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TECHNICAL REPORT

ROAD SURFACES AND LIGHTING
Joint technical report CIE / PIARC

CIE 66 - 1984

This technical report deals basically with the relationship between the photometric characteristics (reflection properties) of road surfaces and their construction (compositions and texture). It is intended as a guide for road constructors and for lighting designers. Therefore the report has been drafted jointly by experts on reflection by road surfaces in the CIE and by experts on road constructions in PIARC. The report is a summary of recommendations or technical reports of the CIE and gives supplementary information known by experts on this subject, which has not yet officially been published by CIE or PIARC. Some of this information is provisional. It is hoped that it will stimulate investigators who are interested in this field to collect valuable additional data which may lead to more accurate information.

Dieser Technische Bericht behandelt das Verhältnis zwischen photometrischen Charakteristika (Reflexionseigenschaften) von Straßenbelägen und ihrer Konstruktion (Zusammensetzung und Struktur). Es ist als Richtlinie für Straßenbauer und Lichtplaner gedacht. Deshalb wurde der Bericht von Experten für Reflexion durch Straßenbeläge in der CIE und von Straßenbauexperten in PIARC gemeinsam zusammengestellt. Der Bericht stellt eine Zusammenfassung von Empfehlungen oder Technischen Berichten der CIE dar und gibt weitere Informationen, die noch nicht von CIE oder PIARC offiziell veröffentlicht wurden. Einige dieser Informationen sind vorläufig. Es steht zu wünschen, daß interessierte Forscher dadurch angeregt werden, wertvolle zusätzliche Daten zu sammeln, die zu genaueren Informationen führen können.

Ce rapport technique traite de la relation entre les caractéristiques photométriques (qualités de réflexion) des revêtements routiers et de leur construction (composition et structure). Il est destiné à servir comme guide pour les constructeurs de routes et pour les éclairagistes. Pour cette raison le rapport a été élaboré en commun par des experts en réflexion par des revêtements routiers dans la CIE et par des experts en construction de routes dans la PIARC. Le rapport est un résumé des recommandations ou rapports techniques de la CIE et offre des informations supplémentaires qui n'ont pas été publiées officiellement par la CIE ou la PIARC. Une partie de ces informations est provisoire. Il est à espérer qu'il va stimuler les chercheurs intéressés dans ce sujet à rassembler d'autres données importantes qui conduiront à une information plus exacte.

The preparation of this technical report started in October 1977. Engineers for road lighting and road construction worked together in the joint subcommittee "Fundamentals of Road Surfaces" of CIE TC-4.6 "Road Lighting", and PIARC TC "Surface Characteristics".

The report concerns civil engineering properties as well as the reflection properties of road surfaces under day and night time conditions.

Construction and maintenance of road surfaces are always based on a compromise of different parameters which are relevant for the comfort and safety of the road users.

There is an urgent need for further research work in this field especially with regard to road markings as a covering part of the road surface.

In 1983 the report was approved by the majority of the relevant technical committees of CIE and PIARC and is recommended for study and application. This report is not an officially agreed CIE/PIARC recommendation approved by the National Committees of the member countries. It should be noted that any recommendations in this report are advisory and not mandatory.

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SUMMARY

This report contains basic information on road surfaces as a guide for road constructors and lighting designers.

Chapter 1.

This chapter presents the scope of the report and indicates the importance of the road reflection, which depends on the nature of the pavement, its physical state and the kind of illumination (street-light, headlight, daylight).

Chapter 2.

Civil engineering properties such as skid resistance, evenness and surface drainage, rolling noise level and lightness influencing traffic are dealt with. The composition of road pavements (cement concrete and asphaltic pavements) and the influence of the macro and micro texture of the upper layer on the above mentioned characteristics are also discussed. A classification of road surfaces based on their macrotexture is presented.

Chapter 3.

The reflection properties of road surfaces for streetlights are characterised by luminance coefficients q (luminance divided by horizontal illuminance) for fixed observation and variable light incidence. A simplified characterisation for dry conditions is defined by means of the average luminance coefficient Q_0 (fixed illumination zone) and the specular factor S_1 (ratio of 2 individual luminance coefficients). For design purposes a new classification system with 2 dry standards based on S_1 is recommended which leads to the same order of accuracy as the former 4-class systems. For wet conditions reference is made to CIE publication n° 47.

