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REFLECTION PROPERTIES
OF ROAD SURFACES
IN HEADLIGHT ILLUMINATION

Dependence on measuring geometry

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PREFACE

The investigation is a part of the research plan out-
lined in Mörkertrafik 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 surfaces. The measuring geometries
are representative of the situation of illumination
by the drivers own headlights.

Although the findings represented here are well suited
for application purposes, a general instruction for
this, including a standard measuring geometry for
portable instruments, must wait for the completion of
a similar investigation on road markings.

The investigation is carried out by the National
Swedish Road and Traffic Research Institute (VTI) and
the Danish Illuminating Engineering Laboratory (LTL)
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 (VO-N) - Norway

- The Norwegian Research Institute for Electricity
  Supply (EFI) - Norway

- The National Swedish Road and Traffic Research
  Institute (VTI) - Sweden

- The National Swedish Road Administration (VV)
  - Sweden

The activities are co-ordinated by a group (co-ordination group), presently composed by:

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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 co-ordination group has studied and approved the contents of the report.

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ABSTRACT

Title: Reflection properties of road surfaces in head-
       light illumination - dependence on measuring
       geometry

Publisher: Nordic Research Co-operation for Night
           Traffic. Report No. 4, 1982. (The report
           can be obtained from the National Swedish
           Road and Traffic Research Institute,
           S-581 01 LINKÖPING, Sweden).

This investigation concerns the dependence of the
geometry on the specific luminance of road surfaces
in headlight illumination. The geometries considered
are representative for the illumination of the road
surface by the drivers own headlights.

The investigation comprises 10 road samples, each
measured in 51 geometries both in dry and a humid
condition. For the measurements is used an existing
laboratory equipment, which has been modified and
supplied with a semi-automatic data-registration.

The analysis of the data is based on model considera-
tions of the reflection, leading to expressions for
the influence of the geometry. The expressions are
essentially confirmed by the analysis.

It is suggested, that for application purposes a
standard measuring geometry is selected, as the speci-
fic luminance for other geometries can be estimated
by the expressions.

A standard measuring geometry will be proposed later,
when a similar investigation on road markings is
completed.

RESUMÉ

Titel: Reflexionsegenskaper hos vägbeläggningar i
       strålkastarbelysning - mätgeometrins inverkan.

Utgivare: Nordiskt forskningssamarbete rörande syn-
          betingelser i mörkertrafik. Rapport nr. 4,
          1982. (Rapporten kan beställas hos Statens
          väg- och trafikinstitut, S-581 01 LINKÖPING,
          Sverige.)

Denna undersökning avser de geometriska förhållande-
nas inverkan på den specifika luminansen hos väg-
beläggningar i strålkastarbelysning. De geometriska
förhållandena svarar mot den situation där vägbelägg-
ningen belyses av bilistens egna lyktor.

Undersökningen omfattar 10 vägprover, som alla har
mätts i 51 geometrier, både i torrt och i ett fuk-
tigt tillstånd. Till mätningarna har använts en
befintlig laboratorieutrustning, som modifierats och
försetts med en halvautomatisk dataregistrering.

Analysen av mätresultaten baseras på modellbetrak-
telser av reflexionen, vilka lett till formeluttryck
för geometrins inverkan. Dessa formeluttrycks giltig-
het bekräftas i det väsentligaste av analysen.

Det föreslås att man väljer ut en standardiserad
mätgeometri för tillämpning, då den specifika lumi-
nansen för andra geometrier kan uppskattas då man
använder formeluttrycken.

En standardiserad mätgeometri kommer senare att före-
slås när en liknande undersökning rörande vägmarke-
ringar är färdig.

TIIVISTELMÄ

Otsikko: Valonheittimellä valaistun tienpäällysteen
heijastusominaisuudet - mittausgeometrian vaikutukset.

Julkaisija: Pohjoismainen pimeän liikenteen
näköedellytyksiä tutkiva yhteistyöryhmä. Raportti no.
4, 1982. (Raporttia voi tilata osoitteella Statens
väg- och trafikinstitut, S-581 01 LINKÖPING, Sverige)

Tässä tutkimuksessa selviteään geometristen olo-
su-teitten vaikutusta tienpäällysteen ominaisvaloi-
suuteen (eli spesifiseen luninanssiin), kun päälystettä
valaistaan valonheittimellä. Geometriset olosuhteet
vastaavat tilannetta, jossa kuljettaja tarkastelee
oman autonsa ajovalojen valaisemaa tietä.

Tutkimus käsittää 10 tienäytettä, joilla kullakin on
suoritettu yhteensä 51 mittausta geometriaa vaihdellen
sekä kuivan tien että märän tien olosuhteissa.
Mittauksiin käytettiin saatavissa ollutta laboratorio-
kalustoa, jota muunneltiin ja varustettiin puoli-
automaattisella tulostenrekisteröinnillä.

Mittaustulosten analyysi perustuu heijastumista
koskevien mallien tarkasteluun. Niiden perusteella
geometrian vaikutukset estitetään yhtälämuodossa.
Näiden yhtälöiden soveltuvuus on analyyseissä
varmistettu.

Tutkimuksen perusteella ehdotetaan sovellettavaksi
käytätöön standardisoitua mittausgeometriaa. Tällöin
kyetään muiden geometrioiden ominaisvaloisuudet
arvioimaan yhtälöiden avulla.

Ehdotus tällaiseksi standardigeometriaksi tullaan
tekemään myöhemmin, sen jälkeen kun vastaava
ajoratamerkintöjä koskeva tutkimus on valmis.

1. INTRODUCTION

By Sven-Olof Lundkvist, VTI

This investigation concerns the dependence of the geometry on the specific luminance of road surfaces in headlight illumination. The geometries considered are reperesentative for the illumination of the road surface by the drivers own headlights.

Reflection properties of a road suface are very important in night time traffic. So far, most studies concerning reflection properties, have dealt with roads with stationary lighting. However, these properties of the road surface are as important on unlit roads as on roads with public lighting. The driver has to detect an obstacle on or very close to the roadway, at safe distances, i.e. mostly the luminance pattern of the background shall be as uncomplicated as possible. Further, obstacles must have a high contrast against the background. On unlit roads it is also important that the road surface with its road markings give the driver an acceptable visual guidance.

Our knowledge of the reflection properties of an unlit road surface - dry or humid - and how these properties influence the task of the driver is today too small; the essential is rendered in Mörkertrafik report No. 3, chapter 3.2 (Sørensen, 1980) and concerning detection of obstacles on unlit roads in VTI report No. 202 (Helmers & Ytterbom, 1980).

Today a good method of measurement is missing for specular reflection as well as for retroreflection. The purpose of this work is to investigate empirically if earlier theories on retroreflection of road pave-

ments are according to reality. These theories deal
with the specific luminance dependence of the measur-
ing geometry and of the texture of the road surface.
They are valid for one light-source only, but as addi-
tivity applies, they are useful also in the situation
of a car driver. From the theories a mathematical
model for non-retroreflective surfaces can be built up.

Physical measurements under different geometrical con-
ditions have therefore been carried out. Considera-
tion has been taken not only to observation- and illu-
mination angles, but also the angle between the direc-
tion of observation and the direction of illumination
in a horizontal plane, called the azimuthal angle.

In the study ten different road pavements were inves-
tigated. The specific luminance was measured in dry
and humid, but not wet conditions.

Briefly, this report contains, in chapter 2, a
description of the road samples, followed by defini-
tions in chapter 3. In chapter 4 the equipment, which
was used, is described. Measuring procedures and results
will be found in chapter 5, followed by a description
of how to apply the results onto measurement methods
for the specific luminance.

Appendix A includes reflection tables for all ten
pavements under the two conditions. The theories
and mathematical models are described in Appedix B.

Reflection properties of retroreflective surfaces at
similar geometrical conditions will be presented in a
later report.

2. CHOICE OF ROAD SURFACE SAMPLES

The samples included in the investigation are 4
samples from Danish roads and 6 samples from Swedish
roads. Those samples have been selected from the
collection of road surface samples at LTL, on which
the r-tables of LTL-report No. 10 were measured. The
dimensions of the samples are 20 cm times 40 cm. Before
the measurement they have been inspected to see if
they were perfectly plane. If not plane, the top
layer has been separated, planed out and re-based on
3 mm thick steelplates. The ten samples are described
shortly in table 2.1 and presented on photos in
figure 2.1.

Table 2.1   Short description of the samples

LTL No.	Type of light coloured stones	Size of aggregate, type	Country
63	35 % Calcined flint	0/3 mm, Thin aspalt carpet	DK
601	20 % Calcined flint	0/12 mm Asphalt concrete	DK
609	20 % Calcined flint	0/18 mm, Asphalt concrete	DK
460	13 % Synopal (4/8 mm) 13 % Calc. flint (5/8 mm)	0/8 mm, Asphalt concrete	S
617	Light granite	12/16 mm, Surface treatment	DK
87	Quartzite	0/16 mm, Asphalt concrete	S
90	Diabase (0/12 mm) Gneiss (0/12 mm)	0/12 mm, Asphalt concrete	S
176	Swedish granite	0/8 mm, Asphalt concrete	S
177	Swedish granite	0/12 mm, Asphalt concrete	S
182	Precoated chippings of Sw. granite	Topeka ashpalt concrete (ABS II)	S

Tabell 2.1 Kort beskrivning av samplerna

LTL Nr	Typ av ljust stenmaterial	Stenstorlek, typ	Land
63	35 % calc. flintsten	0/3 mm, pulverasfalt	DK
601	20 % calc. flintsten	0/12 mm, asfaltbetong	DK
609	20 % calc. flintsten	0/18 mm, asfaltbetong	DK
460	13 % synopal (4/8 mm) 13 % calc. flintsten(5/8 mm)	0/8 mm, asfaltbetong	S
617	ljus granit	12/16 mm, ytbehandling	DK
87	kvartsit	0/16 mm, asfaltbetong	S
90	diabas (0/12 mm) gnejs (0/12 mm)	0/12 mm, asfaltbetong	S
176	svensk granit	0/8 mm, asfaltbetong	S
177	svensk granit	0/12 mm, asfaltbetong	S
182	skärvor av svensk granit °	Topeka (ABS II)	S

To the samples the following comments apply.

Samples 63, 601 and 609 are Danish road surfaces with light coloured stones of varying size. Sample 63 is special in the meaning that the stones are not protruding above the surface of the sample.

In sample 460 there are two types of stone materials. Those stones are protruding above the surface of the sample, which makes it rough.

Sample 617 is a surface treatment with rather large chippings of a light coloured type of granite.

Of all the Swedish samples all except No. 90 are common on public roads. Sample 90 is rather rare although there are no light stones in it; it contains almost black gneiss and diabas which is speckled but rather dark. Sample 87 is taken from a 9 year old surface and therefore more worn than the others. Samples 176 and 177 are very common on Swedish roads and contain

Swedish granite.

Sample 182, ABS, is mainly used on roads with heavy traffic. ABS is more durable than an ordinary asphalt concrete. All white precoated stones are here concentrated at the surface of the pavement. In this particular sample there is a relative small amount of those stones, so that the black matrix dominates the visual perception at large angles of observation.

63, SL = 19.1

601, SL = 18.4

609, SL = 19.2

460, SL = 29.3

617, SL = 14.9

87, SL = 19.0

90, SL = 11.0

176, SL = 14.7

177, SL = 15.0

182, SL = 16.4

Figure 2.1   The appearance of the samples. Below each
              sample is the LTL no. (see table 2.1) and
              the SL-value in the geometry of
              $\alpha=1,37^{O}$, $\varepsilon=0,74^{O}$, $\beta=180^{O}$ and dry condition
              $((mcd/m^2)/lux)$

Figur 2.1   Vägytornas utseende. Under varje sample har
              angivits dess LTL-nr (se tabell 2.1) och
              SL-värde i geometrin
              $\alpha=1,37^{O}$, $\varepsilon=0,74^{O}$, $\beta=180^{O}$ vid torr vägbana
              $((mdc/m^2)/lux)$

3. DEFINITIONS AND NOTATIONS

The relative amount of light of a road surface
reflected back to the eyes of the driver in vehicle
headlight illumination on unlit roads can be described
by the specific luminance (SL) of the road surface.
The concept of specific luminance is defined as
follows

$$SL = \frac{L}{E} \; (cd/m^2)/lux \qquad (1)$$

where L is the luminance (cd/m^2) of the road surface
at the point P, and E is the illuminance (lux) on a
fictive plane situated at the point P and orientated
perpendicular to the direction of illumination.

The specific luminance of a surface is dependent on
the geometry of measurement, defined by the angles ε,
α and β in figure 3.1 below.

Figure 3.1   Definition of parameters determining
the geometry of observation and illumina-
tion

Definition av parametrar som bestämmer
observations- och belysningsgeometrin.

Denotations in figure 3.1:

ε = illumination angle

α = observation angle

β = azimuthal angle

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

H_o = observation height

H_h = illumination height

D_o = distance of observation

D_h = distance of light source

D_T = transverse displacement of headlight

P = point of measurement

Beteckningar i figur 3.1:

ε = belysningsvinkel

α = observationsvinkel

β = azimuthalvinkel

β' = azimuthalvinkelns supplementvinkel (=$180^{\circ}-\beta$)

H_o = observationshöjd

H_h = belysningshöjd

D_o = observationsavstånd

D_h = belysningsavstånd

D_T = sidoförskjutning mellan observatör och ljuskälla

P = mätpunkt

In this study the angle of observation has been varied within the range of 0.57° to 8.53°, the angle of illumination between 0.37° and 3.72° and the azimuthal angle between 180° and 185°. The combinations of those angles have been chosen so that they simulate realistic distances of observation and illumination and an adequate displacement between observer and light source.

This means that the azimuthal angle adopted values near 180°. The specific luminance is then often called retroreflection. This concept, however, indicates that the luminance is due to retroreflective

elements of a surface, which is not the case here. Therefore, the more general concept of specific luminance (SL) is used in this report. However, one has to emphasize that this is no internationally accepted concept.

4. MEASURING EQUIPMENT

The measurements of specific luminance have been carried out with a Pritchard Photometer Model 1980. The light source was a projector with a halogen bulb.

To adjust the measuring geometry properly, the photometer and projector were mounted in a special type of goniometer, which has a quality of beeing able to vary the illumination and observation angles continuously. The azimuthal angle on the other hand could vary in 5 discrete values. This was made possible with a special arrangement of mirrors. The goniometer is presented in figure 4.1. The projector was equipped with a slide giving a rectangular illuminated field at the sample. Further it had an iris diaphragm giving an aperture of about 8'. The photometer was also equipped with an iris diaphragm giving it an aperture of about 10'. The shape of the measuring field was rectangular with the size 3.3' x 21'.

The sample was placed on a special sample holder which could be displaced horizontally (figure 4.2). This made it possible to measure as many values as were needed to get an adequate mean value of the SL of each sample. The sample holder was also adjustable in order to get the sample absolutely horizontally located.

All samples were measured in dry and a humid condition. Before the measurement for the dry contion the sample was properly cleaned. The humid condition was created by the following procedure: First the sample was wet with ordinary water containing detergent (to reduce surface tension). After that it was wiped off twice with a sponge. In that way a humid condition which was stable for about 15 minutes was attained.

All data were stored on paper-tape for later computer
analysis.

Figure 4.1   Goniometer equipment. To the left is seen
             the photometres (1) and the light-source
             (2). Simulated distances can be varied by
             moving the arms (3) and (4) up and down
             independently, and the transverse dist-
             ance by a turning of the mirror (5). To
             the right is shown the sample holder,
             which is adjustable in all directions.

             Goniometerutrustning. Till vänster ses
             luminansmätaren (1) och ljuskällan (2).
             Simulerade avstånd kan varieras genom
             att föra armarna (3) och (4) upp och ned
             oberoende av varandra samt sidoförskjut-
             ningen genom att vrida spegeln (5). Till
             höger ses sample-bordet, som är juster-
             bart i alla riktningar.

Figure 4.2   The adjustable sample holder

Det justerbara sample-bordet

5.   MEASUREMENTS
          By Peder Øbro and Kai Sørensen, LTL

5.1   Measuring geometries - reflection table
          The measuring geometries are defined by a number of
          combinations of the illumination angle, ε, the ob-
          servation angle, α and the azimuthal angle, β. See
          fig. 3.1.

          The combinations of the angles ε and α were chosen
          to simulate the geometries shown in fig. 5.1. These
          angles are shown in table 5.1 also. It is remarked
          that whenever the letter D is used, this implies
          that the distances of illumination and observation
          are assumed to be equal, i.e.: $D = D_h = D_o$.

          The azimuthal angle, β should preferably be chosen
          also on the basis of simulated geometries of the
          vehicle. A convenient measure is the distance of the
          headlight from the vertical plane containing the di-
          rection of observation. This distance is in the fol-
          lowing called the transverse distance of the head-
          light, D_t and is defined as shown in fig. 5.2. In
          fig. 5.2 is introduced also the angle, β', which is
          supplemental to the azimuthal angle, β $(\beta' = 180^o - \beta)$.

          When considering transverse distances, D_t between
          0 m and 1.5 m, this undoubtedly covering the geo-
          metry of most vehicles, the angle β' should vary
          according to the distance, D as shown in table
          5.2.

          However, table 5.2 contains 14 different values of
          the angle β', while the mirror arrangement for the
          setting of this angle allows the use of only 5 mir-
          rors at a time, see fig. 4.1. It is possible to set
          all of the angles of table 5.2 by means of the mir-
          ror arrangement, but only in a tedious procedure in-
          volving adjustments of the mirrors.

H_O = 1.5 M

1.2 M

1.0 M

H_H = 0.65 M

D = 10 M, 15 M, 30 M, 50 M, 75 M, AND 100 M

Figure 5.1 Combinations of distance on the road, D headlight mounting height, H_h and observer eye height, H_o simulated in the measurements.

Kombinationer af afstanden på kørebanen, D, forlygtens monteringshøjde, H_h og observatørens øjenhøjde, H_o, som simuleres under målingerne.

Table 5.1 Variation of the illumination angle, ε and the observation angle, α with the distance on the road, D. The headlight mounting height, H_h is assumed to be 0.65 m, while the observer eye height, H_o is either 1 m, 1.2 m or 1.5 m.

Variation af belysningsvinklen, ε og observationsvinklen, α med afstanden målt på kørebanen. Forlygtens monteringshøjde antages at være 0,65 m, mens observatørens øjenhøjde er enten 1 m, 1,2 m eller 1,5 m.

