of the variation might be preferred distributions of the beads in the top or bottom of the surface texture, as it has been discussed for f_{beads} already.

Changes in $f_{visible\ beads}$ will, however, always be linked with changes in the factor f_{retro}. It is neither possible nor worthwhile to separate the individual variations of these factors.

A.4.6 - Conclusion regarding the model

For the contribution of the glass beads to the specific luminance of road markings, SL(beads) an expression containing four factors can be set up. These four factors are well defined and can be compared one by one to the four factors in the expression for the contribution by the surface, SL(surface).

The expression for SL(beads) does not, however, have the same direct usefulness for the prediction of the variations of SL(beads) with the angles.

The reason for this is mainly that the factor, f_{retro} varies strongly with the angles (in contradiction to the $\bar{q}$ for the surface). This variation enhances variations indicated by the other factors and prohibits the separation of the sources of variation.

This conclusion does not mean that the model considerations for SL(beads) are less accurate than for SL(surface), but rather that road markings with glass beads do show a larger variability with the angles and from road marking to road marking. This larger variability will cause difficulties in any interpretation or application of measurements.

The usefulness of the model considerations is, therefore, in explaining the reasons and the nature of the variations rather than in predicting their magnitude.

APPENDIX D

DANISH ROAD MARKING SAMPLES

By Peder Øbro and Kai Sørensen, LTL

Contents

D.1 - Introduction to the samples and the measuring data

The road markings to be included are chosen on the basis of the preliminary investigation reported in note No. 145 to the information group at LTL.

This preliminary investigation concluded that a large number of manufacturers offer a wide selection of materials. The marking is carried out in some cases by the technical departments of the administrations, and otherwise by contractors.

In the note No. 145 is further given a list of road markings, which is to represent some of the variety in this field, while simultaneously covering markings of different conditions of age and wear. For practical reasons only markings in the Copenhagen region are included in the list.

Samples were taken from the first 12 markings of the list in December 1980 by the Danish Road Laboratory. These samples are described in table D.1, using for identification the No's. on the original list.

It is seen from table D.1 that one of the samples was damaged in transport, this reducing the number of samples to 11. These samples include paints and thermoplast materials with and without retroreflective glass beads. An impression of the samples is given by means of photographs in fig. D.1, D.2 and D.3.

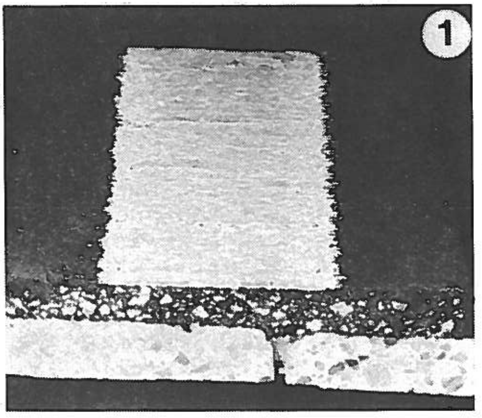
The full reflection tables for dry and humid condition of the 11 samples are given in section D.4.

An important aspect of the samples is whether they contain glass beads or not, this effectively dividing the samples into two groups. The group of samples withous glass beads includes samples 1, 3, 4, 5 and 6, while the other group includes samples 2, 7, 9, 10, 11 and 12.

Table D1 Short description of the samples.
The paints have only drop-on glass beads, while the thermoplastics have also premix glass beads. Premix glass beads are in all cases in the amount of 15 wt %, while drop-on glass beads are in the amount of 30 kg/100 m^2.
The age of the samples is counted from the date of laying of the marking until December 1980, where the samples were taken.

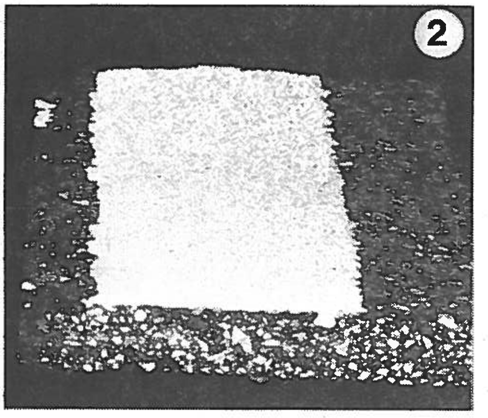
Kort beskrivelse af prøverne.
De malinger, som har glasperler, har kun afstrøede perler, mens de termoplastmaterialer, som har glasperler, også har iblandede perler. Iblandingen er i alle tilfælde i mængden 15 vægt %, mens afstrøningen er til mængden 30 kg/100 m^2.
Prøvernes alder regnes fra udlægningsdatoen indtil december 1980, hvor prøverne blev taget.

Sample No.	Paint or thermoplastic	Glass beads Yes/No	Manufacturer or trade name	Date of laying
1	Paint	No	Danstriben	June 80
2	Thermoplastic	Yes	Nordsjö	77
3	Thermoplastic	No	Zebraflex	76
4	Thermoplastic	No	LKF/Zebraflex	78
5	Thermoplastic	No	Merkalin	June 80
6	Thermoplastic	No	Langeland	May 80
7	Thermoplastic	Yes	Nordsjö	July 80
8	Damaged, not measured			
9	Thermoplastic	Yes	Globeflex	79
10	Paint	Yes	Hygæa	80
11	Paint	Yes	Hygæa	Summ.80
12	Paint	Yes	Hygæa, special	June 80



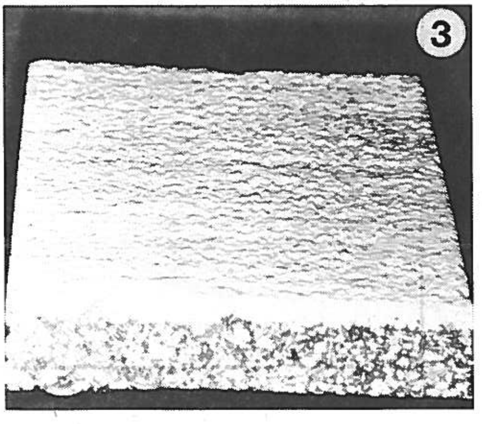
Paint without glass beads.
Age appr. 1.5 year.

Maling uden glasperler.
Alder ca. 1,5 år.



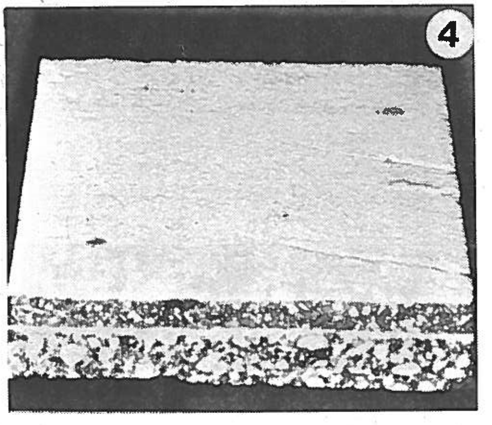
Thermoplastic with drop-on and premix glass beads.
Age appr. 2.5 year.

Termoplast med afstrøede og iblandede glasperler.
Alder ca. 2,5 år.



Thermoplastic without glass beads.
Age appr. 3.5 year.

Termoplast uden glasperler.
Alder ca. 3,5 år.

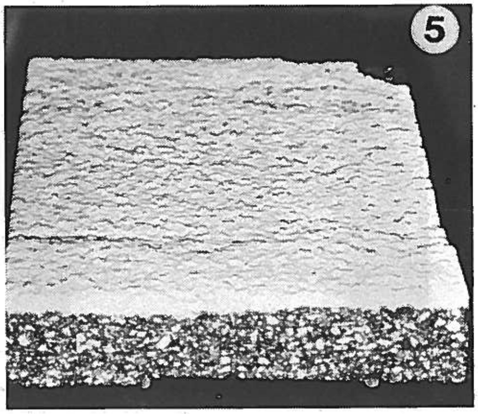


Thermoplastic without glass beads.
Age appr. 2,5 year.

Termoplast uden glasperler.
Alder ca. 2,5 år.

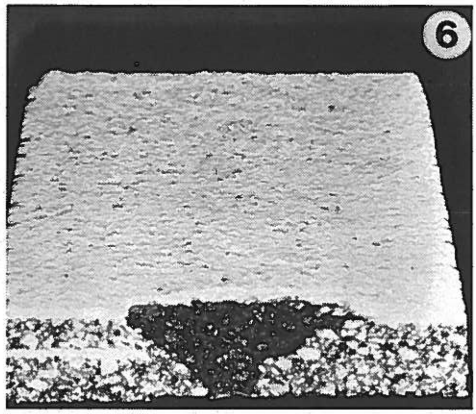
Fig. D.1 Photographs of samples 1, 2, 3 and 4 taken with illumination from a point below the camera.

Fotografier af prøverne 1, 2, 3 og 4 taget med belysning fra et punkt under kameraet.



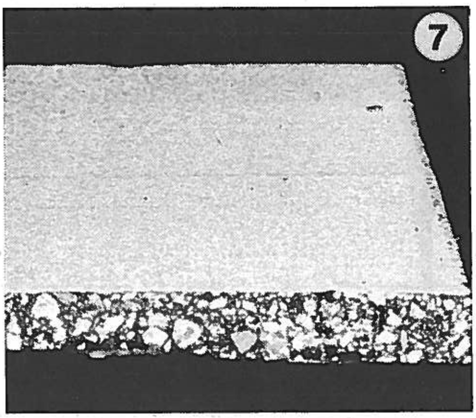
Thermoplastic without glass beads.
Age 0.5 year.

Termoplast uden glasperler.
Alder 0,5 år.



Thermoplastic without glass beads.
Age 0.5 year.

Termoplast uden glasperler.
Alder 0,5 år.



Thermoplastic with drop-on and premix glass beads.
Age 0.5 year.

Termoplast med afstrøede og iblandede glasperler.
Alder 0,5 år.

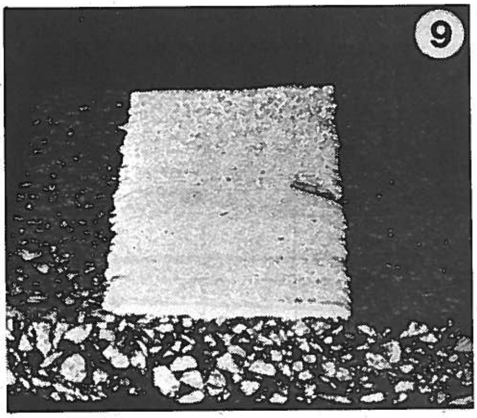
8

The sample was damaged in transport.

Prøven blev beskadiget under transport.

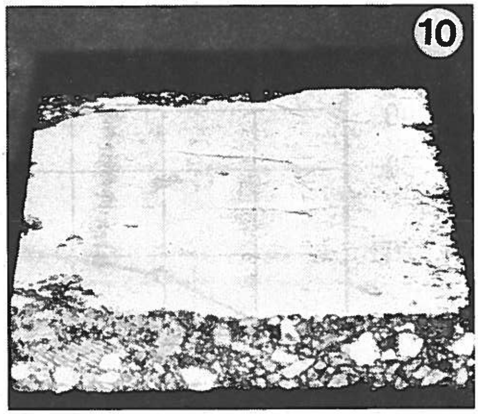
Fig. D.2 Photographs of samples 5, 6 and 7 taken with illumination from a point below the camera.

Fotografier af prøverne 5, 6 og 7 taget med belysning fra et punkt under kameraet.



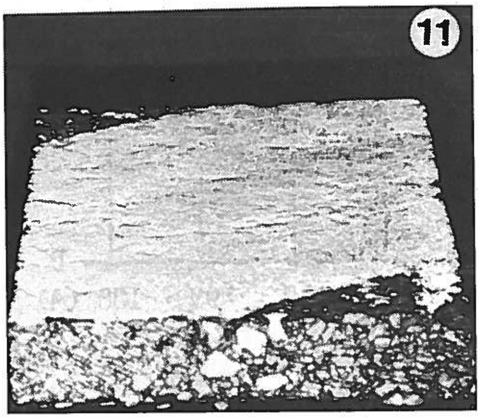
Thermoplastic with drop-on and premix glass beads.
Age appr. 1.5 year.

Termoplast med afstrøede og iblandede glasperler.
Alder ca. 1,5 år.



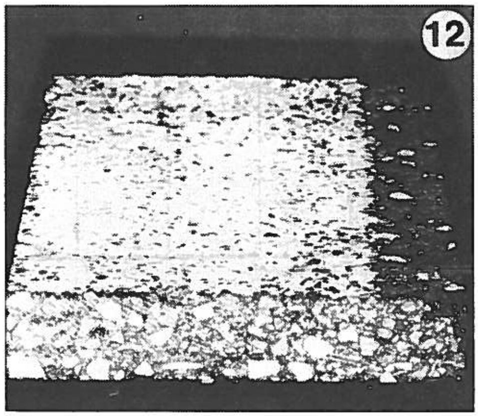
Paint with drop-on glass beads.
Age 0.5 year.

Maling med afstrøede glasperler.
Alder 0,5 år.



Paint with drop-on glass beads.
Age 1.5 year.

Maling med afstrøede glasperler.
Alder 1,5 år.

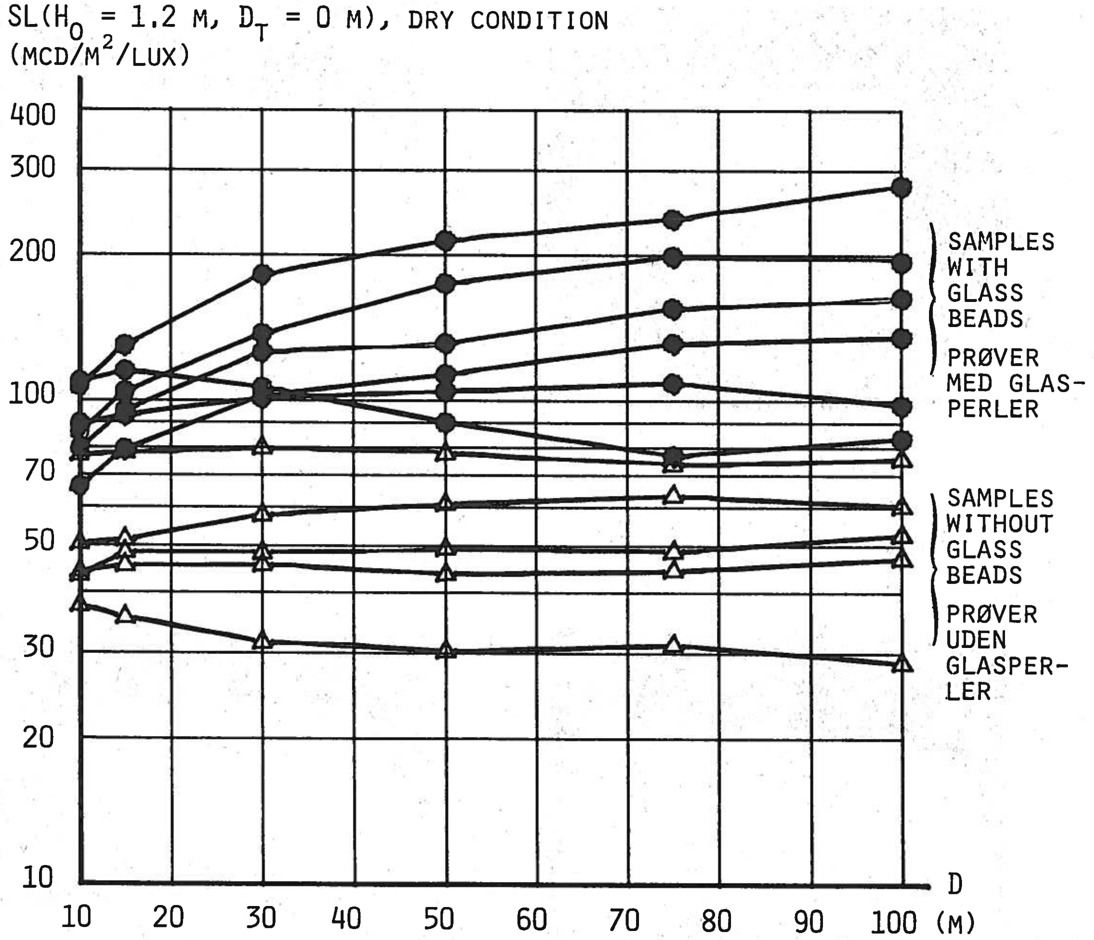


Paint with drop-on beads
Age 0.5 year.

Maling med afstrøede glasperler.
Alder 0,5 år.

<u>Fig. D.3</u> Photographs of samples 9, 10, 11 and 12 taken with illumination from a point below the camera.

Fotografier af prøverne 9, 10, 11 og 12 taget med belysning fra et punkt under kameraet.



<u>Fig. D.4</u> SL(H_o = 1.2 m, D_t = 0 m) for the dry condition as a function of the distance on the road, D.

SL(H_o = 1,2 m, D_t = 0 m) for den tørre tilstand som funktion af afstanden på vejen, D.

That the two groups show different features is illustrated in fig. D.4, giving for the dry condition the SL(H_o = 1.2 m, D_t = 0 m) as a function of the distance, D.

The samples with glass beads show SL's, which increase with D (except for sample No. 2), and which are higher than for the samples without glass beads.

This shows that the glass beads do have a substantial retroreflection in the dry condition and do modify the manner of variation with the geometry. For this reason the two groups of samples are studied separately in the following sections.

For samples with glass beads the number of active beads in the surface is important for the SL of the dry condition. For other samples the surface texture must be the most important property, as the samples are all clean and fairly white of colour.

In the humid condition the two grups of samples should show SL's of more similar magnitudes, as the retroreflective action of the glass beads is disturbed by a water film.

These features are confirmed by table D.2, which gives the SL(D = 50 m, H_o = 1.2 m) for both the dry and the humid condition and their ratios, together with comments to the samples.

For the dry condition the paints with drop-on glass beads (samples No. 10, 11 and 12) show the highest SL-values, up to 200 mcd/m^2/lux. The reason for this is probably that the beads are more often embedded in a favourable depth in a paint, than in a thermoplastic.

The paints further clearly show the influence of the condition of wear. Thus the marking from the previous year (sample No. 11) has a significantly lower SL, than the other two paints with glass beads (samples Nos. 10 and 12).

The thermoplastic with glass beads (samples Nos. 2, 7 and 9) have medium values of SL of appr. 100 mcd/m^2/lux in the dry condition.

Next comes the thermoplastic without beads (samples Nos. 3, 4, 5 and 6). The two samples with a good, pronounced surface texture (samples Nos. 3 and 5) have the highest SL of 60-80 mcd/m^2/lux.

The smallest SL in the dry condition is found for the rather smooth paint without beads (sample No. 1). The value is 30 mcd/m^2/lux.

In the humid condition a high SL is maintained only by sample No. 10. This sample perhaps still repels water, as it is often observed for new road markings.

The other samples with glass beads seem to loose most of the retroreflection of the beads in the humid condition and the distinction between the two groups in no longer so obvious as for the dry condition. The SL's are in the range of 30 to 55 mcd/m^2/lux, except for sample No. 1, which has an SL of only 18 mcd/m^2/lux.

Sample No.	Paint or thermoplastic	Glass beads Yes/No	SL-dry $mcd/m^2/lux$	SL-humid $mcd/m^2/lux$	Ratio Humid/Dry	Comment	Age year
1	Paint	No	30	18	0.60	Weak surface texture	1.5
2	Thermoplastic	Yes	90	43	0.48		2.5
3	Thermoplastic	No	78	47	0.60	Good surface texture	3.5
4	Thermoplastic	No	44	30	0.68	Some surface texture	2.5
5	Thermoplastic	No	61	46	0.75	Good surface texture	0.5
6	Thermoplastic	No	49	35	0.71	Some surface texture	0.5
7	Thermoplastic	Yes	105	37	0.35		0.5
9	Thermoplastic	Yes	131	51	0.39		1.5
10	Paint	Yes	215	135	0.63	Numerous active micro-beads	0.5
11	Paint	Yes	113	56	0.50		1.5
12	Paint	Yes	175	44	0.25	Seems worn, but has numerous active micro-beads	0.5

Table D.2 Values of SL(D = 50 m, H_o = 1.2 m) for both dry and humid condition and their ratio. The variation of these data among the samples can to some extent be accounted for by the glass beads, the surface texture and the age of the samples.

Værdier af SL(D = 50 m, H_o = 1,2 m) for både tør og fugtig tilstand samt forholdet her imellem. Variationen af disse data mellem prøverne kan i nogen grad forklares ved glasperlerne, overfladeteksturen og alderen af prøverne.

D.2 - Influence of the geometry-dry condition

D.2.1 - Influence of the observer eye height

Fig. D.5 shows the ratios SL(H_o = 1 m)/SL(H_o = 1.2 m) and SL(H_o = 1.5 m)/SL(H_o = 1.2 m) for dry road markings without glass beads (and D_t = 0), while fig. D.6 shows these ratios for road markings with glass beads.

From fig. D.5 is seen that road markings without beads behave in the same manner as road surfaces. The variation can be accounted for by the factor of geometry:

$$f_{geometry} = \frac{H_h}{H_o} \qquad \text{for } D_o = D_h = D$$

According to this factor the SL-value is inversily proportional to the observer eye height, and hence the two ratios should be appr. 1.2 and 0.8, as it is also observed.

From fig. D.6 is seen a somewhat stronger influence of the observer eye height for road markings with glass beads. This can be explained by the additional variation of the factor, f_{retro} introduced in Appendix A, which decrease/increase with increasing/decreasing angular distance between directions of illumination of observation.

D.2.2 - Influence of the distance on the road

As the influence of the observer eye height has been accounted for in the previous section, the influence of the distance on the road has to be studied for one eye height only.

This is done for H_o = 1.2 m in figs. D.7 and D.8 for road markings without and with glass beads respectively. In these figures, the SL-values are further scaled, so that SL(D = 50 m) is unity.

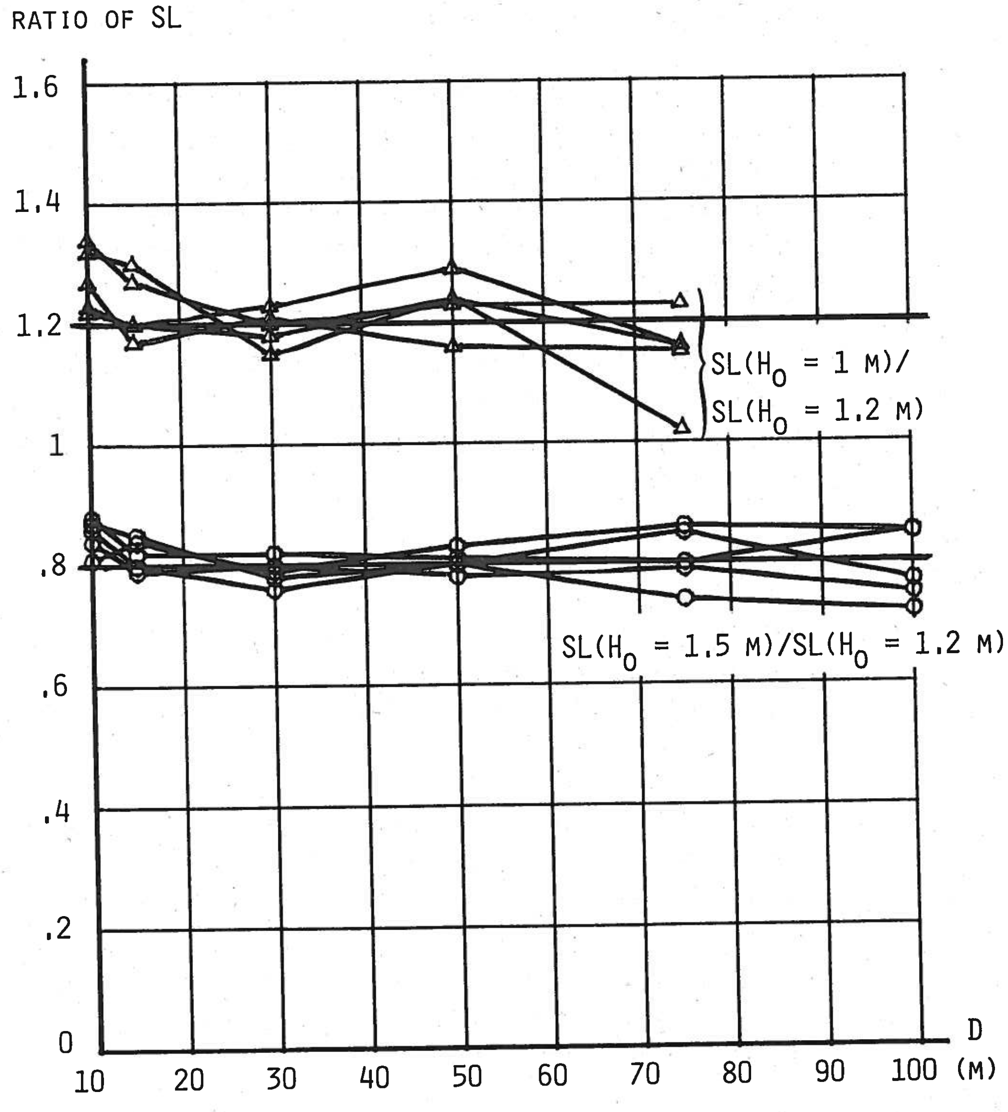


Fig. D.5 Influence of the observer eye height for dry samples without glass beads. The figure gives the ratios $SL(H_o=1\ m)/SL(H_o=1.2\ m)$ and $SL(H_o=1.5\ m)/SL(H_o=1.2\ m)$ for $D_t=0$.