The reflection properties of road surfaces for a driver's own headlights are characterised by the coefficient q_H (luminance divided by vertical illuminance) which seems to be strongly dependent on the ratio of incidence to observation angles. Some data on road surfaces with different macrotexture in dry and wet conditions are presented. There is little knowledge about reflection properties valid for opposing headlights.

The reflection properties of road surfaces for daylight illumination can be described as for streetlights. The overcast sky leads to an average luminance coefficient very similar to Q_0 (dry condition). The same holds for the clear sky. A special case occurs only for opposing sunlight under glancing angles. In many cases the simplified system for streetlights is valid also for daylight.

Chapter 4.

The requirements for measurements of the reflection properties are presented, taking into account streetlight or daylight and headlight as illuminator. The chapter includes laboratory equipment as well as portable set-ups for simplified measurements. Special attention is paid to the sampling, the optical system of the measuring device, the measuring field and illuminated field, the angles of illumination and observation, the apertures and the calibration procedure. Measuring problems with headlight as illuminator have not yet been solved.

Chapter 5.

Firstly a list of references states the relationship between lighting characteristics and macrotexture plus colour or lightness.

Secondly preferred road surfaces should lead to high values of luminance and uniformity. These are met with low values of the specular factor $S_1 < 0.4$, and high values of the average luminance coefficient Q_0 (dry condition). This recommendation holds for all types of illuminators. The effect on the visibility of road markings is not yet clear.

Thirdly with regard to the composition of the top layer, asphaltic pavements including at least 30 % of white chippings, or cement concrete, should be used.

These recommendations are based only on lighting considerations. In practice additional economic considerations and requirements from civil engineering properties have to be taken into account in order to find an acceptable compromise.

Chapter 6.

Road markings as a covering part of the road pavement must be visible in all situations : during day and night time, in dry and wet conditions.

Their photometric characteristics are colour, average luminance coefficient and the coefficient of retroreflective luminance.

In practice white or yellow materials, sometimes improved by retroreflective glass beads (to work with headlights) are in use. Many visibility problems, on light road surfaces or in adverse weather conditions remain unsolved. There is thus a need for further research work in this field, and CIE and PIARC, always in close cooperation, will prepare a separate report about road markings.

1. INTRODUCTION

1.1 - Scope

This technical report deals basically with the relationship between the photometric characteristics (reflection properties) of road surfaces and their construction (compositions and texture).

It is intended as a guide for road constructors and for lighting designers. Therefore the report has been drafted jointly by experts on reflection by road surfaces in the CIE and by experts on road construction in PIARC.

The report is a summary of recommendations or technical reports of the CIE and gives supplementary information known by experts on this subject, which has not yet officially been published by CIE or PIARC. Some of this information is provisional. It is hoped that it will stimulate investigators who are interested in this field to collect valuable additional data which may lead to more accurate information.

1.2 - Importance of road reflection

What the eye perceives from a secondary source, like an illuminated surface, depends not only on the illuminance (*) but also on its reflection characteristics. No level of illumination can cause a luminance (*) on a pure black surface.

Visual perception, e.g. of an obstacle on the road, results from a subjective impression of a brightness contrast and of colour contrast originated by a difference of luminances between the obstacle and its background.

Data with regard to the relationship between minimum value of contrast and the luminance level with regard to visibility are well known (Dunbar, 1938 ; de Boer, 1951). These considerations indicate the importance of the reflection characteristics of a road surface.

Another aspect of the importance of road reflection is the fact that the current quality criteria for road lighting call for a minimum level of the mean luminance of the road. Those recommendations take into account security, comfort and economy. This luminance level depends on both the quantity of luminous flux put on the road, and the interrelation between the reflection indicatrix of the road surface and the luminous intensity distribution of the luminaires involved (CIE, 1973).

For both reasons a good knowledge of road surfaces (and associated aspects, e.g. road markings, tunnel walls and ceiling, etc.) is necessary.