	Distance, D					
	10 m	15 m	30 m	50 m	75 m	100 m
Illumination angle, ε	3.72°	2.48°	1.24°	0.74°	0.50°	0.37°
Observation angle, α at observer eye height, H_o of:						
1 m	5.71°	3.81°	1.91°	1.15°	0.76°	0.57°
1.2 m	6.84°	4.57°	2.29°	1.37°	0.92°	0.69°
1.5 m	8.53°	5.71°	2.86°	1.72°	1.15°	0.86°

<u>Figure 5.2</u> The geometry of illumination and observation as projected onto the road surface. The transverse distance of the headlight, D_t is the distance of the headlight from the vertical plane containing the direction of observation.
The angle, β' is defined as the supplemental to the azimuthal angle, β.
$(\beta'=180^\circ-\beta)$.

$$D_t = D_h \cdot \sin\beta' \cong D_h \cdot \beta' \quad (\beta' \text{ in radians})$$

$$\beta' = \sin^{-1}\left(\frac{D_t}{D_h}\right) \cong D_t/D_h \quad \text{(radians)}$$

Belysnings- og observationsgeometri vist projiceret på vejens plan.
Forlygtens sideforskydning, D_t er forlygtens afstand fra det lodrette plan, som indeholder observationsretningen.
Vinklen, β' er supplementvinkel til azimutvinklen β. $(\beta'= 180^\circ-\beta)$.

$$D_t = D_h \cdot \sin\beta' \cong D_h \cdot \beta' \quad (\beta' \text{ i radianer})$$

$$\beta' = \text{Arcsin}\left(\frac{D_t}{D_h}\right) \cong D_t/D_h \quad \text{(radianer)}$$

It was decided, therefore, to use a procedure in which SL-values for the β' indicated in table 5.2 should be obtained by interpolations in a set of measurements that include only 5 different β'.

This set of values of β' were chosen to 0°, 1^O, 2^O, 3.5^O and 5°. At each simulated distance (at each ε) a subset of two to four of these β' values were further chosen on the basis of two considerations. Firstly, the subset should approximately cover the range of β' given in table 5.2 and, secondly, for reasons of measuring economy each subset should be as small as possible.

Table 5.2 Variation of the angle β' supplemental to the azimuthal angle with the transverse distance of the headlight, D_t and the distance of the road, D.

Variation af supplementvinklen, β' til azimut vinklen med forlygtens sideforskydning, D_t og afstanden målt på kørebanen, D.

| | Distance, D at H_h = 0.65 m | | | | | |
	10 m	15 m	30 m	50 m	75 m	100 m
Illumination angle, ε	3.72^O	2.48^O	1.24^O	0.74^O	0.50^O	0.37^O
Supplemental, β' to the azimuthal angle at transverse distance of headlight, D_t:						
0 m	0°	0°	0°	0°	0°	0°
0.5 m	2.87^O	1.91^O	0.95^O	0.57^O	0.38^O	0.27^O
1 m	5.74^O	3.82^O	1.91^O	1.15^O	0.76^O	0.57^O
1.5 m	8.63^O	5.74^O	2.87^O	1.72^O	1.15^O	0.85^O

The choice of subsets of values of β' is shown in table 5.3. It is seen that a reproduction of the β' angles of table 5.2 can in most cases be based on interpolation, but that extrapolation is required for some geometries.

The total set of measuring geometries is obtained by taking all possible combinations of the geometries of table 5.1 and 5.3. This total set is illustrated in

table 5.4, which also shows the format of a reflection
table with 51 positions.

It appears from a comparison of table 5.1 to table 5.4
that the combination ($\alpha = 0.86°$, $\varepsilon = 0.37°$) has been
replaced by ($\alpha = 0.76°$, $\varepsilon = 0.37°$). This was done in
order to simplify the measuring procedure, and has
the consequence that the SL for (D = 100 m; H_o =
1.5 m) has to be based on an extrapolation. In recent
measurements on road markings this geometry has been
included directly in the measuring programme.

Table 5.3   Set of 5 supplemental azimuthal angles, β'
and choice of subsets for different il-
lumination angles, ε.

Sæt af 5 supplementvinkler, β' til azi-
mut vinklen, samt valg af undersæt for
forskellige belysningsvinkler, ε.

| | Distance, D at H_n = 0.65 m | | | | | |
	10 m	15 m	30 m	50 m	75 m	100 m
Illumination angle, ε	3.72°	2.48°	1.24°	0.74°	0.50°	0.37°
Set of supplemental azimuthal angles, β' 0°	x	x	x	x	x	x
1°			x	x	x	x
2°	x	x	x	x		
3.5°			x			
5°	x	x				

The format of the reflection table thus covers those
geometrical situations that appear from fig. 5.1,
with the further addition that D_t can be up to appr.
1.5 m. As the angles are the fundamental parameters,
the table does cover also all geometries, whose
relative proportions are within the ranges of the

above-mentioned situations. These ranges of relative
proportions are:

$$1.54 \ H_h \leq H_o \leq 2.31 \ H_h$$

$$|D_t| \leq 2.31 \ H_h$$

$$15.4 \ H_h \leq D_o \ \text{and} \ D_h \leq 154 \ H_h$$

Therefore, the format of the reflection tables does
in fact cover a wide range of geometries.

5.2   Measuring procedures and data handling
Each of the ten samples are successively placed in the
measuring equipment, accurately aligned and then ex-
posed to the full measuring program, first for the
dry and then for the humid condition.

In the measuring program the angles were set in a suc-
cession starting in the upper left corner and going
down to the right lower corner of the reflection table
of table 5.4. This succession was chosen so that the
values of ε and α were set only once, while the easier
setting of the values of β' was carried out repeatedly.

At each combination of angles 18 readings were taken
for reasons explained below.

The measuring field of 3.3' x 21' results at the actual
measuring distance of 3.6 m in a measuring field, whose
width is 2.2 cm. The length varies between 35 cm at the
smallest α of 0.57^o to 2.3 cm at the largest α of 8.53^o.

At the largest α of 8.53^o the measuring field is, there-
fore, only 2.2 x 2.3 cm^2 = 5.1 cm^2. As a total measuring
field of appr. 100 cm^2 is desirable, the sledge of the
sample holder was used to move the sample in 9 steps in
the longitudinal direction and 2 steps in the transverse
direction. In this way the number of 18 readings results
in a total measuring field of appr. 5 x 20 cm^2 = 100 cm^2.

ε	β' \ α	0.57°	0.69°	0.76°	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 5.4 Format of reflection table containing 51 positions.

Format af refleksionstabel, som indeholder 51 værdier.

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In order to handle this large number of readings safely and within a reasonable time, the sledge was equipped with a trigger mechanism, so that the movement of the sledge (by hand) triggers the reading and the punching of the data on papertape.

For practical reasons this measuring procedure was used for all of the different values of α. The full measuring program, therefore, results in a papertape with 18 times 51 values to be sorted out in a subsequent computer run.

In this handling of the data, each SL was computed as a weighted average of the 18 readings. For geometries of the largest α of 8.53°, the individual measuring fields do not overlap and all readings are given identical weights in the calculation of the average.

For decreasing α the individual measuring fields will overlap to an increasing extent, and, therefore, the weights will have to be graduated in order to give all parts of the total measuring field an equal contribution to the average SL.

Further, at small α some of the readings will correspond to individual measuring fields, that cannot be safely contained within the surface of the sample. These readings have to be disregarded, i.e.: their weights are set to zero.

The weights were computed and fed into a computer program SLMAL, which reads the tapes, computes the SL-values of the reflection table, checks the consistency of the readings and prints the reflection table and information regarding the result of the checking.

The total amount of measuring data consists of two reflection tables, one for the dry and one for the

humid condition for each of the ten road samples
described in chapter 2. An example of a reflection
table is shown in table 5.5.

These tables were stored in a permanent file and
further computer programs were successively designed
to allow the analyses described in the following sec-
tions. The tables are shown in Appendix A.

Table 5.5   An example of a computer-printed re-
flection table (sample No. 601 in dry
condition.

Et eksempel på en EDB-udskrevet reflek-
sionstabel (prøve nr. 601 i tør tilstand).

```
LYSTEKNISK LABORATORIUM      PROG. SLMAL 1981M323

PRØVE NR: 601 TOER
**********************
SPECIFIK LUMINANS (RETROREFLEKSION)
*************************************
SL(EPSILON,ALFA,BETA')  [MCD/KVM/LUX]   (BETA' = 180-BETA)


       ALFA    .57   .69   .76   .92  1.15  1.37  1.72  1.91  2.29  2.86
EPSI BETA'
 .37    .00   10.25 20.20 18.00   I     I     I     I     I     I     I
       1.00    8.20 13.85 15.35   I     I     I     I     I     I     I

 .50    .00   ----- ----- 21.00 18.80 14.00   I     I     I     I     I
       1.00   ----- ----- 13.65 15.25 13.55   I     I     I     I     I

 .74    .00   ----- ----- ----- ----- 23.85 18.35 15.94   I     I     I
       1.00   ----- ----- ----- ----- 17.65 16.90 14.69   I     I     I
       2.00   ----- ----- ----- ----- 20.30 16.18 14.48   I     I     I

1.24    .00   ----- ----- ----- ----- ----- ----- ----- 23.92 18.81 15.99
       1.00   ----- ----- ----- ----- ----- ----- ----- 22.04 18.46 15.59
       2.00   ----- ----- ----- ----- ----- ----- ----- 22.24 19.87 14.92
       3.50   ----- ----- ----- ----- ----- ----- ----- 20.92 18.19 15.13


       ALFA   3.81  4.57  5.71  6.84  8.53
EPSI BETA'
2.48    .00   22.43 19.41 15.54   I     I
       2.00   22.78 18.97 15.63   I     I
       5.00   19.50 18.30 14.88   I     I

3.72    .00   ----- ----- 20.12 18.18 15.19
       2.00   ----- ----- 21.54 17.65 15.11
       5.00   ----- ----- 18.49 16.28 15.99
```

5.3   General remarks to the measurements

It was attempted to use a straightforward presenta-
tion of the data as exemplified by the diagram of
fig. 5.3. In this diagram the SL is given as a func-
tion of the simulated distance, D by means of curves
for all six combinations of the three values of H_o
and two values of D_t.

It is seen, however, that a diagram of this type
does not clearly show the influence of the para-
meters. For this reason the influence of the para-
meters is illustrated in the next sections by means
of various types of diagrams.

Fig. 5.3 does illustrate, however, that the
measured SL-values for H_o = 1 m at D = 100 m (α =
0.57^o) are too uncertain to be useful.

In this geometry the measuring field is almost as
long as the sample, when the surface is plane. Due
to the surface texture of the sample the measuring
field is often, in fact, elongated to the extent
that it cannot be contained on the sample. The   ef-
fect of this will depend on where precisely the cen-
ter of the measuring field is placed on the sample,
but the net result can be considered to be the above-
mentioned uncertainty.

For these reasons the SL-values for H_o = 1 m at D =
100 m are excluded from the diagrams of the fol-
lowing sections.

The SL-values for H_o = 1.5 m at D = 100 m must, as
stated in section 5.1 be obtained by extrapolation,
using values for α = 0.69^o and 0.76^o to obtain a
value at α = 0.86^o. This procedure results in a
value, whose uncertainty is almost 3 times the un-
certainty of the measured values. This increase in
uncertainty was found to impair the usefulness of

Figure 5.3 Example of diagram (for sample No. 601),
giving SL as a function of the simulated
distance, D by means of curves for dif-
ferent combinations of H_o and D_t.
The measuring uncertainty for H_o = 1 m
at D = 100 m (points marked by *) is
large, while for H_o = 1.5 m at D = 100 m
(points marked by **) the extrapolation
in α causes a large uncertainty.

Eksempel på diagram (for vejprøve nr. 601),
som viser SL som en funktion af den simu-
lerede afstand, D med kurver for forskel-
lige kombinationer af H_o og D_t.
Måleusikkerheden er stor for H_o = 1 m ved
D = 100 m (punkterne er markeret med *),
mens den til grund liggende ekstrapola-
tion i α bevirker en stor usikkerhed for
H_o = 1.5 m ved D = 100 m (punkterne er
markeret ved **).

the data for H_o = 1.5 m at D = 100 m, and, therefore,
these data are also excluded from diagrams using D
as the abscissa. In other types of diagrams the SL-
values for (ε = 0.50^o, α = 0.76^o) are used, as they
are in themselves correct.

In conclusion, for D = 100 m SL-values for H_o = 1 m
and 1.5 m are excluded, leaving only SL-values for
H_o = 1.2 m at this distance. SL-values correspond-
ing to H_o = 1 m at D = 100 m (ε = 0.37^o, α = 0.57^o)
are excluded from all diagrams, while the SL-values
for (ε = 0.57^o, α = 0.76^o) are used whenever pos-
sible.

5.4   Dry condition - influence of geometry
5.4.1   Influence_of_observer_eye_height
According to the model considerations of Appendix B,
the influence of the observer eye height should,
when D_t = 0, mainly be accounted for by the factor of
geometry, $f_{geometry}$, which is given by:

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

Therefore, SL values for H_o = 1 m and 1.5 m should
be respectively 20 % higher and 20 % lower than SL
values for H_o = 1.2 m. This is tested in fig. 5.4,
in which 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) are given as
functions of D for all measurements, where D_t = 0.

Fig. 5.4 shows that the measurements of course de-
viate from the model considerations because of
measuring uncertainties.

Apart from measuring uncertainties the ratios also
seem to differ on the average somewhat less than
20 % from unity. This can be taken to indicate that
$f_{texture}$ of section B.5 is not completely indepen-
dent of the observation angle, but does increase

Figure 5.4 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 $D_t = 0$ and dry samples.

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 $D_t = 0$ og tør tilstand af vejprøverne.

slowly with this angle. In the words of Appendix B,
facets of a small inclination give a small, but
measurable contribution to SL.

It is to be concluded, however, that $f_{geometry}$ ac-
counts for the major part of the influence of the ob-
server eye height (of α).

5.4.2   Influence of distance

When D_t = 0, the influence of the observer eye height
is accounted for by the factor $f_{geometry}$ as stated in
the previous section. The remaining parameter, whose in-
fluence is to be investigated, is then the simulated
distance on the road. It is sufficient to consider the
influence of the distance for only one observer eye
height.

Fig. 5.5 shows SL as a function of the distance for
H_o = 1.2 m and for all samples in the dry condition.

It is seen that for sample No. 460 SL increases with
the distance, until D = 50 m where the SL-value remains
appr. constant. This variation is explained by a varia-
tion in the average luminance coefficient, $\bar{q}$, which is
introduced in section B.3 of Appendix B.

This sample (No. 460) is a special asphalt concrete
containing small (less than 2 mm), dark aggregates in
a mixture with larger (4 to 8 mm) light coloured aggre-
gates (Synopal and calcined flint in equal proportions).
The surface, therefore, appears with white stones pro-
truding somewhat from the dark matrix.

At short distances a part of the incident luminous flux
falls on the dark matrix, and hence $\bar{q}$ has a relatively
small value. With increasing distance larger propor-
tions of the luminous flux fall on the white stones,
and from appr. 50 m and upwards all of the luminous
flux falls on the white stones in the surface. Hence $\bar{q}$

Figure 5.5 Ratios SL/SL(D = 50 m) for D_t = 0 and
dry samples. For most of the samples the
SL is roughly independent of the distance.
For the samples indicated variations are
caused by variations in $\bar{q}$ (No.s 460 and 63)
or in $f_{texture}$ (No. 617).

Forholdene SL/SL(D = 50) for D_t = 0 og tør
tilstand af vejprøverne. For de fleste af
prøvernes vedkommende er SL omtrent uaf-
hængig af afstanden. For de angivne prøver
skyldes variationerne enten variationer i
$\bar{q}$ (nr. 460 og 63) eller i $f_{texture}$ (nr.
617).

is expected to vary as the measured SL, and can explain the variation of SL.

Sample No. 63 has, on the other hand a fine-grained light coloured aggregate (0-3 mm calcined flint) mixed with a darker aggregate of somewhat larger grain size. Hence this surface appears as having relatively dark stones protruding from a matrix of a more light colour, and $\bar{q}$ is expected to be large at small distances, but decreasing with distance. This is the type of variation shown by the measured SL, which again is presumedly well accounted for by the variation of $\bar{q}$.

Sample No. 617 is a surface treatment with large chippings of a uniform size (12 to 16 mm) and lightness. For this surface $\bar{q}$ should be expected to be roughly independent of the distance and thus cannot account for the measured variation of SL.

The initial decrease in SL at short distances for this sample is considered to represent a decrease in the factor of texture, $f_{texture}$.

For this surface the SL is very high at short distances considering the moderate lightness of the chippings (light granite). At 15 m the SL of 20.4 mcd/m²/lux is matched only by sample No. 63 with its very light matrix.

The value of $f_{texture}$ is, therefore, assumed to be high for sample No. 617 at short distances. This assumption is reasonable, as at short distances the strongly inclined sides of the coarse chippings can be illuminated.

At larger distances the illumination of the sides of the chippings must decrease strongly, $f_{texture}$ must decrease to values typical of less coarse surfaces, and

SL must take a value typical of a surface with aggregates of moderate lightness. This last-mentioned aspect is verified by the SL-value at 50 m of 14.9 $mcd/m^2/lux$, which is surpassed by most of the other samples.

Hence the initial decrease in SL for sample No. 617 for distances up to 50 m is explained by a variation of the factor of texture. This variation is, on the other hand, explained by the "uniformity" of the surface, consisting of densely packed chippings of one size only.

The following variation in SL, a decrease at 75 m followed by an increase at 100 m, is ascribed to measuring uncertainty. In this very coarse surface the measuring field is strongly elongated and cannot be contained on the sample at either of the above-mentioned distances.

The other seven samples all show an SL, which is roughly independent of the distance.

It is concluded, therefore, in agreement with the model considerations that for most road surfaces neither $\bar{q}$ nor $f_{texture}$ will vary significantly with the distance (with ε). Some surfaces do, however, show variations that relate to the appearance of the surface.

5.4.3   Influence of transverse distance of the headlight
As discussed in section B.4 a transverse displacement of the headlight to a supplemental azimuthal angle, β' differing from zero is expected to cause a reduction in SL. The magnitude of this reduction is further expected to be determined by two parameters, p_1 and p_2:

$$p_1 = \left| \frac{\beta'}{\alpha - \varepsilon} \right| \sim \left| \frac{D_t}{H_o - H_h} \right| \qquad p_2 = \alpha - \varepsilon \sim \frac{H_o - H_h}{D}$$

In order to test these expectations, fig. 5.6 shows
the measured deviations as a function of D for H_o =
1.2 m and for D_t = 0.5 m, 1 m and 1.5 m. In this dia-
gram, p_1 changes with D_t only and has the values of
0.91, 1.82 and 2.73 respectively. The other parameter,
p_2 is independent of D_t, but varies with D.

It is seen that the deviations follow curves for the
various D_t that are of similar shapes, but of different
magnitudes. This is taken as a confirmation of the as-
sumption of independent actions of p_1 and p_2 through
factors; i.e. the reduction is given as the product
$F_1 \cdot F_2$, where F_1 is a function of p_1 only and F_2 is a
function only of p_2.

In this sense $F_2(p_2)$ determines the shape of the
curves, while $F_1(p_1)$ determines the magnitude of the
reductions in SL.

When taking F_1 to be almost at its maximum at p_1 = 2.73,
F_1 is seen to be larger than half its maximum at p_1 =
1.82, but less than half its maximum at p_1 = 0.91. This
is also in agreement with the model considerations.

The shape of the curves is further in agreement with
the model considerations. F_2 is small, when p_2 is large,
and then increases, when p_2 decreases below a critical
value, p'_2. This critical value seems to be appr. 0.01
radians.

A further illustration of the influence of p_2 is given
in fig. 5.7 which shows the reduction in SL as a func-
tion of D for D_t = 1 m and H_o = 1 m, 1.2 m and 1.5 m.
Assuming a p'_2 of appr. 0.01 radians, the decrease in
SL should remain small at D up to appr. 30 m, 50 m and
75 m respectively. This actually is observed.