Øjenhøjdens indflydelse for tørre prøver uden perler. Figuren viser forholdene $SL(H_o=1\ m)/SL(H_o=1,2\ m)$ og $SL(H_o=1,5\ m)/SL(H_o=1,2\ m)$ for $D_t=0$.

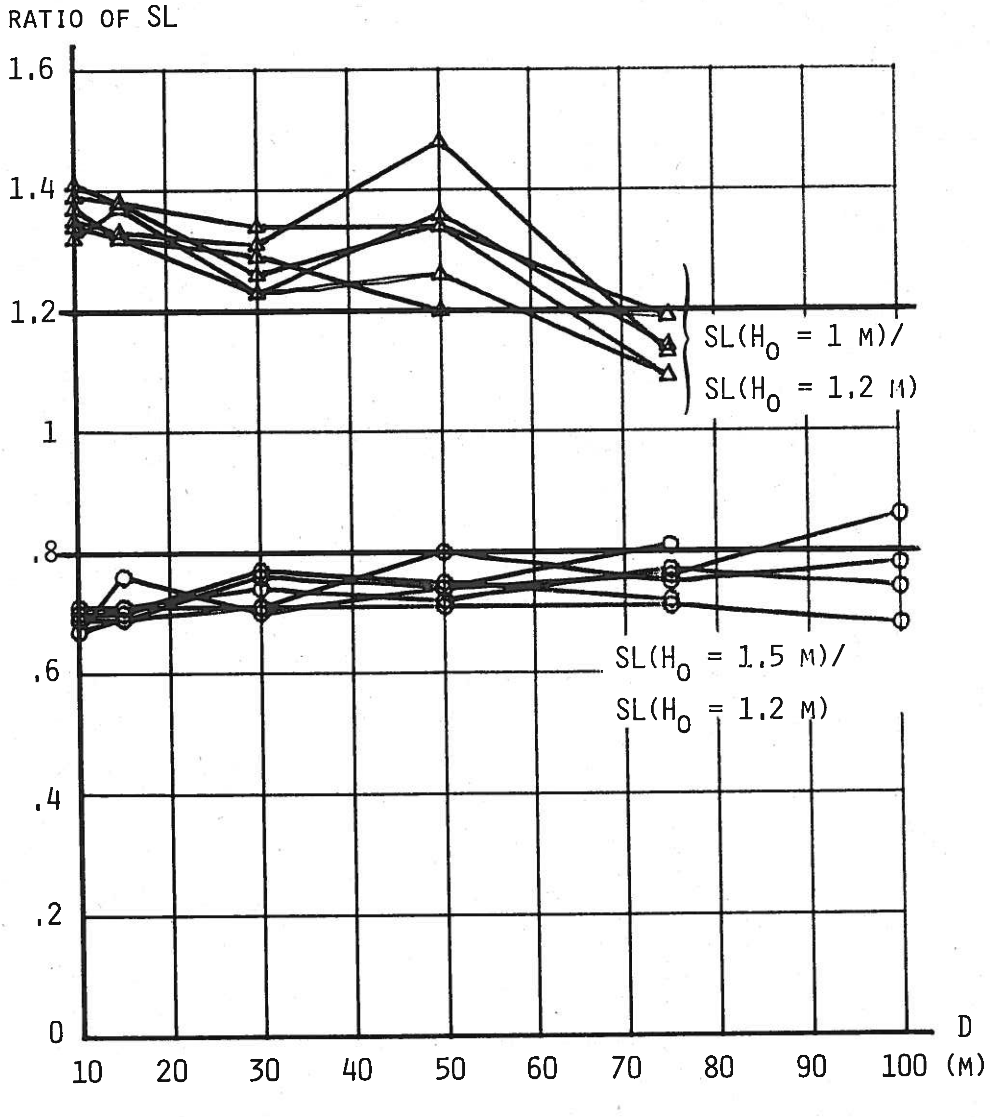
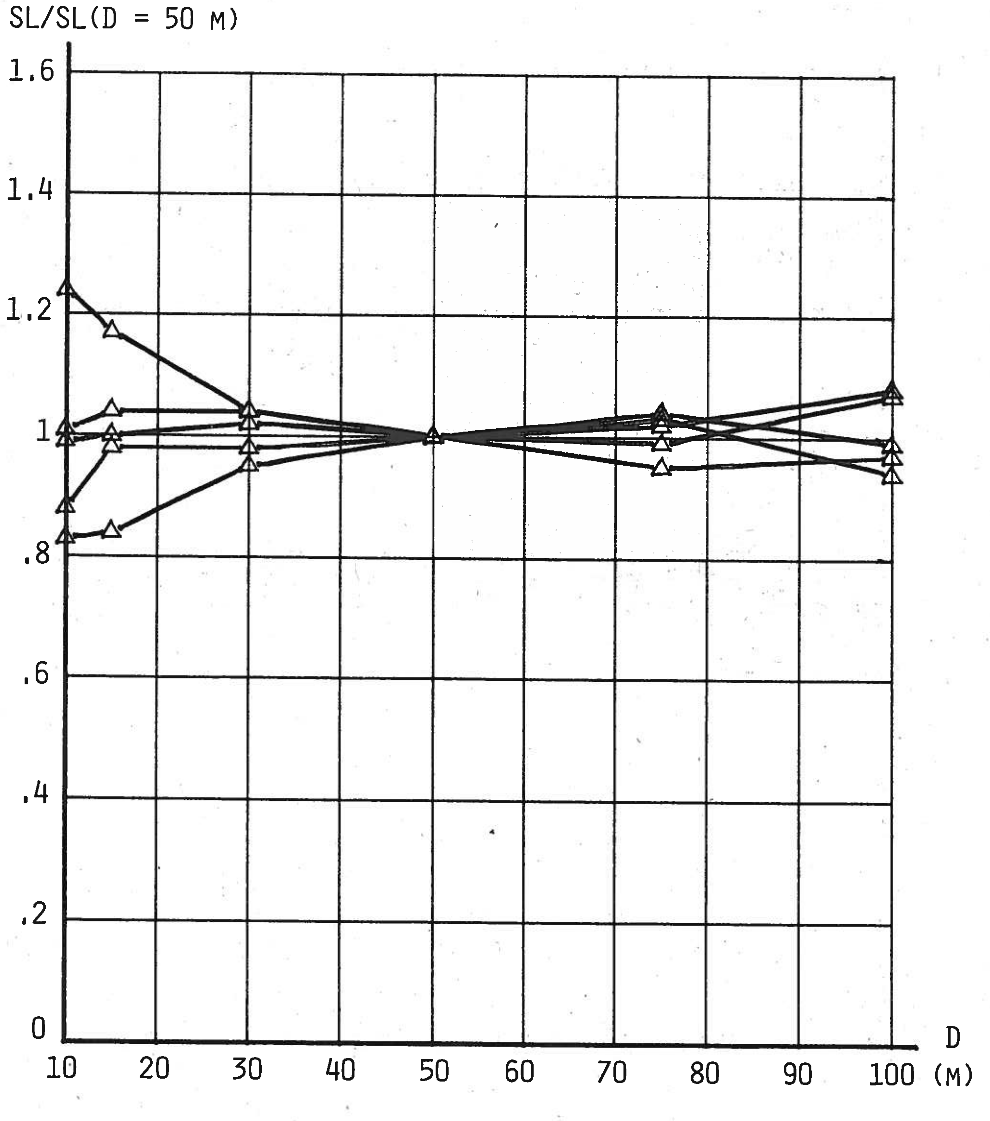


Fig. D.6 Influence of the observer eye height for dry samples with glass beads. The figure shows the ratios $SL(H_o=1\ m)/SL(H_o=1.2\ m)$ and $SL(H_o=1.5\ m)/SL(H_o=1.2\ m)$ for $D_t=0$.

Øjenhøjdens indflydelse for tørre prøver med glasperler. Figuren viser for forholdene $SL(H_o=1\ m)/SL(H_o=1,2\ m)$ og $SL(H_o=1,5\ m)/SL(H_o=1,2\ m)$ for $D_t=0$.



<u>Fig. D.7</u> Ratios SL/SL(D=50 m) for H_o=1.2 m; D_t=0 and dry samples without glass beads. For these samples the SL's are roughly independent of the distance.

Forholdene SL/SL(D=50 m) for H_o=1,2 m; D_t=0 og tørre prøver uden glasperler. For disse prøver er SL-værdierne omtrent uafhængige af afstanden.

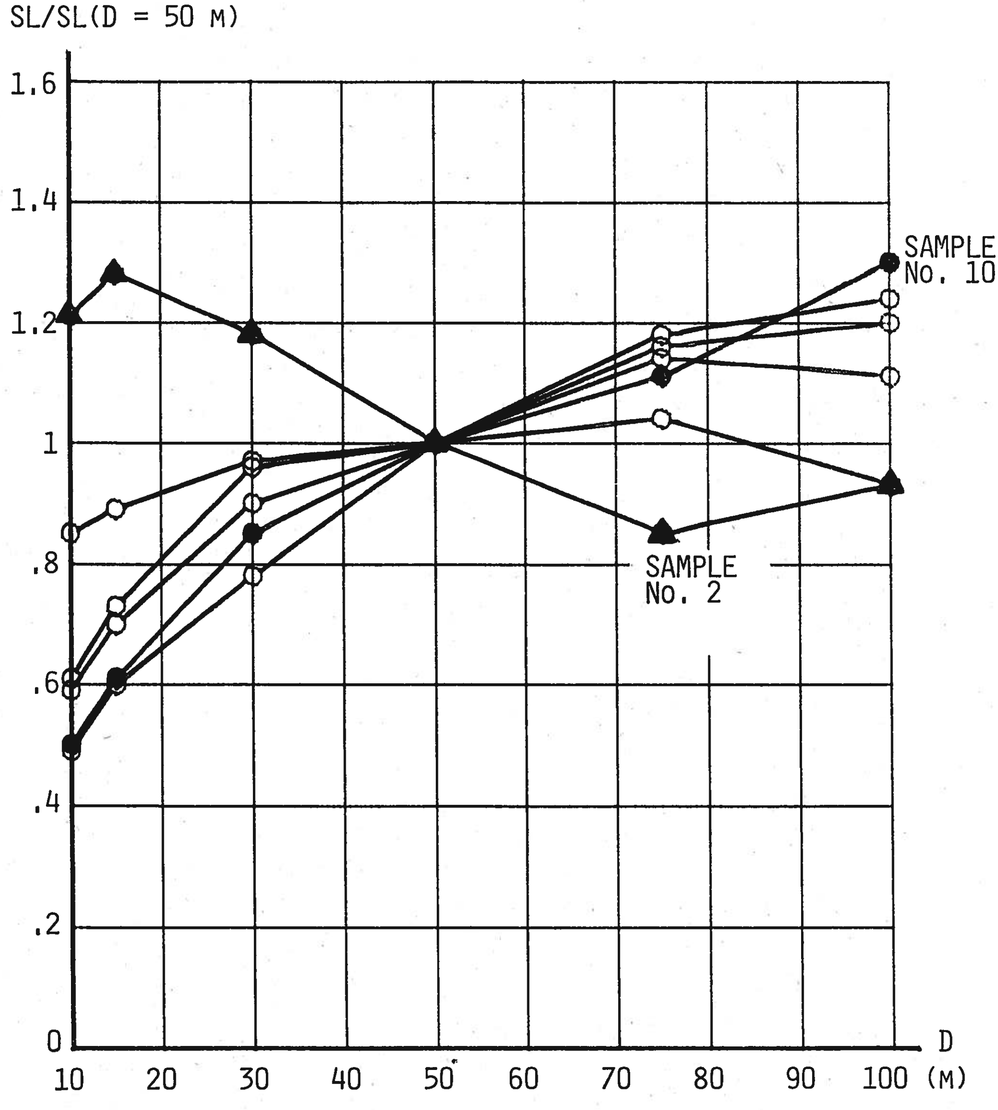


Fig. D.8 Ratios SL/SL(D=50 m) for H_o=1.2 m, D_t=0 and dry samples with glass beads. For these samples the SL's vary markedly with the distance. The two extremes are the samples No. 2 and 10 indicated on the diagram.

Forholdene SL/SL(D=50 m) for H_o=1,2 m, D_t=0 og tørre prøver med glasperler. For disse prøver ses en udtalt variation med afstanden. De to ydertilfælde udgøres af prøverne nr. 2 og 10, som er angivet i diagrammet.

For road markings without glass beads is seen from fig. D.7, that the variation with the distance is quite small in agreement with the model considerations for road surfaces. The variation is even smaller than for road surfaces, probably for two reasons.

Firstly, the road markings have a uniform colour of lightness, so that the average luminance coefficient, $\bar{q}$ is appr. constant. Secondly, there are no samples of a very strong surface texture, this indicating that the factor of texture, $f_{texture}$ is appr. constant also.

The road markings with glass beads, on the other hand have a pronounced variation with the distance, see fig. D.8.

Most of the samples show an increase in SL with distance. The strongest increase is shown by sample No. 10, whose SL increases by 160 % in the range of 10 m to 100 m. Sample No. 2 in the other extreme shows a decrease in SL by 23 %.

Thus the variations with the distance are clearly consirable. An ordering of the markings according to their SL's of one distance can easily break down at another distance. Thus the above-mentioned sample No. 2 has at 10 m the highest SL of all the samples with glass beads (109 $mcd/m^2/lux$), while at 100 m this sample has the smallest SL (84 $mcd/m^2/lux$).

The factor for the retroreflected luminous intensity, f_{retro} must cause the major part of the increase in SL seen for most of the samples (see Appendix A). The factor for the incident luminous flux falling on glass beads, f_{beads} might increase or decrease. For sample No. 2 at least this factor must show a decrease, which is capable of offsetting an increase in f_{retro} and thus of determining the observed decrease in SL.

D.2.3 - Influence of the transverse displacement of the headlight

Fig. D.9 and D.10 give the reductions in SL as a function of the transverse displacement of the headlight, D_t for all samples without glass beads. Fig. D.9 gives diagrams for D_t = 0.5 m, 1 m and 1.5 m, the observer eye height is 1.2 m. Fig. D.10, on the other hand, is for D_t = 1 m and has diagrams for H_o = 1 m, 1.2 m and 1.5 m.

These reductions are very similar to those observed for road markings in Night Traffic Report No. 4, and thus the model considerations given there (and summarized in Appendix A) seem to apply equally well to road markings without glass beads.

The fig.'s D.11 and D.12 are similar to respectively fig.'s D.9 and D.10, but for samples with glass beads.

A comparison of these figures shows that for samples with glass beads the decrease in SL as caused by D_t, is generally larger than for samples without glass beads.

One new feature for samples with glass beads is that there is also at short distances a significant decrease in SL with D_t. See in particular the diagram for D_t = 1.5 in fig. D.11, which at D = 10 m shows a decrease in SL of appr. 40 %.

This new feature is probably caused by a decrease in f_{retro}, as this factor should decrease with the increase in β' (see Appendix A).

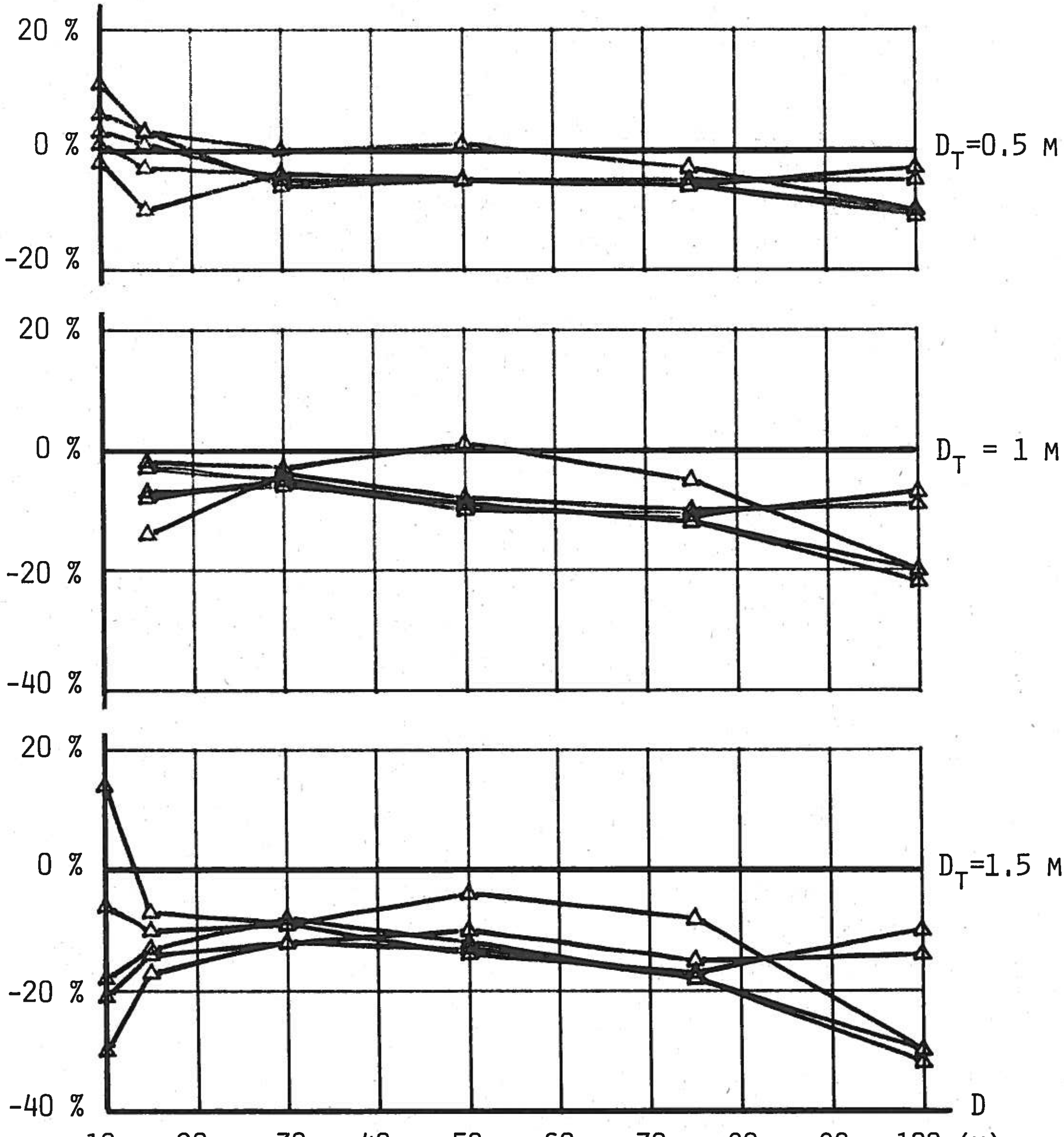
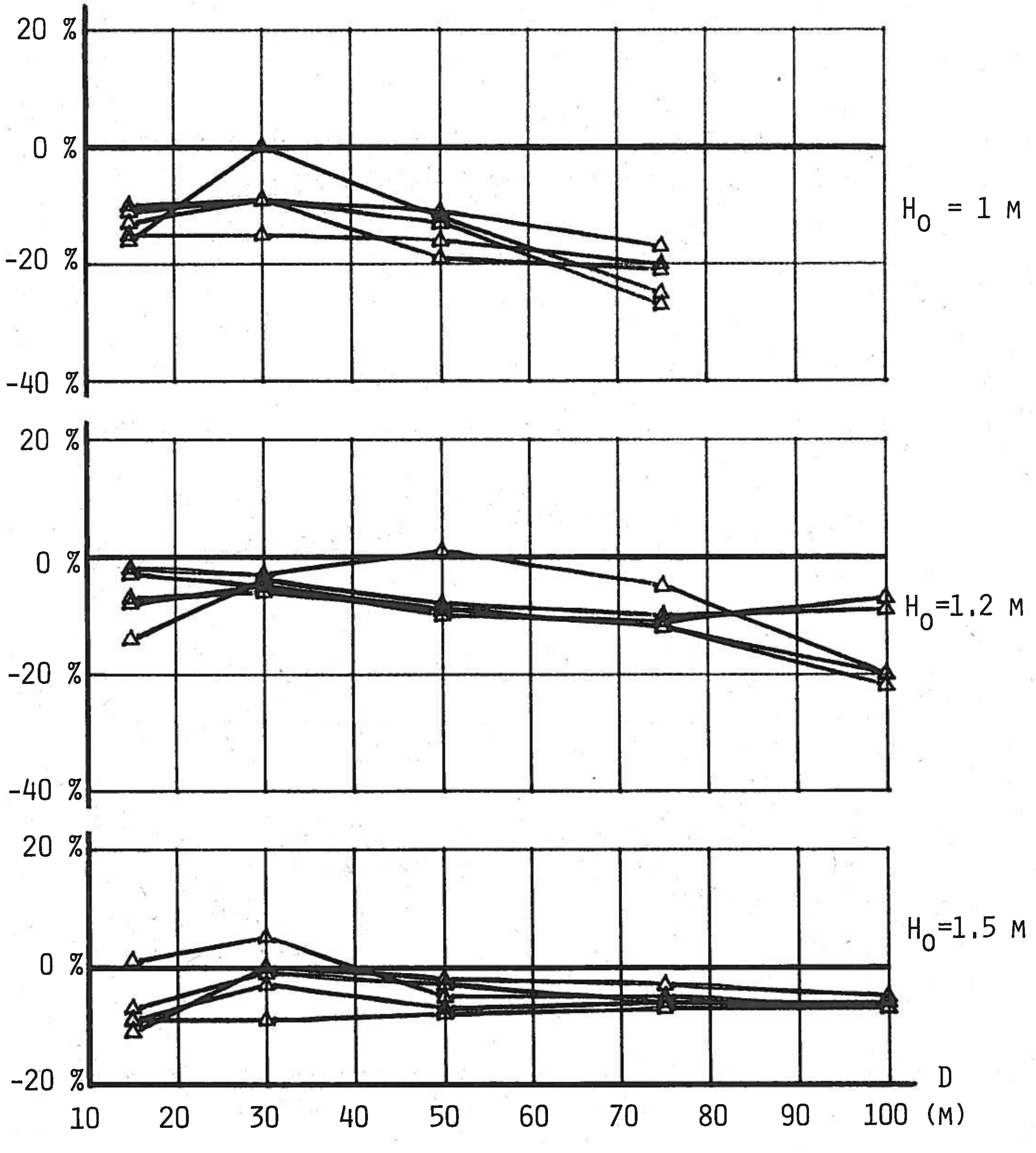


Fig. D.9 Changes in SL for dry samples without glass beads for H_o=1.2 m and D_t=0.5 m, 1 m and 1.5 m as compared to SL for D_t=0 m.

Ændringer i SL for tørre prøver uden glasperler for H_o=1,2 m og D_t=0,5 m; 1 m og 1,5 m i forhold til SL for D_t=0 m.



<u>Fig. D.10</u> Changes in SL for dry samples without glass beads for H_o=1 m, 1.2 m and 1.5 m at D_t=1 m, as compared to SL for D_t=0 m.

Ændringer i SL for tørre prøver uden glasperler for H_o=1 m; 1,2 m og 1,5 m ved D_t=1 m i forhold til SL ved D_t=0 m.

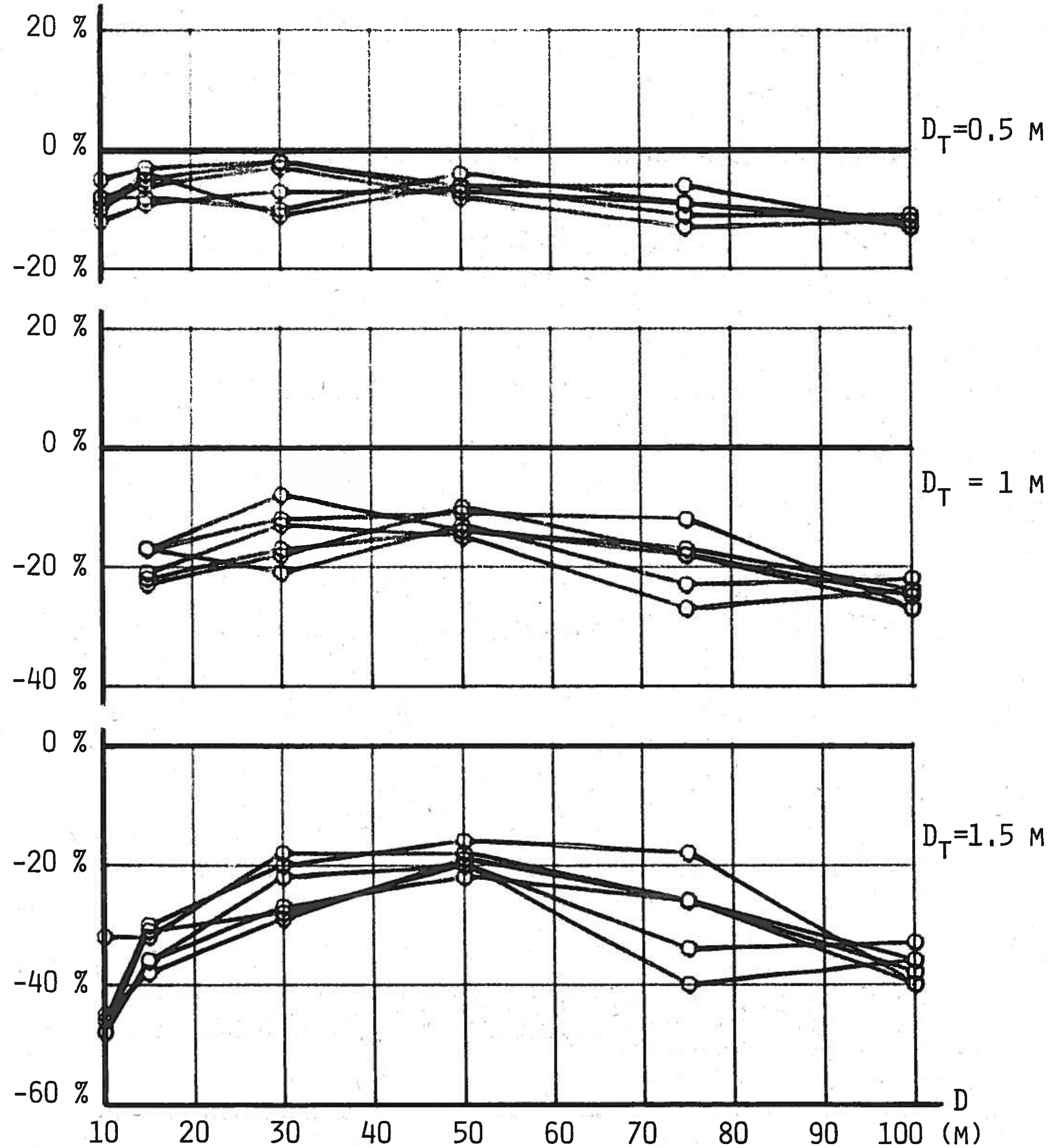


Fig. D.11 Changes in SL for dry samples with glass beads for H_o=1.2 m and D_t=0.5 m, 1 m and 1.5 m, as compared to SL for D_t=0 m.