1.3 - Influence of illuminator on contrast rendition and visibility

In general, the reflection properties of road surfaces depend to an approximate order of importance (CIE, 1977) on :

- (I) their nature (composition, texture, method of construction, etc.),
- (II) their physical state (wear, humidity),
- (III) the direction of the illumination defined by the two angles β and γ (figure 3.1), and the direction of observation defined by the angles α and δ .

Fortunately, these four angles may be reduced to two, in the special circumstances of road lighting.

The visual aspect of a road surface, or any associated traffic sign painted on it, depends considerably on the kind of illumination, daylight or road lighting. With the same level of energy put on an elementary surface, the luminance may be quite different, e.g. at the border of an obstacle and its background, where the incident energy is practically the same but the luminance differs. So the way of illumination is important. Under certain circumstances the contrast, as a result of the particular reflection characteristics of a road and a sign, may be lowered, or even disappear.

(*) Terms defined in appendix – Chapter 8.

Three ways of illumination must be taken into consideration :

- (I) road lighting, in which the most important direction of illumination is AGAINST the direction of a driver or a pedestrian.
- (II) automobile headlights, in which the direction of illumination is practically speaking the same as the driving direction.
- (III) daylight, in which the illumination results from the combination of a diffuse sky (clear or cloudy) and from direct sunlight.

All three types of illumination will be taken into consideration in this technical report.

2. CIVIL ENGINEERING PROPERTIES OF ROAD PAVEMENTS

2.1 - Characteristic functions

2.1.0. Preamble

The road user expects that the pavement of a road will provide both safe and comfortable travel. It is difficult to make a clear-cut distinction between the road surface characteristics which affect safety and those which relate to comfort. It is nevertheless possible to suggest that the noise level and the longitudinal evenness of the road surface play, in the first place, a role in comfort, while surface drainage (and consequently transverse evenness) and skid resistance affect, above all, safety. Surface luminance of the pavement affects both safety and comfort, which is also the case for the contrast between the road surface and road markings.

The road user makes these demands of a new pavement but he expects that both safety and comfort will be maintained as time goes on : a road should, thus, be designed and constructed in such a way that these characteristics are preserved during a reasonable length of time. The thickness design should, therefore, be sufficient and the carriageway protected against the entrance of water. The pavement should resist the action of traffic, de-icing salt, studded tyres and climatic conditions (frost, high temperatures). It should be noted that the action due to traffic (number and weight of vehicles) will differ from lane to lane.

Below, the characteristic functions of pavements are described, with the exception of photometric and reflectometric properties. Some of the terms used are defined in the appendix and are marked in the text with a (*).

2.1.1. Skid resistance

Studies carried out in various countries have shown that the skid resistance (*) of vehicles, on wet pavements, is linked to the micro and macro texture (*) of the surface : these two types of texture can be combined as shown in figure 2.1.

Surface	Scale of texture	
	Macro (large)	Micro (fine)
A 	Rough	Harsh
B 	Rough	Polished
C 	Smooth	Harsh
D 	Smooth	Polished

Figure 2.1. — Terms used for describing pavement surface texture (PIARC, 1971)

At low speeds, for example 20 km/h, the coefficient of friction e.g. sideways force coefficient - SFC (*) or braking force coefficient - BFC (*), being solely influenced by the microtexture, is higher with a harsh microtexture (A,C) than with a polished microtexture (B,D) (figure 2.2.). The fall in SFC or BFC with increasing speed, being dependent essentially on the macrotexture, is less marked with a rough macrotexture (AA' and BB') than with a smooth one (CC' and DD') (figure 2.2.).