Figure 5.6 Deviations in SL 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.

Ændringer i SL 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.

Figure 5.7 Deviations in SL 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.

Ændringer i SL for H_o = 1 m, 1,2 m og 1,5 m ved D_t = 1 m, i forhold til SL for D_t = 0.

It is to be explained in connection with fig. 5.7 that not only p_2, but also p_1 changes with H_o, p_1 having the values of 2.86, 1.82 and 1.18. For this reason the decrease in SL in addition to setting in at shorter distances is also stronger, when H_o is small.

The actual reductions of SL for the various positions in the reflection table are shown in table 5.5 as averages for the 10 samples. The values of p_1 and p_2 are given in tables 5.6 and 5.7 respectively.

On the basis of a comparison of the above-mentioned tables, it is suggested that F_2 is given by:

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

This allows a computation of F_2 for each of the positions in the reflection table, and hence F_1 can be computed as the ratio of the reduction of SL to the computed value of F_2. In this way F_1 is determined for all positions in the reflection table (for which the p_1 values are also known).

The results af these calculations are shown in the F_1-p_1 diagram of fig. 5.8. The scatter in this diagram is due partly to measuring uncertainty, and partly to an even more complex variation of the reduction in SL with the measuring angles.

The model considerations are, therefore, not precise in accounting for the variation of the factor $f_{visible}$, which seems to be quite complex.

ε	β' \ α	0.57°	0.69°	0.76°	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°	0	0													
	1°	31.7 %	24.8 %													
0.50°	0°			0	0	0										
	1°			35.4 %	24.0 %	6.6 %										
0.74°	0°					0	0	0								
	1°					22.9 %	6.3 %	3.1 %								
	2°					12.1 %	8.2 %	5.2 %								
1.24°	0°								0	0	0					
	1°								4.3 %	4.9 %	1.2 %					
	2°								6.5 %	3.2 %	3.7 %					
	3.5°								11.3 %	7.5 %	3.7 %					
2.48°	0°											0	0	0		
	2°											2.7 %	2.5 %	0		
	5°											12.3 %	9.1 %	5.8 %		
3.72°	0°													0	0	0
	2°													2.1 %	0	0
	5°													11.1 %	6.9 %	6.0 %

Table 5.6   Average reductions in SL, as compared to SL for β' = 0°.

Gennemsnitlige reduktioner af SL i forhold til SL for β' = 0°.

ε	β'	α 0.57°	0.69°	0.76°	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°	0	0	0												
	1°	5	3.12	2.56												
0.50°	0°			0	0	0										
	1°			3.85	2.38	1.54										
0.74°	0°					0	0	0								
	1°					2.44	1.59	1.02								
	2°					4.88	3.17	2.04								
1.24°	0°								0	0	0					
	1°								1.49	0.95	0.62					
	2°								2.98	1.90	1.23					
	3.5°								5.22	3.33	2.16					
2.48°	0°											0	0	0		
	2°											1.50	0.96	0.62		
	5°											3.76	2.39	1.55		
3.72°	0°													0	0	0
	2°													1.01	0.64	0.42
	5°													2.51	1.60	1.04

<u>Table 5.7</u>   Values of $p_1 = \beta'/(\alpha-\varepsilon)$

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

ε	β'	0.57°	0.69°	0.76°	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° 1°	0.0035	0.0056	0.0068												
0.50°	0° 1°			0.0045	0.0073	0.0113										
0.74°	0° 1° 2°					0.0071	0.0110	0.0171								
1.24°	0° 1° 2° 3.5°								0.0117	0.0183	0.0282					
2.48°	0° 2° 5°											0.0232	0.0365	0.0564		
3.72°	0° 2° 5°													0.0347	0.0545	0.0840

Table 5.8   Values of $p_2 = \alpha - \varepsilon$ (radians)

Værdierne af $p_2 = \alpha - \varepsilon$ (radianer)

However, the function indicated in fig. 5.8 does account for the major part of the variations. This function is:

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

The reductions in SL are then approximated by:

$$
F_1 \cdot F_2
$$

where F_1 and F_2 are the functions of p_1 and p_2 respectively, as given above.

A comparison between computed and measured reductions in SL is given in fig. 5.9.

5.5   Moist condition

In the moist condition the stones in the surface are covered by a water film, and for some surfaces, water "pools" can form in the bottom of the texture.

These water films and surfaces create a strong specular reflection, which is important in some illumination situations. For the reflection in the illumination of the drivers own headlight, specular reflection is, however, not important. Only a few illuminated facets will have the almost vertical orientation required for mirror reflection, and in this orientation the reflectance of a water film is small.

The important aspect of the moisture is, therefore, a dark-colouring of the stones, and the further dark-colouring of such lower parts of the texture covered by water.

Figure 5.8 Average values of F_1 determined by means of the average reductions of SL given in table 5.5 and plotted against $p_1 = \beta'/(\alpha-\varepsilon)$.

Gennemsnitlige værdier af F_1 beregnet på baggrund af de gennemsnitlige reduktioner af SL, som er givet i tabel 5.5, og afsat i forhold til $p_1 = \beta'/(\alpha-\varepsilon)$.

MEASURED REDUCTIONS OF SL
$1-SL/SL(\beta' = 0^0)$

Figure 5.9 Comparison between measured and computed
reductions of SL.

Sammenligning mellem målte og beregnede
reduktioner af SL.

The influence of the moisture can thus be expected to
be a reduction of the average luminance coefficient of
illuminated facets, $\bar{q}$ and a consequent reduction of
SL-values. There is no reason to expect a significant
change in the influence of the geometry.

The above-mentioned expectations have been partly con-
firmed in previous measurements. In the investigation
reported in Mörkertrafik Report No. 2, the effect of

moisture was found to be a reduction of SL by a
factor of 2 to 7.

A further expectation, also partly confirmed in pre-
vious measurements, is that the degree of moisture is
not important over a wide range. This was tested and
confirmed for the 10 road samples prior to the main
measurements. For this reason the very simple wetten-
ing procedure described in chapter 4 was used.

The diagrams of fig. 5.10 to 5.13 are set up in order
to test the assumption that for a certain road sample
any SL-value for the humid condition is approximately
a certain fraction of the corresponding SL-value for
the dry condition. The fraction is characteristic of
the road surface, but can vary among road surfaces.

If this assumption is verified, the influence of the
geometry, as established in section 5.4 for the dry
condition, can be considered to be valid also for the
humid condition.

In the log-log diagrams giving SL(humid) in relation
to SL(dry) for identical geometries, the assumption
means that all points are to lie close to a line of
the slope one decade per decade (45° in the diagrams).
Lines of this slope are, therefore, drawn through one
of the points. The selected point is for the geometry
of ($\varepsilon = 0.74^{\circ}$, $\alpha = 1.37^{\circ}$, $\beta' = 0^{\circ}$).

It is seen from the diagrams that the points do fit
to some extent around the lines. Deviations from this
fit are partly due to measuring uncertainty for the
dry and in particular for the humid condition.

Measuring uncertainties are clearly largest for the
humid condition for at least two reasons. First,
variations in the degree of humidity do cause an in-
crease in the uncertainty. Next, the values are

smaller and closer to the lower range of the equipment. For sample No. 90, 4 very small values (0.1 to 0.7 mcd/m^2/lux) have been deleted from the diagram, as they were clearly very uncertain.

For some of the samples, e.g. No. 609, a better fit could obviously be obtained to a line of a steeper slope. This could be taken to mean that the influence of the geometry is somewhat different in the humid condition.

A closer study of the influence of the geometry by means of diagrams as for the dry condition (the diagrams are not shown) revealed the following.

Some of the samples show a tendency of SL (humid) increasing somewhat with the distance. The reason for this is probably a relatively stronger reduction of SL at short distances, where the very dark, flooded lower parts of the texture are illuminated.

Another difference from the dry condition seems to be a stronger influence of the observer eye height, being in fact in better agreement to the model considerations for the humid condition. The reason for this is again presumedly that facets of a low inclination are covered by water.

Figure 5.10 SL(humid) in relation to SL(dry) for
samples Nos. 63, 601 and 609.

SL(fugtig) i relation til SL(tør) for
prøver nr. 63, 601 og 609.

Figure 5.11 SL(humid) in relation to SL(dry) for samples Nos. 460, 617 and 87.

SL(fugtig) i relation til SL(tør) for prøver nr. 460, 617 og 87.

Figure 5.12 SL(humid) in relation to SL(dry) ror
          samples Nos. 90 and 176.

          SL(fugtig) i relation til SL(tør) for
          prøver nr. 90 og 176.

Fig. 5.13 SL(humid) in relation to SL(dry) for
samples Nos. 177 and 182.

SL(fugtig) i relation til SL(tør) for
prøver nr. 177 og 182.

6.   APPLICATION
          By Kai Sørensen, LTL

6.1   Introduction to a description system
          A necessary basis for applications of reflection pro-
          perties of road surfaces is that the reflection pro-
          perties can be described (or classified) in a way
          that permits simple measurements of parameters, which
          describe the reflection properties to a sufficient
          accuracy.

          For the illumination by street lighting the choice of
          descriptions and classifications has involved a large
          amount of research that is still carried on.

          In the case of illumination by the drivers own head-
          lights, as considered in this report, it seems pos-
          sible to introduce a rather simple description.

          The parameter of a simple description can be the SL-
          value for a selected standard geometry. The SL-value
          for the standard geometry can be distinguished by a
          mark, SL'.

          The description of the reflection properties consists of
          course of an estimation of the SL for other geometries
          than the standard geometry. This estimation can be
          carried out by means of the model for the influence of
          the geometry, as introduced in Appendix B and as in-
          vestigated and completed in chapter 5.

          A further convenient feature is that the same model
          applies to both the dry and the humid condition. A de-
          scription of the reflection properties for both con-
          ditions involves, therefore, only the specific lumi-
          nances for the two conditions, SL'(dry) and SL'(humid).

          The SL'(humid) can even represent a wide range of
          humid conditions, due to the relative insensitivity

of SL to the actual degree of humidity of the surface.

This simple description is defined, when the standard
geometry is selected, and when also the formulas for
the transformation to other geometries are given.

Some considerations concerning the choice of a standard
geometry are given in section 6.2. A standard geometry
is not actually proposed yet, as it should be attempt-
ed to select a standard geometry, which is applicable
to road markings as well as road surfaces.

Section 6.3 gives, on the other hand, a proposal for a
set of formulas, which need not be common to road
surfaces and road markings.

6.2   Considerations concerning a standard measuring geometry

It is natural for reasons of symmetry to select a
standard measuring geometry, where the azimuthal angle,
β is 180° ($\beta' = 0^{\circ}$).

The choice of the observation angle, α is best done in
relation to the illumination angle, ε, assuming a typical
geometry of the vehicle.

The critical step in the choice of the standard measur-
ing geometry, therefore, concerns the illumination angle,
ε. As headlight mounting heights presumedly vary little,
the choice of ε can be considered to be a choice of a
simulated distance on the road.

One consideration concerning the simulated distance on
the road is its consequences for the measuring equipment.
Without going into detail it can be stated that large
measuring distances are much more demanding than small
distances.

This is undoubtedly the reason why existing portable
equipments, with a few exceptions, use geometries cor-

responding to very short distances of appr. 10 m on the road. One such geometry of $\varepsilon = 3.5^O$, $\alpha = 5^O$ is even given in DIN Standard No. 67520, part 1-3 (draft) for the measurement of road markings.

Two other instruments use geometries corresponding to longer distances of appr. 30 m and 50 m, see VTI Report No. 188A concerning these two instruments and an instrument built according to the DIN-standard.

It is interesting to see, if the shortest distance of appr. 10 m permits a description of a sufficient accuracy, or whether the longer distances are required and lead to worthwhile improvements.

In the analysis the three distances of 10 m, 30 m and 50 m are represented by the positions of the reflection table of ($\varepsilon = 3.72^O$, $\alpha = 5.71^O$), ($\varepsilon = 1.24^O$, $\alpha = 2.29^O$) and ($\varepsilon = 0.74^O$, $\alpha = 1.37^O$) respectively. The first-mentioned geometry corresponds to an observer eye height, H_O of 1 m, giving the best agreement to the DIN-standard, while the other two geometries corresponds to $H_O = 1.2$ m.

The analysis is further based on the implication of the model considerations that reflection tables for different road surfaces, and even for dry and humid conditions, are identical except for the scale of the SL-values of the tables.

A measure of the potential accuracy of a certain position to be used for the standard geometry is obtained in the following manner.

Each of the tables for the 10 road samples are rescaled, so that the value at the position in question is unity. At all other positions the values will vary from table to table. This variation is expressed as the RMS percentage variation around the average value.

The result is a table in the format of the reflection
table, which position for position expresses a percen-
tage uncertainty.

These uncertainties include measuring uncertainties,
which will enter any analysis. The uncertainties in-
clude further deviations from the above-mentioned im-
plication of the model considerations. It is actually
such deviations that make some geometries preferable
to other geometries for the use as the standard geo-
metry. If the model considerations had led to a very
accurate picture of the SL-values of real surfaces,
all geometries would do equally well as the standard
geometry.

The model considerations not only imply the above-
mentioned similarity of reflection tables, but give
also the variation of the SL-value from position to
position in the table.

The complete account of the reflection table is a
further approximation to the SL-values of real surfaces,
which again increases the uncertainty of the complete
description. This increase in uncertainty is considered
in section 6.3, but does not enter the analysis of this
section, which, therefore, gives an improved judgement
of the consequences of the choice of the standard geo-
metry.

The uncertainty tables for the 10 m, 30 m and 50 m geo-
metry are shown in tables 6.1 to 6.3 respectively, as
computed for the reflection tables for the dry condition.

Assuming a maximum permissible uncertainty of 15 % for
the dry condition, it is seen from table 6.1 that the
10 m geometry covers geometries with a satisfactory ac-
curacy in a range up to 30 m only. The 30 m geometry simi-
larly covers a range from 10 m to 50 m, while the 50 m
geometry covers a range of geometries from 30 m to 75 m.

ε	β \ α	0.57°	0.69°	0.76°	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°	✕	30	28												
	1°		30	29												
0.50°	0°			24	28	26										
	1°			22	25	26										
0.74°	0°					19	17	19								
	1°					16	16	18								
	2°					18	16	18								
1.24°	0°								9.7	11	11					
	1°								10	10	11					
	2°								10	11	8.5					
	3.5°								11	10	10					
2.48°	0°											9.7	11	10		
	2°											9.4	11	10		
	5°											9.6	11	12		
3.72°	0°													0	3.4	4.5
	2°													4.1	4.6	5.9
	5°													3.6	4.8	9.1

Table 6.1 Variations (percent) among the SL-values of the ten road samples in the dry condition after a rescaling of the SL for the 10 m geometry (ε = 3.72°, α = 5.71°) to unity.

Variationer (procent) blandt SL-værdierne for de ti vejprøver i tør tilstand efter en omskalering, så SL for 10 m geometrien (ε = 3,72°, α = 5,71°) er én.

ε	β' \ α	0.57°	0.69°	0.76°	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	27	22												
	1°		28	24												
0.50°	0°			16	19	17										
	1°			16	17	17										
0.74°	0°					12	7.3	8.7								
	1°					9.6	6.4	8.9								
	2°					10	6.5	8.3								
1.24°	0°								4.5	0	3.0					
	1°								3.8	2.9	2.6					
	2°								3.6	4.4	4.4					
	3.5°								4.3	3.6	3.6					
2.48°	0°											13	13	12		
	2°											12	14	13		
	5°											12	13	12		
3.72°	0°													11	11	9.7
	2°													11	12	11
	5°													11	13	12

Table 6.2   Variations (percent) among the SL-values of the ten road samples in the dry condition after a rescaling of the SL for the 30 m geometry ($\varepsilon = 1.24°$, $\alpha = 2.29°$) to unity.

Variationer (procent) blandt SL-værdierne for de ti vejprøver i tør tilstand efter en omskalering, så SL for 30 m geometrien ($\varepsilon = 1,24°$, $\alpha = 2,29°$) er én.

ε	β' \ α	0.57°	0.69°	0.76°	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°	✕	26	18												
	1°	✕	28	22												
0.50°	0°			12	14	11										
	1°			14	12	11										
0.74°	0°					11	0	5.8								
	1°					10	3.1	4.6								
	2°					10	3.8	4.7								
1.24°	0°								9.4	7.2	6.9					
	1°								8.8	8.0	7.4					
	2°								8.8	8.6	9.4					
	3.5°								9.2	8.9	7.8					
2.48°	0°											18	19	18		
	2°											17	20	19		
	5°											18	20	18		
3.72°	0°													18	18	16
	2°													17	19	18
	5°													17	20	17

Table 6.3   Variations (percent) among the SL-values of the ten road samples in the dry condition after a rescaling of the SL for the 50 m geometry (ε = 0.74°, α = 1.37°) to unity.

Variationer (procent) blandt SL-værdierne for de ti vejprøver i tør tilstand efter en omskalering, så SL for 50 m geometrien (ε = 0,74°, α = 1,34°) er én.

Similar conclusions are reached for the humid condi-
tion assuming a maximum permissible uncertainty of
25 % (tables not shown).

It is to be pointed out that a significant part of
these uncertainties are due to the rather large varia-
tions of SL with the distance, as shown by the
samples No.s 460, 63 and 617 for the reasons given
in chapter 5.

When these three samples are excluded from the cal-
culation of the uncertainties, the above-mentioned
ranges of distances are covered to an uncertainty
of only 10 % for the dry condition, and 20 % for
the humid condition (tables not shown).

In interpreting these findings emphasis should be
put on the accuracy of description for the larger
distances. This emphasis does not necessarily mean
that short distances are irrelevant to the drivers
visual needs. The meaning is rather that the longer
distances are certainly as important as the shorter
ones, and they are simultaneously more critical, as
the illumination is much smaller.

In this sence the 50 m geometry is clearly the best,
the 30 m geometry is perhaps acceptable, and the
10 m geometry is unacceptable.

6.3   Transformation to other geometries
The SL-value for the standard geometry, SL' is as-
sumed to be determined in a measurement. The SL for
other geometries can then according to Appendix B and
chapter 5 be estimated by:

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

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

$f_{geometry}$ is the factor of geometry for the geometry considered

and $f_{visible}$ is the factor of visible, illuminated facets of the geometry considered.

In setting up this expression for the estimation of SL it has been assumed that $f_{visible}$ is unity for the standard geometry ($\beta' = 0^\circ$ in this geometry). It is further assumed, the $\bar{q}$ and $f_{texture}$ do not change from one geometry to another.

The factor, $f_{geometry}$ has a fixed value, which has to be computed only once for a selected standard geometry.

The factor $f_{geometry}$ is given by:

$$f_{geometry} = \frac{\sin\varepsilon}{\sin\alpha}$$

where ε and α are the angles of illumination and observation for the geometry considered.