Ændringer i SL for tørre prøver med glasperler for H_o=1,2 m og D_t=0,5 m; 1 m og 1,5 m i forhold til SL ved D_t=0 m.

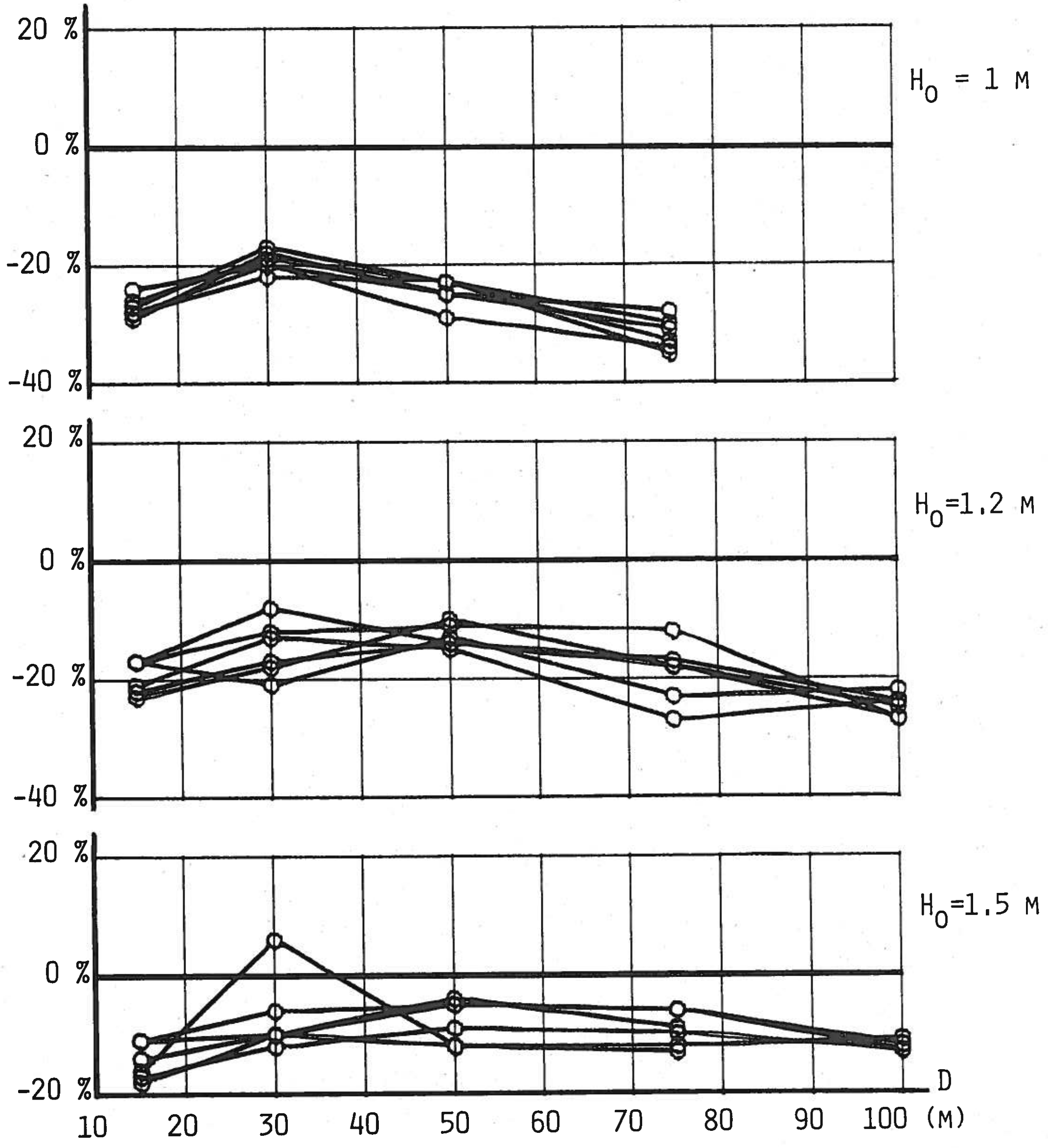


Fig. D.12 Changes in SL for dry samples with glass beads for H_o=1 m, 1.2 m and 1.5 m at D_t=1 m, as compared to SL for D_t=0 m.

Ændringer i SL for tørre prøver med glasperler for H_o=1 m; 1,2 m og 1,5 m ved D_t=1 m i forhold til SL ved D_t=0 m.

An assumption that the factor, f_{retro} is mainly responsible for the decrease in SL at all distances would on the other hand lead to difficulties. It does not seem natural then that the decrease is larger at large, than at medium distances, and it is unlikely that the decrease should generally be larger than for samples without glass beads.

It is natural to assume then that at large distances not all of the illuminated glass beads are visible when $D_t \neq 0$. This is to mean that the transverse displacement leads to a hiding of illuminated glass beads in the same way as illuminated facets are hidden, and as accounted for by the factor $f_{visible\ beads}$ (see Appendix A).

Therefore, for road markings with glass beads new features must be taken into account in order to explain the already complex vaiation of SL with D_t.

D.3 - The moist condition

Road markings without glass beads can in some respects be considered as road surfaces, being however, extreme in lightness and sometimes also in lack of surface texture.

For this reason, the influence of the moist condition as outlined for road surfaces in Mörkertrafik Report No. 4 should be expected to apply also to road markings without glass beads.

This turns out to be true, with, however, a rather large uncertainty for the SL's of the humid condition (diagrams not shown).

The decrease in specific luminance in the moist condition is further relatively small, by 30-40 %, as would be the case for a very light road surface.

For road markings with glass beads is expected a relatively strong decrease in the specific luminance for the moist condition, as the moist impairs the retroreflective action of the glass beads.

This expected features is confirmed by the measurement. The decrease in specific luminance is by up to appr. 75 %, while the "uncertainty" of the measurements is surprisingly small.

However, the glass beads still have some retroreflection in the humid condition, this leading among else to a variation with the distance approximately as for the dry condition. This is shown in fig. D.13 for the observer eye height of 1.2 m.

For road markings with or without glass beads it is, therefore, reasonable to investigate the assumption that the specific luminance for the moist condition is a fraction of the specific luminance for the dry condition, where the fraction is approximately independent of the geometry.

This is done in fig. D.14 to D.17, which contains diagrams giving SL(humid) in relation to SL(dry). The above-mentioned assumption means that the points are to lie around a line of unity slope, which, therefore, is drawn through the point for the geometry of ($\varepsilon = 0.74^{o}$, $\alpha = 1.37^{o}$, $\beta' = 0^{o}$).

The rather large scatter of the points in these diagrams is ascribed mainly to variations in the humid condition and to other sources of uncertainty.

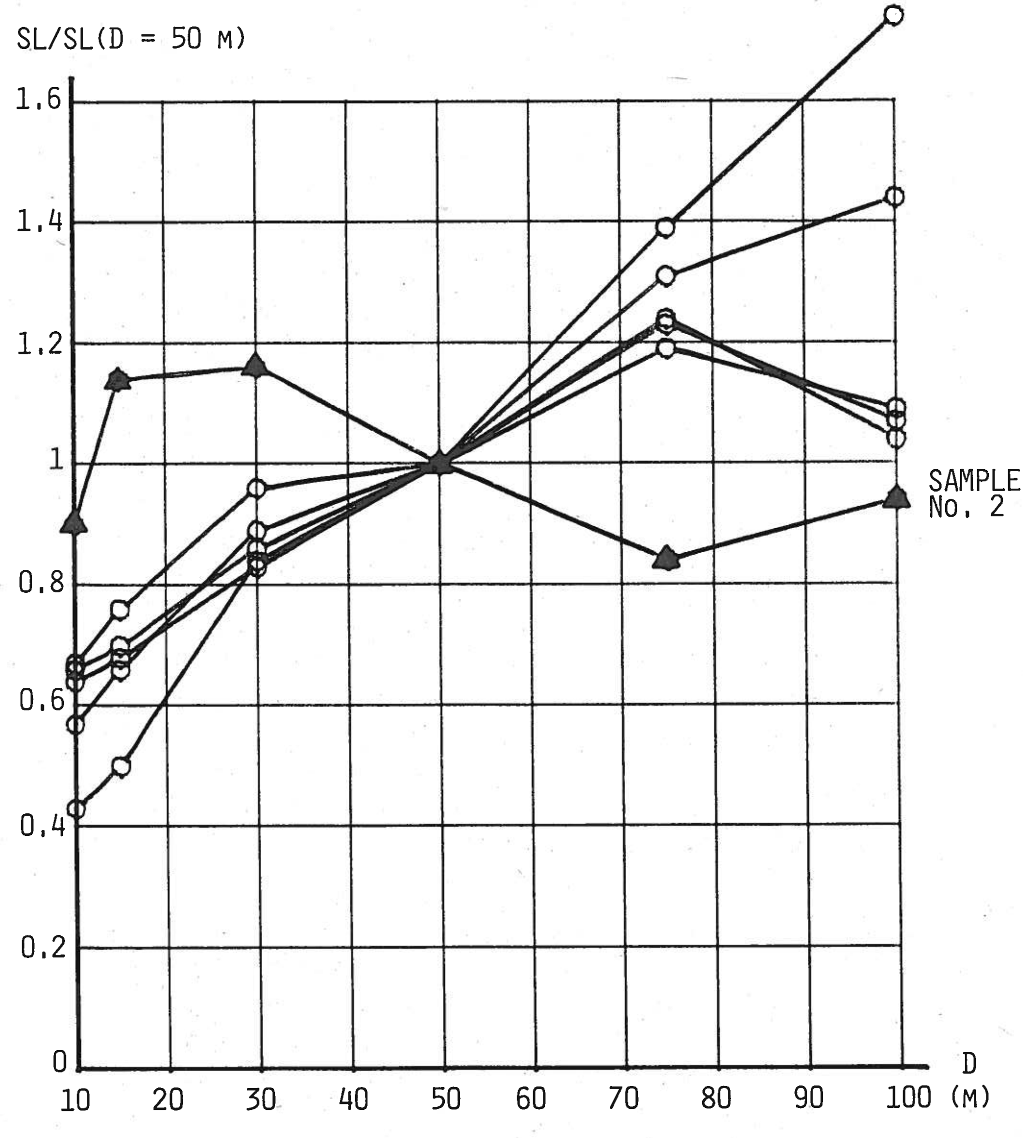


Fig. D.13 Ratios SL/SL(D=50 m) for H_o=1.2 m, D_t=0 and humid samples with glass beads.

Forholdene SL/SL(D=50 m) for H_o=1,2 m, D_t=0 og fugtige prøver med glasperler.

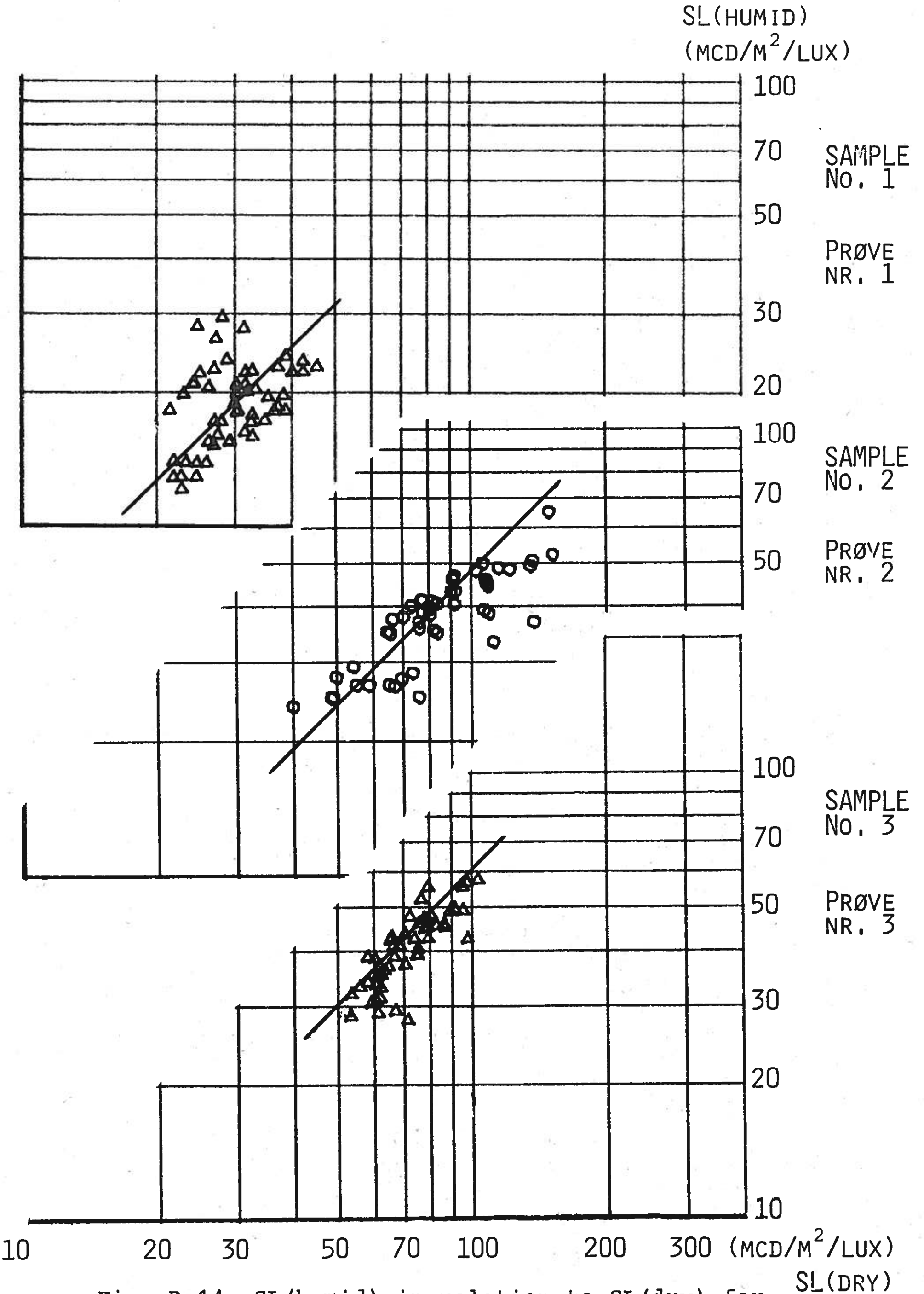
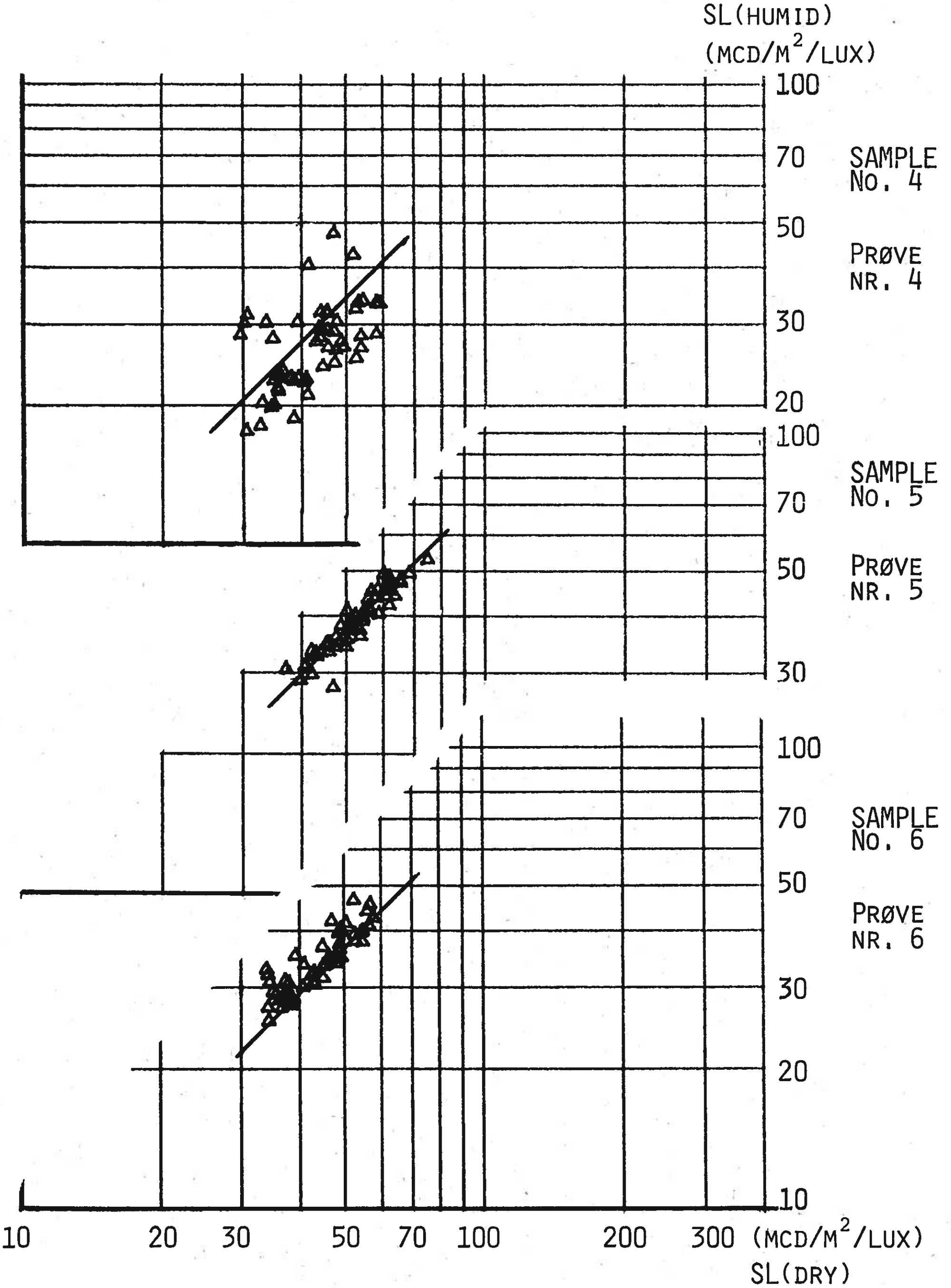


Fig. D.14 SL(humid) in relation to SL(dry) for samples Nos. 1, 2 and 3.

SL(fugtig) i relation til SL(tør) for prøver nr. 1, 2 og 3.



<u>Fig. D.15</u> SL(humid) in relation to SL(dry) for samples Nos. 4, 5 and 6.

SL(fugtig) i relation til SL(tør) for prøver nr. 4, 5 og 6.

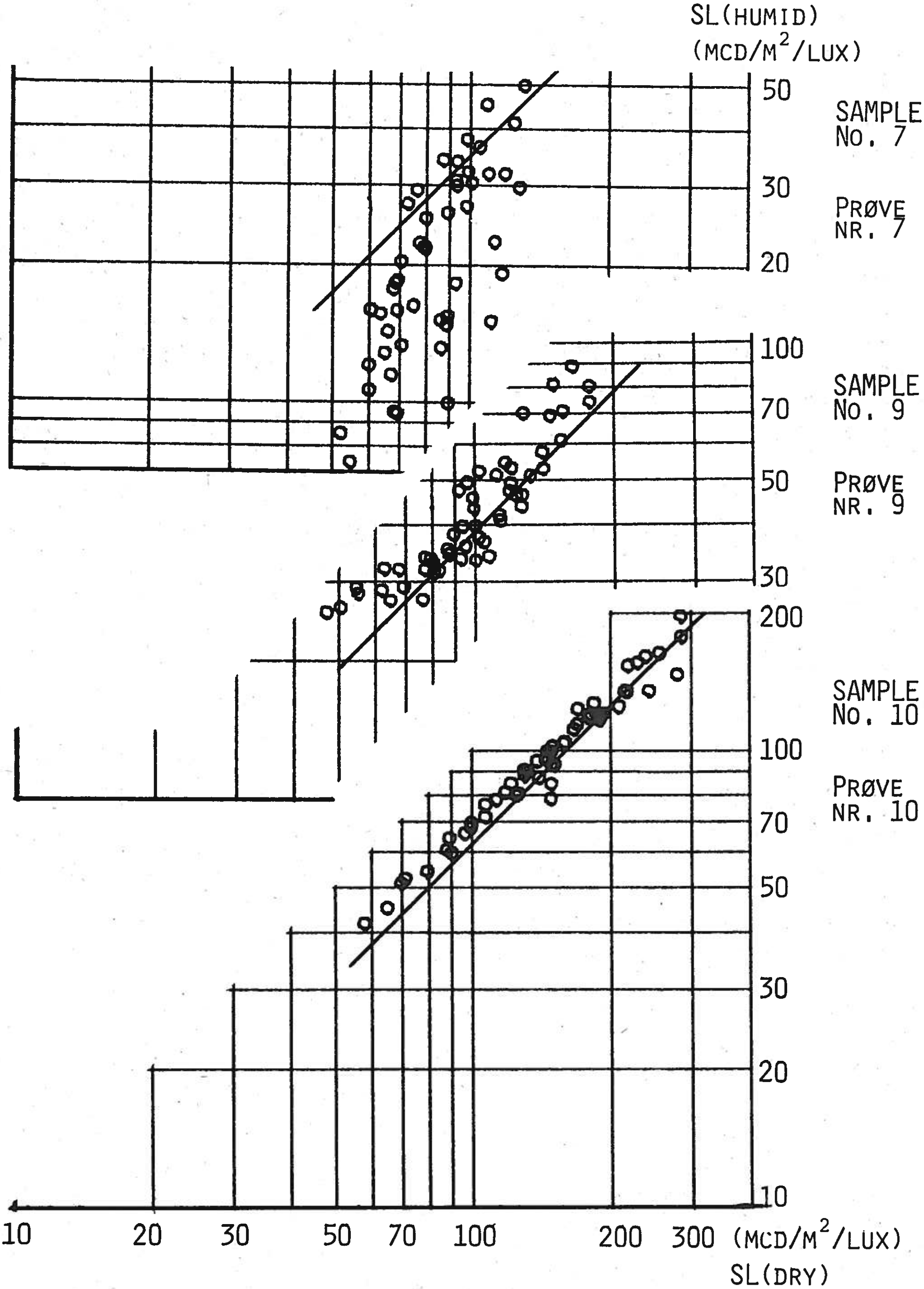


Fig. D.16 SL(humid) in relation to SL(dry) for samples Nos. 7, 9 and 10.

SL(fugtig) i relation til SL(tør) for prøver nr. 7, 9 og 10.