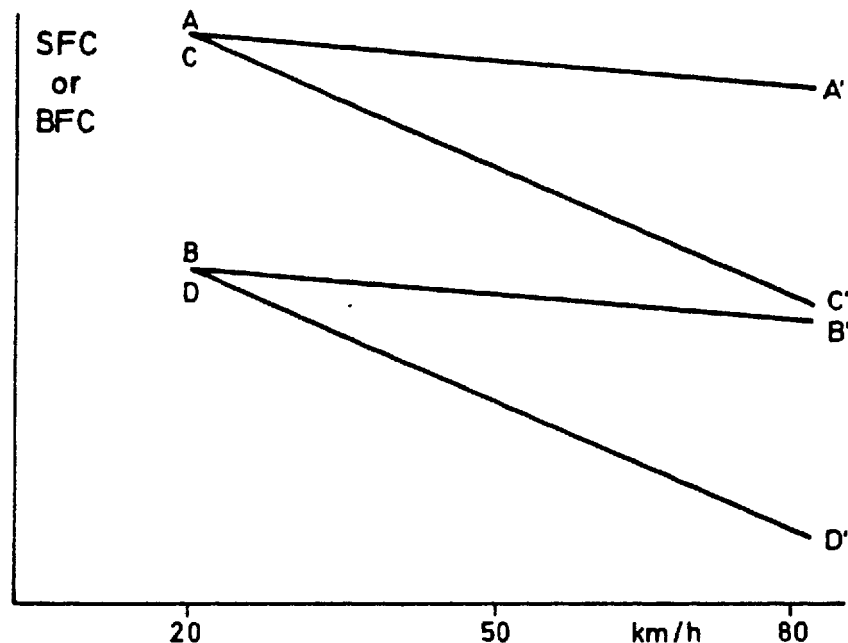


Figure 2.2. — Skid resistance for wet surfaces of the types illustrated in figure 2.1.
(the position of the points and the curves have no absolute value)

In order to obtain durable skid-resistant pavements, both a harsh microtexture (which excludes polishable materials at the surface) and a rough macrotexture (which supposes an adequate surface treatment) have to be achieved. Thus, with regard to skid resistance, there is a need to construct surfaces of type A illustrated in figures 2.1. & 2.2.

2.1.2. Evenness and surface drainage

The longitudinal and transverse evenness of a road, at any given moment, depends on the initial profile of the pavement as well as on the deterioration of the surface or on uneven settlement of the structure appearing after construction.

For asphalt roads, transverse unevenness can develop markedly with the apparition of a rutting (*) phenomenon. In this case, the driver finds himself confronted with a rail effect, which is particularly uncomfortable. When the reverse gradient in the wheel tracks equals or exceeds the crossfall of the pavement, rainwater accumulates, which gives rise to the phenomenon of aquaplaning and the formation of a dense splash and spray behind each vehicle.

Rutting caused by the plastic deformation of a bituminous (or asphaltic) pavement can be prevented by using the right composition of the mix, especially regarding the binder (*) content, by judiciously choosing the aggregate (*) and the binder to be used and by intense compaction.

2.1.3. Rolling noise level (*)

The use of techniques which create a rough macrotexture, aimed at providing a high skid resistance (see 2.1.1.), have made the acoustic comfort of road users and roadside dwellers a major subject of concern.

Rolling noise levels rise with the speed of the vehicle and are different for wet and dry roads : the value measured depends, of course, also on the characteristics of the vehicle. Maximum and minimum rolling noise levels measured on various sorts of pavements (all other circumstances of the measurement being otherwise equal) differ by a maximum of 10 dB (A) (*), outside the vehicle with the engine off.

Some studies carried out demonstrate that rolling noise increases as the macrotexture becomes rougher (figure 2.3.). Some pavements having a rough texture are, nevertheless, an exception to this rule, e.g. the porous bituminous mixes.