The factor, $f_{visible}$ can according to chapter 5 be estimated by:

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

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

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

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

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

ε	β'	0.57°	0.69°	0.76°	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	29	21												
	1°		30	24												
0.50°	0°			19	18	12										
	1°			17	23	13										
0.74°	0°					11	0	6.3								
	1°					13	3.4	5.3								
	2°					16	4.1	6.2								
1.24°	0°								9.4	7.4	8.5					
	1°								8.8	8.0	9.2					
	2°								10	9.9	11					
	3.5°								9.2	10	12					
2.48°	0°											19	20	18		
	2°											18	21	20		
	5°											21	21	18		
3.72°	0°													18	18	16
	2°													18	19	18
	5°													19	20	17

Table 6.4 Variations (percent) of the measured SL-values of the ten road samples in the dry condition from the values predicted by the transformation from the 50 m geometry (ε = 0.74°, α = 1.37°).

Variationer (procent) af de målte SL-værdier for de ti vejprøver i tør tilstand i forhold til de værdier, som forudsiges ved transformation fra 50 m geometrien (ε = 0.74°, α = 1.37°).

The accuracy of the estimation can possibly be improved by taking variations of $\bar{q}$ and $f_{texture}$ into account for such surfaces, where these factors are expected to vary in a certain fashion.

The expression for $f_{geometry}$ is one of definition and cannot be modified. The expression for $f_{visible}$ has been derived by a fit to the measuring data and can possibly be improved, if more data become available.

When using this method of estimation, and assuming the 50 m standard geometry ($\varepsilon = 0.74^{\circ}$, $\alpha = 1.37^{\circ}$), the RMS uncertainties for the 10 road samples can be computed for all positions in the reflection table. The results of such computations are given in table 6.4 for the dry condition.

A comparison of table 6.4 to table 6.3 shows some increase in the uncertainties, which is due to the more detailed assumptions given above. The increase in uncertainties is, however, not a serious one.

Example_of_transformation
For a geometry of ($\varepsilon = 0.74^{\circ}$, $\alpha = 1.37^{\circ}$, $\beta' = 0^{\circ}$) SL' has been measured for a certain road surface to 20 mcd/m^2/lux. The factor of geometry, $f'_{geometry}$ is $0.74^{\circ}/1.37^{\circ} = 0.54$.

For this road surface is desired an estimation of the SL for both headlights at a distance $D = D_h = D_o = 100$ m for a sportscar with a headlight mounting height, H_h of 0.70 m and an observer eye height, H_o of 1 m.

The factor of geometry, $f_{geometry}$ for this vehicle is 0.70 m/1 m = 0.7. Hence a correction factor of 0.70/0.54 = 1.30 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) = 1.30 x 20 mcd/m^2/lux = 26 mcd/m^2/lux.

For the other headlight D_t = 1 m and a smaller value of $f_{visible}$ applies.

The parameter, p_1 is computed to $D_t/(H_o-H_h)$ = 3.33, which is higher than 3. Therefore, the values of 1 is taken for F_1.

The parameter, p_2 is $(H_o-H_h)/D$ = 0.003. This value is smaller than 0.01 and, therefore, F_2 is calculated by:

$$F_2 = 0.1 + 0.5(1 - \frac{p_2}{0.01}) = 0.1 + 0.5(1 - 0.3) = 0.45$$

This gives an $f_{visible}$ of $1 - F_1 \cdot F_2 = 1 - 0.45 = 0.55$ and:

SL(other headlight) = 1.30 x 0.55 $\cdot$ 20 mcd/m^2/lux = 14 mcd/m^2/lux.

7.   SUMMARY

By Kai Sørensen, LTL

A measuring equipment at the National Road & Traffic
Research Institute (VTI), Linköping, Sweden has pre-
viously been used for the study of reflection pro-
perties of road surfaces and road markings in vehicle
headlight illumination. The equipment allows the set-
ting of the angles of illumination, ε and of obser-
vation, α.

This equipment has been fitted with a mirror arrange-
ment, which allows also the third angle of the geo-
metry, the azimuthal angle, β to be set. The equip-
ment has further been fitted with a displaceable
sampleholder used for the scanning of the measuring
field, and a semiautomatic data-registration using
paper-tape. The equipment is described in chapter 4.

This equipment is intended for a number of studies
of road surfaces and road markings with the aim of
selecting standard measuring geometries for in situ
measurements. Plans for these studies are found in
Mörkertrafik Report No. 3.

This study concerns the specific luminance, SL of
road surfaces in the illumination of the drivers
own headlights. Among existing road samples were
selected a number of ten. Some of these are typical
of Swedish and Danish road surfaces, while others
were included for the reason that they were suspect-
ed to show special features of reflection proper-
ties.

The road samples are introduced in chapter 2, while
definitions and notations are given in chapter 3.

The measuring geometries were selected with re-
ference to geometrical situations in car driving.

Situations of simulated distances of 10 m to 100 m,
observer eye height of 1 m to 1.5 m and transverse
displacements between observer and headlight up to
1.5 m are considered, when assuming a headlight mount-
ing height of 0.65 m.

The measuring geometries are, however, specified in
terms of the measuring angles and are given by a re-
flection table of 51 positions. The reflection tables
for the ten samples in dry and a humid condition are
given in Appendix A.

In order to facilitate the discussion of the measur-
ing data, and to give a general understanding of the
reflection, model considerations of the reflection are
discussed in Appendix B.

The model considerations indicate that SL can be re-
presented as the product of 4 factors:

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

where $\bar{q}$ is the average luminance coefficient of il-
luminated facets and represents the lightness of the
aggregates in the surface

$f_{geometry}$ equals $\sin\varepsilon/\sin\alpha$ and accounts for the major
part of the influence of the angles ε and α

$f_{texture}$ is a measure of the average inclination of
the illuminated facets

and $f_{visible}$ is the fraction of illuminated facets
that are also visible. This factor accounts for the
loss in SL, when β differs from 180°.

The model considerations further imply that $\bar{q}$ and
$f_{texture}$ will often be approximately independent of

the geometry, and that $f_{visible}$ is to some approxima-
tion the same function of the angles for all surfaces.

This indicates that SL will approximately be the
same function of the angles for most road surfaces,
and that the scale of this function is given by the
lightness of the aggregates ($\bar{q}$) and the texture
($f_{texture}$).

The measurements discussed in chapter 5 confirm
the model considerations for the dry condition with
the remark that those samples for which special
features were expected, do show such features.

Thus two samples having light-coloured facets mainly
in respectively the upper and lower parts of the
texture do show variations in $\bar{q}$ with the angles. An-
other sample, a surface treatment with chippings of
a uniform size, shows a very high $f_{texture}$, at large
illumination angles, decreasing to a normal values
at smaller illumination angles.

The function, $f_{visible}$ is estimated empirically
from the measuring data.

For the humid condition is established that the SL's
are a fraction of the SL's for the dry condition.
This fraction varies from surface to surface, but is
approximately independent of the geometry. Thus the
model considerations are indirectly confirmed for
the humid condition also.

The reduction in SL for the humid condition is a-
scribed essentially to a reduction of $\bar{q}$, which is
due to the dark-colouring of the humid aggregates.
Some slight changes in the influence of the geometry
for the humid condition are explained by the addi-
tional dark-colouring of the more humid, lower parts
of the surface texture.

It is further stated, as it has been observed at
earlier occasions that SL does not vary strongly with
the actual degree of humidity. For this reason a
simple wetting procedure has been used.

In chapter 6 it is concluded that the findings are
favourable for application purposes. A description
can be based on the SL-value of a standard measur-
ing geometry, with the estimation of SL-values for
other geometries carried out by means of the for-
mulas derived in the model considerations and supple-
mented by the measuring data.

The observed deviations from the formulas do, on
the other hand, necessitate a proper choice of the
standard geometry. It is shown that when emphasis
is put to the accuracy of the description for geo-
metries of middle and long simulated distances, a
geometry corresponding to a simulated distance of
50 m is better than geometries corresponding to
shorter distances. Geometries corresponding to appr.
10 m, as found in some commercially available instru-
ments, are very poor in this respect.

The accuracy of the complete description system, as
based on an assumed standard geometry of 50 m, is
found to be acceptable.

However, a proposal for a standard geometry is not
included, as a standard geometry should, if possible,
apply also to road markings. A study of road markings
similar to this one is, therefore, being undertaken.

8.   SAMMENFATNING

Af A.O. Bohn, for Statens Vejlaboratorium

Veje med faste belysningsanlæg kan lysteknisk set
bedst karakteriseres ved luminansen i candela pr.
m² af de af trafikanten betragtede områder af vej-
overfladen. Luminansen kan siges at være et mål for,
hvor lys vejen ser ud for trafikanten. For veje, der
oplyses udelukkende af bilistens egne lygter, duer
luminansen ikke - den ville være afhængig af bilens
belysningsanlægs effektivitet. Mest formålstjenligt
er det, at interessere sig for den såkaldte speci-
fikke luminans, SL som i diagrammerne måles i mil-
licandela pr. m² pr. lux. SL blev tidligere kaldt
retrorefleksionen; den angiver, hvor stor en del af
trafikantens eget lys, der rammer det betragtede
sted på vejen, som reflekteres i retning af trafi-
kantens øjne. Den eksakte definition findes i kapi-
tel 3.

LTL (Lysteknisk Laboratorium) har støttet af Vejdi-
rektoratet været med i et nordisk samarbejde om må-
ling af SL af vejprøver og vejafmærkninger.

Det i tabel 2.1 viste udvalg af typiske (og lystek-
nisk interessante) skandinaviske vejprøver er blevet
undersøgt på VTI (Statens Väg- och Trafikinstitut)
i Linköping på en derværende velegnet stationær må-
leopstilling (fig. 4.1).

I samarbejde med LTL blev måleopstillingen forbed-
ret; blandt andet blev den ændret, så at man ikke
alene kunne måle SL for situationen, hvor iagttage-
ren befandt sig lodret over lygten ("motorcykelsi-
tuationen"), men også, når der var en vis afstand
til siden, som tilfældet er ved automobilkørsel.

Betragtes figur 3.1, betød ændringen, at man nu og-
så kunne ændre den for sideforskydningen, D_t

afgørende vinkel β'- hidtil havde man kun kunnet ændre belysningsvinklen ε og observationsvinklen α. Observationsafstanden D_o til det betragtede punkt P bestemmer, som det ses af figuren, disse to vinkler i forbindelse med henholdsvis lygtehøjden H_h og observationshøjden H_o. Ved målingerne benyttes et mod punktet P rettet luminansmeter, placeret i observationspunktet. En situation på vejen, hvor observatøren betragter et område af vejen, der f.eks. er 75 m borte, kan simuleres ved laboratorieopstillingen trods de relativt små dimensioner ved at vælge samme geometri, d.v.s. samme værdier af ε, α og β'. Det var muligt med et spejlarrangement direkte at indstille 5 forskellige, faste værdier af β'. SL for andre værdier kunne findes ved interpolation.

På fig. 5.1 og i tabel 5.1 ses hvilke afstande, D på vejen (fra 10-100 m), hvilke øjenhøjder H_o (fra 1-1.5 m) og hvilken lygtehøjde H_h (0,65 m) man ønskede at simulere ved valget af vinkelsættene, og hvilke værdier af ε og α der svarer hertil. Fig. 5.2 viser, hvordan man finder de β' værdier, der svarer til de ønskede lygtesideforskydninger D_t. De tilstræbte værdier for D_t (fra 0-1,5 m) fremgår af tabel 5.2, hvor man ser, hvilke værdier β' skal have for de valgte værdier for D og D_t. I tabel 5.4 er der afkrydset hvilke vinkelkombinationer, der valgtes til målingerne - at de afkrydsede felter grupperer sig om en diagonal, betyder blot, at man, når man vælger en række belysningsvinkler ε, kun har interesse i at måle med de observationsvinkler α, der svarer til, at man ser på det belyste sted på vejen.

Måleudstyret var udbygget med en semiautomatisk dataregistrering på hulbånd. Tabel 5.5. viser, som et eksempel, en EDB-udskrevet refleksionstabel for prøve 601, en 0/12 mm asfaltbeton med 20 % tilslag af calcineret flint. Refleksionstabeller for samtlige vej-

prøver i våd og tør tilstand findes i Appendix A.
På figur 5.3 ses en grafisk afbildning af tabel-
lens tal - her er der ikke anført vinklerne, men
de hertil svarende kombinationer af observations-
afstande D, observationshøjder H_o, lygtehøjde H_h
og lygtesideforskydninger D_t. Der gøres her opmærk-
som på det hensigtsmæssige i at se bort fra visse
diagrampunkter, hvor usikkerheden er stor.

Af figuren ses - hvad der fremgår endnu tydeligere
af fig. 5.4, at SL er relativt større for små obser-
vationshøjder end for store. Det stemmer - også
kvantitativt - med de i Appendix B anførte modelbe-
tragtninger, hvorefter man skulle forvente, at SL
var proportional med størrelsen $f_{geometry}$, som er
forholdet mellem sinus til henholdsvis belysnings-
vinklen ε og observationsvinklen α.

Modelbetragtningerne antyder, at SL kan repræsente-
res af et produkt af 4 faktorer:

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

hvor $\bar{q}$ er den gennemsnitlige luminanskoefficient af
belyste facetter og dermed er et mål for lysheden af
stenene i overfladen

$f_{geometry}$ er givet ved $sin\varepsilon/sin\alpha$ og redegør for ho-
vedparten af indflydelsen af vinklerne ε og α

$f_{texture}$ er et mål for den gennemsnitlige hældning
af de belyste facetter

og $f_{visible}$ er den brøkdel af de belyste facetter,
der også er synlig. Denne faktor redegør for det
fald i SL, der indtræffer, når $\beta' \neq 0^o$.

Modelbetragtningerne antyder desuden, at $\bar{q}$ og $f_{texture}$ med nogen tilnærmelse er den samme funktion af vinklerne for alle vejbelægninger.

Dette medfører, at SL med tilnærmelse er den samme funktion af vinklerne for de fleste vejbelægninger, og at denne funktions skalaforhold bestemmes af lysheden af stenene i overfladen ($\bar{q}$) og af teksturen ($f_{texture}$).

Funktionen $f_{visible}$ bestemmes empirisk ved tilpasning til måleresultaterne.

Måleresultaterne, som diskuteres i kapitel 5, bekræfter modelbetragtningernes gyldighed for de tørre vejprøver med den bemærkning, at de prøver, for hvilke der forventedes specielle forhold, også udviser sådanne forhold.

På fig. 5.5 vises SL for samtlige prøver uden tværforskydning af lygten. Der er divideret med SL værdien for D = 50 m, således at samtlige kurver går gennem 50,1. Resultaterne, som er vigtige for diskussionen af, hvilken geometri man bør vælge til et transportabelt refleksionsmåleapparat, viser, at for 7 af de 10 undersøgte asfaltbelægninger var der ingen større variation i SL med afstanden. Der var 3 undtagelser fra dette: a) En belægning - nr. 460 - med 4/8 mm nedtromlede lyse sten i en mørk, finkornet grundmasse. Her var SL lille ved kort betragtningsafstand, hvor måleapparatet "så" ned på den mørke grundmasse mellem de hvide sten, mens man ved lang betragtningsafstand kun så de lyse sten. b) En belægning - nr. 63 - hvor 0/3 mm lyse sten befandt sig i en mørk grundmasse med større maksimalkornstørrelse. Her var det omvendt: SL var størst ved kort betragtningsafstand - på lang betragtningsafstand var de mørke store sten åbenbart dominerende. I disse to tilfælde er der åbenbart en stor afhængighed i $\bar{q}$ med

geometrien. c) En overfladebehandling - nr. 617 -
med en lys granit. SL var stor for små afstande;
ved større afstande var SL ikke større end for an-
dre belægninger.

De på figur 5.6 og 5.7 og i tabel 5.5 viste reduk-
tioner i SL med voksende sideforskydning, D_T, af
lygten er også i overensstemmelse med modelbetragt-
ningerne, idet faktoren $f_{visible}$ netop forklarer
iagttagelsen. Det ses, at virkningen af sideforskyd-
ningen afhænger af D, betragtningsafstanden. Fig.
5.9 viser, hvorledes de målte reduktioner i SL i for-
hold til SL for sideforskydningen 0 stemmer med de
beregnede, hvor man opnår reduktion ved at gange med
reduktionsfaktorerne F_1 og F_2, hvor F_1 og F_2 hver
kun er afhængig af de i tabellerne 5.6 og 5.7 viste
vinkelafhængige størrelser p_1 og p_2. Overensstem-
melsen er nogenlunde. F_1 skulle afhænge entydigt af
p_1, men som vist i fig. 5.8 er der tale om ikke ube-
tydelige usikkerheder. Anderledes udtrykt: indenfor
en vis fejlmargin kan SL for forskellige sidefor-
skydninger findes, når SL for sideforskydningen 0
kendes.

Fugtes vejoverfladerne, reduceres SL; det skyldes,
at luminanskoefficienten $\bar{q}$ formindskes. Da de andre
faktorer i modeludtrykket: $f_{geometry}$ og $f_{texture}$ ik-
ke ændres, kan man ikke forvente at ændringer i geo-
metrien, d.v.s. ændringer i vinklerne ε, α og β' vil
have større betydning. Det fremgår også af figurer-
ne 5.10-5.13. Her er sammenhørende værdier af SL
(fugtig) og SL (tør) for hver enkelt vejprøve for
hver af de undersøgte geometrier afbildet i et log-
log diagram. Vi ser, at punkterne nogenlunde ligger
på en 45° linie, her tegnet gennem punktet svarende
til vinkelsituationen: $\varepsilon = 0,74^O$, $\alpha = 1,37^O$ og $\beta' = 0^O$.

I afsnit 6 diskuteres det vigtige spørgsmål, om
hvilke afvigelser, man kan få, når man ved hjælp af

modelbetragtninger prøver at beregne SL for en
vilkårlig vinkelsituation, når der foreligger en
måling SL' ved en standardgeometri. Nærliggende
er det at vælge β' = 0 (svarende til ingen side-
forskydning af billygten). Ved valget af ε - og
dermed af modelbetragtningsafstanden - må man ikke
for at lette apparatkonstruktionen vælge en stor
værdi for belysningsvinklen ε. I tabellerne 6.1,
6.2 og 6.3 vises de store variationer man ville få,
midlet for de 10 vejprøver ved at gange SL-tallene
med faktorer, der ville bevirke, at alle tal ved ε
svarende til, at de tre afstande på henholdsvis 10,
30 og 50 m var ens. Man ser, at tillades 15 % af-
vigelse, vil et ε valg, svarende til D = 50 m være
velegnet til at forudsige SL ved afstande fra
30-75 m, hvilket er mere tilfredsstillende end de
to andre valg af ε, som giver uanvendeligt dårlige
esitmater ved denne relativt store afstand, som må
være den vigtigste for brugeren.

Afsnittet slutter med en anvisning på, hvordan man
udfra modelloven for SL regner om fra en geometri
til en anden ved at multiplicere med forholdet mel-
lem $f_{geometry}$ før og nu og beregne $f_{visible}$ udfra
den ændrede vinkelsituation ($f_{visible}$ = 1 i standard-
geometrien). $\bar{q}$ og $f_{texture}$ forudsættes ikke at ændre
sig. Der foretages en gennemregning af et eksempel,
hvor opgaven var at finde SL 100 m fra en bil, når
lygtehøjden, den indbyrdes lygteafstand og iagttage-
rens øjenhøjde er givet, og når SL' for ε = 0,74°,
α = 1,37° og β' = 0 er kendt. Det pointeres, at det
endnu er for tidligt at udtale, at netop disse vink-
ler er optimale med henblik på konstruktionen af et
transportabelt reflektometer - man må afvente resulta-
tet af målinger på vejstriber.