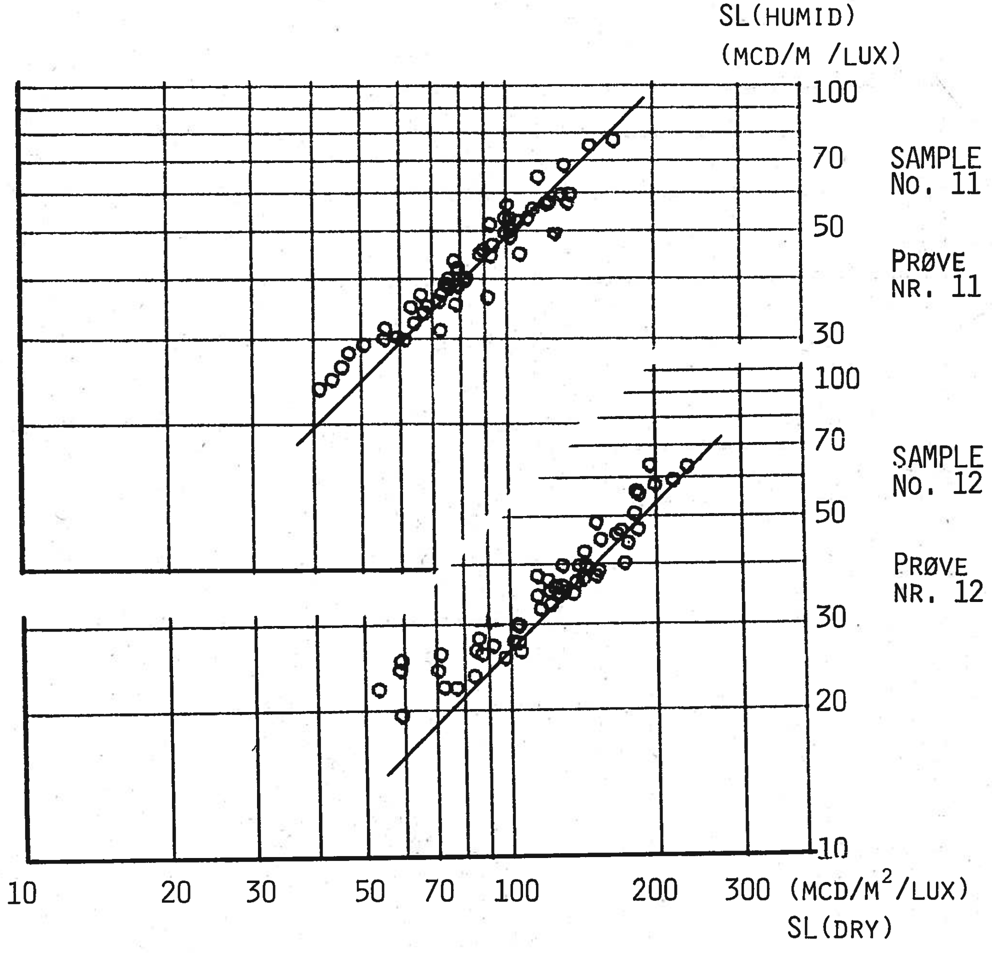


Fig. D.17 SL(humid) in relation to SL(dry) for samples Nos. 11 and 12.

SL(fugtig) i relation til SL(tør) for prøver nr. 11 og 12.

D.4 - Reflection tables

EPSI	ALFA / BETA'	.57	.69	.76	.86	.92	1.15	1.37	1.72	1.91	2.29	2.86
.37	.00	~~22.15~~	28.80	-----	24.30	I	I	I	I	I	I	I
	1.00	~~17.58~~	24.15	-----	21.45	I	I	I	I	I	I	I
.50	.00	-----	-----	36.65	-----	31.40	25.00	I	I	I	I	I
	1.00	-----	-----	26.85	-----	27.20	22.80	I	I	I	I	I
.74	.00	-----	-----	-----	-----	-----	38.95	30.38	24.60	I	I	I
	1.00	-----	-----	-----	-----	-----	32.80	27.98	22.73	I	I	I
	2.00	-----	-----	-----	-----	-----	31.60	26.95	21.84	I	I	I
1.24	.00	-----	-----	-----	-----	-----	-----	-----	-----	38.84	31.65	25.90
	1.00	-----	-----	-----	-----	-----	-----	-----	-----	34.99	30.20	24.65
	2.00	-----	-----	-----	-----	-----	-----	-----	-----	32.67	30.23	23.33
	3.50	-----	-----	-----	-----	-----	-----	-----	-----	30.26	26.17	21.87

dry condition

tør tilstand

EPSI	ALFA / BETA'	3.81	4.57	5.71	6.84	8.53
2.48	.00	42.62	35.51	29.19	I	I
	2.00	40.21	31.95	27.45	I	I
	5.00	33.37	29.89	26.16	I	I
3.72	.00	-----	-----	45.70	37.48	32.89
	2.00	-----	-----	42.57	38.58	31.52
	5.00	-----	-----	37.42	32.81	29.13

EPSI	ALFA / BETA'	.57	.69	.76	.86	.92	1.15	1.37	1.72	1.91	2.29	2.86
.37	.00	~~17.25~~	23.65	-----	20.90	I	I	I	I	I	I	I
	1.00	~~14.48~~	20.90	-----	18.20	I	I	I	I	I	I	I
.50	.00	-----	-----	18.20	-----	27.85	22.85	I	I	I	I	I
	1.00	-----	-----	15.20	-----	26.35	12.10	I	I	I	I	I
.74	.00	-----	-----	-----	-----	-----	24.10	18.20	12.90	I	I	I
	1.00	-----	-----	-----	-----	-----	22.35	17.19	12.92	I	I	I
	2.00	-----	-----	-----	-----	-----	22.20	17.23	12.86	I	I	I
1.24	.00	-----	-----	-----	-----	-----	-----	-----	-----	18.21	20.86	13.88
	1.00	-----	-----	-----	-----	-----	-----	-----	-----	17.32	19.88	13.87
	2.00	-----	-----	-----	-----	-----	-----	-----	-----	17.14	20.79	13.91
	3.50	-----	-----	-----	-----	-----	-----	-----	-----	18.07	20.54	13.98

humid condition

våd tilstand

EPSI	ALFA / BETA'	3.81	4.57	5.71	6.84	8.53
2.48	.00	22.32	19.51	15.51	I	I
	2.00	22.29	20.03	16.06	I	I
	5.00	20.33	18.87	15.47	I	I
3.72	.00	-----	-----	22.82	18.56	15.92
	2.00	-----	-----	23.52	19.69	16.31
	5.00	-----	-----	22.84	17.82	15.45

Table D.4.1 Reflection tables for sample No. 1. Paint without glass beads, Danstriben, taken at the age of appr. 1.5 year.

Refleksionstabeller for prøve nr. 1. Maling uden glasperler, Danstriben, optaget i alderen ca. 1,5 år.

dry condition

tør tilstand

EPSI	ALFA / BETA'	.57	.69	.76	.86	.92	1.15	1.37	1.72	1.91	2.29	2.86
.37	.00	~~51.75~~	83.85	64.55	-----	I	I	I	I	I	I	I
	1.00	~~30.00~~	48.65	40.00	-----	I	I	I	I	I	I	I
.50	.00	-----	-----	91.45	-----	76.35	55.15	I	I	I	I	I
	1.00	-----	-----	54.35	-----	49.90	49.05	I	I	I	I	I
.74	.00	-----	-----	-----	-----	-----	107.6	98.24	67.11	I	I	I
	1.00	-----	-----	-----	-----	-----	82.15	77.76	65.15	I	I	I
	2.00	-----	-----	-----	-----	-----	76.20	70.10	58.78	I	I	I
1.24	.00	-----	-----	-----	-----	-----	-----	-----	-----	136.9	106.1	81.49
	1.00	-----	-----	-----	-----	-----	-----	-----	-----	121.5	102.4	77.55
	2.00	-----	-----	-----	-----	-----	-----	-----	-----	108.4	90.73	73.13
	3.50	-----	-----	-----	-----	-----	-----	-----	-----	91.87	77.28	66.41

EPSI	ALFA / BETA'	3.81	4.57	5.71	6.84	8.53
2.48	.00	152.0	114.9	80.67	I	I
	2.00	135.3	108.1	80.50	I	I
	5.00	91.49	80.09	65.63	I	I
3.72	.00	-----	-----	149.2	109.1	76.09
	2.00	-----	-----	137.6	106.6	73.56
	5.00	-----	-----	111.8	83.63	69.47

humid condition

våd tilstand

EPSI	ALFA / BETA'	.57	.69	.76	.86	.92	1.15	1.37	1.72	1.91	2.29	2.86
.37	.00	~~20.95~~	40.60	35.00	-----	I	I	I	I	I	I	I
	1.00	~~12.95~~	24.95	23.90	-----	I	I	I	I	I	I	I
.50	.00	-----	-----	46.75	-----	35.75	26.65	I	I	I	I	I
	1.00	-----	-----	29.25	-----	27.75	25.00	I	I	I	I	I
.74	.00	-----	-----	-----	-----	-----	45.85	43.09	26.49	I	I	I
	1.00	-----	-----	-----	-----	-----	35.40	38.73	26.68	I	I	I
	2.00	-----	-----	-----	-----	-----	36.85	37.85	26.64	I	I	I
1.24	.00	-----	-----	-----	-----	-----	-----	-----	-----	50.49	49.87	41.04
	1.00	-----	-----	-----	-----	-----	-----	-----	-----	48.35	48.11	41.24
	2.00	-----	-----	-----	-----	-----	-----	-----	-----	44.35	46.06	40.87
	3.50	-----	-----	-----	-----	-----	-----	-----	-----	43.21	41.31	37.39

EPSI	ALFA / BETA'	3.81	4.57	5.71	6.84	8.53
2.48	.00	52.17	48.69	39.61	I	I
	2.00	49.22	45.06	38.23	I	I
	5.00	40.43	39.08	34.77	I	I
3.72	.00	-----	-----	65.05	38.53	25.08
	2.00	-----	-----	36.90	39.30	28.40
	5.00	-----	-----	33.32	34.87	27.52

Table D.4.2 Reflection tables for sample No. 2. Thermoplastic with drop-on and premix glass beads, Nordsjø, taken at the age of appr. 2.5 year.

Refleksionstabeller for prøve nr. 2. Termoplast med afstrøede og iblandede glasperler, Nordsjø, taget i alderen ca. 2,5 år.

dry condition

tør tilstand

EPSI	BETA' \ ALFA	.57	.69	.76	.86	.92	1.15	1.37	1.72	1.91	2.29	2.86
.37	.00	~~64.00~~	75.60	-----	58.30	I	I	I	I	I	I	I
	1.00	~~61.05~~	67.05	-----	53.30	I	I	I	I	I	I	I
.50	.00	-----	-----	91.45	-----	74.15	62.55	I	I	I	I	I
	1.00	-----	-----	71.50	-----	63.50	60.60	I	I	I	I	I
.74	.00	-----	-----	-----	-----	-----	95.40	77.86	61.81	I	I	I
	1.00	-----	-----	-----	-----	-----	86.35	70.50	60.80	I	I	I
	2.00	-----	-----	-----	-----	-----	79.60	65.87	59.27	I	I	I
1.24	.00	-----	-----	-----	-----	-----	-----	-----	-----	95.45	79.56	61.88
	1.00	-----	-----	-----	-----	-----	-----	-----	-----	89.21	74.96	60.93
	2.00	-----	-----	-----	-----	-----	-----	-----	-----	87.08	75.42	62.19
	3.50	-----	-----	-----	-----	-----	-----	-----	-----	75.58	70.66	55.99

EPSI	BETA' \ ALFA	3.81	4.57	5.71	6.84	8.53
2.48	.00	99.14	77.89	66.50	I	I
	2.00	97.64	80.55	80.37	I	I
	5.00	79.54	72.33	58.28	I	I
3.72	.00	-----	-----	103.4	76.90	66.79
	2.00	-----	-----	97.44	83.06	65.44
	5.00	-----	-----	79.66	78.17	61.94

humid condition

våd tilstand

EPSI	BETA' \ ALFA	.57	.69	.76	.86	.92	1.15	1.37	1.72	1.91	2.29	2.86
.37	.00	~~46.30~~	45.90	-----	34.00	I	I	I	I	I	I	I
	1.00	~~29.20~~	29.30	-----	28.50	I	I	I	I	I	I	I
.50	.00	-----	-----	49.60	-----	42.55	35.40	I	I	I	I	I
	1.00	-----	-----	27.90	-----	36.15	33.65	I	I	I	I	I
.74	.00	-----	-----	-----	-----	-----	55.55	47.17	31.33	I	I	I
	1.00	-----	-----	-----	-----	-----	45.85	43.49	30.80	I	I	I
	2.00	-----	-----	-----	-----	-----	46.80	42.84	30.49	I	I	I
1.24	.00	-----	-----	-----	-----	-----	-----	-----	-----	49.16	42.61	35.43
	1.00	-----	-----	-----	-----	-----	-----	-----	-----	49.09	39.08	34.96
	2.00	-----	-----	-----	-----	-----	-----	-----	-----	45.18	39.11	33.07
	3.50	-----	-----	-----	-----	-----	-----	-----	-----	40.40	37.19	33.17

EPSI	BETA' \ ALFA	3.81	4.57	5.71	6.84	8.53
2.48	.00	~~18.42~~	47.05	41.00	I	I
	2.00	42.48	48.08	38.48	I	I
	5.00	45.14	47.72	38.72	I	I
3.72	.00	-----	-----	57.59	52.16	38.78
	2.00	-----	-----	56.86	45.57	42.28
	5.00	-----	-----	55.49	44.74	36.94

<u>Table D.4.3</u> Reflection tables for sample No. 3. Thermoplastic without glass beads, Zebraflex, taken at the age of appr. 3.5 year.

Refleksionstabeller for prøve nr. 3. Termoplast uden perler, Zebraflex, taget i alderen ca. 3,5 år.

dry condition / tør tilstand

EPSI	ALFA / BETA'	.57	.69	.76	.86	.92	1.15	1.37	1.72	1.91	2.29	2.86
.37	.00	~~40.30~~	47.10	-----	33.70	I	I	I	I	I	I	I
	1.00	~~28.10~~	30.60	-----	29.55	I	I	I	I	I	I	I
.50	.00	-----	-----	51.90	-----	44.55	32.70	I	I	I	I	I
	1.00	-----	-----	34.75	-----	41.30	30.50	I	I	I	I	I
.74	.00	-----	-----	-----	-----	-----	53.75	43.75	34.98	I	I	I
	1.00	-----	-----	-----	-----	-----	47.55	44.62	33.01	I	I	I
	2.00	-----	-----	-----	-----	-----	45.75	40.99	34.48	I	I	I
1.24	.00	-----	-----	-----	-----	-----	-----	-----	-----	52.47	45.58	34.87
	1.00	-----	-----	-----	-----	-----	-----	-----	-----	54.35	45.47	35.74
	2.00	-----	-----	-----	-----	-----	-----	-----	-----	52.46	44.11	36.53
	3.50	-----	-----	-----	-----	-----	-----	-----	-----	47.22	39.33	35.72

EPSI	ALFA / BETA'	3.81	4.57	5.71	6.84	8.53
2.48	.00	59.11	45.50	36.27	I	I
	2.00	53.05	47.10	38.55	I	I
	5.00	47.76	43.05	35.57	I	I
3.72	.00	-----	-----	58.06	44.09	38.05
	2.00	-----	-----	58.17	48.79	39.48
	5.00	-----	-----	53.72	49.43	35.72

humid condition / våd tilstand

EPSI	ALFA / BETA'	.57	.69	.76	.86	.92	1.15	1.37	1.72	1.91	2.29	2.86
.37	.00	~~50.30~~	47.45	-----	30.35	I	I	I	I	I	I	I
	1.00	~~34.30~~	31.50	-----	26.55	I	I	I	I	I	I	I
.50	.00	-----	-----	42.60	-----	24.30	18.10	I	I	I	I	I
	1.00	-----	-----	28.00	-----	21.10	17.60	I	I	I	I	I
.74	.00	-----	-----	-----	-----	-----	28.40	29.57	20.08	I	I	I
	1.00	-----	-----	-----	-----	-----	26.45	29.16	20.28	I	I	I
	2.00	-----	-----	-----	-----	-----	26.75	22.86	19.81	I	I	I
1.24	.00	-----	-----	-----	-----	-----	-----	-----	-----	32.45	31.77	22.68
	1.00	-----	-----	-----	-----	-----	-----	-----	-----	33.89	32.05	23.31
	2.00	-----	-----	-----	-----	-----	-----	-----	-----	25.34	31.98	23.79
	3.50	-----	-----	-----	-----	-----	-----	-----	-----	24.83	30.44	23.52

EPSI	ALFA / BETA'	3.81	4.57	5.71	6.84	8.53
2.48	.00	33.37	29.25	22.99	I	I
	2.00	33.52	29.03	22.69	I	I
	5.00	30.50	27.58	21.87	I	I
3.72	.00	-----	-----	33.50	28.20	22.94
	2.00	-----	-----	28.66	27.59	22.98
	5.00	-----	-----	26.76	26.90	21.53

<u>Table D.4.4</u> Reflection tables for sample No. 4. Thermoplastic without glass beads, LKF/Zebraflex, taken at the age of appr. 2.5 year.

Refleksionstabeller for prøve nr. 4. Termoplast uden glasperler, LKF/Zebraflex, taget i alderen ca. 2,5 år.

dry condition

tør tilstand

EPSI	BETA' \ ALFA	.57	.69	.76	.86	.92	1.15	1.37	1.72	1.91	2.29	2.86
.37	.00	~~61.20~~	60.30	-----	51.25	I	I	I	I	I	I	I
	1.00	~~37.70~~	37.55	-----	46.00	I	I	I	I	I	I	I
.50	.00	-----	-----	65.30	-----	63.75	54.15	I	I	I	I	I
	1.00	-----	-----	46.85	-----	53.45	50.20	I	I	I	I	I
.74	.00	-----	-----	-----	-----	-----	75.05	61.12	50.61	I	I	I
	1.00	-----	-----	-----	-----	-----	61.15	56.21	47.66	I	I	I
	2.00	-----	-----	-----	-----	-----	61.90	52.29	46.15	I	I	I
1.24	.00	-----	-----	-----	-----	-----	-----	-----	-----	68.48	57.83	45.69
	1.00	-----	-----	-----	-----	-----	-----	-----	-----	65.63	54.62	45.36
	2.00	-----	-----	-----	-----	-----	-----	-----	-----	61.93	54.39	44.14
	3.50	-----	-----	-----	-----	-----	-----	-----	-----	55.72	48.74	42.16

EPSI	BETA' \ ALFA	3.81	4.57	5.71	6.84	8.53
2.48	.00	61.84	51.42	43.33	I	I
	2.00	61.76	51.80	42.99	I	I
	5.00	50.34	45.61	37.11	I	I
3.72	.00	-----	-----	61.89	50.34	40.69
	2.00	-----	-----	58.67	53.68	42.21
	5.00	-----	-----	55.79	47.40	39.89

humid condition

våd tilstand

EPSI	BETA' \ ALFA	.57	.69	.76	.86	.92	1.15	1.37	1.72	1.91	2.29	2.86
.37	.00	~~46.60~~	49.25	-----	39.20	I	I	I	I	I	I	I
	1.00	~~29.80~~	29.80	-----	33.40	I	I	I	I	I	I	I
.50	.00	-----	-----	47.80	-----	44.20	38.85	I	I	I	I	I
	1.00	-----	-----	27.95	-----	37.25	35.50	I	I	I	I	I
.74	.00	-----	-----	-----	-----	-----	53.05	46.10	38.10	I	I	I
	1.00	-----	-----	-----	-----	-----	44.10	41.20	36.04	I	I	I
	2.00	-----	-----	-----	-----	-----	42.05	39.99	34.93	I	I	I
1.24	.00	-----	-----	-----	-----	-----	-----	-----	-----	49.41	43.79	34.88
	1.00	-----	-----	-----	-----	-----	-----	-----	-----	47.07	40.82	34.61
	2.00	-----	-----	-----	-----	-----	-----	-----	-----	45.42	39.55	33.25
	3.50	-----	-----	-----	-----	-----	-----	-----	-----	41.70	38.02	33.52

EPSI	BETA' \ ALFA	3.81	4.57	5.71	6.84	8.53
2.48	.00	47.99	39.04	32.66	I	I
	2.00	45.47	37.68	33.18	I	I
	5.00	41.09	34.61	30.64	I	I
3.72	.00	-----	-----	48.50	37.19	31.02
	2.00	-----	-----	45.85	36.08	29.78
	5.00	-----	-----	43.61	34.18	28.94

<u>Table D.4.5</u> Reflection tables for sample No. 5. Thermoplastic without glass beads, Merkalin, taken at the age of 0.5 year.

Refleksionstabeller for prøve nr. 5. Termoplast uden glasperler, Merkalin, taget i alderen 0,5 år.

EPSI	BETA' \ ALFA	.57	.69	.76	.86	.92	1.15	1.37	1.72	1.91	2.29	2.86
.37	.00	~~50.60~~	52.50	-----	39.30	I	I	I	I	I	I	I
	1.00	~~29.80~~	34.10	-----	34.65	I	I	I	I	I	I	I
.50	.00	-----	-----	56.10	-----	48.70	38.05	I	I	I	I	I
	1.00	-----	-----	35.70	-----	41.10	35.15	I	I	I	I	I
.74	.00	-----	-----	-----	-----	-----	57.00	49.34	38.23	I	I	I
	1.00	-----	-----	-----	-----	-----	49.60	45.14	37.14	I	I	I
	2.00	-----	-----	-----	-----	-----	49.30	42.65	37.65	I	I	I
1.24	.00	-----	-----	-----	-----	-----	-----	-----	-----	58.10	48.23	38.79
	1.00	-----	-----	-----	-----	-----	-----	-----	-----	54.90	45.97	38.56
	2.00	-----	-----	-----	-----	-----	-----	-----	-----	52.83	45.68	38.34
	3.50	-----	-----	-----	-----	-----	-----	-----	-----	48.97	43.12	36.71

dry condition

tør tilstand

EPSI	BETA' \ ALFA	3.81	4.57	5.71	6.84	8.53
2.48	.00	56.68	48.36	38.23	I	I
	2.00	54.34	46.86	37.43	I	I
	5.00	49.02	43.02	34.32	I	I
3.72	.00	-----	-----	54.83	43.34	36.24
	2.00	-----	-----	53.03	45.13	37.95
	5.00	-----	-----	48.31	40.78	34.41

EPSI	BETA' \ ALFA	.57	.69	.76	.86	.92	1.15	1.37	1.72	1.91	2.29	2.86
.37	.00	~~41.40~~	46.50	-----	35.30	I	I	I	I	I	I	I
	1.00	~~29.66~~	32.90	-----	30.85	I	I	I	I	I	I	I
.50	.00	-----	-----	44.10	-----	39.55	30.70	I	I	I	I	I
	1.00	-----	-----	29.05	-----	33.75	29.45	I	I	I	I	I
.74	.00	-----	-----	-----	-----	-----	45.55	34.96	28.90	I	I	I
	1.00	-----	-----	-----	-----	-----	39.85	33.44	28.37	I	I	I
	2.00	-----	-----	-----	-----	-----	40.25	32.03	28.73	I	I	I
1.24	.00	-----	-----	-----	-----	-----	-----	-----	-----	42.50	34.01	28.43
	1.00	-----	-----	-----	-----	-----	-----	-----	-----	39.86	34.50	28.00
	2.00	-----	-----	-----	-----	-----	-----	-----	-----	39.18	33.77	27.50
	3.50	-----	-----	-----	-----	-----	-----	-----	-----	37.36	32.46	27.14

humid condition

våd tilstand

EPSI	BETA' \ ALFA	3.81	4.57	5.71	6.84	8.53
2.48	.00	48.96	33.94	28.96	I	I
	2.00	39.48	34.54	29.19	I	I
	5.00	36.40	30.94	27.20	I	I
3.72	.00	-----	-----	37.78	30.51	28.26
	2.00	-----	-----	37.95	31.55	27.62
	5.00	-----	-----	35.01	30.09	25.37

<u>Table D.4.6</u> Reflection tables for sample No. 6. Thermoplastic without glass beads, Langeland, taken at the age of 0.5 year.

Refleksionstabeller for prøve nr. 6. Termoplast uden glasperler, Langeland, taget i alderen 0,5 år.

dry condition

tør tilstand

EPSI	BETA' \ ALFA	.57	.69	.76	.86	.92	1.15	1.37	1.72	1.91	2.29	2.86
.37	.00	~~59.40~~	98.40	98.95	-----	I	I	I	I	I	I	I
	1.00	~~30.65~~	60.45	69.00	-----	I	I	I	I	I	I	I
.50	.00	-----	-----	118.9	-----	108.4	87.15	I	I	I	I	I
	1.00	-----	-----	64.80	-----	76.30	72.70	I	I	I	I	I
.74	.00	-----	-----	-----	-----	-----	130.7	104.8	77.37	I	I	I
	1.00	-----	-----	-----	-----	-----	93.55	93.40	69.25	I	I	I
	2.00	-----	-----	-----	-----	-----	93.10	79.81	63.43	I	I	I
1.24	.00	-----	-----	-----	-----	-----	-----	-----	-----	124.2	100.8	70.28
	1.00	-----	-----	-----	-----	-----	-----	-----	-----	109.3	89.25	68.45
	2.00	-----	-----	-----	-----	-----	-----	-----	-----	98.07	79.08	75.00
	3.50	-----	-----	-----	-----	-----	-----	-----	-----	79.59	67.66	65.88

EPSI	BETA' \ ALFA	3.81	4.57	5.71	6.84	8.53
2.48	.00	127.7	93.04	70.55	I	I
	2.00	112.9	88.78	66.97	I	I
	5.00	86.06	69.19	54.54	I	I
3.72	.00	-----	-----	117.5	89.27	59.91
	2.00	-----	-----	111.0	86.24	59.98
	5.00	-----	-----	89.58	68.05	52.03

humid condition

våd tilstand

EPSI	BETA' \ ALFA	.57	.69	.76	.86	.92	1.15	1.37	1.72	1.91	2.29	2.86
.37	.00	~~27.15~~	37.85	-----	23.85	I	I	I	I	I	I	I
	1.00	~~11.50~~	15.90	-----	15.80	I	I	I	I	I	I	I
.50	.00	-----	-----	31.85	-----	45.20	34.15	I	I	I	I	I
	1.00	-----	-----	12.80	-----	29.30	27.25	I	I	I	I	I
.74	.00	-----	-----	-----	-----	-----	49.80	36.52	22.41	I	I	I
	1.00	-----	-----	-----	-----	-----	33.85	30.02	18.51	I	I	I
	2.00	-----	-----	-----	-----	-----	30.80	25.35	16.63	I	I	I
1.24	.00	-----	-----	-----	-----	-----	-----	-----	-----	41.23	30.40	20.37
	1.00	-----	-----	-----	-----	-----	-----	-----	-----	31.88	26.86	18.33
	2.00	-----	-----	-----	-----	-----	-----	-----	-----	26.92	21.89	16.31
	3.50	-----	-----	-----	-----	-----	-----	-----	-----	21.76	17.72	14.30

EPSI	BETA' \ ALFA	3.81	4.57	5.71	6.84	8.53
2.48	.00	29.76	18.29	13.33	I	I
	2.00	22.58	14.82	11.46	I	I
	5.00	15.16	9.42	7.37	I	I
3.72	.00	-----	-----	19.23	15.47	12.82
	2.00	-----	-----	15.08	13.16	10.62
	5.00	-----	-----	9.96	9.52	8.54

<u>Table D.4.7</u> Reflection tables for sample No. 7. Thermoplastic with drop-on and premix glass beads, Nordsjø, taken at the age of 0.5 year.