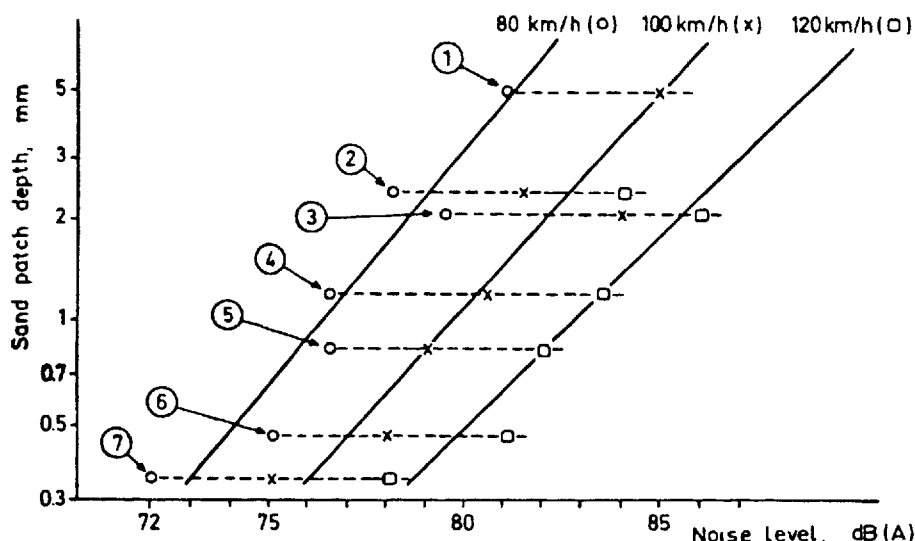


Figure 2.3. — Relation between noise (sound outside vehicle with motor off) and macrotexture (expressed as sand patch depth) on a dry pavement (Elsenaar, Reichert, Sauterey, 1977).

- | | |
|-------------------------------|----------------------------|
| 1. Paving blocks | 5. New cement concrete |
| 2. New surface dressing 10/14 | (burlap drag) |
| 3. Grooved concrete | 6. 0/8 bituminous mix |
| 4. Grooved concrete | 7. Bituminous grout (worn) |

2.1.4. Lightness (*)

The lightness of a road is a qualitative aspect of the road, seen as a whole. In particular, the lightness can describe in general terms the way in which the road can be seen as a band, extending in the forward direction through the landscape. It is an important factor to judge how well the run of the road can be distinguished within the visual complexity of the surrounds. In most cases, an important contributing factor in this is the brightness contrast. This is enhanced under most circumstances when the road is light.

The assessment of the lightness of the road is usually made by visual inspection. This is a valid method, because the lightness as described here is more subjective than objective. One should be warned, however, to look, when making such visual inspections, in the way a driver does. Not only the reflection characteristics, but also the general aspect of the road surface are usually quite different when one looks at the road from the point of view of a driver, as compared with the point of view of a pedestrian.

Obviously, the lightness is closely related to the reflection properties discussed in chapter 3.

2.2 - Construction

2.2.1. Cement concrete pavements (Anon, 1973 ; Anon, 1978 ; Elsenaar, Reichert, Sauterey, 1977 ; Leyder, Reichert, 1974 ; PIARC, 1971 ; PIARC, 1975 ; PIARC, 1979)

Composition

These are made, depending on the country, of 55 % to 65 % of stones (*) (often of the crushed type), 20 to 30 % sand (*) (natural and/or crushed) and 15 to 17 % of cement (*) (Portland or blast furnace). The largest aggregate sizes (*) are in the region 30 to 40 mm, for concrete thicknesses of 20 to 30 cm.

Surface characteristics

a) Macrotexture

The macrotexture is achieved by an appropriate surface treatment on the fresh concrete. In the majority of countries, this treatment is superficial and consists of smoothing with burlap or light transverse brushing (figure 2.4.) : recourse to deeper methods, such as deep grooving (figure 2.5.) has become common practice in the last few years in countries such as Belgium and France (transverse grooving) and Spain (longitudinal grooving). The profile of the grooves is not the same everywhere : their depth varies generally between 3 and 7 mm and the distance between them from 20 to 50 mm.

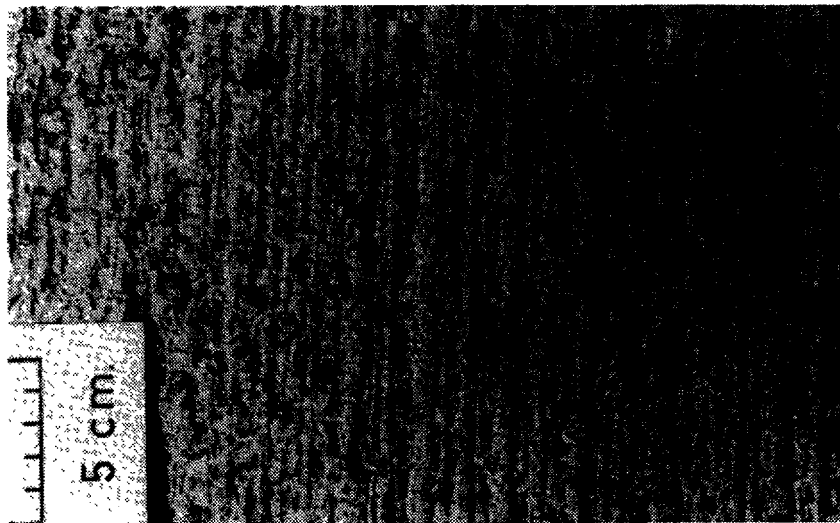


Figure 2.4. – Appearance after laying lightly brushed cement concrete.