I Appendix A bringes SL tabellerne for de 10 tørre
og våde vejprøver, og i Appendix B udledes den før
omtalte modellov SL = $\bar{q} \cdot f_{geometry} \cdot f_{texture} \cdot f_{visible}$.

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APPENDIX A

REFLECTION TABLES
By Kai Sørensen, LTL

EPSI	BETA'	ALFA .57	.69	.76	.92	1.15	1.37	1.72	1.91	2.29	2.86	
.37	.00	~~3.45~~	6.10	8.80	I	I	I	I	I	I	I	
	1.00	~~2.73~~	4.30	6.00	I	I	I	I	I	I	I	
.50	.00	-----	-----	14.25	13.10	12.05	I	I	I	I	I	dry
	1.00	-----	-----	9.10	10.05	11.65	I	I	I	I	I	condition
.74	.00	-----	-----	-----	-----	18.35	19.06	15.66	I	I	I	
	1.00	-----	-----	-----	-----	15.15	17.41	15.59	I	I	I	
	2.00	-----	-----	-----	-----	15.95	17.07	14.64	I	I	I	tør
1.24	.00	-----	-----	-----	-----	-----	-----	-----	23.28	20.21	16.17	tilstand
	1.00	-----	-----	-----	-----	-----	-----	-----	21.86	19.40	16.60	
	2.00	-----	-----	-----	-----	-----	-----	-----	22.03	19.44	16.14	
	3.50	-----	-----	-----	-----	-----	-----	-----	19.58	16.54	16.19	

EPSI	BETA'	ALFA 3.81	4.57	5.71	6.84	8.53
2.48	.00	27.46	20.45	17.43	I	I
	2.00	25.86	19.86	16.81	I	I
	5.00	22.75	17.98	15.99	I	I
3.72	.00	-----	-----	25.58	22.63	17.01
	2.00	-----	-----	25.07	21.41	17.61
	5.00	-----	-----	22.42	20.08	16.42

EPSI	BETA'	ALFA .57	.69	.76	.92	1.15	1.37	1.72	1.91	2.29	2.86	
.37	.00	~~5.60~~	5.55	5.05	I	I	I	I	I	I	I	
	1.00	~~3.96~~	3.75	2.30	I	I	I	I	I	I	I	
.50	.00	-----	-----	8.05	7.00	4.90	I	I	I	I	I	humid
	1.00	-----	-----	4.00	4.70	5.70	I	I	I	I	I	condition
.74	.00	-----	-----	-----	-----	9.90	8.55	6.45	I	I	I	
	1.00	-----	-----	-----	-----	6.95	8.00	6.03	I	I	I	
	2.00	-----	-----	-----	-----	8.20	7.53	6.13	I	I	I	fugtig
1.24	.00	-----	-----	-----	-----	-----	-----	-----	11.29	9.25	5.95	tilstand
	1.00	-----	-----	-----	-----	-----	-----	-----	11.15	8.34	6.28	
	2.00	-----	-----	-----	-----	-----	-----	-----	10.46	7.04	6.13	
	3.50	-----	-----	-----	-----	-----	-----	-----	10.50	6.60	6.60	

EPSI	BETA'	ALFA 3.81	4.57	5.71	6.84	8.53
2.48	.00	8.39	8.01	6.60	I	I
	2.00	8.27	7.75	6.11	I	I
	5.00	7.54	7.52	5.61	I	I
3.72	.00	-----	-----	8.98	8.78	6.22
	2.00	-----	-----	8.70	8.95	6.32
	5.00	-----	-----	8.41	9.08	6.73

Table A.1 Reflection tables for samples No. 63.

Refleksionstabeller for prøve nr. 63.

```
       ALFA   .57    .69    .76    .92   1.15   1.37   1.72   1.91   2.29   2.86
EPSI BETA'
 .37   .?? 19.25 20.20 18.00     I      I      I      I      I      I      I
       1.20  6.??  13.85 15.35    I      I      I      I      I      I      I

 .50   .??  ----- ----- 21.00 18.80 14.00     I      I      I      I      I
       1.??  ----- ----- 13.65 15.25 13.55     I      I      I      I      I

 .74   .??  ----- ----- ----- ----- 23.85 18.35 15.94     I      I      I
       1.??  ----- ----- ----- ----- 17.65 16.90 14.69     I      I      I
       2.??  ----- ----- ----- ----- 20.30 16.18 14.48     I      I      I

1.24   .??  ----- ----- ----- ----- ----- ----- ----- 23.92 18.81 15.99
       1.??  ----- ----- ----- ----- ----- ----- ----- 22.84 18.46 15.59
       2.??  ----- ----- ----- ----- ----- ----- ----- 22.24 19.87 14.92
       3.5?  ----- ----- ----- ----- ----- ----- ----- 20.92 18.19 15.13
```

dry
condition

tør
tilstand

```
       ALFA  3.81   4.57   5.71   6.84   8.53
EPSI BETA'
2.48   .?? 22.43 19.41 15.54     I      I
       2.?? 22.78 18.97 15.63     I      I
       5.?? 19.50 18.30 14.88     I      I

3.72   .?? ----- ----- 20.12 18.18 15.19
       2.?? ----- ----- 21.54 17.65 15.11
       5.?? ----- ----- 18.49 16.28 15.99
```

```
       ALFA   .57    .69    .76    .92   1.15   1.37   1.72   1.91   2.29   2.86
EPSI BETA'
 .37   .?? 7.?? 10.00 10.20     I      I      I      I      I      I      I
       1.?? 6.?? 7.55  8.35     I      I      I      I      I      I      I

 .50   .??  ----- ----- 12.85 10.65  9.00     I      I      I      I      I
       1.??  ----- ----- 8.70  9.05  8.20     I      I      I      I      I

 .74   .??  ----- ----- ----- ----- 12.85 10.64  8.44     I      I      I
       1.??  ----- ----- ----- ----- 10.95  9.68  8.42     I      I      I
       2.??  ----- ----- ----- ----- 12.05 10.02  8.20     I      I      I

1.24   .??  ----- ----- ----- ----- ----- ----- ----- 11.88 10.44  8.70
       1.??  ----- ----- ----- ----- ----- ----- ----- 11.41 10.68  8.83
       2.??  ----- ----- ----- ----- ----- ----- ----- 11.55 10.32  9.69
       3.5?  ----- ----- ----- ----- ----- ----- ----- 11.60 10.01  8.60
```

humid
condition

fugtig
tilstand

```
       ALFA  3.81   4.57   5.71   6.84   8.53
EPSI BETA'
2.48   .?? 11.18  9.48  7.16     I      I
       2.?? 10.95  9.82  7.30     I      I
       5.??  9.28  8.59  7.27     I      I

3.72   .?? ----- ----- 11.84 10.15  8.74
       2.?? ----- ----- 10.66  9.96  8.91
       5.?? ----- -----  9.66  9.52  8.16
```

Table A.2 Reflection tables for sample No. 601.

Refleksionstabeller for prøve nr. 601.

EPSI	BETA'	.57	.69	.76	.92	1.15	1.37	1.72	1.91	2.29	2.86
.37	.00	~~17.60~~	21.80	17.85	I	I	I	I	I	I	I
	1.00	~~13.48~~	15.05	14.25	I	I	I	I	I	I	I
.50	.00	-----	-----	22.00	17.35	13.55	I	I	I	I	I
	1.00	-----	-----	16.40	14.30	12.55	I	I	I	I	I
.74	.00	-----	-----	-----	-----	21.55	19.19	15.19	I	I	I
	1.00	-----	-----	-----	-----	18.00	17.89	14.58	I	I	I
	2.00	-----	-----	-----	-----	18.95	16.77	14.14	I	I	I
1.24	.00	-----	-----	-----	-----	-----	-----	-----	24.53	20.19	17.38
	1.30	-----	-----	-----	-----	-----	-----	-----	23.65	19.98	16.62
	2.30	-----	-----	-----	-----	-----	-----	-----	23.25	20.02	16.81
	3.50	-----	-----	-----	-----	-----	-----	-----	22.84	19.38	16.63

dry condition

tør tilstand

EPSI	BETA'	3.81	4.57	5.71	6.84	8.53
2.48	.00	19.37	16.33	13.64	I	I
	2.00	19.42	16.53	14.05	I	I
	5.00	17.98	15.80	13.18	I	I
3.72	.00	-----	-----	24.68	21.69	17.43
	2.00	-----	-----	24.07	21.72	17.99
	5.30	-----	-----	22.37	21.01	17.97

EPSI	BETA'	.57	.69	.76	.92	1.15	1.37	1.72	1.91	2.29	2.86
.37	.00	~~N.80~~	7.05	6.33	I	I	I	I	I	I	I
	1.00	~~5.51~~	5.60	5.00	I	I	I	I	I	I	I
.50	.00	-----	-----	7.75	5.15	3.05	I	I	I	I	I
	1.00	-----	-----	5.25	4.30	3.08	I	I	I	I	I
.74	.00	-----	-----	-----	-----	7.80	6.51	3.80	I	I	I
	1.00	-----	-----	-----	-----	6.30	5.84	3.95	I	I	I
	2.00	-----	-----	-----	-----	6.15	5.88	3.68	I	I	I
1.24	.00	-----	-----	-----	-----	-----	-----	-----	9.68	7.23	5.13
	1.00	-----	-----	-----	-----	-----	-----	-----	9.75	6.76	4.83
	2.00	-----	-----	-----	-----	-----	-----	-----	8.96	5.96	4.65
	3.50	-----	-----	-----	-----	-----	-----	-----	9.03	6.58	4.69

humid condition

fugtig tilstand

EPSI	BETA'	3.81	4.57	5.71	6.84	8.53
2.48	.00	9.58	6.98	5.64	I	I
	2.00	9.96	7.59	5.91	I	I
	5.30	8.56	6.98	5.61	I	I
3.72	.00	-----	-----	8.61	6.99	5.41
	2.00	-----	-----	8.90	6.60	5.87
	5.00	-----	-----	8.56	6.17	5.36

Table A.3 Reflection tables for sample No. 609.

Refleksionstabeller for prøve nr. 609.

dry condition

tør tilstand

EPSI	BETA'	.57	.69	.76	.92	1.15	1.37	1.72	1.91	2.29	2.86
.37	.00	~~17.40~~	28.15	25.70	I	I	I	I	I	I	I
	1.00	~~11.72~~	19.10	19.45	I	I	I	I	I	I	I
.50	.00	-----	-----	34.10	30.90	25.60	I	I	I	I	I
	1.00	-----	-----	21.40	22.50	22.60	I	I	I	I	I
.74	.00	-----	-----	-----	-----	36.20	29.30	22.84	I	I	I
	1.00	-----	-----	-----	-----	26.75	27.12	22.75	I	I	I
	2.00	-----	-----	-----	-----	30.25	26.71	22.13	I	I	I
1.24	.00	-----	-----	-----	-----	-----	-----	-----	30.81	25.96	21.70
	1.00	-----	-----	-----	-----	-----	-----	-----	29.63	25.12	20.44
	2.00	-----	-----	-----	-----	-----	-----	-----	26.61	24.93	20.63
	3.50	-----	-----	-----	-----	-----	-----	-----	27.74	24.36	21.26

EPSI	BETA'	3.81	4.57	5.71	6.84	8.53
2.48	.00	23.04	19.71	16.01	I	I
	2.00	22.94	19.33	16.67	I	I
	5.00	19.74	17.68	14.62	I	I
3.72	.00	-----	-----	25.82	22.49	18.31
	2.00	-----	-----	25.58	22.41	17.24
	5.00	-----	-----	23.88	20.18	16.26

humid condition

fugtig tilstand

EPSI	BETA'	.57	.69	.76	.92	1.15	1.37	1.72	1.91	2.29	2.86
.37	.00	~~9.60~~	14.75	14.00	I	I	I	I	I	I	I
	1.00	~~7.65~~	11.00	11.45	I	I	I	I	I	I	I
.50	.00	-----	-----	18.50	14.15	11.90	I	I	I	I	I
	1.00	-----	-----	13.65	12.00	12.10	I	I	I	I	I
.74	.00	-----	-----	-----	-----	17.30	13.17	11.73	I	I	I
	1.00	-----	-----	-----	-----	14.20	12.41	11.54	I	I	I
	2.00	-----	-----	-----	-----	16.70	12.33	11.67	I	I	I
1.24	.00	-----	-----	-----	-----	-----	-----	-----	14.71	15.51	12.54
	1.00	-----	-----	-----	-----	-----	-----	-----	14.36	15.35	12.96
	2.00	-----	-----	-----	-----	-----	-----	-----	14.03	15.71	13.70
	3.50	-----	-----	-----	-----	-----	-----	-----	13.78	15.43	13.24

EPSI	BETA'	3.81	4.57	5.71	6.84	8.53
2.48	.00	13.87	10.27	10.10	I	I
	2.00	13.51	10.78	9.68	I	I
	5.00	13.96	10.95	14.43	I	I
3.72	.00	-----	-----	11.22	8.75	8.31
	2.00	-----	-----	10.69	8.92	7.83
	5.00	-----	-----	12.09	8.73	7.69

Table A.4 Reflection tables for sample No. 460.

Refleksionstabeller for prøve nr. 460.

EPSI	BETA'	ALFA .57	.69	.76	.92	1.15	1.37	1.72	1.91	2.29	2.86	
.37	.00	~~12.00~~	15.70	11.50	I	I	I	I	I	I	I	
	1.00	~~9.70~~	11.55	10.15	I	I	I	I	I	I	I	
.50	.00	-----	-----	14.35	10.20	10.35	I	I	I	I	I	dry
	1.00	-----	-----	10.90	9.30	9.15	I	I	I	I	I	condition
.74	.00	-----	-----	-----	-----	20.55	14.88	11.62	I	I	I	
	1.00	-----	-----	-----	-----	16.25	14.69	11.37	I	I	I	
	2.00	-----	-----	-----	-----	17.95	14.83	11.25	I	I	I	
1.24	.00	-----	-----	-----	-----	-----	-----	-----	21.69	17.31	13.74	tør
	1.00	-----	-----	-----	-----	-----	-----	-----	19.96	16.72	13.58	tilstand
	2.00	-----	-----	-----	-----	-----	-----	-----	19.17	16.70	14.18	
	3.50	-----	-----	-----	-----	-----	-----	-----	19.67	16.78	13.63	

EPSI	BETA'	ALFA 3.81	4.57	5.71	6.84	8.53
2.48	.00	21.28	20.37	16.06	I	I
	2.00	20.98	20.58	16.90	I	I
	5.00	19.72	18.86	15.41	I	I
3.72	.00	-----	-----	23.10	19.41	15.69
	2.00	-----	-----	22.21	20.20	15.44
	5.00	-----	-----	20.42	19.35	13.78

EPSI	BETA'	ALFA .57	.69	.76	.92	1.15	1.37	1.72	1.91	2.29	2.86	
.37	.00	~~3.85~~	8.65	4.85	I	I	I	I	I	I	I	
	1.00	~~2.90~~	4.55	4.60	I	I	I	I	I	I	I	
.50	.00	-----	-----	7.90	5.95	3.40	I	I	I	I	I	humid
	1.00	-----	-----	4.60	5.35	2.90	I	I	I	I	I	condition
.74	.00	-----	-----	-----	-----	7.20	5.67	3.67	I	I	I	
	1.00	-----	-----	-----	-----	6.50	5.92	3.88	I	I	I	
	2.00	-----	-----	-----	-----	7.20	7.10	3.43	I	I	I	
1.24	.00	-----	-----	-----	-----	-----	-----	-----	6.86	7.16	5.40	fugtig
	1.00	-----	-----	-----	-----	-----	-----	-----	6.77	6.58	5.85	tilstand
	2.00	-----	-----	-----	-----	-----	-----	-----	6.31	6.58	5.97	
	3.50	-----	-----	-----	-----	-----	-----	-----	6.20	6.71	5.26	

EPSI	BETA'	ALFA 3.81	4.57	5.71	6.84	8.53
2.48	.00	8.69	7.95	6.40	I	I
	2.00	8.42	7.72	6.49	I	I
	5.00	8.23	7.76	6.55	I	I
3.72	.00	-----	-----	10.31	7.66	6.97
	2.00	-----	-----	10.29	7.95	7.29
	5.00	-----	-----	9.30	7.76	6.67

Table A.5 Reflection tables for sample No. 617.

Refleksionstabeller for prøve nr. 617.

```
     ALFA   .57   .69   .76   .92  1.15  1.37  1.72  1.91  2.29  2.86
EPSI BETA'
 .37  .00  11.30 17.50 16.35   I     I     I     I     I     I     I
      1.00  8.76 11.15 11.90   I     I     I     I     I     I     I

 .50  .00  ----- ----- 20.90 18.45 16.05   I     I     I     I     I
      1.00  ----- ----- 13.45 13.60 15.55   I     I     I     I     I

 .74  .00  ----- ----- ----- ----- 22.50 18.96 16.04   I     I     I
      1.00  ----- ----- ----- ----- 17.05 18.56 15.70   I     I     I
      2.00  ----- ----- ----- ----- 20.75 17.79 16.32   I     I     I

1.24  .00  ----- ----- ----- ----- ----- ----- ----- 23.49 15.57 16.46
      1.00  ----- ----- ----- ----- ----- ----- ----- 22.21 16.65 16.52
      2.00  ----- ----- ----- ----- ----- ----- ----- 21.64 19.10 16.09
      3.50  ----- ----- ----- ----- ----- ----- ----- 20.75 17.90 16.65
```

dry condition

tør tilstand

```
     ALFA  3.81  4.57  5.71  6.84  8.53
EPSI BETA'
2.48  .00  22.54 19.38 16.11   I     I
      2.00  22.31 19.47 17.69   I     I
      5.00  20.28 17.62 15.24   I     I

3.72  .00  ----- ----- 22.35 19.22 16.49
      2.00  ----- ----- 22.13 19.26 16.23
      5.00  ----- ----- 19.95 18.38 15.21
```

```
     ALFA   .57   .69   .76   .92  1.15  1.37  1.72  1.91  2.29  2.86
EPSI BETA'
 .37  .00   8.50  7.30  5.40   I     I     I     I     I     I     I
      1.00  7.90  5.10  4.55   I     I     I     I     I     I     I

 .50  .00  ----- -----  6.95  7.40  6.60   I     I     I     I     I
      1.00  ----- -----  5.05  5.80  6.60   I     I     I     I     I

 .74  .00  ----- ----- ----- -----  7.65  7.34  5.99   I     I     I
      1.00  ----- ----- ----- -----  6.90  6.96  6.18   I     I     I
      2.00  ----- ----- ----- -----  8.75  7.14  5.76   I     I     I

1.24  .00  ----- ----- ----- ----- ----- ----- -----  7.43  7.42  6.37
      1.00  ----- ----- ----- ----- ----- ----- -----  7.33  7.50  5.84
      2.00  ----- ----- ----- ----- ----- ----- -----  6.41  7.52  6.11
      3.50  ----- ----- ----- ----- ----- ----- -----  6.77  7.40  5.67
```

humid condition

fugtig tilstand

```
     ALFA  3.81  4.57  5.71  6.84  8.53
EPSI BETA'
2.48  .00   7.67  6.66  5.67   I     I
      2.00  7.93  6.61  6.90   I     I
      5.00  6.51  6.21  5.62   I     I

3.72  .00  ----- -----  7.13  7.36  6.84
      2.00  ----- -----  7.19  7.27  6.76
      5.00  ----- -----  7.04  6.93  6.67
```

Table A.6 Reflection tables for sample No. 87.