Refleksionstabeller for prøve nr. 7. Termoplast med afstrøede og iblandede glasperler, Nordsjø, taget i alderen 0,5 år.

EPSI	ALFA / BETA'	.57	.69	.76	.86	.92	1.15	1.37	1.72	1.91	2.29	2.86
.37	.00	~~146.4~~	163.2	-----	127.1	I	I	I	I	I	I	I
	1.00	~~[illegible]~~	91.90	-----	101.9	I	I	I	I	I	I	I
.50	.00	-----	-----	177.6	-----	155.3	116.0	I	I	I	I	I
	1.00	-----	-----	99.05	-----	119.6	98.60	I	I	I	I	I
.74	.00	-----	-----	-----	-----	-----	177.6	131.4	104.1	I	I	I
	1.00	-----	-----	-----	-----	-----	139.5	122.2	92.63	I	I	I
	2.00	-----	-----	-----	-----	-----	119.3	99.95	82.91	I	I	I
1.24	.00	-----	-----	-----	-----	-----	-----	-----	-----	154.0	125.7	89.50
	1.00	-----	-----	-----	-----	-----	-----	-----	-----	140.1	113.0	86.60
	2.00	-----	-----	-----	-----	-----	-----	-----	-----	118.5	101.6	80.36
	3.50	-----	-----	-----	-----	-----	-----	-----	-----	93.60	88.78	69.17

dry condition

tør tilstand

EPSI	ALFA / BETA'	3.81	4.57	5.71	6.84	8.53
2.48	.00	126.0	95.21	67.62	I	I
	2.00	112.5	87.41	62.76	I	I
	5.00	77.13	64.56	50.40	I	I
3.72	.00	-----	-----	106.8	79.47	55.03
	2.00	-----	-----	99.88	77.30	54.54
	5.00	-----	-----	76.25	61.90	46.96

EPSI	ALFA / BETA'	.57	.69	.76	.86	.92	1.15	1.37	1.72	1.91	2.29	2.86
.37	.00	~~[illegible]~~	88.60	-----	70.10	I	I	I	I	I	I	I
	1.00	~~[illegible]~~	47.55	-----	52.25	I	I	I	I	I	I	I
.50	.00	-----	-----	80.25	-----	70.70	54.55	I	I	I	I	I
	1.00	-----	-----	43.25	-----	53.20	45.65	I	I	I	I	I
.74	.00	-----	-----	-----	-----	-----	74.10	51.15	36.62	I	I	I
	1.00	-----	-----	-----	-----	-----	57.55	46.13	33.56	I	I	I
	2.00	-----	-----	-----	-----	-----	49.20	39.87	31.68	I	I	I
1.24	.00	-----	-----	-----	-----	-----	-----	-----	-----	61.18	43.78	38.02
	1.00	-----	-----	-----	-----	-----	-----	-----	-----	52.92	40.88	35.31
	2.00	-----	-----	-----	-----	-----	-----	-----	-----	47.35	37.42	32.92
	3.50	-----	-----	-----	-----	-----	-----	-----	-----	39.60	31.39	29.15

humid condition

våd tilstand

EPSI	ALFA / BETA'	3.81	4.57	5.71	6.84	8.53
2.48	.00	46.39	35.80	31.87	I	I
	2.00	42.00	34.45	31.99	I	I
	5.00	31.80	27.22	26.29	I	I
3.72	.00	-----	-----	34.03	33.53	28.19
	2.00	-----	-----	33.33	33.79	29.09
	5.00	-----	-----	27.35	28.67	25.59

Table D.4.8 Reflection tables for sample No. 9. Thermoplastic with drop-on and premix glass beads, Globeflex, taken at the age of appr. 1.5 year.

Refleksionstabeller for prøve nr. 9. Termoplast med afstrøede og iblandede glasperler, Globeflex, taget i alderen ca. 1,5 år.

EPSI	BETA' \ ALFA	.57	.69	.76	.86	.92	1.15	1.37	1.72	1.91	2.29	2.86
.37	.00	~~[illegible]~~	279.0	-----	189.9	I	I	I	I	I	I	I
	1.00	~~[illegible]~~	148.1	-----	148.7	I	I	I	I	I	I	I
.50	.00	-----	-----	283.9	-----	238.4	166.3	I	I	I	I	I
	1.00	-----	-----	179.6	-----	183.7	144.2	I	I	I	I	I
.74	.00	-----	-----	-----	-----	-----	284.5	214.8	151.2	I	I	I
	1.00	-----	-----	-----	-----	-----	216.4	188.8	139.6	I	I	I
	2.00	-----	-----	-----	-----	-----	192.8	158.9	126.0	I	I	I
1.24	.00	-----	-----	-----	-----	-----	-----	-----	-----	229.8	181.8	129.6
	1.00	-----	-----	-----	-----	-----	-----	-----	-----	208.2	169.2	124.3
	2.00	-----	-----	-----	-----	-----	-----	-----	-----	186.2	149.2	112.6
	3.50	-----	-----	-----	-----	-----	-----	-----	-----	145.6	121.3	96.17

dry condition

tør tilstand

EPSI	BETA' \ ALFA	3.81	4.57	5.71	6.84	8.53
2.48	.00	179.6	129.9	89.10	I	I
	2.00	158.4	118.0	87.83	I	I
	5.00	106.5	89.95	64.79	I	I
3.72	.00	-----	-----	148.8	106.8	71.03
	2.00	-----	-----	132.0	99.50	69.57
	5.00	-----	-----	99.47	79.46	57.84

EPSI	BETA' \ ALFA	.57	.69	.76	.86	.92	1.15	1.37	1.72	1.91	2.29	2.86
.37	.00	~~[illegible]~~	146.3	-----	118.2	I	I	I	I	I	I	I
	1.00	~~[illegible]~~	78.35	-----	93.20	I	I	I	I	I	I	I
.50	.00	-----	-----	196.5	-----	160.7	111.2	I	I	I	I	I
	1.00	-----	-----	117.7	-----	126.5	95.80	I	I	I	I	I
.74	.00	-----	-----	-----	-----	-----	177.4	134.8	93.07	I	I	I
	1.00	-----	-----	-----	-----	-----	134.2	116.3	87.27	I	I	I
	2.00	-----	-----	-----	-----	-----	120.3	104.1	80.58	I	I	I
1.24	.00	-----	-----	-----	-----	-----	-----	-----	-----	155.9	119.5	90.76
	1.00	-----	-----	-----	-----	-----	-----	-----	-----	124.7	114.1	79.90
	2.00	-----	-----	-----	-----	-----	-----	-----	-----	120.4	102.0	78.14
	3.50	-----	-----	-----	-----	-----	-----	-----	-----	99.58	84.67	65.91

humid condition

våd tilstand

EPSI	BETA' \ ALFA	3.81	4.57	5.71	6.84	8.53
2.48	.00	119.5	88.17	64.24	I	I
	2.00	103.7	81.16	60.62	I	I
	5.00	71.65	59.71	45.16	I	I
3.72	.00	-----	-----	99.44	76.18	52.41
	2.00	-----	-----	90.15	69.53	51.16
	5.00	-----	-----	67.90	54.30	41.76

Table D.4.9 Reflection tables for sample No. 10. Paint with drop-on glass beads, Hygæa, taken at the age of 0.5 year.

Refleksionstabeller for prøve nr. 10. Maling med afstrøede glasperler, Hygæa, taget i alderen 0,5 år.

EPSI	ALFA / BETA'	.57	.69	.76	.86	.92	1.15	1.37	1.72	1.91	2.29	2.86
.37	.00	~~126.6~~	135.4	-----	99.35	I	I	I	I	I	I	I
	1.00	~~74.05~~	72.40	-----	77.80	I	I	I	I	I	I	I
.50	.00	-----	-----	148.5	-----	131.7	100.4	I	I	I	I	I
	1.00	-----	-----	79.10	-----	118.6	92.50	I	I	I	I	I
.74	.00	-----	-----	-----	-----	-----	166.5	113.4	81.68	I	I	I
	1.00	-----	-----	-----	-----	-----	129.7	101.8	78.24	I	I	I
	2.00	-----	-----	-----	-----	-----	122.5	92.71	72.68	I	I	I
1.24	.00	-----	-----	-----	-----	-----	-----	-----	-----	133.6	101.7	78.84
	1.00	-----	-----	-----	-----	-----	-----	-----	-----	125.8	99.42	73.18
	2.00	-----	-----	-----	-----	-----	-----	-----	-----	106.4	87.99	67.42
	3.50	-----	-----	-----	-----	-----	-----	-----	-----	91.30	75.95	61.22

EPSI	ALFA / BETA'	3.81	4.57	5.71	6.84	8.53
2.48	.00	105.6	79.22	55.96	I	I
	2.00	93.70	74.72	55.64	I	I
	5.00	68.43	59.35	43.66	I	I
3.72	.00	-----	-----	89.33	66.29	47.16
	2.00	-----	-----	82.46	63.19	45.67
	5.00	-----	-----	64.29	50.63	41.12

dry condition

tør tilstand

EPSI	ALFA / BETA'	.57	.69	.76	.86	.92	1.15	1.37	1.72	1.91	2.29	2.86
.37	.00	~~50.60~~	59.65	-----	53.20	I	I	I	I	I	I	I
	1.00	~~24.35~~	35.85	-----	43.45	I	I	I	I	I	I	I
.50	.00	-----	-----	75.20	-----	68.50	56.60	I	I	I	I	I
	1.00	-----	-----	38.50	-----	53.20	51.60	I	I	I	I	I
.74	.00	-----	-----	-----	-----	-----	77.15	55.63	39.55	I	I	I
	1.00	-----	-----	-----	-----	-----	59.55	48.67	35.25	I	I	I
	2.00	-----	-----	-----	-----	-----	57.35	44.50	31.15	I	I	I
1.24	.00	-----	-----	-----	-----	-----	-----	-----	-----	57.11	53.12	39.89
	1.00	-----	-----	-----	-----	-----	-----	-----	-----	49.47	49.58	37.87
	2.00	-----	-----	-----	-----	-----	-----	-----	-----	44.84	44.77	33.98
	3.50	-----	-----	-----	-----	-----	-----	-----	-----	36.51	38.23	29.85

EPSI	ALFA / BETA'	3.81	4.57	5.71	6.84	8.53
2.48	.00	52.42	41.88	31.49	I	I
	2.00	46.78	38.61	29.85	I	I
	5.00	35.04	30.08	24.63	I	I
3.72	.00	-----	-----	45.69	36.89	27.98
	2.00	-----	-----	40.03	34.85	26.16
	5.00	-----	-----	32.28	29.13	23.61

humid condition

våd tilstand

Table D.4.10 Reflection tables for sample No. 11. Paint with drop-on glass beads, Hygæa, taken at the age of appr. 1.5 year.

Refleksionstabeller for prøve nr. 11. Maling med afstrøede perler, Hygæa, taget i alderen ca. 1,5 år.

EPSI	BETA' \ ALFA	.57	.69	.76	.86	.92	1.15	1.37	1.72	1.91	2.29	2.86
.37	.00	~~160.4~~	194.5	-----	165.7	I	I	I	I	I	I	I
	1.00	~~98.90~~	113.5	-----	128.0	I	I	I	I	I	I	I
.50	.00	-----	-----	217.1	-----	199.2	158.6	I	I	I	I	I
	1.00	-----	-----	129.2	-----	153.9	138.6	I	I	I	I	I
.74	.00	-----	-----	-----	-----	-----	232.2	175.2	128.1	I	I	I
	1.00	-----	-----	-----	-----	-----	188.6	152.5	123.7	I	I	I
	2.00	-----	-----	-----	-----	-----	169.3	141.2	113.6	I	I	I
1.24	.00	-----	-----	-----	-----	-----	-----	-----	-----	183.9	137.0	103.8
	1.00	-----	-----	-----	-----	-----	-----	-----	-----	172.1	134.8	104.7
	2.00	-----	-----	-----	-----	-----	-----	-----	-----	158.3	125.5	97.85
	3.50	-----	-----	-----	-----	-----	-----	-----	-----	121.2	103.0	83.69

dry condition

tør tilstand

EPSI	BETA' \ ALFA	3.81	4.57	5.71	6.84	8.53
2.48	.00	143.3	104.1	71.29	I	I
	2.00	125.9	101.3	70.35	I	I
	5.00	91.78	76.89	59.15	I	I
3.72	.00	-----	-----	120.5	85.71	58.81
	2.00	-----	-----	115.4	84.48	59.20
	5.00	-----	-----	86.96	72.42	53.19

EPSI	BETA' \ ALFA	.57	.69	.76	.66	.92	1.15	1.37	1.72	1.91	2.29	2.86
.37	.00	~~58.50~~	63.65	-----	45.90	I	I	I	I	I	I	I
	1.00	~~38.50~~	37.70	-----	36.00	I	I	I	I	I	I	I
.50	.00	-----	-----	59.35	-----	57.85	48.55	I	I	I	I	I
	1.00	-----	-----	35.00	-----	44.80	39.55	I	I	I	I	I
.74	.00	-----	-----	-----	-----	-----	63.30	44.06	39.68	I	I	I
	1.00	-----	-----	-----	-----	-----	50.60	38.65	35.93	I	I	I
	2.00	-----	-----	-----	-----	-----	46.70	37.27	34.39	I	I	I
1.24	.00	-----	-----	-----	-----	-----	-----	-----	-----	47.01	36.71	27.54
	1.00	-----	-----	-----	-----	-----	-----	-----	-----	40.05	34.70	26.45
	2.00	-----	-----	-----	-----	-----	-----	-----	-----	37.71	34.44	25.65
	3.50	-----	-----	-----	-----	-----	-----	-----	-----	33.00	30.02	23.48

humid condition

våd tilstand

EPSI	BETA' \ ALFA	3.81	4.57	5.71	6.84	8.53
2.48	.00	39.52	29.98	26.06	I	I
	2.00	34.68	27.70	24.13	I	I
	5.00	27.15	22.23	19.51	I	I
3.72	.00	-----	-----	35.06	28.11	24.14
	2.00	-----	-----	32.28	26.50	25.29
	5.00	-----	-----	26.07	22.29	22.14

Table D.4.11 Reflection tables for sample No. 12. Paint with drop-on glass beads, Special Hygæa, taken at the age of 0.5 year.

Refleksionstabeller for prøve nr. 12. Maling med afstrøede perler, Special Hygæa, taget i alderen 0,5 år.

APPENDIX S

SWEDISH ROAD MARKING SAMPLES

By S.-O. Lundkvist, VTI

Contents Page

S.1 - Introduction to the Swedish samples and the measuring data

The samples chosen have all been selected from a test field near Umeå in the north of Sweden. This test includes the types of thermoplastic compositions found on the Swedish roads in 1980.

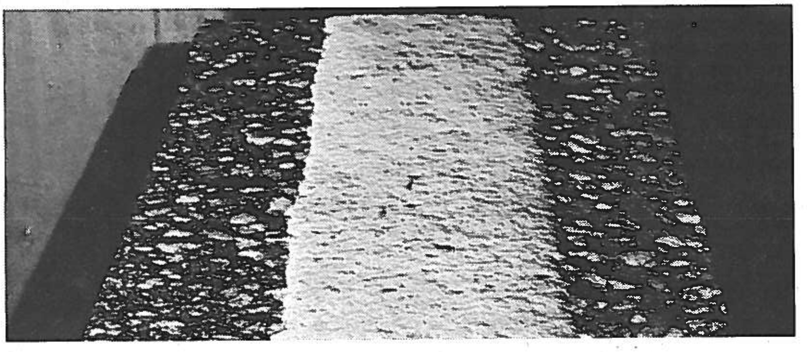
Twelve road markings of six different types have been measured. Two of each type were measured in order to get an idea of the variation between different samples. The compositions can roughly be divided into two types - soft, designed for the north of Sweden and standard compositions, designed for the middle and southern parts of Sweden.

The samples are presented in table S.1. Figures S.1 and S.2 give the appearance of the different types of compositions.

Table S.1 Description of the Swedish samples. "Standard" composition refer to compositions used in the southern and middle parts of Sweden. "Soft" compositions refer to compositions used in the north of Sweden (cold climate).
The amount of beads refers to percentage in weight.

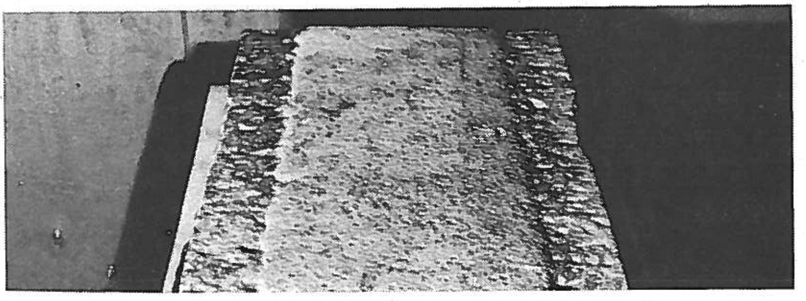
Beskrivning av de svenska proverna. Med "standard"-massa avses massor som används i södra och mellersta Sverige. Med "mjuka" massor avses massor avsedda för norra Sverige (kallt klimat).
Angiven pärlmängd avser viktsprocent.

Sample No.	Type	Fraction glass beads	Age (months)	Symbol
AR1/AR2	Standard	30 %	14	●
BR1/BR2	Standard	20 %	14	▲
CR1	Standard	20 %	14	▲
AN1/AN2	Soft	30 %	14	●
BN1/BN2	Soft	20 %	14	▲
CN1/CN2	Soft	20 %	14	▲



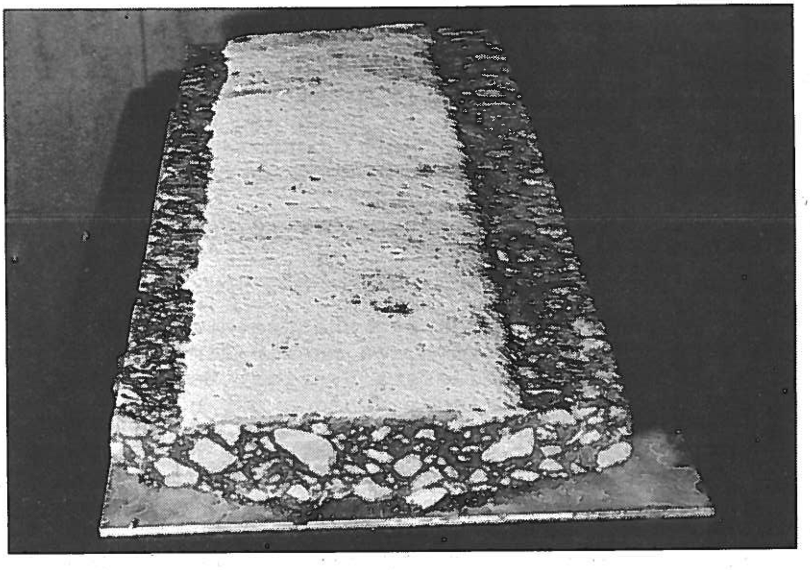
Sample AR

Prov AR



Sample BR

Prov BR

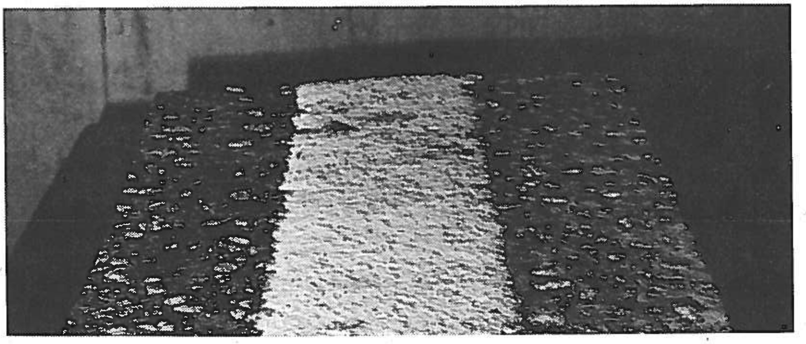


Sample CR

Prov CR

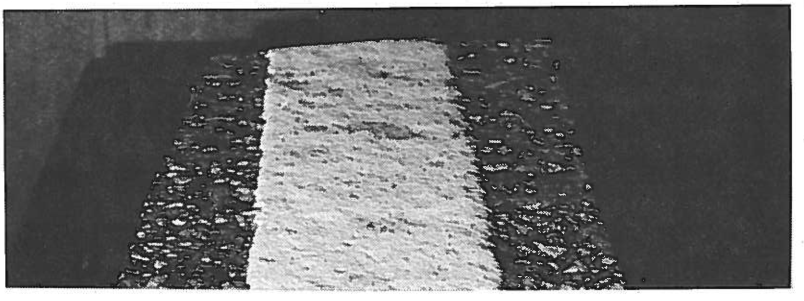
Fig. S.1 Photographs of the standard samples taken with illumination from a point below the camera.

Fotografier av standardproverna tagna med belysning från en punkt under kameran.



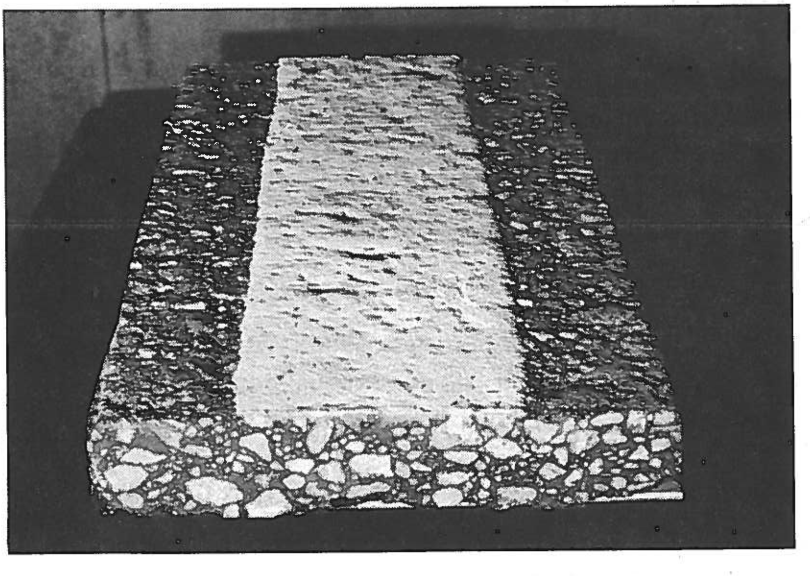
Sample AN

Prov AN



Sample BN

Prov BN



Sample CN

Prov CN

Fig. S.2 Photographs of the soft samples taken with illumination from a point below the camera.

Fotografier av standardproverna tagna med belysning från en punkt under kameran.

Due to damage, one sample had to be rejected. Consequently, the measurements comprise 11 samples. The complete reflection tables for these 11 samples will be found in section S.4.

Figure S.4 shows the specific luminance as a function of the observation distance. For all the standard compositions the specific luminance increases with distance. This is well in accordance with the measurements on the Danish samples with beads (see Figure D.4). Regarding the soft compositions, designed for cold climate, the SL has in several cases decreased with distance. Undoubtedly, this can be explained by the fact that the beads in a soft composition are low down in the texture.

Figure S.4 and the reflection tables in section S.4 also show that the deviation of the SL ($D_o = 50$ m, $H_o = 1.2$ m) for two samples of the same type is 26 % on an average. Consequently, the SL varies considerably within the samples. The variation is true to a certain extent, but to some extent it also depends on random differences. These differences increase with long observation distances (low value of α).

In a humid condition the SL decreases 70 % at a maximum (table S.2) to a large extent depending on the loss of the reflective power of the glass beads.

The mean value of the SL is 80 mcd/m^2/lux in a dry condition while in a humid condition it is 39 mcd/m^2/lux, i.e. appr. half the value in a dry condition. Furthermore, of the soft compositions those with 30 % beads have the lowest specific luminance, suprisingly enough. But these compositions lose only 20 % of their specific luminance changing to a humid condition. This is a indication of a bad effect of the beads and that, presumably, the composition had a low SL-value due to the low position of the beads in the texture. The inclination of the lines (round, unfilled) in Figure S.4 also points to this fact.