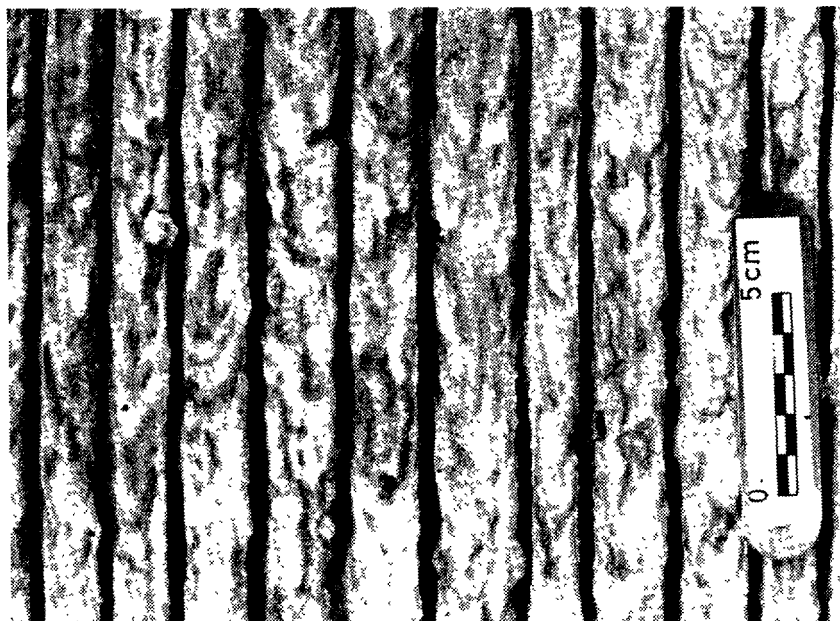


Figure 2.5. – Appearance after laying deeply grooved cement concrete.

In some countries, experiments have been carried out with other techniques :

- stripping (figure 2.6.) : this consists of removing the surface mortar in such a way as to lay the mosaic of stones bare right from the opening to traffic (Belgium, Denmark),
- chipping, using chipping stones, either large size (figure 2.7.) as in bituminous pavements (Belgium, France) or small size (Switzerland). The chipping stones must be of high quality regarding both hardness and resistance to polishing.

As a result of the effect of traffic and de-icing salts, the macrotexture becomes smoother with age (figure 2.8.), especially in the wheel tracks of the traffic.

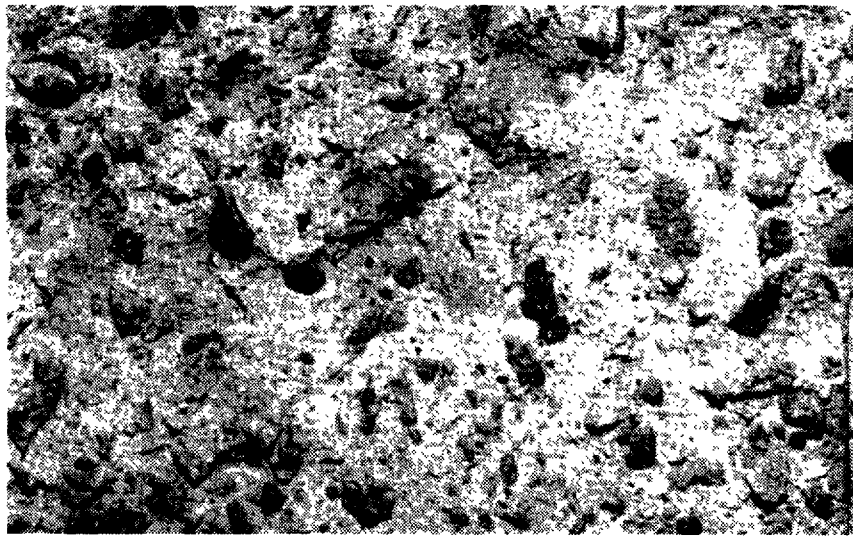


Figure 2.6. — Appearance after laying stripped cement concrete.