Refleksionstabeller for prøve nr. 87.

ALFA	.57	.69	.76	.92	1.15	1.37	1.72	1.91	2.29	2.86	
EPSI BETA'											
.37 .00	~~1.70~~	8.60	8.60	I	I	I	I	I	I	I	
1.00	~~1.48~~	5.40	6.40	I	I	I	I	I	I	I	
.50 .00	-----	-----	12.25	10.30	8.25	I	I	I	I	I	
1.00	-----	-----	7.40	7.30	7.70	I	I	I	I	I	dry condition
.74 .00	-----	-----	-----	-----	12.05	11.63	8.86	I	I	I	
1.00	-----	-----	-----	-----	5.15	9.95	8.56	I	I	I	
2.00	-----	-----	-----	-----	10.95	10.12	8.42	I	I	I	tør tilstand
1.24 .00	-----	-----	-----	-----	-----	-----	-----	13.97	11.42	9.63	
1.00	-----	-----	-----	-----	-----	-----	-----	13.59	10.61	9.33	
2.00	-----	-----	-----	-----	-----	-----	-----	13.14	10.27	9.30	
3.50	-----	-----	-----	-----	-----	-----	-----	12.24	10.18	8.76	

ALFA	3.81	4.57	5.71	6.84	8.53
EPSI BETA'					
2.48 .00	13.48	10.12	8.42	I	I
2.00	12.82	9.68	8.47	I	I
5.00	11.98	8.92	7.60	I	I
3.72 .00	-----	-----	13.43	11.98	8.87
2.00	-----	-----	12.31	10.12	8.40
5.00	-----	-----	11.12	9.67	8.32

ALFA	.57	.69	.76	.92	1.15	1.37	1.72	1.91	2.29	2.86	
EPSI BETA'											
.37 .00	~~1.88~~	2.05	1.90	I	I	I	I	I	I	I	
1.00	~~.29~~	.95	~~.75~~	I	I	I	I	I	I	I	
.50 .00	-----	-----	2.15	1.70	2.05	I	I	I	I	I	
1.00	-----	-----	~~.36~~	~~.76~~	1.65	I	I	I	I	I	humid condition
.74 .00	-----	-----	-----	-----	3.20	2.19	2.32	I	I	I	
1.00	-----	-----	-----	-----	2.20	2.35	2.43	I	I	I	
2.00	-----	-----	-----	-----	2.85	2.52	1.92	I	I	I	fugtig tilstand
1.24 .00	-----	-----	-----	-----	-----	-----	-----	2.46	2.75	1.75	
1.00	-----	-----	-----	-----	-----	-----	-----	2.32	2.18	2.20	
2.00	-----	-----	-----	-----	-----	-----	-----	2.52	1.72	1.92	
3.50	-----	-----	-----	-----	-----	-----	-----	2.47	1.67	1.44	

ALFA	3.81	4.57	5.71	6.84	8.53
EPSI BETA'					
2.48 .00	2.34	1.61	1.12	I	I
2.00	2.28	1.62	1.29	I	I
5.00	1.98	1.35	.91	I	I
3.72 .00	-----	-----	2.03	2.05	1.10
2.00	-----	-----	1.52	2.29	1.19
5.00	-----	-----	1.48	1.77	~~.45~~

Table A.7 Reflection tables for sample No. 90.

Refleksionstabeller for prøve nr. 90.

	ALFA	.57	.69	.76	.92	1.15	1.37	1.72	1.91	2.29	2.86
EPSI	BETA'										
.37	.00	9.78	12.95	13.90	I	I	I	I	I	I	I
	1.00	9.46	8.70	10.90	I	I	I	I	I	I	I
.52	.00	-----	-----	16.00	13.75	13.10	I	I	I	I	I
	1.00	-----	-----	10.55	10.40	12.35	I	I	I	I	I
.74	.00	-----	-----	-----	-----	16.15	14.71	11.81	I	I	I
	1.00	-----	-----	-----	-----	12.60	13.33	11.67	I	I	I
	2.70	-----	-----	-----	-----	14.45	13.23	11.41	I	I	I
1.24	.00	-----	-----	-----	-----	-----	-----	-----	15.30	13.67	11.55
	1.00	-----	-----	-----	-----	-----	-----	-----	14.69	12.99	11.59
	2.00	-----	-----	-----	-----	-----	-----	-----	14.64	13.42	10.93
	3.50	-----	-----	-----	-----	-----	-----	-----	14.43	13.07	10.90

dry condition

tør tilstand

	ALFA	3.81	4.57	5.71	6.84	8.53
EPSI	BETA'					
2.48	.00	14.37	12.74	10.26	I	I
	2.00	13.99	12.64	10.16	I	I
	5.00	12.70	11.62	10.20	I	I
3.72	.00	-----	-----	14.01	12.18	9.79
	2.00	-----	-----	13.71	12.05	9.21
	5.00	-----	-----	12.91	11.14	9.31

	ALFA	.57	.69	.76	.92	1.15	1.37	1.72	1.91	2.29	2.86
EPSI	BETA'										
.37	.00	2.68	4.15	4.15	I	I	I	I	I	I	I
	1.00	2.20	2.70	2.90	I	I	I	I	I	I	I
.50	.00	-----	-----	6.85	4.85	4.15	I	I	I	I	I
	1.00	-----	-----	5.75	4.00	3.85	I	I	I	I	I
.74	.00	-----	-----	-----	-----	5.20	2.82	2.84	I	I	I
	1.00	-----	-----	-----	-----	3.90	2.56	3.11	I	I	I
	2.30	-----	-----	-----	-----	5.00	3.08	2.03	I	I	I
1.24	.00	-----	-----	-----	-----	-----	-----	-----	3.72	3.64	2.27
	1.00	-----	-----	-----	-----	-----	-----	-----	3.60	3.47	3.20
	2.00	-----	-----	-----	-----	-----	-----	-----	3.79	3.64	2.87
	3.50	-----	-----	-----	-----	-----	-----	-----	3.81	2.26	2.42

humid condition

fugtig tilstand

	ALFA	3.81	4.57	5.71	6.84	8.53
EPSI	BETA'					
2.48	.00	2.66	2.48	1.81	I	I
	2.00	2.30	2.66	1.55	I	I
	5.00	2.34	2.61	1.77	I	I
3.72	.00	-----	-----	2.75	3.30	2.09
	2.00	-----	-----	3.14	2.26	2.33
	5.00	-----	-----	3.02	2.11	2.64

Table A.8 Reflection tables for sample No. 176.

Refleksionstabeller for prøve nr. 176.

EPSI	BETA'	ALFA .57	.69	.76	.92	1.15	1.37	1.72	1.91	2.29	2.86	
.37	.00	~~3.65~~	14.65	14.20	I	I	I	I	I	I	I	
	1.00	~~8.44~~	9.95	9.00	I	I	I	I	I	I	I	
.50	.00	-----	-----	16.95	15.00	12.20	I	I	I	I	I	dry
	1.00	-----	-----	9.85	9.50	10.30	I	I	I	I	I	condition
.74	.00	-----	-----	-----	-----	16.85	14.97	11.30	I	I	I	
	1.00	-----	-----	-----	-----	13.00	13.67	10.83	I	I	I	tør
	2.00	-----	-----	-----	-----	15.15	13.45	10.94	I	I	I	tilstand
1.24	.00	-----	-----	-----	-----	-----	-----	-----	17.75	14.76	11.85	
	1.00	-----	-----	-----	-----	-----	-----	-----	17.27	14.14	11.86	
	2.00	-----	-----	-----	-----	-----	-----	-----	15.62	14.25	11.66	
	3.50	-----	-----	-----	-----	-----	-----	-----	15.39	13.55	11.79	

EPSI	BETA'	ALFA 3.81	4.57	5.71	6.84	8.53
2.48	.00	15.29	13.84	11.33	I	I
	2.00	16.01	13.07	11.11	I	I
	5.00	14.62	12.25	10.41	I	I
3.72	.00	-----	-----	16.01	12.96	10.71
	2.00	-----	-----	15.16	13.26	11.27
	5.00	-----	-----	14.10	12.24	9.79

EPSI	BETA'	ALFA .57	.69	.76	.92	1.15	1.37	1.72	1.91	2.29	2.86	
.37	.00	~~3.30~~	5.80	5.85	I	I	I	I	I	I	I	
	1.00	~~4.02~~	4.35	5.10	I	I	I	I	I	I	I	
.50	.00	-----	-----	7.45	6.70	6.15	I	I	I	I	I	humid
	1.00	-----	-----	5.95	5.20	5.15	I	I	I	I	I	condition
.74	.00	-----	-----	-----	-----	7.55	6.96	4.62	I	I	I	
	1.00	-----	-----	-----	-----	6.20	6.62	4.29	I	I	I	fugtig
	2.00	-----	-----	-----	-----	6.80	6.38	4.32	I	I	I	tilstand
1.24	.00	-----	-----	-----	-----	-----	-----	-----	6.17	5.43	4.65	
	1.00	-----	-----	-----	-----	-----	-----	-----	5.67	6.20	4.53	
	2.00	-----	-----	-----	-----	-----	-----	-----	5.62	5.96	4.19	
	3.50	-----	-----	-----	-----	-----	-----	-----	5.64	5.59	4.41	

EPSI	BETA'	ALFA 3.81	4.57	5.71	6.84	8.53
2.48	.00	5.62	4.58	3.22	I	I
	2.00	5.28	4.48	3.38	I	I
	5.00	5.33	4.49	3.61	I	I
3.72	.00	-----	-----	4.72	3.80	3.08
	2.00	-----	-----	4.23	3.74	2.91
	5.00	-----	-----	4.21	3.45	2.66

Table A.9 Reflection tables for sample No. 177.

Refleksionstabeller for prøve nr. 177.

EPSI	BETA'	ALFA .57	.69	.76	.92	1.15	1.37	1.72	1.91	2.29	2.86
.37	.00	3̶.̶7̶0̶	12.85	12.30	I	I	I	I	I	I	I
	1.00	8̶.̶4̶5̶	8.70	9.65	I	I	I	I	I	I	I
.50	.00	-----	-----	17.65	15.80	12.75	I	I	I	I	I
	1.00	-----	-----	11.05	11.75	12.50	I	I	I	I	I
.74	.00	-----	-----	-----	-----	17.55	16.41	14.97	I	I	I
	1.00	-----	-----	-----	-----	12.85	15.46	13.88	I	I	I
	2.00	-----	-----	-----	-----	15.30	14.78	12.87	I	I	I
1.24	.00	-----	-----	-----	-----	-----	-----	-----	16.18	16.52	13.32
	1.00	-----	-----	-----	-----	-----	-----	-----	17.71	15.20	13.05
	2.00	-----	-----	-----	-----	-----	-----	-----	16.02	15.18	11.67
	3.50	-----	-----	-----	-----	-----	-----	-----	16.50	14.32	12.45

dry condition

tør tilstand

EPSI	BETA'	ALFA 3.81	4.57	5.71	6.84	8.53
2.48	.00	16.59	14.12	12.23	I	I
	2.00	16.01	13.82	11.99	I	I
	5.00	14.86	12.88	12.22	I	I
3.72	.00	-----	-----	16.21	13.57	11.48
	2.00	-----	-----	15.54	13.32	12.03
	5.00	-----	-----	13.76	13.26	11.09

EPSI	BETA'	ALFA .57	.69	.76	.92	1.15	1.37	1.72	1.91	2.29	2.86
.37	.00	5̶.̶3̶0̶	4.40	4.10	I	I	I	I	I	I	I
	1.00	1̶.̶0̶0̶	3.05	2.95	I	I	I	I	I	I	I
.50	.00	-----	-----	6.30	4.75	3.90	I	I	I	I	I
	1.00	-----	-----	4.20	3.10	3.60	I	I	I	I	I
.74	.00	-----	-----	-----	-----	6.25	4.74	3.37	I	I	I
	1.00	-----	-----	-----	-----	4.60	3.20	3.01	I	I	I
	2.00	-----	-----	-----	-----	5.40	3.24	2.96	I	I	I
1.24	.00	-----	-----	-----	-----	-----	-----	-----	5.54	3.42	2.93
	1.00	-----	-----	-----	-----	-----	-----	-----	5.53	3.41	2.66
	2.00	-----	-----	-----	-----	-----	-----	-----	5.14	3.49	3.19
	3.50	-----	-----	-----	-----	-----	-----	-----	4.46	3.68	3.45

humid condition

fugtig tilstand

EPSI	BETA'	ALFA 3.81	4.57	5.71	6.84	8.53
2.48	.00	3.83	3.66	3.00	I	I
	2.00	3.47	3.52	3.12	I	I
	5.00	3.33	3.88	3.10	I	I
3.72	.00	-----	-----	4.66	3.10	2.17
	2.00	-----	-----	4.06	3.24	2.41
	5.00	-----	-----	4.36	3.03	2.58

Table A.10 Reflection tables for sample No. 182.

Refleksionstabeller for prøve nr. 182.

APPENDIX B

A MODEL FOR THE SPECIFIC LUMINANCE OF ROAD
SURFACES
By Kai Sørensen, LTL

B.1 - Introductory remarks

In section B.2 is given a general expression for
the specific luminance, SL of road surfaces. The
only approximation in this expression is a disre-
garding of the interreflection in the texture of
the surface.

The assumption underlying the general expression
is that the surface can be divided into a large
number of small, plane facets. This total group
of facets is separated into subgroups, of which
one contains illuminated facets, another facets
that are visible, a third facets that are illumi-
nated and also visible, and finally a subgroup of
facets that are illuminated, but not visible.

The reflection properties of the facets are spec-
ified by luminance coefficients, whose values can
in principle vary from facet to facet and with the
geometry of illumination and observation. The orien-
tation of a facet is given by the cosines of the
angles between the normal of the plane of the facet
and the directions from the facet towards the head-
light and the observer. When these cosines are
large, the facet is said in more loose terms to
have a large inclination towards the headlight and
the observer (towards the vehicle).

In the following sections B.3 to B.6 are introduced
a number of modifications to the expression for SL.
These modifications lead to an expression for SL
consisting of four factors:

an average luminance coefficient of facets, $\bar{q}$

a factor of geometry, $f_{geometry}$

a factor of texture, $f_{texture}$

a factor of visible, illuminated facets, $f_{visible}$

The modifications are in themselves accurate, but useful only when the factors are interpreted in the following senses, which at the same time introduces approximations.

The average luminance coefficient reflects the lightness of the stone material in the surface and has a value of 0.01 to 0.3 say. The other factors all have values between zero and unity.

The factor of geometry is the ratio between the angles of illumination and observation. This factor reflects the major part of the influence of those angles on the SL-value.

The factor of texture is a measure of how large a part of the incident luminous flux that falls on facets of a large inclination. This factor has a value, which is a substantial fraction of unity.

The factor of visible, illuminated facets tells essentially, how large a fraction of the illuminated facets that are visible. This factor takes a value below unity, when the angle of observation is lower than the angle of illumination, or more interesting, when the supplemental azimuthal angle, β' differs from zero.

For all these factors there is in the relevant section a discussion of how the value relates to the geometry of illumination and observation and to the properties of the surface. Concerning the factor,

$f_{visible}$ it is necessary to introduce further natural
assumptions of the texture of the road surface in
order to derive the principal dependence on the
angles.

The above-mentioned discussion is based to some ex-
tent on the outcome of measurements. In particular
the modifications of the general expression for SL
are based on an observed influence of the angles
and on the rather high value of SL and thereby of
$f_{texture}$.

Otherwise the discussion is carried out on a gen-
eral, or speculative basis, with the aim of giving
a background for the understanding of road surface
reflection properties in vehicle headlight illumina-
tion, and a background for an interpretation of the
measurements.

This appendix has the further aim of showing that
the characteristics of SL-variations with the geo-
metry are not coincidences of some road surfaces,
but rather are caused by the special geometry of
illumination and observation.

B.2 - General expression for the specific luminance
A field on the road surface is chosen on basis of
the following considerations. On one hand the field
is to be of such dimensions compared to those of
the surface texture that the field represents the
surface adequately. The field must be so small, on
the other hand that the angles of the geometry, ε,
α and β' are approximately constant for all points
in the field.

This field of the surface defines a reference plane,
in relation to which the angles of geometry are de-
fined. The surface itself is, however, not plane,

but has a texture both on a macro-scale and a micro-scale. See fig. B.1.

A. FIELD ON THE ROAD SURFACE

   FELT PÅ VEJBELÆGNINGEN

B. THE REFERENCE PLANE OF THE FIELD

   FELTETS REFERENCE PLAN

Figure B.1 Choice of a field on the road surface.
The field has, on one hand, to be so
large as to represent the surface tex-
ture adequately, and, on the other hand,
so small compared to other dimensions of
the geometry that the angles of geometry
are constant for all points in the field.
The angles of the measuring geometry are
defined relatively to a reference plane.

Valg af felt på vejbelægningens overfla-
de. Feltet skal på den ene side være så
stort, så det repræsenterer overflade-
teksturen tilstrækkeligt godt, og på den
anden side så lille i sammenligning med
geometriens dimensioner, at geometriens
vinkler er konstante for alle punkter i
feltet.
Målegeometriens vinkler fastlægges relativt
til feltets reference plan.

In order to facilitate the discussion, the surface
is divided into small, plane facets. This division
has to be so fine that even the micro-texture of
the surface is split up into plane parts. The div-
ision further has to be so fine that it is a good
approximation to ignore phenomena of partly illumi-
nated or partly visible facets. See fig. B.2.

Figure B.2 The surface of the field is divided in-
to a number of small, plane facets. When
this division is sufficiently fine, any
facet is considered to be either fully
illuminated, or not illuminated at all,
and fully visible, or not visible at all.

Feltets overflade inddeles i et antal
små plane facetter. Når denne inddeling
er tilstrækkeligt fin, kan enhver facet
anses for at være enten fuldt belyst el-
ler overhovedet ikke belyst, samt fuldt
synlig, eller slet ikke synlig.

Hence a facet is considered to be either fully il-
luminated all over its surface or not illuminated
at all. Similarly, a facet is completely visible
or not visible at all.

The totality of facets in the field is numbered
from one to the total number of facets. The index,
i serves for this numbering and means, simultaneous-
ly, any facet in the field.

The reflection properties of a facet are described

by a luminance coefficient, q_i, which might in
principle vary with the angles of geometry. The
area of a facet is called a_i.

The important aspect of the orientation of a facet
is the orientation relative to the directions of
illumination and observation. The angles between
the normal of the facet and the directions of il-
lumination and observation are called respectively
u_i and v_i in the following. See fig. B.3 regarding
these angles and other properties of the facets.

FACET No. I

DIRECTION OF OBSERVATION

U_I V_I

DIRECTION OF ILLUMINATION

Figure B.3 The important aspects of the orienta-
tion of a facet (No. i) are the angles
u_i and v_i between the normal of the
facet and the directions of illumination
and observation.
Other properties of a facet are its area,
a_i and its luminance coefficient, q_i.