Table S.2 Values of SL($D = 50$ m, $H_o = 1.2$ m) for both dry and humid conditions.

Värden på SL($D = 50$ m, $H_o = 1.2$ m) för det torra och fuktiga tillståndet.

Sample No.	SL-dry $mcd/m^2/lux$	SL-wet $mcd/m^2/lux$	Ratio humid/dry
AR1	103	42	0,41
AR2	91	66	0,73
BR1	36	18	0,50
BR2	38	20	0,53
CR1	106	39	0,37
AN1	81	58	0,72
AN2	50	46	0,92
BN1	99	46	0,46
BN2	84	26	0,31
CN1	83	29	0,35
CN2	110	44	0,40

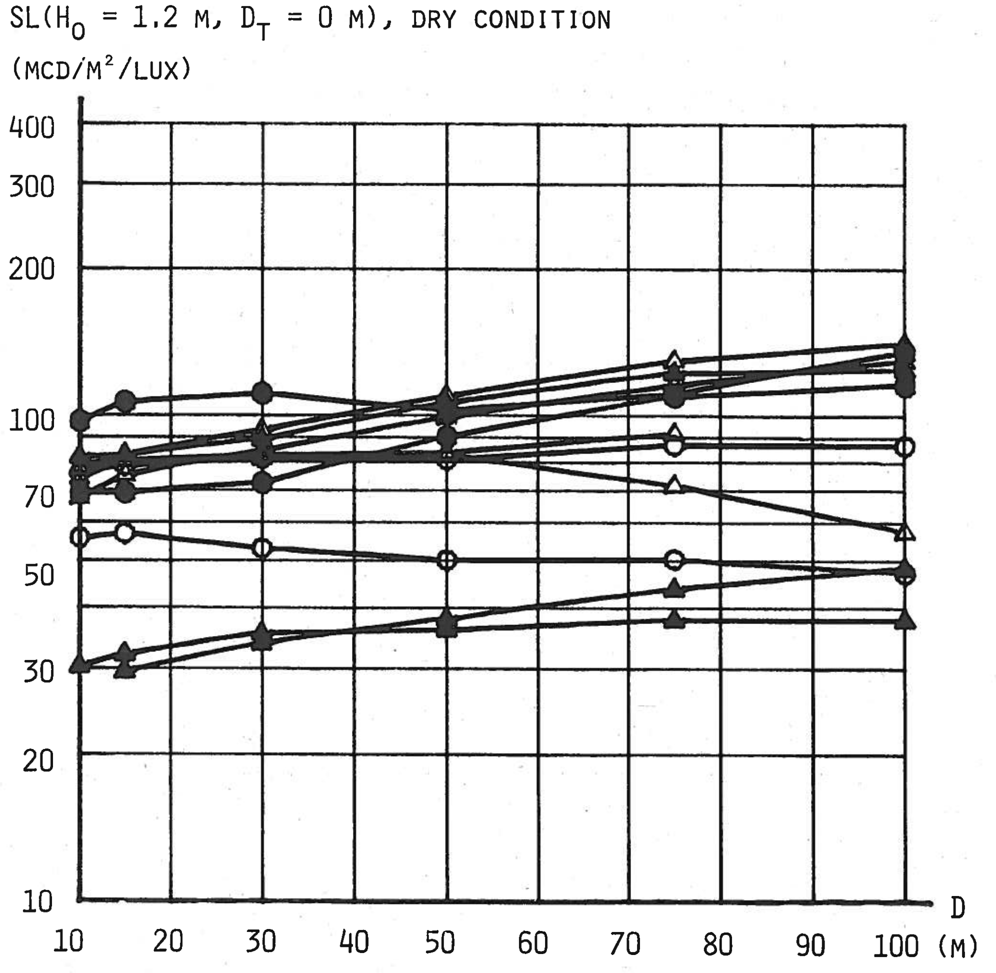


Fig. S.4 SL(H_o = 1.2 m, D_t = 0 m) for the dry condition as a function of the distance on the road, D. The symbols are shown in table S.1.

SL(H_o = 1.2 m, D_t = 0 m) för torrt tillstånd som funktion av avståndet på vägen, D.

S.2 - Influence of the geometry - dry condition

S.2.1 - Influence of the observer eye height

Figure S.6 shows the ratios SL/H_o = 1 m)/SL(H_o = 1.2 m) and SL(H_o = 1.5 m)/SL(H_o = 1.2 m) for dry road markings and D_t = 0 m.

The road markings behave almost, but not exactly, like the Danish road markings without beads (Figure D.5). This indicates that the effect of the beads is relatively low, i.e. the factor f_{retro} is low. The effect of the beads being relatively low is undoubtedly due to exposure to traffic with studded tyres only one month before the measurements were carried out and most likely the beads were damaged. Further, the composition has not been worn enough to make new beads appear.

S.2.2 - Influence of the distance on the road

Figure S.8 shows the influence of the observation distance for the eye height H_o = 1.2 m and D_t = 0 m. SL(D = 50 m) serves as a unity. For most road markings the SL increases with distance. A comparison with the Danish samples (Figures D.7 and D.8) shows that the dependence of the distance for the SL is not as strong as for the Danish samples with beads, i.e. again the f_{retro} is found to be relatively low. For two soft markings (unfilled) the SL decreases with D, at least when $D \geqq 30$ m. As has been mentioned earlier this might be due to the fact that the beads in soft materials are low down in the texture and consequently the factor f_{beads} has a lower value.

S.2.3 - Influence of the transverse displacement of the headlight

The measurements on the Swedish road markings showed, like the Danish ones, that the SL decreases with an increased D_t (Figure S.11). The effect is not as strong as for the Danish samples with beads. Regarding discussion, see Section D.2.3.

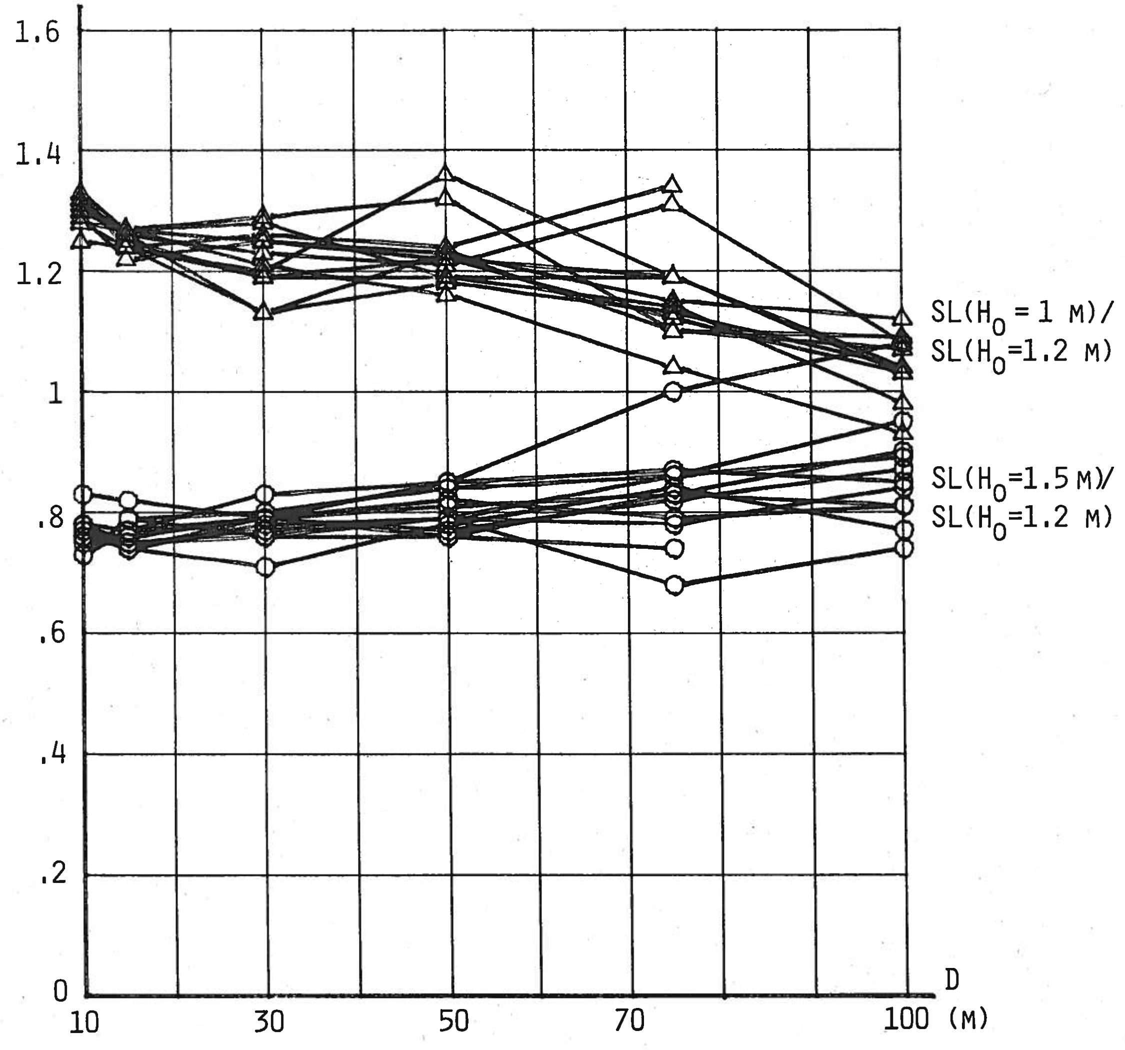


Fig. S.6 Influence of the observer eye height for dry samples with glass beads. The figure shows the ratios $SL(H_o = 1$ m$)/SL(H_o = 1.2$ m$)$ and $SL(H_o = 1.5$ m$)/SL(H_o = 1.2$ m$)$ for $D_t = 0$ m.

Ögonhöjdens inverkan för torra prover med glaspärlor. Figuren visar förhållandena $SL(H_o = 1$ m$)/SL(H_o = 1.2$ m$)$ och $SL(H_o = 1.5$ m$)/SL(H_o = 1.2$ m$)$ för $D_t = 0$ m.

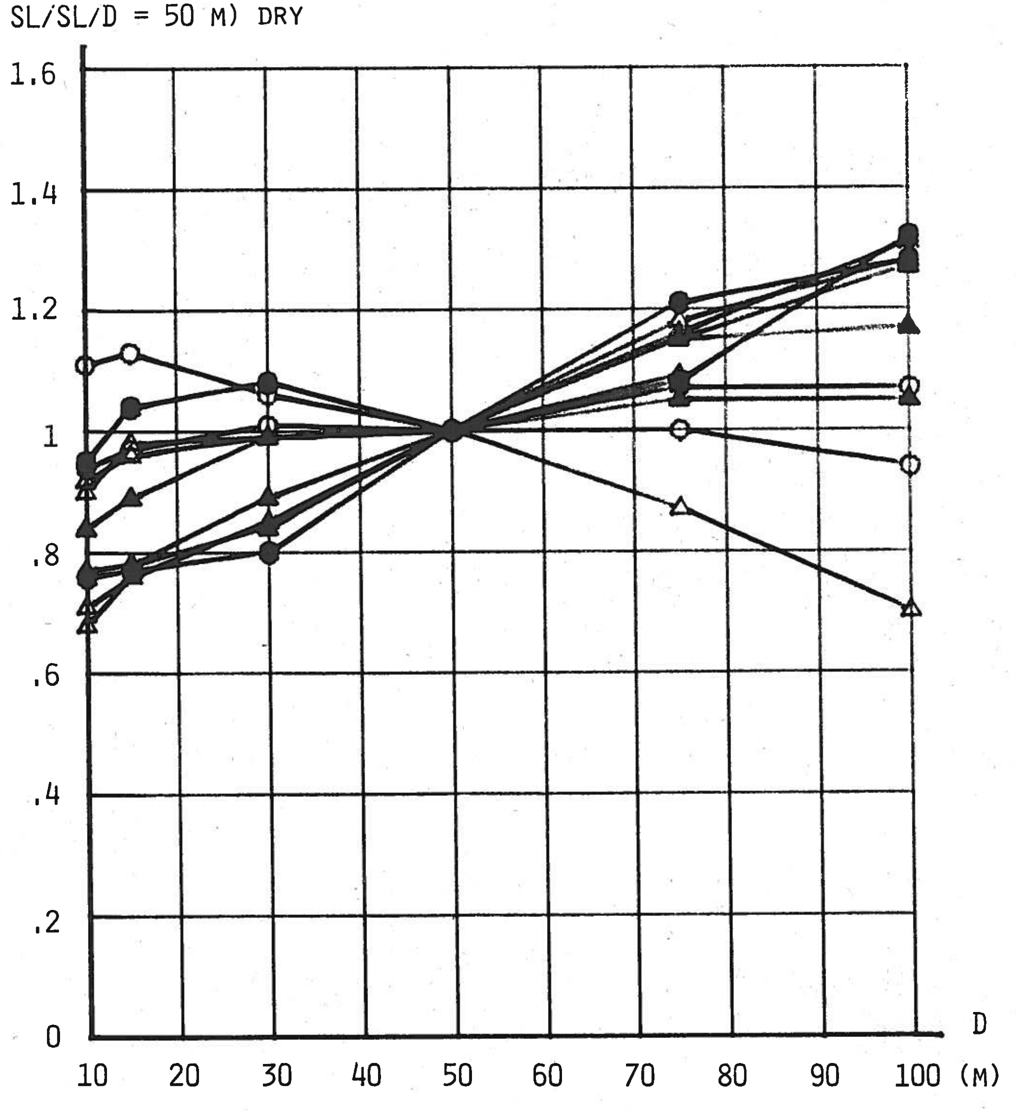


Fig. S.8 Ratios SL/SL(D = 50 m) for H_o = 1.2 m, D_t = 0 m and dry samples. The symbols are shown in table S.1.

Förhållandena SL/SL(D = 50 m) för H_o = 1.2 m, D_t = 0 m och torra prover.

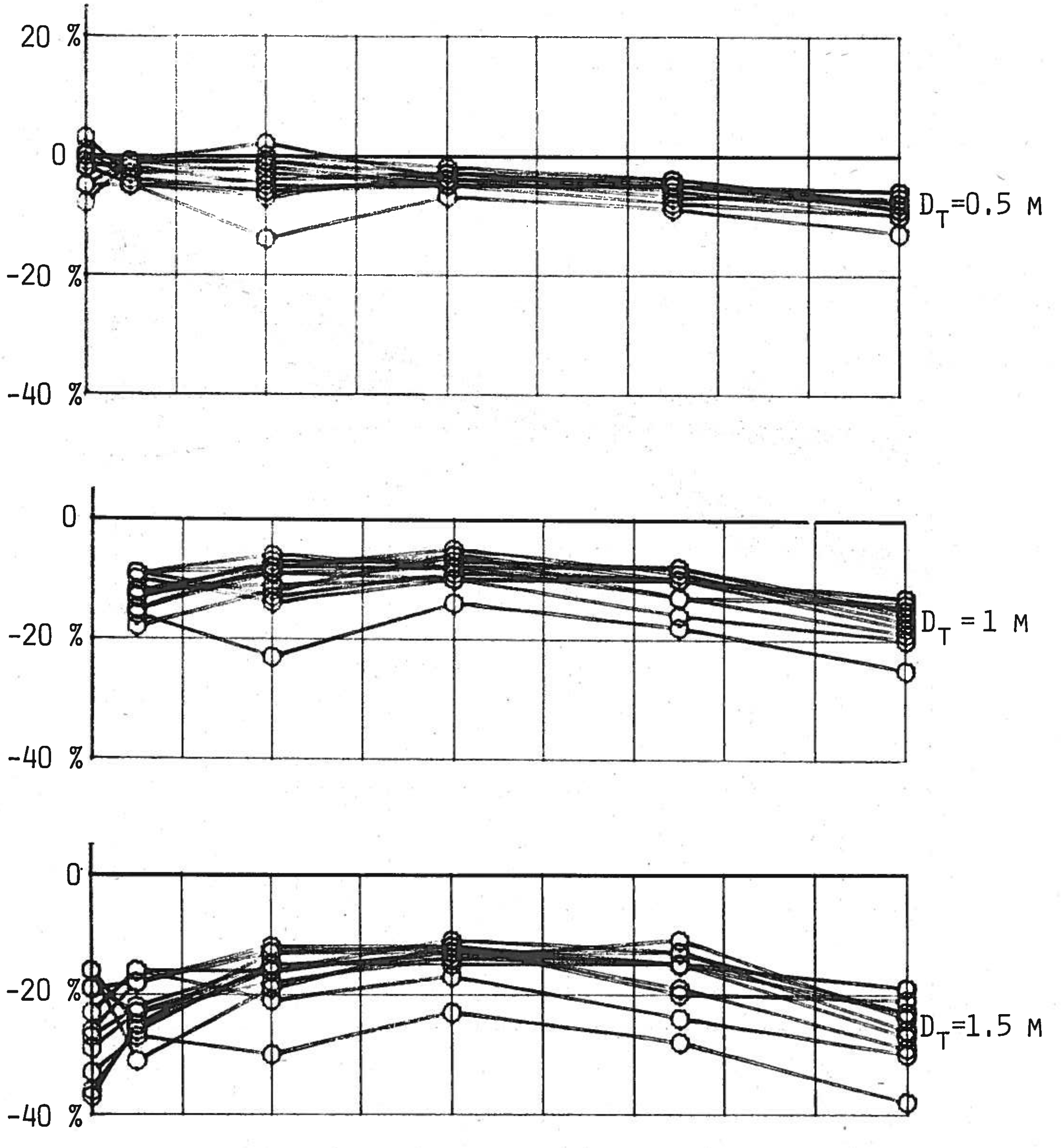


Fig. S.11 Changes in SL for dry samples with glass beads for H_o = 1.2 m and D_t 0.5 m, 1 m and 1.5 m, as compared to SL for D_t = 0 m.

Förändringar i SL för torra prover med glaspärlor för H_o = 1.2 m och D_t = 0.5 m, 1 m och 1.5 m i förhållande till SL vid D_t = 0 m.

S.3 - The moist condition

Figure S.13 shows the specific luminance as a function of the observation distance for humid road markings. The SL tends to increase with an increase in distance, i.e. humid road markings behave almost in the same way as dry road markings (cp. Figure S.8). For the markings with beads, as for the markings without beads and road surfaces the relation between SL(dry) and SL(humid) is independent of geometry. The relation between SL(dry) and SL(humid) is presented in Figures S.14, S.15, S.16 and S.17. The loss in specific luminance is appr. 50 % on an average for soft compositions and appr. 55 % for standard compositions.

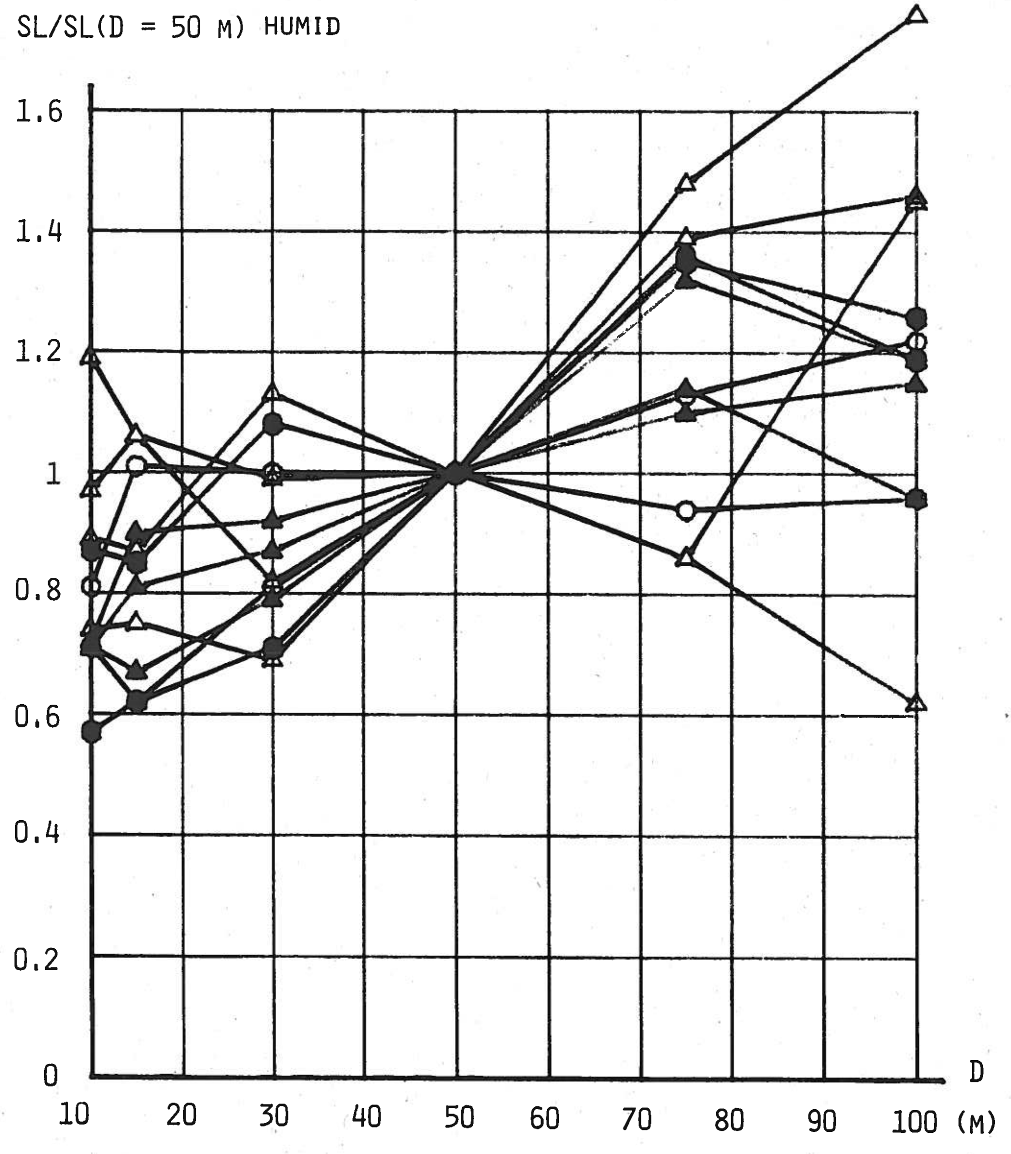


Fig. S.13 Ratios SL/SL(D = 50 m) for H_o = 1.2 m, D_t = 0 m and humid samples. The symbols are shown in table S.1.

Förhållandena SL/SL(D = 50 m) för H_o = 1.2 m, D_t = 0 m och för torra prover.

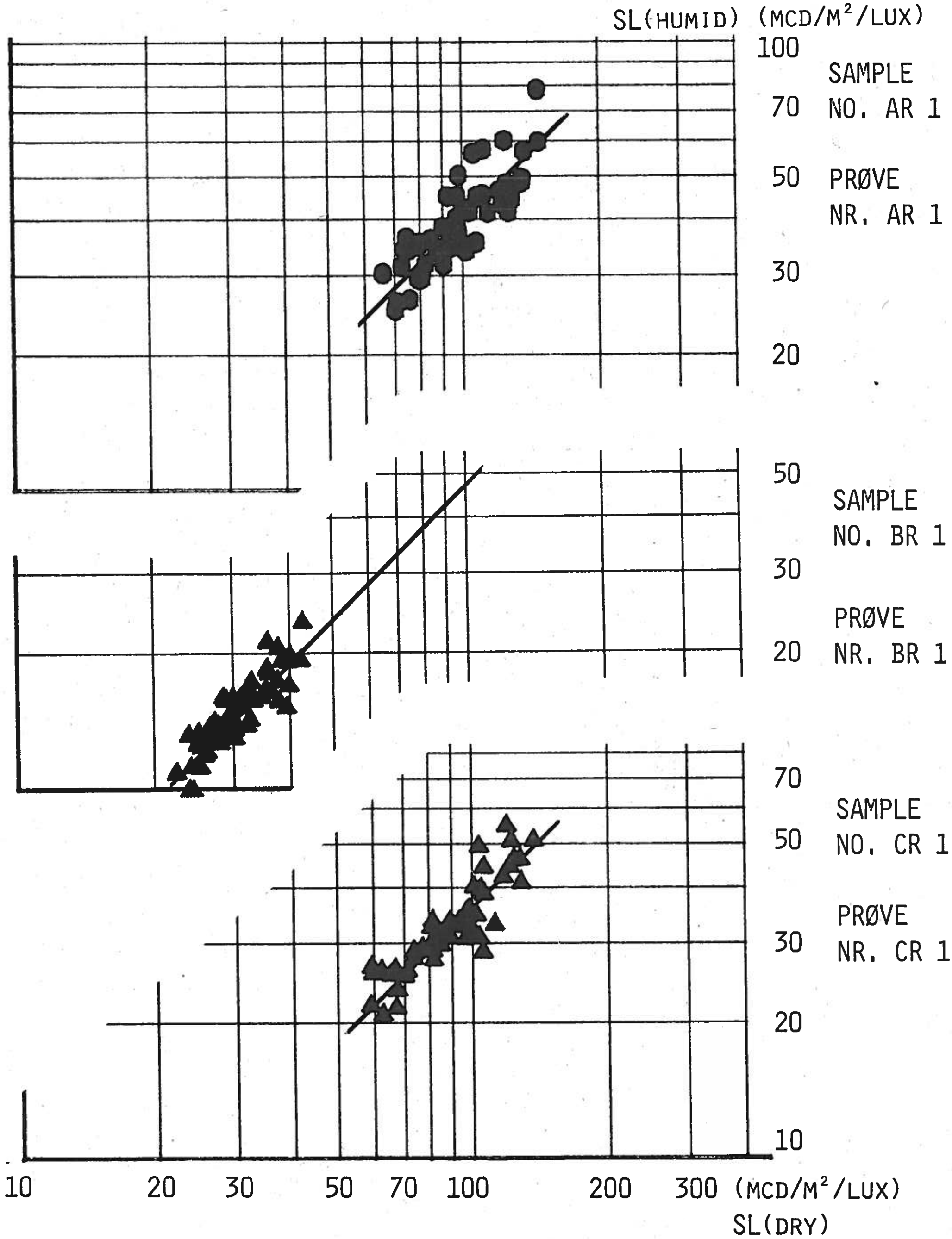


Fig. S.14 SL(humid) in relation to SL(dry) for samples AR1, BR1 and CR1.

SL(fuktig) i förhållande till SL(torr) för proverna AR1, BR1 och CR1.

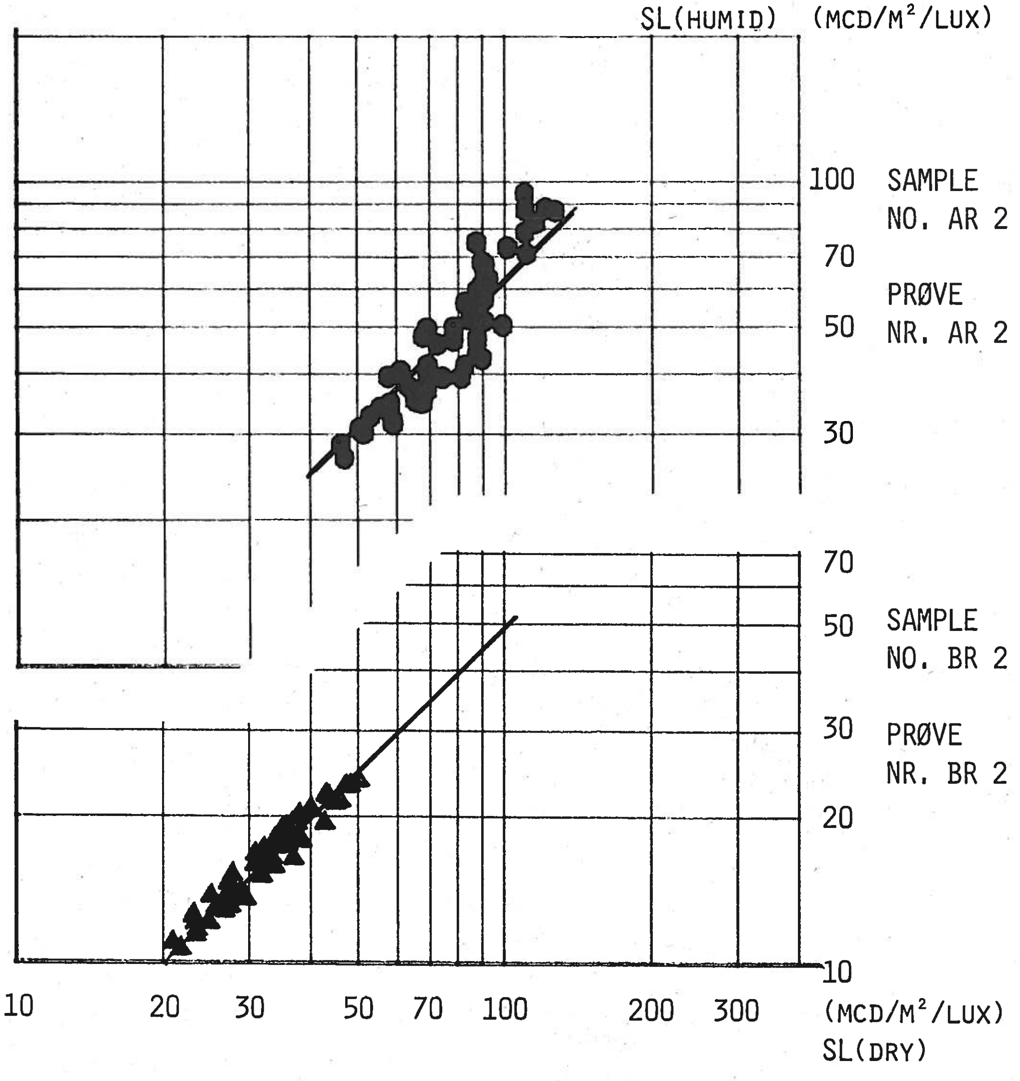


Fig. S.15 SL(humid) in relation to SL(dry) for samples AR2 and BR2.

SL(fuktig) i förhållande till SL(torr). för proverna AR2 och BR2.

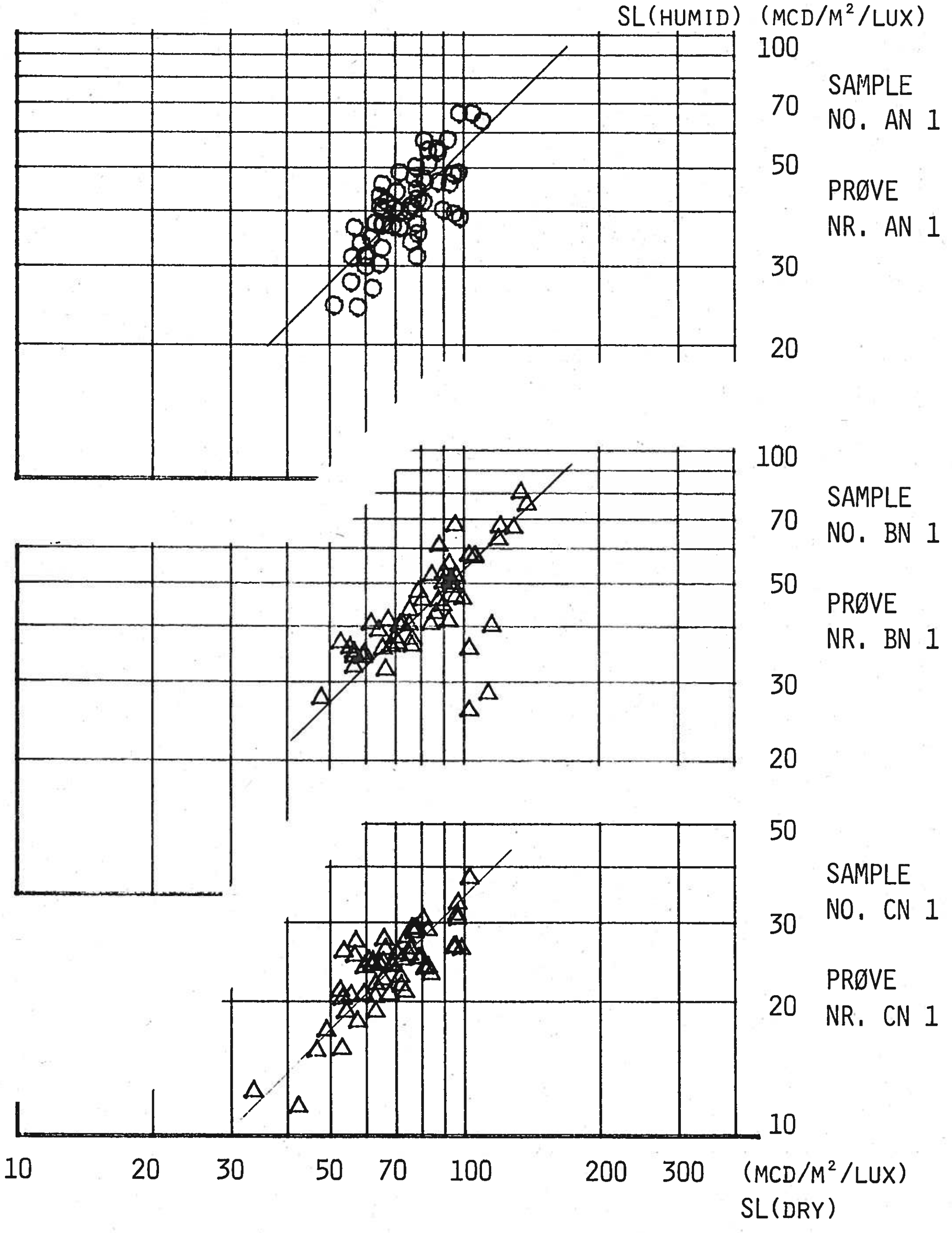


Fig. S.16 SL(humid) in relation to SL(dry) for samples AN1, BN1 and CN1.

SL(fuktig) i förhållande till SL(torr) för proverna AN1, BN1 och CN1.

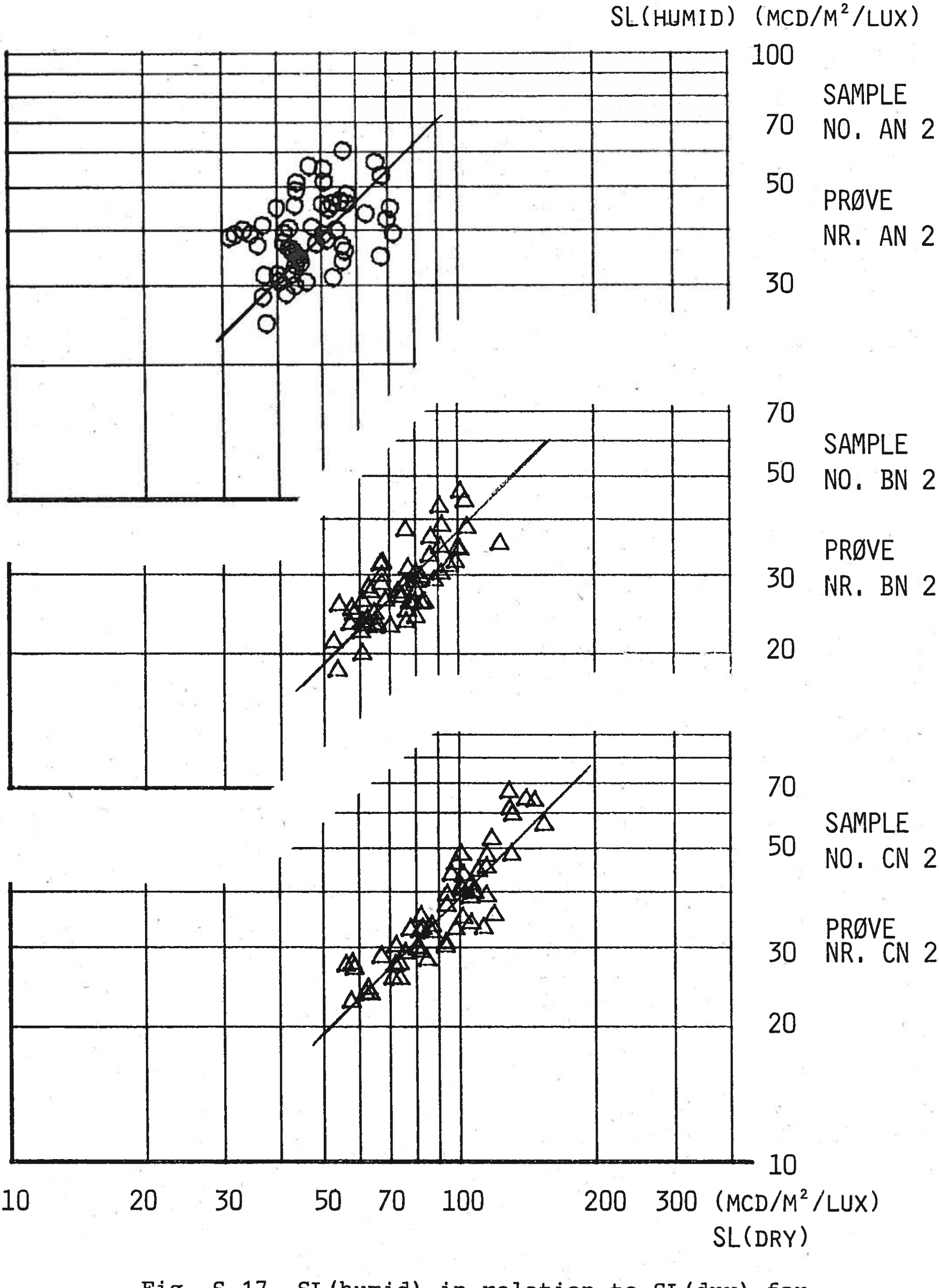


Fig. S.17 SL(humid) in relation to SL(dry) for samples AR1, BR1 and CR1.

SL(fuktig) i förhållande till SL(torr) för proverna AN2, BN2 och CN2.

S.4 - Reflection tables

dry condition

torr tillstånd

EPSI	ALFA / BETA'	.57	.69	.76	.86	.92	1.15	1.37	1.72	1.91	2.29	2.86
.37	.00	146.2	135.0	120.4	99.50	I	I	I	I	I	I	I
	1.00	97.75	92.85	91.39	89.30	I	I	I	I	I	I	I
.50	.00	-----	-----	147.0	105.5	111.0	74.50	I	I	I	I	I
	1.00	-----	-----	92.00	92.31	96.90	72.55	I	I	I	I	I
.74	.00	-----	-----	-----	-----	-----	123.7	102.6	80.49	I	I	I
	1.00	-----	-----	-----	-----	-----	107.4	97.48	75.67	I	I	I
	2.00	-----	-----	-----	-----	-----	96.50	87.41	70.01	I	I	I
1.24	.00	-----	-----	-----	-----	-----	-----	-----	-----	136.4	110.9	86.98
	1.00	-----	-----	-----	-----	-----	-----	-----	-----	124.8	103.1	82.26
	2.00	-----	-----	-----	-----	-----	-----	-----	-----	113.4	97.61	79.01
	3.50	-----	-----	-----	-----	-----	-----	-----	-----	97.06	84.27	70.82

EPSI	ALFA / BETA'	3.81	4.57	5.71	6.84	8.53
2.48	.00	134.6	106.6	78.95	I	I
	2.00	122.2	101.1	79.59	I	I
	5.00	93.81	79.10	65.90	I	I
3.72	.00	-----	-----	128.3	97.09	73.56
	2.00	-----	-----	125.7	97.67	75.47
	5.00	-----	-----	97.11	90.12	65.92

humid condition

fuktig tillstånd

EPSI	ALFA / BETA'	.57	.69	.76	.86	.92	1.15	1.37	1.72	1.91	2.29	2.86
.37	.00	78.35	49.55	45.40	41.90	I	I	I	I	I	I	I
	1.00	50.30	35.30	34.70	33.85	I	I	I	I	I	I	I
.50	.00	-----	-----	59.80	56.37	57.55	36.45	I	I	I	I	I
	1.00	-----	-----	38.55	45.13	45.15	31.50	I	I	I	I	I
.74	.00	-----	-----	-----	-----	-----	60.25	42.33	29.61	I	I	I
	1.00	-----	-----	-----	-----	-----	45.20	37.71	26.56	I	I	I
	2.00	-----	-----	-----	-----	-----	40.40	33.94	25.18	I	I	I
1.24	.00	-----	-----	-----	-----	-----	-----	-----	-----	56.94	45.56	34.64
	1.00	-----	-----	-----	-----	-----	-----	-----	-----	48.07	41.75	31.79
	2.00	-----	-----	-----	-----	-----	-----	-----	-----	41.51	37.08	29.52
	3.50	-----	-----	-----	-----	-----	-----	-----	-----	38.49	36.18	26.17

EPSI	ALFA / BETA'	3.81	4.57	5.71	6.84	8.53
2.48	.00	48.46	35.64	35.01	I	I
	2.00	43.43	34.09	35.50	I	I
	5.00	34.71	29.94	30.40	I	I
3.72	.00	-----	-----	44.49	36.88	34.44
	2.00	-----	-----	41.60	36.86	34.35
	5.00	-----	-----	35.39	31.80	30.37

<u>Table S.4.1</u> Reflection tables for sample No. AR1. Standard thermoplastic containing 30 % glass beads.

Reflexionstabeller för prov nr. AR1. Standard-termoplastmassa innehållande 30 % glaspärlor.

dry condition

torr tillstånd

EPSI	ALFA / BETA'	.57	.69	.76	.86	.92	1.15	1.37	1.72	1.91	2.29	2.86
.37	.00	126.2	115.4	109.4	100.9	I	I	I	I	I	I	I
	1.00	92.60	87.65	89.54	92.25	I	I	I	I	I	I	I
.50	.00	-----	-----	120.6	109.2	109.5	89.60	I	I	I	I	I
	1.00	-----	-----	90.35	87.29	90.75	82.65	I	I	I	I	I
.74	.00	-----	-----	-----	-----	-----	110.3	90.61	69.16	I	I	I
	1.00	-----	-----	-----	-----	-----	98.65	84.31	69.31	I	I	I
	2.00	-----	-----	-----	-----	-----	87.40	78.43	63.46	I	I	I
1.24	.00	-----	-----	-----	-----	-----	-----	-----	-----	90.30	72.50	57.64
	1.00	-----	-----	-----	-----	-----	-----	-----	-----	87.31	74.25	56.19
	2.00	-----	-----	-----	-----	-----	-----	-----	-----	78.13	67.87	55.51
	3.50	-----	-----	-----	-----	-----	-----	-----	-----	70.07	61.04	51.41

EPSI	ALFA / BETA'	3.81	4.57	5.71	6.84	8.53
2.48	.00	84.58	69.28	53.01	I	I
	2.00	82.54	68.50	51.03	I	I
	5.00	67.67	58.91	46.13	I	I
3.72	.00	-----	-----	89.36	69.09	50.33
	2.00	-----	-----	81.09	65.30	50.52
	5.00	-----	-----	67.41	58.71	46.87

humid condition

fuktig tillstånd

EPSI	ALFA / BETA'	.57	.69	.76	.86	.92	1.15	1.37	1.72	1.91	2.29	2.86
.37	.00	87.20	82.45	78.64	73.20	I	I	I	I	I	I	I
	1.00	58.45	59.70	61.12	63.15	I	I	I	I	I	I	I
.50	.00	-----	-----	88.10	94.65	87.50	68.35	I	I	I	I	I
	1.00	-----	-----	57.00	74.95	67.50	56.15	I	I	I	I	I
.74	.00	-----	-----	-----	-----	-----	71.15	65.55	49.68	I	I	I
	1.00	-----	-----	-----	-----	-----	50.45	55.96	41.70	I	I	I
	2.00	-----	-----	-----	-----	-----	47.25	50.00	37.67	I	I	I
1.24	.00	-----	-----	-----	-----	-----	-----	-----	-----	51.56	46.16	39.53
	1.00	-----	-----	-----	-----	-----	-----	-----	-----	43.68	39.36	34.82
	2.00	-----	-----	-----	-----	-----	-----	-----	-----	47.04	47.91	34.14
	3.50	-----	-----	-----	-----	-----	-----	-----	-----	39.70	40.57	30.24

EPSI	ALFA / BETA'	3.81	4.57	5.71	6.84	8.53
2.48	.00	51.98	40.70	32.00	I	I
	2.00	41.50	37.61	30.42	I	I
	5.00	35.11	31.60	28.50	I	I
3.72	.00	-----	-----	43.04	37.07	30.67
	2.00	-----	-----	39.45	35.31	30.76
	5.00	-----	-----	35.02	32.17	26.84

Table S.4.2 Reflection tables for sample No. AR2. Standard thermoplaxtic containing 30 % glass beads.

Reflexionstabeller för prov nr. AR2. Standard-termoplastmassa innehållande 30 % glaspärlor.

dry condition

torr tillstånd

EPSI	ALFA / BETA'	.57	.69	.76	.86	.92	1.15	1.37	1.72	1.91	2.29	2.86
.37	.20	39.45	37.75	34.76	30.50	I	I	I	I	I	I	I
	1.00	23.95	24.45	25.36	26.65	I	I	I	I	I	I	I
.50	.00	-----	-----	43.00	35.87	37.90	29.60	I	I	I	I	I
	1.00	-----	-----	29.15	28.56	30.00	26.45	I	I	I	I	I
.74	.00	-----	-----	-----	-----	-----	42.55	36.14	29.47	I	I	I
	1.20	-----	-----	-----	-----	-----	33.30	33.03	27.27	I	I	I
	2.00	-----	-----	-----	-----	-----	32.80	28.91	23.91	I	I	I
1.24	.00	-----	-----	-----	-----	-----	-----	-----	-----	40.19	35.54	28.19
	1.00	-----	-----	-----	-----	-----	-----	-----	-----	38.57	33.34	27.78
	2.00	-----	-----	-----	-----	-----	-----	-----	-----	36.55	30.23	25.45
	3.50	-----	-----	-----	-----	-----	-----	-----	-----	31.24	26.64	22.44

EPSI	ALFA / BETA'	3.81	4.57	5.71	6.84	8.53
2.48	.00	39.87	32.11	26.25	I	I
	2.00	35.71	30.90	26.01	I	I
	5.20	31.22	27.80	24.17	I	I
3.72	.00	-----	-----	39.99	30.30	25.18
	2.00	-----	-----	37.96	32.25	26.57
	5.00	-----	-----	32.72	28.14	24.97

humid condition

fuktig tillstånd

EPSI	ALFA / BETA'	.57	.69	.76	.86	.92	1.15	1.37	1.72	1.91	2.29	2.86
.37	.20	15.20	17.40	15.98	13.95	I	I	I	I	I	I	I
	1.00	9.95	9.95	11.12	12.80	I	I	I	I	I	I	I
.50	.00	-----	-----	23.45	21.17	20.60	14.25	I	I	I	I	I
	1.20	-----	-----	13.85	15.93	15.95	12.95	I	I	I	I	I
.74	.00	-----	-----	-----	-----	-----	19.30	18.07	14.58	I	I	I
	1.20	-----	-----	-----	-----	-----	16.00	17.28	14.06	I	I	I
	2.00	-----	-----	-----	-----	-----	15.90	15.71	13.16	I	I	I
1.24	.00	-----	-----	-----	-----	-----	-----	-----	-----	19.75	16.61	13.01
	1.00	-----	-----	-----	-----	-----	-----	-----	-----	19.27	15.74	13.02
	2.00	-----	-----	-----	-----	-----	-----	-----	-----	16.40	13.51	12.35
	3.50	-----	-----	-----	-----	-----	-----	-----	-----	15.31	13.35	10.82

EPSI	ALFA / BETA'	3.81	4.57	5.71	6.84	8.53
2.48	.00	19.17	16.20	12.07	I	I
	2.00	18.46	15.21	11.86	I	I
	5.20	15.95	13.02	11.16	I	I
3.72	.00	-----	-----	16.99	12.95	13.27
	2.20	-----	-----	15.66	13.80	13.68
	5.00	-----	-----	14.25	12.62	12.60

Table S.4.3 Reflection tables for sample No. BR1. Standard thermoplastic containing 20 % glass beads.

Reflexionstabeller för prov nr. BR1. Standard-termoplastmassa innehållande 20 % glaspärlor.

dry condition

torr tillstånd

EPSI	ALFA / BETA'	.57	.69	.76	.86	.92	1.15	1.37	1.72	1.91	2.29	2.86
.37	.20	47.25	48.25	46.05	42.90	I	I	I	I	I	I	I
	1.20	35.00	37.40	37.38	37.35	I	I	I	I	I	I	I
.50	.00	-----	-----	50.30	43.16	43.75	37.60	I	I	I	I	I
	1.00	-----	-----	34.00	38.38	37.90	34.30	I	I	I	I	I
.74	.00	-----	-----	-----	-----	-----	45.10	38.06	31.70	I	I	I
	1.00	-----	-----	-----	-----	-----	36.80	34.84	30.67	I	I	I
	2.00	-----	-----	-----	-----	-----	35.75	32.25	27.79	I	I	I
1.24	.00	-----	-----	-----	-----	-----	-----	-----	-----	40.17	33.85	27.01
	1.20	-----	-----	-----	-----	-----	-----	-----	-----	35.21	32.01	26.84
	2.00	-----	-----	-----	-----	-----	-----	-----	-----	33.90	29.18	24.88
	3.50	-----	-----	-----	-----	-----	-----	-----	-----	30.97	27.59	23.56

EPSI	ALFA / BETA'	3.81	4.57	5.71	6.84	8.53
2.48	.00	37.04	29.62	23.37	I	I
	2.20	32.15	26.95	23.13	I	I
	5.20	27.93	25.76	20.97	I	I
3.72	.20	-----	-----	33.48	27.74	-----
	2.00	-----	-----	31.71	27.19	23.42
	5.00	-----	-----	28.84	25.11	21.79

humid condition

fuktig tillstånd

EPSI	ALFA / BETA'	.57	.69	.76	.86	.92	1.15	1.37	1.72	1.91	2.29	2.86
.37	.00	23.15	23.24	21.66	19.45	I	I	I	I	I	I	I
	1.00	17.55	18.04	18.19	18.25	I	I	I	I	I	I	I
.50	.00	-----	-----	23.80	22.26	22.00	19.40	I	I	I	I	I
	1.70	-----	-----	17.45	17.64	16.30	17.35	I	I	I	I	I
.74	.00	-----	-----	-----	-----	-----	21.40	20.14	16.25	I	I	I
	1.20	-----	-----	-----	-----	-----	19.35	16.33	15.98	I	I	I
	2.00	-----	-----	-----	-----	-----	19.00	17.15	15.20	I	I	I
1.24	.20	-----	-----	-----	-----	-----	-----	-----	-----	20.78	15.79	13.80
	1.00	-----	-----	-----	-----	-----	-----	-----	-----	18.92	15.09	12.78
	2.00	-----	-----	-----	-----	-----	-----	-----	-----	17.99	13.78	12.79
	3.50	-----	-----	-----	-----	-----	-----	-----	-----	16.76	13.06	11.69

EPSI	ALFA / BETA'	3.81	4.57	5.71	6.84	8.53
2.48	.20	15.43	13.53	12.12	I	I
	2.00	15.79	13.76	12.52	I	I
	5.00	13.71	12.89	11.03	I	I
3.72	.00	-----	-----	16.44	14.25	10.64
	2.20	-----	-----	15.17	14.61	11.45
	5.00	-----	-----	13.89	13.68	10.67

Table S.4.4 Reflection tables for sample No. BR2. Standard thermoplastic containing 20 % glass beads.