De vigtigste forhold ved orienteringen af
en facet (nr. i) er vinklerne u_i og v_i
mellem facettens normal og belysnings-
samt observationsretning.
Andre af facettens egenskaber er dens are-
al, a_i og dens luminanskoefficient, q_i.

A facet is illuminated, when it is inclined towards
the direction of illumination (when $\cos u_i > 0$),
with the further requirement that the facet is not
in the shadow of other facets.

The subgroup of illuminated facets is numbered from
one to the total number of such facets. For these
facets is used the index j.

As the number of illuminated facets clearly in-

creases, when the illumination angle increases, it
is assumed that the index j always refers to the
actual illumination angle and that the illuminated
facets are renumbered, when this angle changes.

The illuminance on an illuminated facet is called
E_j and found by:

$$E_j = E_\perp \cdot \cos u_j$$

where $E_\perp$ is the illuminance on a plane perpendicu-
lar to the direction of illumination at the posi-
tion of the facet.

To the illuminance $E_\perp$ is remarked that the value
is taken to be the same for all illuminated facets
due to the assumption of a small field.

The illuminance on facets that are not directly
illuminated is taken to be 0. This assumption and
the expression for E_j given above shows that il-
lumination by interreflection among the facets is
disregarded. The validity of this simplification
is discussed in section B.5.

The luminous flux, ϕ_j on an illuminated facet is
found by:

$$\phi_j = a_j \cdot E_j = E_\perp \cdot a_j \cdot \cos u_j$$

Thus the total luminous flux falling on the field,
ϕ is:

$$\phi = E_\perp \cdot \sum_j a_j \cdot \cos u_j$$

where the summation is for all illuminated facets
(the subgroup of index j).

The total luminoux flux can, however, also be computed by means of the illumination angle ε and the area, A of the reference plane of the field:

$$\phi = E_\perp \cdot A \cdot \sin\varepsilon = E_\perp \cdot \sum_j a_j \cdot \cos u_j$$

This shows that:

$$\sum_j a_j \cdot \cos u_j = A \cdot \sin\varepsilon$$

It is convenient for later use to introduce a normalized area, a'_i, of facets by means of:

$$a'_i = a_i / (A \cdot \sin\varepsilon)$$

Hence it is obtained that $a'_j \cdot \cos u_j$ means the fraction of the incident luminous flux that falls on facet No. j and that the sum of these fractions equals unity as shown below:

$$\sum_j a'_j \cdot \cos u_j = \frac{1}{A \cdot \sin\varepsilon} \sum_j a_j \cdot \cos u_j = 1$$

Only facets that are visible contribute to the luminance, L of the field as seen by the observer. Also this subgroup of facets is assumed to be numbered and to be distinguished by a special index, k running from one to the total number of such facets. This subgroup is further assumed to be redefined and renumbered each time the observation angle is changed. See fig. B.4.

The luminance of a visible facet, L_k is given by:

$$L_k = \begin{cases} q_k \cdot E_k & \text{if the facet is illuminated} \\ & \text{(belongs also to the group} \\ & \text{with index j)} \\ 0 & \text{otherwise} \end{cases}$$

This shows that it is convenient to introduce the
further subgroup of facets that are illuminated and
also visible. This subgroup is distinguished by the
index l and is to be redefined at any change in the
geometry of illumination and observation.

Figure B.4 A facet is illuminated, when it is in-
clined towards the headlight (when
$\cos u_i > 0$) and simultaneously not in the
shadow of other facets.
Similarly a facet is visible, when it
is inclined towards the observer (when
$\cos v_i > 0$) and simultaneously not hidden
behind other facets.
Illuminated facets are given the index j,
visible facets the index k, while facets
that are both illuminated and visible
are given the index l.

En facet er belyst, når den hælder i-
mod billygten (når $\cos u_i > 0$) og samtidigt
ikke ligger i skyggen af andre facetter.
Tilsvarende er en facet synlig, når den
hælder mod observatøren (når $\cos v_i > 0$) og
samtidig ikke er skjult bag andre facet-
ter.
Belyste facetter gives indekset j, syn-
lige facetter indekset k, mens facetter,
som er både belyste og synlige gives in-
dekset l.

As the apparent area of a visible facet is $a_k \cdot \cos v_k$
the total intensity I of light reflected towards
the observer, is:

$$I = \sum_k \cdot L_k \cdot a_k \cdot \cos v_k$$

$$= E_\perp \cdot A \cdot \sin \varepsilon \sum_l a'_l \cdot q_l \cdot \cos u_l \cdot \cos v_l$$

Further, the total apparent area of the field is
$A \cdot \sin \alpha$ and the luminance $L = I/(A \cdot \sin \alpha)$. Thus,
the specific luminance, SL is finally given by this
expression:

$$SL = \frac{L}{E_\perp} = \frac{I}{E_\perp \cdot A \cdot \sin \alpha}$$

$$\boxed{SL = \frac{\sin \varepsilon}{\sin \alpha} \cdot \sum_l a'_l \cdot q_l \cdot \cos u_l \cdot \cos v_l}$$

where the summation is for all facets that are
illuminated and also visible.

This expression is modified and interpreted in the
following sections. The derivation of the expres-
sion is summarized in fig. B.5.

B.3 - Average luminance coefficient
An average luminance coefficient, $\bar{q}$ is defined by:

$$\bar{q} \cdot \sum_l a'_l \cdot \cos u_l \cdot \cos v_l = \sum_l a'_l \cdot q_l \cdot \cos u_l \cdot \cos v_l$$

where the summations are for all facets that are
illuminated and also visible.

Introducing $\bar{q}$ into the expression for SL, this ex-
pression is changed into:

$$SL = \bar{q} \cdot \frac{\sin \varepsilon}{\sin \alpha} \cdot \sum_l a'_l \cdot \cos u_l \cdot \cos v_l$$

FACET, WHICH IS
ILLUMINATED AND VISIBLE

I_K = LUMINOUS INTENSITY

$E_\perp$ = ILLUMINANCE ON A PLANE
PERPENDICULAR TO THE DI-
RECTION OF ILLUMINATION

Figure B.5 The luminous intensity of reflected light from a facet, which is illuminated and visible, is:

$$I_k = E_\perp \cdot a_1 \cdot q_1 \cdot \cos u_1 \cdot \cos v_1$$

The total luminous intensity, I is obtained by summation for all facets of index 1, and the specific luminance can be computed:

$$SL = \frac{I}{A \cdot \sin\alpha} \cdot \frac{1}{E_\perp} = \frac{1}{A \cdot \sin\alpha} \Sigma a_1 \cdot q_1 \cdot \cos u_1 \cdot \cos v_1$$

$$\boxed{SL = \frac{\sin\varepsilon}{\sin\alpha} \cdot \Sigma a'_1 \cdot q_1 \cdot \cos u_1 \cdot \cos v_1}$$

where A is the area of the field measured in the reference plane, and $A \cdot \sin\alpha$ is the apparent area, and $a'_1 = a_1/(A \cdot \sin\varepsilon)$ is a normalized area of the facet.

Lysstyrken af det reflekterede lys fra en facet, som er både belyst og synlig, er:

$$I_k = E_\perp \cdot a_1 \cdot q_1 \cdot \cos u_1 \cdot \cos v_1$$

Den totale lysstyrke fra feltet, I fås ved summation for alle facetter med indeks k, og den specifikke luminans kan beregnes til:

$$SL = \frac{I}{A \cdot \sin\alpha} \cdot \frac{1}{E_\perp} = \frac{1}{A \cdot \sin\alpha} \Sigma a_1 \cdot q_1 \cdot \cos u_1 \cdot \cos v_1$$

$$\boxed{SL = \frac{\sin\varepsilon}{\sin\alpha} \cdot \Sigma a'_1 \cdot q_1 \cdot \cos u_1 \cdot \cos v_1}$$

hvor A er arealet af feltet målt i referenceplanet, og $A \cdot \sin\alpha$ er det tilsyneladende areal, og $a'_1 = a_1/(A \cdot \sin\varepsilon)$ er facettens normerede areal.

This modification of the expression for SL is a convenient one, when the value of $\bar{q}$ is relatively insensitive to variations in the geometry of illumination and observation.

One source for a variation of $\bar{q}$ with the geometry would be a possible variation of the individual q_1 of the facets.

It is, however, demonstrated in section B.5 that the major part of SL is caused by facets of a large inclination. For these facets the luminance coefficients are certainly determined mainly by a diffuse type of reflection, and the values are not likely to change significantly within the small angular ranges of the interesting geometries.

Therefore, $\bar{q}$ will hardly change significantly because of changes in the individual q_1.

Another source of variation of $\bar{q}$ could be a variation of the factors to the q_1 in the sums.

One of these factors is the scaled area of the facet a'_1, which changes with the angle of illumination, ε, see section B.2. As the a'_1 all changes by the same factor, these changes will not affect the value of $\bar{q}$.

The other factors are cosines, which for the facets of large contributions to SL have relatively large values. The rate of change of these cosines with the angles will, therefore, be small relative to the values of the cosines themselves.

The factors to the individual q_1 can, therefore, hardly introduce rapid changes in the value of $\bar{q}$.

The final possible source of variation of the value of $\bar{q}$ is the change of the subset of illuminated and

visible facets (those with index 1) that will re-
sult from a change in the geometry.

Clearly, a change in the subset of the facets is
not important, when all facets that can be illumi-
nated, have similar q_1. This is the case, when all
the stones in the surface are of a uniform and
similar lightness.

Further, a change in the subset of the facets is
not important, when facets of dissimilar q_1 are
placed randomly in the texture, so that their re-
lative populations do not change. Surfaces of this
property could have stones that are similar, but
each with patterns of lightness. Surfaces would have
this property also, even when the stones vary in
lightness, when only this variation is not coupled
with a systematic variation in size, shape or po-
sition in the surface.

Most road surfaces can, therefore, be expected to
have a $\bar{q}$, whose value reflects the lightness or
perhaps the average lightness of the stone material
in the surface, and whose value is relatively in-
sensitive to changes in the geometry of illumination
and observation.

Some surfaces will, on the other hand, show signifi-
cant changes in $\bar{q}$, but these changes relate in a na-
tural way to the properties of the surface. An example
of such a surface is shown in fig. B.6.

B.4 - Factor of geometry
The expression for SL contains a factor, which is
the ratio of the sinus of the illumination angle, ε
and the sinus of the observation angle, α.

This factor obviously changes with the lighting
geometry, and does, as it will appear from the fol-

DARK COLOURED BASE

LIGHT COLOURED STONES

A. A SURFACE WITH LIGHT COLOURED STONES IN A DARK COLOURED BASE

EN OVERFLADE MED LYSE STEN I EN MØRK MATRIX

ε

B. AT SMALL ILLUMINATION ANGLES, ε ONLY THE LIGHT COLOURED STONES ARE ILLUMINATED

VED SMÅ BELYSNINGSVINKLER, ε ER KUN DE LYSE STEN BELYSTE

ε

C. AT LARGE ILLUMINATION ANGLES, ε PARTS OF THE DARK COLOURED BASE ARE ILLUMINATED

VED STORE BELYSNINGSVINKLER, ε BELYSES DELE AF DEN MØRKE MATRIX

Figure B.6 The average luminance coefficient, $\bar{q}$ is an average of the luminance coefficients of facets that are illuminated and visible defined by:

$$\bar{q} \cdot \Sigma a'_1 \cdot \cos u_1 \cdot \cos v_1 = \Sigma a'_1 \cdot q_1 \cdot \cos u_1 \cdot \cos v_1$$

A surface with light coloured stones in a dark coloured base (fig. a.) will have a large $\bar{q}$ at small illumination angles (fig. b.) and a smaller $\bar{q}$ at large illumination angles (fig. c.).

Den gennemsnitlige luminanskoefficient, $\bar{q}$ er et gennemsnit af luminanskoefficienten for facetter, som er belyste og synlige:

$$\bar{q} \cdot \Sigma a'_1 \cdot \cos u_1 \cdot \cos v_1 = \Sigma a'_1 \cdot q_1 \cdot \cos u_1 \cdot \cos v_1$$

En overflade med lyse sten i en mørk matrix (fig. a.) vil have en høj $\bar{q}$ ved små belysningsvinkler (fig. b.) og en lavere $\bar{q}$ ved store belysningsvinkler (fig. c.).

lowing sections, account for the major part of the
influence of the geometry. An appropriate name for
this factor is, therefore, factor of geometry,
$f_{geometry}$:

$$f_{geometry} = \frac{\sin\varepsilon}{\sin\alpha} \cong \frac{\varepsilon}{\alpha} \cong \frac{H_h}{H_o} \cdot \frac{D_o}{D_h}$$

The factor of geometry is thus easily determined
from the geometry of illumination and observation.
At medium and large distances the factor further
approximately equals the ratio between the headlight
mounting height, H_h and the observer eye height, H_o:

$$f_{geometry} \cong \frac{H_h}{H_o} \quad \text{at medium and large distances}$$

A simple interpretation of this factor is given in
fig. B.7.

B.5 - Factor of texture
B.5.1 - Definition of the factor of texture
According to the previous sections, the expression
for SL reads as follows:

$$SL = \bar{q} \cdot f_{geometry} \cdot \sum_l a'_l \cdot \cos u_l \cdot \cos v_l$$

where the summation is for all facets that are il-
luminated and also visible.

The group of facets of index l can be thought of
as containing facets that are illuminated, exclud-
ing those facets that are illuminated, but not
visible. The first-mentioned group (illuminated
facets) has already been given the index j; the
last-mentioned group (illuminated, but not visible
facets) is given the index m.

ILLUMINATED
STONES OR FACETS

A. THE FIELD SEEN IN PERSPECTIVE
FROM THE POSITION OF THE
HEADLIGHT ($F_{GEOMETRY}$ = 1)

FELTET SET I PERSPEKTIV FRA
ET PUNKT VED LYGTEN
($F_{GEOMETRY}$ = 1)

SHADOWS BEHIND
ILLUMINATED STONES

B. THE FIELD SEEN IN PERSPECTIVE
FROM A POSITION ABOVE THE
HEADLIGHT ($F_{GEOMETRY}$ < 1)

FELTET SET I PERSPEKTIV FRA
ET PUNKT OVER LYGTEN
($F_{GEOMETRY}$ < 1)

<u>Figure B.7</u> The factor of geometry, $f_{geometry}$ = sinε/sinα approximately gives the fraction of the apparent area of the field, which is filled with illuminated facets.

Faktoren for geometrien, $f_{geometry}$ = sinε/sinα er med nogen tilnærmelse den brøkdel af feltets tilsyneladende areal, som er udfyldt med belyste facetter.

In this way, the SL expression is changed into:

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

where $f_{texture} = \sum_{j} a'_j \cdot \cos u_j \cdot \cos v_j$

and $f_{visible} = 1 - \frac{1}{f_{texture}} \cdot \sum_{m} a'_m \cdot \cos u_m \cdot \cos v_m$

The factor of visible, illuminated facets, $f_{visible}$ is discussed in the next section, while the factor of texture, $f_{texture}$ is the aim of discussion of this section.

B.5.2 - Range of variation of the factor of texture

In interpreting the expression for $f_{texture}$ it is to be recalled that the products of the first two factors of the terms are the fractions of the incident luminous flux that fall on the facets. The third factor is the cosine of the angle between the normal of the facet and the direction towards the observer. This cosine represents the inclination of the facet towards the observer.

Broadly speaking $f_{texture}$ is then the average inclination of facets towards the observer, as weighted by the incident luminous flux on the facets.

As the highest possible value of the third factor is unity, and as the sum of the weights (the product of the first two factors) is also unity, the highest possible value of $f_{texture}$ is unity.

The lowest possible value of the third factor is of course zero for a visible facet (otherwise the facet would not be visible). As the angular separation between the observer and the headlight is small in all interesting situations, the lower limit of the third factor is appr. zero also for all illuminated facets. For practical applications it is assumed, therefore, that the lower limit of $f_{texture}$ is zero:

$$0 \leq f_{texture} \leq 1$$

The value actually taken by $f_{texture}$ is obviously a matter of the texture of the surface, which explains the choice of name and notation for the factor. In principle the value can be a function of the geometry

also, as directions of illumination and observation
enter via the cosines of the terms of the sum, and
as the direction of illumination determines what
facets are to be included into the sum.

It is, therefore, perhaps somewhat surprising that
the results of measurements can be explained only by
assuming that $f_{texture}$ is roughly independent of
the geometry. It is further surprising that the
value of $f_{texture}$ is quite high, a substantial frac-
tion of unity, considering the large angles formed
between the normal of the reference plane of the
surface and the directions towards the headlight
and the observer.

The aim of the following is to explain these conclu-
sions of the measurements, pointing out that even
a smooth road surface has some texture, and that
the special geometry leads to a strong emphasis on
those facets that have an inclination towards the
vehicle. See fig. B.8.

B.5.3 - The factor of texture in relation to the surface texture

The most obvious surface to consider is a perfectly
plane and smooth (polished) surface.

For this surface $f_{texture}$ is as shown in fig. B.9
computed to $\sin\alpha$, and thus has a value of appr. 0.1
at short distances decreasing to appr. 0.01 at large
distances. The corresponding behaviour of SL would
be a low value decreasing to very small values at
large distances.

This behaviour of SL is in contradiction with the
measurements, which show larger values of SL that
are maintained even at large distances. The assump-
tion of a plane and smooth surface is even in strong
disagreement with the observations, as such a surface

FACET OF A
SMALL INCLI-
NATION

A. A FACET OF A SMALL INCLINATION HAS A SMALL CONTRIBU-
TION TO $F_{TEXTURE}$, AS $COSU_J$ AND $COSV_J$ ARE BOTH SMALL

EN FACET MED EN LILLE HÆLDNING GIVER ET LILLE BIDRAG
TIL $F_{TEXTURE}$, DA $COSU_J$ OG $COSV_J$ BEGGE ER SMÅ

FACET OF A
LARGE INCLI-
NATION

A. A FACET OF A LARGE INCLINATION TOWARDS THE VEHICLE
GIVES A RELATIVELY LARGE CONTRIBUTION TO $F_{TEXTURE}$,
AS $COSU_J$ AND $COSV_J$ ARE BOTH CLOSE TO UNITY

EN FACET MED EN STOR HÆLDNING MOD KØRETØJET GIVER
ET RELATIVT STORT BIDRAG TIL $F_{TEXTURE}$, DA $COSU_J$ OG
$COSV_J$ BEGGE HAR VÆRDIER TÆT PÅ EN

Figure B.8 The factor, $f_{texture}$ is the sum of
$a'_j \cdot cosu_j \cdot cosv_j$ for all illuminated
facets (index j). The maximum value is
unity. Facets of a small inclination to-
wards the vehicle gives a small contribu-
tion (fig. a.), while facets of a large
inclination gives a relatively large con-
tribution (fig. b.)

Faktoren, $f_{texture}$ er summen af
$a'_j \cdot cosu_j \cdot cosv_j$ for alle belyste facet-
ter (index j). Den maximale værdi er en.
Facetter med en lille hældning mod køre-
tøjet giver et lille bidrag (fig. a.),
mens facetter med en stor hældning giver
et relativt stort bidrag (fig. b.).

would show Fresnel-type properties with small values of $\bar{q}$ decreasing with distance.