Reflexionstabeller för prov nr. BR2. Standard-termoplastmassa innehållande 20 % glaspärlor.

EPSI	ALFA / BETA'	.57	.69	.76	.86	.92	1.15	1.37	1.72	1.91	2.29	2.86
.37	.00	126.2	124.2	121.5	117.7	I	I	I	I	I	I	I
	1.00	81.10	96.70	98.57	101.2	I	I	I	I	I	I	I
.50	.00	-----	-----	137.5	119.8	122.6	104.8	I	I	I	I	I
	1.00	-----	-----	93.65	103.8	106.4	97.45	I	I	I	I	I
.74	.00	-----	-----	-----	-----	-----	128.9	106.4	84.16	I	I	I
	1.00	-----	-----	-----	-----	-----	112.4	98.60	84.89	I	I	I
	2.00	-----	-----	-----	-----	-----	98.90	90.67	77.43	I	I	I
1.24	.00	-----	-----	-----	-----	-----	-----	-----	-----	105.8	89.14	67.81
	1.00	-----	-----	-----	-----	-----	-----	-----	-----	103.9	87.84	71.46
	2.00	-----	-----	-----	-----	-----	-----	-----	-----	96.04	81.72	67.52
	3.50	-----	-----	-----	-----	-----	-----	-----	-----	81.63	73.96	62.97

dry
condition

torr
tillstånd

EPSI	ALFA / BETA'	3.81	4.57	5.71	6.84	8.53
2.48	.00	102.4	82.72	65.57	I	I
	2.00	98.53	81.94	67.23	I	I
	5.00	83.57	70.46	59.23	I	I
3.72	.00	-----	-----	102.3	81.86	59.99
	2.00	-----	-----	98.27	79.72	62.57
	5.00	-----	-----	89.49	73.69	59.53

EPSI	ALFA / BETA'	.57	.69	.76	.86	.92	1.15	1.37	1.72	1.91	2.29	2.86
.37	.00	46.35	46.25	44.66	42.40	I	I	I	I	I	I	I
	1.00	32.70	30.85	34.72	40.25	I	I	I	I	I	I	I
.50	.00	-----	-----	51.05	55.07	50.85	39.75	I	I	I	I	I
	1.00	-----	-----	33.75	49.37	44.45	35.45	I	I	I	I	I
.74	.00	-----	-----	-----	-----	-----	41.20	38.85	30.56	I	I	I
	1.00	-----	-----	-----	-----	-----	33.20	35.82	29.85	I	I	I
	2.00	-----	-----	-----	-----	-----	34.90	32.69	29.40	I	I	I
1.24	.00	-----	-----	-----	-----	-----	-----	-----	-----	28.76	33.68	23.68
	1.00	-----	-----	-----	-----	-----	-----	-----	-----	31.06	32.02	26.12
	2.00	-----	-----	-----	-----	-----	-----	-----	-----	34.26	28.97	21.65
	3.50	-----	-----	-----	-----	-----	-----	-----	-----	33.82	28.95	20.92

humid
condition

fuktig
tillstånd

EPSI	ALFA / BETA'	3.81	4.57	5.71	6.84	8.53
2.48	.00	34.90	31.48	25.60	I	I
	2.00	33.29	30.11	26.35	I	I
	5.00	30.12	25.45	21.87	I	I
3.72	.00	-----	-----	31.01	27.69	25.79
	2.00	-----	-----	31.26	28.99	26.16
	5.00	-----	-----	31.07	27.89	26.66

Table S.4.5 Reflection tables for sample No. CR1. Standard thermoplastic containing 20 % glass beads.

Reflexionstabeller för prov nr. CR1. Standard-termoplastmassa innehållande 20 % glaspärlor.

dry condition

torr tillstånd

EPSI	ALFA / BETA'	.57	.69	.76	.86	.92	1.15	1.37	1.72	1.91	2.29	2.86
.37	.00	89.60	86.75	83.21	78.15	I	I	I	I	I	I	I
	1.00	57.60	63.[illegible]5	65.46	68.90	I	I	I	I	I	I	I
.50	.00	-----	-----	104.4	77.68	87.50	71.45	I	I	I	I	I
	1.00	-----	-----	65.70	71.65	78.65	69.55	I	I	I	I	I
.74	.00	-----	-----	-----	-----	-----	110.0	81.24	65.43	I	I	I
	1.00	-----	-----	-----	-----	-----	94.65	77.17	64.62	I	I	I
	2.00	-----	-----	-----	-----	-----	87.30	66.96	56.69	I	I	I
1.24	.00	-----	-----	-----	-----	-----	-----	-----	-----	97.54	81.46	64.59
	1.00	-----	-----	-----	-----	-----	-----	-----	-----	91.91	80.98	65.51
	2.00	-----	-----	-----	-----	-----	-----	-----	-----	82.86	75.26	61.77
	3.50	-----	-----	-----	-----	-----	-----	-----	-----	70.41	65.29	56.02

EPSI	ALFA / BETA'	3.81	4.57	5.71	6.84	8.53
2.48	.00	97.41	78.71	59.86	I	I
	2.00	92.79	78.13	60.13	I	I
	5.00	71.45	62.24	51.04	I	I
3.72	.00	-----	-----	95.12	75.84	58.58
	2.00	-----	-----	97.92	78.15	60.14
	5.00	-----	-----	75.86	64.52	55.69

humid condition

fuktig tillstånd

EPSI	ALFA / BETA'	.57	.69	.76	.86	.92	1.15	1.37	1.72	1.91	2.29	2.86
.37	.00	40.20	55.25	50.95	44.80	I	I	I	I	I	I	I
	1.00	24.30	37.50	37.27	36.95	I	I	I	I	I	I	I
.50	.00	-----	-----	66.55	50.24	54.40	48.85	I	I	I	I	I
	1.00	-----	-----	37.25	39.99	42.55	40.45	I	I	I	I	I
.74	.00	-----	-----	-----	-----	-----	63.90	57.62	45.93	I	I	I
	1.00	-----	-----	-----	-----	-----	48.40	47.55	40.87	I	I	I
	2.00	-----	-----	-----	-----	-----	46.50	41.81	36.66	I	I	I
1.24	.00	-----	-----	-----	-----	-----	-----	-----	-----	66.52	46.55	43.20
	1.00	-----	-----	-----	-----	-----	-----	-----	-----	58.00	42.07	40.11
	2.00	-----	-----	-----	-----	-----	-----	-----	-----	54.82	39.97	34.71
	3.50	-----	-----	-----	-----	-----	-----	-----	-----	44.19	33.00	31.51

EPSI	ALFA / BETA'	3.81	4.57	5.71	6.84	8.53
2.48	.00	48.88	35.59	31.62	I	I
	2.00	46.23	31.65	30.03	I	I
	5.00	36.74	26.61	24.57	I	I
3.72	.00	-----	-----	39.50	41.06	33.83
	2.00	-----	-----	38.67	37.46	31.64
	5.00	-----	-----	34.01	30.39	27.69

Table S.4.6 Reflection tables for sample No. AN1. Soft thermoplastic containing 30 % glass beads.

Reflexionstabeller för prov nr. AN1. Mjuk termoplastmassa innehållande 30 % glaspärlor.

dry condition

torr tillstånd

EPSI	ALFA / BETA'	.57	.69	.76	.86	.92	1.15	1.37	1.72	1.91	2.29	2.86
.37	.00	50.55	47.10	44.14	39.90	I	I	I	I	I	I	I
	1.00	37.00	31.10	32.11	33.55	I	I	I	I	I	I	I
.50	.00	-----	-----	55.05	44.13	50.60	43.70	I	I	I	I	I
	1.20	-----	-----	34.80	36.11	42.50	41.35	I	I	I	I	I
.74	.00	-----	-----	-----	-----	-----	66.05	50.30	42.40	I	I	I
	1.00	-----	-----	-----	-----	-----	57.10	47.71	41.15	I	I	I
	2.00	-----	-----	-----	-----	-----	51.90	42.99	37.32	I	I	I
1.24	.00	-----	-----	-----	-----	-----	-----	-----	-----	68.14	53.02	44.06
	1.20	-----	-----	-----	-----	-----	-----	-----	-----	62.87	50.55	42.89
	2.00	-----	-----	-----	-----	-----	-----	-----	-----	55.21	48.72	39.95
	3.50	-----	-----	-----	-----	-----	-----	-----	-----	51.42	43.78	36.97

EPSI	ALFA / BETA'	3.81	4.57	5.71	6.84	8.53
2.48	.00	72.09	56.96	43.66	I	I
	2.20	67.65	54.07	41.76	I	I
	5.00	53.09	44.91	37.64	I	I
3.72	.00	-----	-----	71.09	55.71	43.26
	2.20	-----	-----	69.92	55.77	44.63
	5.00	-----	-----	56.36	46.25	40.31

humid condition

fuktig tillstånd

EPSI	ALFA / BETA'	.57	.69	.76	.86	.92	1.15	1.37	1.72	1.91	2.29	2.86
.37	.00	55.00	55.75	51.24	44.80	I	I	I	I	I	I	I
	1.20	42.95	38.50	39.14	40.05	I	I	I	I	I	I	I
.50	.00	-----	-----	60.50	49.14	51.50	45.45	I	I	I	I	I
	1.30	-----	-----	39.20	36.99	40.40	39.45	I	I	I	I	I
.74	.00	-----	-----	-----	-----	-----	56.90	45.73	36.39	I	I	I
	1.00	-----	-----	-----	-----	-----	48.20	40.68	37.53	I	I	I
	2.00	-----	-----	-----	-----	-----	44.70	36.29	31.69	I	I	I
1.24	.00	-----	-----	-----	-----	-----	-----	-----	-----	53.12	45.83	35.10
	1.00	-----	-----	-----	-----	-----	-----	-----	-----	43.60	39.25	31.79
	2.00	-----	-----	-----	-----	-----	-----	-----	-----	46.60	37.31	31.80
	3.50	-----	-----	-----	-----	-----	-----	-----	-----	36.10	33.28	28.29

EPSI	ALFA / BETA'	3.81	4.57	5.71	6.84	8.53
2.48	.00	39.38	45.96	30.92	I	I
	2.20	34.96	40.01	28.79	I	I
	5.00	31.36	33.73	24.72	I	I
3.72	.00	-----	-----	41.87	37.05	35.62
	2.00	-----	-----	42.22	34.07	34.58
	5.00	-----	-----	35.92	30.60	30.64

Table S.4.7 Reflection tables for sample No. AN2. Soft thermoplastic containing 30 % glass beads.

Reflexionstabeller för prov nr. AN2. Mjuk termoplastmassa innehållande 30 % glaspärlor.

dry condition

torr tillstånd

	ALFA	.57	.69	.76	.86	.92	1.15	1.37	1.72	1.91	2.29	2.86
EPSI	BETA'											
.37	.00	133.9	129.2	119.3	105.2	I	I	I	I	I	I	I
	1.00	92.65	94.55	94.04	93.30	I	I	I	I	I	I	I
.50	.00	-----	-----	138.1	113.2	115.4	95.35	I	I	I	I	I
	1.00	-----	-----	89.70	102.7	102.7	87.70	I	I	I	I	I
.74	.00	-----	-----	-----	-----	-----	120.4	99.34	75.29	I	I	I
	1.00	-----	-----	-----	-----	-----	102.7	92.40	76.40	I	I	I
	2.00	-----	-----	-----	-----	-----	95.90	83.95	66.56	I	I	I
1.24	.00	-----	-----	-----	-----	-----	-----	-----	-----	105.7	84.39	64.32
	1.00	-----	-----	-----	-----	-----	-----	-----	-----	95.53	78.93	65.59
	2.00	-----	-----	-----	-----	-----	-----	-----	-----	89.99	76.24	61.72
	3.50	-----	-----	-----	-----	-----	-----	-----	-----	80.59	66.53	56.61

	ALFA	3.81	4.57	5.71	6.84	8.53
EPSI	BETA'					
2.48	.00	95.79	75.20	56.57	I	I
	2.00	86.36	71.55	56.60	I	I
	5.00	70.81	59.22	47.77	I	I
3.72	.00	-----	-----	89.78	67.47	52.61
	2.00	-----	-----	87.50	69.91	55.42
	5.00	-----	-----	72.55	59.67	48.91

humid condition

fuktig tillstånd

	ALFA	.57	.69	.76	.86	.92	1.15	1.37	1.72	1.91	2.29	2.86
EPSI	BETA'											
.37	.00	82.30	66.90	62.97	57.35	I	I	I	I	I	I	I
	1.00	55.30	49.00	49.91	51.20	I	I	I	I	I	I	I
.50	.00	-----	-----	75.55	28.33	40.25	67.60	I	I	I	I	I
	1.00	-----	-----	44.65	25.97	35.70	60.90	I	I	I	I	I
.74	.00	-----	-----	-----	-----	-----	67.50	46.28	43.55	I	I	I
	1.00	-----	-----	-----	-----	-----	57.95	41.24	37.48	I	I	I
	2.00	-----	-----	-----	-----	-----	51.90	40.57	36.10	I	I	I
1.24	.00	-----	-----	-----	-----	-----	-----	-----	-----	57.58	52.24	39.15
	1.00	-----	-----	-----	-----	-----	-----	-----	-----	52.08	47.89	35.65
	2.00	-----	-----	-----	-----	-----	-----	-----	-----	52.88	36.20	40.51
	3.50	-----	-----	-----	-----	-----	-----	-----	-----	45.85	31.97	34.99

	ALFA	3.81	4.57	5.71	6.84	8.53
EPSI	BETA'					
2.48	.00	46.77	40.34	34.32	I	I
	2.00	42.82	40.31	32.51	I	I
	5.00	36.65	34.10	27.60	I	I
3.72	.00	-----	-----	50.29	41.26	36.80
	2.00	-----	-----	45.80	37.72	35.88
	5.00	-----	-----	40.46	34.70	32.06

Table S.4.8 Reflection tables for sample No. BN1. Soft thermoplastic containing 20 % glass beads.

Reflexionstabeller för prov nr. BN1. Mjuk termoplastmassa innehållande 20 % glaspärlor.

EPSI	BETA' \ ALFA	.57	.69	.76	.86	.92	1.15	1.37	1.72	1.91	2.29	2.86
.37	.00	-----	101.3	90.94	76.15	I	I	I	I	I	I	I
	1.00	62.45	67.35	67.19	66.95	I	I	I	I	I	I	I
.50	.00	-----	-----	123.9	86.78	91.90	67.60	I	I	I	I	I
	1.00	-----	-----	76.60	75.39	80.20	62.80	I	I	I	I	I
.74	.00	-----	-----	-----	-----	-----	103.6	84.01	63.66	I	I	I
	1.00	-----	-----	-----	-----	-----	91.20	76.33	61.02	I	I	I
	2.00	-----	-----	-----	-----	-----	86.25	70.28	57.30	I	I	I
1.24	.00	-----	-----	-----	-----	-----	-----	-----	-----	104.6	82.84	65.16
	1.00	-----	-----	-----	-----	-----	-----	-----	-----	101.0	80.28	62.58
	2.00	-----	-----	-----	-----	-----	-----	-----	-----	88.28	73.02	60.83
	3.50	-----	-----	-----	-----	-----	-----	-----	-----	77.82	64.78	53.56

dry condition

torr tillstånd

EPSI	BETA' \ ALFA	3.61	4.57	5.71	6.84	8.53
2.48	.00	99.82	80.51	60.84	I	I
	2.00	91.44	79.70	60.49	I	I
	5.00	74.65	65.64	52.48	I	I
3.72	.00	-----	-----	98.70	77.09	58.35
	2.00	-----	-----	95.59	80.06	57.73
	5.00	-----	-----	82.52	68.49	54.04

EPSI	BETA' \ ALFA	.57	.69	.76	.86	.92	1.15	1.37	1.72	1.91	2.29	2.86
.37	.00	41.80	46.15	42.71	37.80	I	I	I	I	I	I	I
	1.00	23.90	28.60	29.54	31.60	I	I	I	I	I	I	I
.50	.00	-----	-----	35.25	36.43	38.70	31.90	I	I	I	I	I
	1.00	-----	-----	24.95	28.38	30.30	28.05	I	I	I	I	I
.74	.00	-----	-----	-----	-----	-----	43.90	26.08	27.49	I	I	I
	1.00	-----	-----	-----	-----	-----	34.70	23.54	26.21	I	I	I
	2.00	-----	-----	-----	-----	-----	33.10	23.05	23.25	I	I	I
1.24	.00	-----	-----	-----	-----	-----	-----	-----	-----	38.31	25.94	22.89
	1.00	-----	-----	-----	-----	-----	-----	-----	-----	34.24	24.19	23.15
	2.70	-----	-----	-----	-----	-----	-----	-----	-----	29.14	27.41	19.97
	3.50	-----	-----	-----	-----	-----	-----	-----	-----	26.09	24.59	18.32

humid condition

fuktig tillstånd

EPSI	BETA' \ ALFA	3.81	4.57	5.71	6.84	8.53
2.48	.00	34.56	27.67	23.50	I	I
	2.00	30.18	26.03	22.33	I	I
	5.00	26.81	23.21	21.17	I	I
3.72	.00	-----	-----	32.11	31.04	24.51
	2.00	-----	-----	31.44	28.93	25.21
	5.00	-----	-----	29.65	26.29	25.69

Table S.4.9 Reflection tables for sample No. BN2. Soft thermoplastic containing 20 % glass beads.

Reflexionstabeller för prov nr. BN2. Mjuk termoplastmassa innehållande 20 % glaspärlor.

dry condition

torr tillstånd

	ALFA	.57	.69	.76	.86	.92	1.15	1.37	1.72	1.91	2.29	2.86
EPSI	BETA'											
.37	.00	53.00	57.45	59.34	62.05	I	I	I	I	I	I	I
	1.00	33.70	42.35	46.55	52.55	I	I	I	I	I	I	I
.50	.00	-----	-----	75.05	62.06	72.25	71.85	I	I	I	I	I
	1.00	-----	-----	48.90	54.17	62.85	67.65	I	I	I	I	I
.74	.00	-----	-----	-----	-----	-----	95.55	82.67	70.42	I	I	I
	1.00	-----	-----	-----	-----	-----	82.70	75.38	68.78	I	I	I
	2.00	-----	-----	-----	-----	-----	78.80	68.66	63.04	I	I	I
1.24	.00	-----	-----	-----	-----	-----	-----	-----	-----	96.45	81.34	64.43
	1.00	-----	-----	-----	-----	-----	-----	-----	-----	94.48	79.81	66.45
	2.00	-----	-----	-----	-----	-----	-----	-----	-----	83.92	73.47	63.07
	3.50	-----	-----	-----	-----	-----	-----	-----	-----	71.70	65.59	55.57

	ALFA	3.81	4.57	5.71	6.84	8.53
EPSI	BETA'					
2.48	.00	102.8	80.70	59.61	I	I
	2.00	96.61	77.99	60.83	I	I
	5.00	77.09	65.59	53.22	I	I
3.72	.00	-----	-----	96.22	73.98	56.67
	2.00	-----	-----	96.52	76.18	57.04
	5.00	-----	-----	77.06	65.86	53.57

humid condition

fuktig tillstånd

	ALFA	.57	.69	.76	.86	.92	1.15	1.37	1.72	1.91	2.29	2.86
EPSI	BETA'											
.37	.20	15.65	18.00	20.68	24.50	I	I	I	I	I	I	I
	1.20	12.55	11.60	15.51	21.10	I	I	I	I	I	I	I
.50	.20	-----	-----	25.40	24.13	24.85	21.70	I	I	I	I	I
	1.20	-----	-----	17.20	18.96	20.45	20.70	I	I	I	I	I
.74	.20	-----	-----	-----	-----	-----	26.50	28.86	25.57	I	I	I
	1.20	-----	-----	-----	-----	-----	23.85	26.27	23.95	I	I	I
	2.20	-----	-----	-----	-----	-----	24.95	24.09	21.83	I	I	I
1.24	.20	-----	-----	-----	-----	-----	-----	-----	-----	26.24	23.75	24.20
	1.20	-----	-----	-----	-----	-----	-----	-----	-----	26.46	25.13	26.14
	2.20	-----	-----	-----	-----	-----	-----	-----	-----	23.09	21.01	18.97
	3.50	-----	-----	-----	-----	-----	-----	-----	-----	22.73	22.39	20.65

	ALFA	3.61	4.57	5.71	6.84	8.53
EPSI	BETA'					
2.46	.20	37.84	30.50	23.85	I	I
	2.20	33.18	29.09	24.65	I	I
	5.20	29.03	24.41	20.27	I	I
3.72	.20	-----	-----	31.26	27.85	25.23
	2.20	-----	-----	30.61	29.08	27.19
	5.20	-----	-----	28.59	27.50	25.79

Table S.4.10 Reflection tables for sample No. CN1. Soft thermoplastic containing 20 % glass beads.

Reflexionstabeller för prov nr. CN1. Mjuk termoplastmassa innehållande 20 % glaspärlor.

EPSI	ALFA / BETA'	.57	.69	.76	.86	.92	1.15	1.37	1.72	1.91	2.29	2.86
.37	.20	147.0	140.6	131.2	117.7	I	I	I	I	I	I	I
	1.00	96.05	98.15	102.1	107.8	I	I	I	I	I	I	I
.50	.00	-----	-----	154.5	129.0	129.5	101.0	I	I	I	I	I
	1.00	-----	-----	105.9	114.8	114.7	93.80	I	I	I	I	I
.74	.00	-----	-----	-----	-----	-----	130.4	109.9	86.68	I	I	I
	1.20	-----	-----	-----	-----	-----	114.7	106.0	81.30	I	I	I
	2.00	-----	-----	-----	-----	-----	107.1	93.89	75.90	I	I	I
1.24	.00	-----	-----	-----	-----	-----	-----	-----	-----	119.2	93.10	72.05
	1.00	-----	-----	-----	-----	-----	-----	-----	-----	112.8	93.22	73.67
	2.00	-----	-----	-----	-----	-----	-----	-----	-----	100.8	84.89	71.20
	3.50	-----	-----	-----	-----	-----	-----	-----	-----	86.82	73.88	62.78

dry
condition

torr
tillstånd

EPSI	ALFA / BETA'	3.81	4.57	5.71	6.84	8.53
2.48	.00	125.4	82.83	62.04	I	I
	2.00	98.11	82.16	63.53	I	I
	5.00	81.85	67.25	57.63	I	I
3.72	.00	-----	-----	101.7	77.85	58.06
	2.00	-----	-----	101.7	80.59	58.58
	5.00	-----	-----	82.23	72.41	56.12

EPSI	ALFA / BETA'	.57	.69	.76	.86	.92	1.15	1.37	1.72	1.91	2.29	2.86
.37	.20	64.[illegible]5	64.60	59.64	52.55	I	I	I	I	I	I	I
	1.00	43.65	46.15	43.54	39.80	I	I	I	I	I	I	I
.50	.00	-----	-----	56.60	67.14	61.45	48.45	I	I	I	I	I
	1.00	-----	-----	34.00	48.11	45.40	37.30	I	I	I	I	I
.74	.00	-----	-----	-----	-----	-----	48.45	44.47	32.50	I	I	I
	1.00	-----	-----	-----	-----	-----	39.20	41.54	29.99	I	I	I
	2.00	-----	-----	-----	-----	-----	40.10	39.27	29.17	I	I	I
1.24	.00	-----	-----	-----	-----	-----	-----	-----	-----	35.52	30.63	27.36
	1.00	-----	-----	-----	-----	-----	-----	-----	-----	33.24	30.11	27.64
	2.20	-----	-----	-----	-----	-----	-----	-----	-----	40.93	28.11	25.60
	3.50	-----	-----	-----	-----	-----	-----	-----	-----	33.52	25.54	24.28

humid
condition

fuktig
tillstånd

EPSI	ALFA / BETA'	3.91	4.57	5.71	6.64	8.53
2.48	.00	38.84	33.09	23.70	I	I
	2.20	33.02	29.33	23.53	I	I
	5.20	32.70	28.60	22.73	I	I
3.72	.20	-----	-----	40.43	32.90	27.67
	2.20	-----	-----	34.96	29.91	26.98
	5.00	-----	-----	35.21	30.20	27.39

Table S.4.11 Reflection tables for sample No. CN2. Soft thermoplastic containing 20 % glass beads.

Reflexionstabeller för prov nr. CN2. Mjuk termoplastmassa innehållande 20 % glaspärlor.

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