The assumption of a plane and smooth surface is, therefore, not valid. This can be considered a good piece of furtune, as such a surface would have extremely low SL-values, in particular at large distances, and could hardly be given any useful luminance by headlight illumination.

Figure B.9 A perfectly plane and smooth surface is illuminated all over and has a cosv of $\cos(90^{o}-\alpha) = \sin\alpha$. Hence $f_{texture}$ is $\sin\alpha$ for this surface.

En fuldstændig plan og glat overflade er belyst på hele overfladen og har en cosv lig med $\cos(90^{o}-\alpha) = \sin\alpha$. Faktoren, $f_{texture}$ er således $\sin\alpha$ for denne overflade.

In the other extreme, one could consider a surface, in which all the illuminated facets are vertical and turned towards the observer and the headlight, see fig. B.10. This assumption leads to a $f_{texture}$, which in agreement with observations is independent of the geometry, but whose value is clearly to large, being close to unity.

A natural modification of this model of vertical facets is to assume that the illuminated facets are vertical but otherwise of a random orientation, e.i.: that they put together can form the front half of a vertical cylinder. Even with this modification the result remains essentially as given above. The

factor, $f_{texture}$ is approximately constant with a value reduced to 0,79, but still too large to explain observations.

Figure B.10 A surface, whose illuminated facets are all vertical and turned towards the observer, has facets of a cosv = cosα. Hence $f_{texture}$ = cosα ≅ 1 for interesting geometries.

En overflade, hvis belyste facetter alle er lodrette og orienteret imod observatøren, har facetter hvis cosv = cosα. Derfor er faktoren, $f_{texture}$ = cosα ≅ 1 for relevante geometrier.

A combination of the two extremes of respectively horizontal and vertical facets can give a better account of the observations.

Such a combined model could have vertical facets of a random orientation receiving say 40 % of the incident luminous flux and horizontal facets receiving the remaining 60 % of the luminous flux. In such a model the vertical facets will contribute a constant value of 0.30 to $f_{texture}$, while the horizontal facets will contribute a variable, but much smaller value.

For the vertical facets to receive 40 % of the luminous flux, their area needs to be quite small only (e.g. 2 % of the area of the horizontal facets at an illumination angle of 1°). Thus the dominating contribution of the vertical facets to $f_{texture}$ is achieved, even when they are not obviously important in the texture.

In a more realistic model one has to consider illumi-
nated facets of all possible angles. Such models are
not considered here in detail, but conclusions are
very similar to those given above, when "vertical
facets" are understood as facets with a large in-
clination and "horizontal facets" are understood as
facets with a small inclination.

In conclusion the special geometry of illumination
and observation will single out some facets of a
large inclination to receive a significant part of
the incident luminous flux and to give a dominant
contribution to $f_{texture}$ and thus to the SL of the
surface.

It appears from the discussion above that when a
constant fraction of the incident luminous flux
falls on facets of a large inclination, $f_{texture}$
will remain essentially constant.

This shows that $f_{texture}$ should to a good approxi-
mation be independent of the observation angle α
(and of the angle β'), since the illumination angle,
ε alone determines what facets are illuminated.

Obviously the fraction of luminous flux falling on
facets of a large inclination, must be roughly in-
dependent of the illumination angle ε also, as the
measurements can be explained by the assumption of
a roughly constant $f_{texture}$.

Intuitively one would think that facets of a large
inclination are found mainly in the lower parts of
the surface texture, and that these can be illumi-
nated at relatively large illumination angles only.
Hence one could expect a decrease in $f_{texture}$ at
decreasing illumination angles (at increasing dis-
tance).

This decrease in $f_{texture}$ with ε is, however, not
observed in general, which shows that even at small
ε the illumination of facets with large inclinations
does occur. One reason for this could be that such
facets exist also in the upper part of the texture,
perhaps due to micro-texture or to variations in the
size of stones. Another reason could be that the
random arrangement of the stones in the surface
leaves "paths" for light to penetrate down into the
texture even at small illumination angles.

It is thus to be concluded that $f_{texture}$ is rough-
ly independent of the angles of the geometry. This
leaves the factor $f_{geometry}$ to give the main account
of the influence of the angles ε and α. A further
influence of these angles is discussed in the next
section.

The factor, $f_{texture}$ can then be considered to be
a function mainly of the surface texture.

The important aspect of the texture is what fraction
of the luminous flux that will fall on facets of
a large inclination. This is a result of relative
proportions of the texture and not of the dimen-
sions of stones, edges etc.

The correlation between $f_{texture}$ and the tradition-
al measure of the texture by means of the texture
depth (sand-patch method) need, therefore, not to
be good.

This is probably the reason that some attempts to
correlate SL to the texture depth did not succeed.
However, different types of surfaces can have values
of $f_{texture}$ at different levels and also different
ranges of texture depths, thus giving an indirect
correlation. See Sørensen and Nielsen (1975) and
Mörkertrafik Report No. 2 (1978).

B.5.4 - Interreflections in the texture

The discussion above gives a clue as to why inter-
reflection in the texture has been ignored.

The fact that $f_{texture}$ is quite large, is a sign
that the direct illumination is effectively reflect-
ed back towards the observer. The name retroreflec-
tion used for SL at some occasions has in fact some
justification.

The reflected luminous flux does not posses this
efficiency, as it falls on the more numerous non-
visible facets as well as on visible facets. Only
a small fraction will fall on visible facets with
a large inclination towards the observer.

Further, the secondary luminous flux to fall on the
surface is reduced compared to the direct luminous
flux by reflection losses and by escape upwards,
away from the surface. The first-mentioned reduc-
tion is large for common, dark surfaces, while the
last-mentioned reduction must always be large.

For these reasons, interreflections in the texture
can hardly raise the SL of road surfaces by more
than a very small amount.

B.6 - Factor of illuminated, visible facets

B.6.1 - Definition of factor of illuminated, visible
        facets

In section B.5.1 was introduced a factor of illumi-
nated, visible facets, $f_{visible}$ defined by:

$$f_{visible} = 1 - \frac{1}{f_{texture}} \cdot \sum_m a'_m \cdot \cos u_m \cdot \cos v_m$$

where the summation is for all facets that are il-
luminated, but not visible.

When none of the illuminated facets are visible,

$f_{visible}$ has the lowest possible value of zero, and
when all of the illuminated facets are visible, the
highest possible value of unity is attained. Thus

$$0 \le f_{visible} \le 1$$

B.6.2 - The situation, when $\beta' \cong 0^{O}$ (as for a motorcyclist)

As illustrated in fig. B.11 an edge of an illuminated
facet has a shadow, which lies higher than the edge,
when $\alpha > \epsilon$ and also $\beta' = 0^{O}$. Therefore, in this
geometry there can be no illuminated facets hiding
below the edge, i.e.: behind the facet.

A facet, which is in the shadow behind other facets,
cannot either hide an illuminated facet, because
the argument given above applies, if the facets in
the front are removed.

Further, a facet, which is not inclined towards the
headlight, will always be in the shadow of other
facets, which are inclined towards the headlight.
It is, therefore, also impossible for such facets
to hide an illuminated facet.

As there are no facets that do not belong to one
of the above-mentioned categories, it is concluded
that for $\alpha > \epsilon$ and $\beta' = 0^{O}$ all illuminated facets
are visible, and hence:

$$f_{visible} = 1 \quad \text{for } \alpha > \epsilon, \text{ when also } \beta' = 0^{O}$$

An implicit assumption behind fig. B.11 is that all
free edges in the texture (those that define con-
tours of stones) are at most vertical. This seems
a reasonable assumption, as the texture should other-
wise show paths for illumination, which have "roofs"
as for instance shown by a hole in a stone or by an
overhang. It is possible that such paths can occa-
sionally be found, but hardly in numbers to signifi-

cantly reduce the validity of the statement given above.

SHADOW ON A BACKGROUND IN A
DISTANCE, S BEHIND THE EDGE

$S \cdot TAN(\alpha - \varepsilon)$

EDGE OF ILLUMINATED FACET

Figure B.11 The edge of an illuminated facet casts
a shadow on a background in a distance,
S behind the edge.
As the shadow lies above the edge by
$S \cdot \tan(\alpha - \varepsilon)$, there can be no illuminated
facets behind the facet with the edge.
In reality the distance to the background,
S will vary along the edge, giving the
shadow of the edge a irregular shape,
but still lying above the edge at all
points.

Kanten af en belyst facet kaster en skyg-
ge på en baggrund i afstanden, S bag kan-
ten.
Da skyggen ligger over kanten i en højde
på $S \cdot \tan(\alpha - \varepsilon)$, kan der ikke være belyste
facetter bag kanten.
I realiteten varierer afstanden, S til
baggrunden langs kanten, hvad der giver
skyggen en ujævn form. Skyggen ligger dog
over kanten ved alle punkter langs kanten.

In the geometry experienced by a motorcyclist,
$f_{visible}$ is, therefore, unity.

A hiding of illuminated facets and hence a reduction
of $f_{visible}$ is certainly to be expected, if the mo-

torcyclist lowers his head below his headlight (if this is possible) so that a situation of $\alpha < \varepsilon$ and $\beta' = 0°$ occurs. Another way to achieve this situation is for a driver to turn on a searchlight on the roof of the car.

The reason that there must be non-visible illuminated facets for $\alpha < \varepsilon$ is that the sum of the apparent areas of illuminated facets is larger than the apparent area of the field, and therefore, cannot be contained in this area.

At $\alpha = \varepsilon$ and $\beta' = 0°$ the two above-mentioned areas match perfectly and all illuminated areas are also visible and vice versa. At a further decreasing α, the apparent area of the field decreases and more and more illuminated facets must become hidden. At $\alpha = 0°$ no facets are in principle visible as the total apparent area is zero. Therefore (see fig. B.12):

for $\underline{\beta' = 0°}$

$$
f_{visible} \begin{cases} = 1 \text{ for } \alpha \geq \varepsilon \\ \text{decreases for } \alpha < \varepsilon \\ = 0 \text{ for } \alpha = 0° \end{cases}
$$

The decrease of $f_{visible}$ for decreasing α must further occur in such a manner as to counteract the increase in $f_{geometry}$. Probably the product of $f_{geometry}$ and $f_{visible}$ is roughly constant for $\alpha < \varepsilon$, so that the road surface luminance is approximately constant.

B.6.3 - The situation of $\beta' \neq 0°$ (as for a car driver)

A more interesting situation is, however, the one of $\alpha > \varepsilon$ and $\beta' \neq 0°$. For a common vehicle the headlight in the steering side will have a small β', while the headlight in the other side has a β' comparable to the other angles of the geometry.

SHADOW ILLUMINATED
STONE

A. WHEN THE FIELD IS SEEN FROM A
POINT ABOVE THE HEADLIGHT, ALL
ILLUMINATED STONES ARE VISIBLE
AND SEEN ON THE BACKGROUND OF
THEIR OWN SHADOWS

NÅR FELTET SES FRA ET PUNKT O-
VER LYGTEN, ER ALLE BELYSTE
STEN SYNLIGE OG SES PÅ BAGGRUND
AF DERES EGNE SKYGGER

B. WHEN THE FIELD IS SEEN FROM THE
POSITION OF THE HEADLIGHT, THE
ILLUMINATED STONES ARE PRECISE-
LY ALSO VISIBLE

NÅR FELTET SES FRA LYGTENS POSI-
TION, ER DE BELYSTE STEN NETOP
SYNLIGE

LESS IS SEEN OF
THIS STONE

C. WHEN THE FIELD IS SEEN FROM A
POINT BELOW THE HEADLIGHT, NOT
ALL OF THE ILLUMINATED PARTS
(FACETS) OF THE STONES ARE
VISIBLE

NÅR FELTET SES FRA ET PUNKT UNDER
LYGTEN, ER IKKE ALLE DELE (FACET-
TER) AF STENENE SYNLIGE

Fig. B.12 The factor, $f_{visible}$ accounts for what
fraction of illuminated facets are also
visible.
In the situation as for a motorcyclist
($\beta' = 0^{\circ}$) all illuminated facets are
visible and hence $f_{visible}$ = 1 (figs. a.
and b.), except if the point of observa-
tion is below the headlight (fig. c.).

Faktoren, $f_{visible}$ er den brøkdel af de
belyste facetter, som også er synlige.
I situationen, som for en motorcyklist
($\beta' = 0^{\circ}$) er alle belyste facetter syn-
lige og derfor $f_{visible}$ = 1 (fig. a. og
b.), undtagen hvis observationspunktet
ligger under lygten (fig. c.).

As shown in fig. B.13, β' can change somewhat and
still leave an illuminated facet on the background
of its own shadow. When β' increases further, some
of the illuminated facets will become hidden and thus
not visible, and $f_{visible}$ will decrease. See fig. B.14.

At large β' the ordered arrangement between illumi-
nated facets and shadows, which was found at $\beta' = 0^{\circ}$,
breaks down and it becomes a random event, whether
the background behind a facet is illuminated or not.

The value of $f_{visible}$, which is found at large β',
must have some bearing on the population of illumi-
nated facets in the background behind other facets.
This population (and thus the value of $f_{visible}$ at
large β') is clearly not a function of β', but of
the other angles of geometry.

According to this, the expression for $f_{visible}$ is re-
arranged to:

$$f_{visible} = 1 - F_1 \cdot F_2 \quad \text{for } \alpha > \epsilon$$

where F_1 is a sort of threshold function $(0 \leq F \leq 1)$

and
$$F_2 = \frac{1}{f_{texture}} \cdot \max_m \left(\Sigma_m \, a'_m \cdot \cos u_m \cdot \cos v_m \right)$$

By the maximum sum in the expression for F_2 is meant
the sum found at the relevant α and ϵ and at a numeri-
cally large β'. F_1 is a measure of what fraction
of the maximum sum of F_2 is found at the relevant β'.

F_1 must clearly be a function of a parameter, p_1
which contains β'. It is tempting according to fig.
B.13 to use:

$$F_1 = F_1(p_1)$$
$$\text{where } p_1 = \left| \frac{\beta'}{\alpha - \epsilon} \right|$$

SHADOW OF EDGE

EDGE

$S \cdot TAN(\alpha-\epsilon)$

$S \cdot \dfrac{TAN(\alpha-\epsilon)}{TAN\theta}$

Figure B.13 For $\beta' = 0°$ the shadow of an edge of an illuminated facet lies $S \cdot \tan(\alpha-\epsilon)$ above the edge, or a distance of $S \cdot \tan(\alpha-\epsilon)/\tan\theta$ transverse to the edge (S = distance to background; θ = angle of edge to the horizontal).
When the observer moves ($\beta' \neq 0°$), the edge and its shadow shift relative to each other in the transverse direction by $S \cdot \tan\beta'$.
The edge will reach its shadow at:

$$\tan\beta' = \frac{\tan(\alpha-\epsilon)}{\tan\theta}$$

or $\quad \dfrac{\tan\beta'}{\tan(\alpha-\epsilon)} \cong \dfrac{\beta'}{\alpha-\epsilon} = \dfrac{1}{\tan\theta}$

For $\beta' = 0°$ ligger skyggen af en kant af en belyst facet højden $S \cdot \tan(\alpha-\epsilon)$ over kanten, og derfor en afstand på $S \cdot \tan(\alpha-\epsilon)/\tan\theta$ til siden for kanten (S = afstand til baggrunden; θ = kantens vinkel med vandret).
Når observatøren bevæger sig ($\beta' \neq 0°$), flytter kanten og dens skygge til siden i forhold til hinanden med $S \cdot \tan\beta'$.
Kanten falder sammen med sin skygge ved:

$$\tan\beta' = \frac{\tan(\alpha-\epsilon)}{\tan\theta}$$

ell. $\dfrac{\tan\beta'}{\tan(\alpha-\epsilon)} \cong \dfrac{\beta'}{\alpha-\epsilon} = \dfrac{1}{\tan\theta}$

SHADOW   ILLUMINATED
          STONE

A. AN ILLUMINATED STONE IN
   THE FIELD AS SEEN FROM
   A POINT ABOVE THE HEAD-
   LIGHT

   EN BELYST STEN I FELTET
   SOM SET FRA ET PUNKT
   OVER LYGTEN

B. THE POINT OF OBSERVATION
   IS SHIFTED SOMEWHAT TO
   THE LEFT OF THE HEADLIGHT

   OBSERVATIONSPUNKTET ER
   FLYTTET LIDT TIL VENSTRE
   FOR LYGTEN

THIS PART OF THE STONE CAN
HIDE ILLUMINATED FACETS

C. THE POINT OF OBSERVATION
   IS SHIFTED FURTHER TO
   THE LEFT, AND A PART OF
   THE STONE IS OUTSIDE ITS
   SHADOW

   OBSERVATIONSPUNKTET ER
   FLYTTET YDERLIGERE TIL
   VENSTRE, HVORVED EN DEL
   AF STENEN LIGGER UDEN
   FOR SIN SKYGGE

Figure B.14 When the point of observation is direct-
ly above the headlight ($\beta' = 0^\circ$, fig. a.)
or when the point is shifted only little
(β' small, fig. b.) all illuminated stones
are seen on the background on their own
shadows, hence $f_{visible} = 1$. At a sufficient-
ly large shift (fig. c.) the il-
luminated stones can hide each other and
$f_{visible} < 1$.

Når observationspunktet ligger lige over
lygten ($\beta' = 0^\circ$, fig. a.), eller når det
kun er flyttet lidt (β' lille, fig. b.),
ses alle belyste sten på baggrund af deres
egne skygger og $f_{visible} = 1$. Ved en til-
strækkelig stor flytning (fig. c.) kan de
belyste sten skjule hinanden og $f_{visible} < 1$.

It is further reasonable to assume that F_1 is zero
for $p_1 = 0$ and increases asymptotical to unity for
increasing p_1 with a steep increase around $p_1 = 1$.

F_2 is a function of a parameter, p_2 which, as men-
tioned above, includes α and ε, but not β'.

The depth into the texture, into which there are il-
luminated facets, increases undoubtedly with ε. This
depth is, however, larger than indicated by ε as
there are paths in the disordered texture, into which
the incident light can penetrate deeper. It is assum-
ed that the total depth into the texture of illumi-
nated facets is given by ε plus an additional angle
p'_2 , which is characteristic of the texture.

The depth into the texture in which the observer can
see illuminated facets is given, on the other hand,
by α. In this case p'_2 cannot be considered to in-
crease the depth, as the paths into the texture for
observation are not identical to those for illumi-
nation (β' is not zero). The paths into the texture
for observation should, therefore, not often turn up
to show illuminated facets.

These arguments lead to:

$$F_2 \text{ is } \begin{cases} \text{small, when} & \alpha - \varepsilon > p'_2 \\ \text{increasing, when } \alpha - \varepsilon \text{ decreases} \end{cases}$$

Without further arguments $\alpha - \varepsilon$ is used as the para-
meter p_2. The reason for this is mainly that this
choice can explain the result of the measurements.

The function F_2 is then considered a function of p_2:

$$F_2 = F_2(p_2)$$

where $p_2 = \alpha - \varepsilon$

The largest value to be considered for F_2 is the one found for $\alpha - \varepsilon = 0^\circ$. This value has to be at most unity, but should in practise be smaller.

The estimation of the functions F_1 and F_2 is to be done on the basis of measurements.