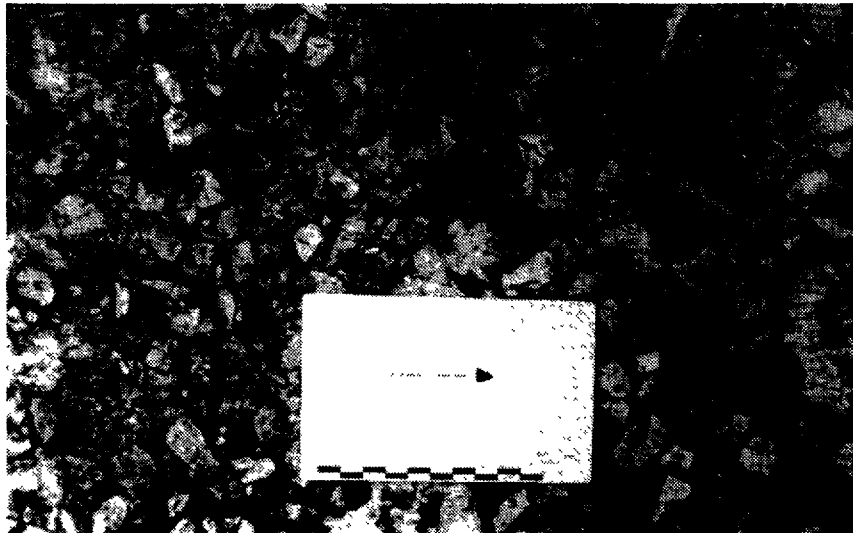


Figure 2.7. — Appearance after laying cement concrete chipped with 6 kg 14/20 chippings per sq.m.

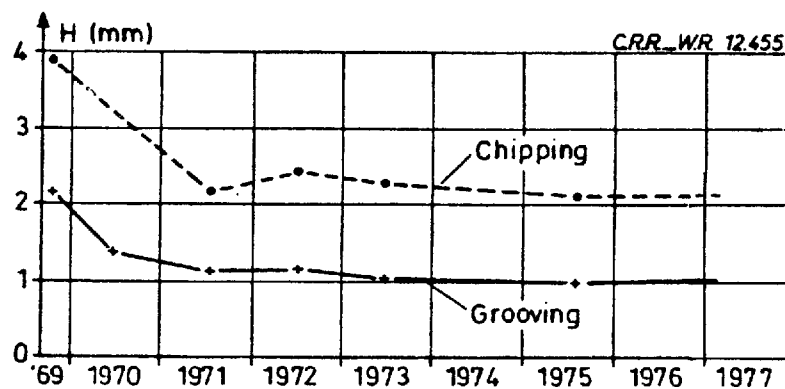


Figure 2.8. — Evolution of the macrotexture (sand patch depth H) of a grooved and a chipped cement concrete with time (Anon, 1978).

The durability of the texture is proportionate to the richness of concrete in mortar (viz. cement) and the effectiveness of the curing compound used for protection of the fresh concrete after finishing.

In the case of brushing and grooving, wear will sooner or later cause the disappearance of the grooves, the abrasion of the surface mortar and the appearance of stony aggregate at the surface. Other sorts of surface treatment, particularly chipping with large hard stones, appear to give a greater durability to the macrotexture thus obtained (figure 2.8.).

b) Microtexture

For high volume roads, many countries impose restrictions regarding the use of polishable aggregates, such as limestone, in order to make sure of achieving a harsh microstructure. These restrictions can bear either on the sand, on the stones, or only a part of them or even on all the aggregates.

The chip-sprinkling process with large chipping stones permits nevertheless the use of polishable aggregates in the bulk mix composition without impairing the skid resistance, since the contact surface between the pavement and the tyre tread is provided by the sprinkled stones. This is of considerable economic interest in regions where adequately polish resistant aggregates are rare.

The microtexture deteriorates with time as a result of aggregate polishing by traffic (figure 2.9.) and of the carbonation of certain types of cement.

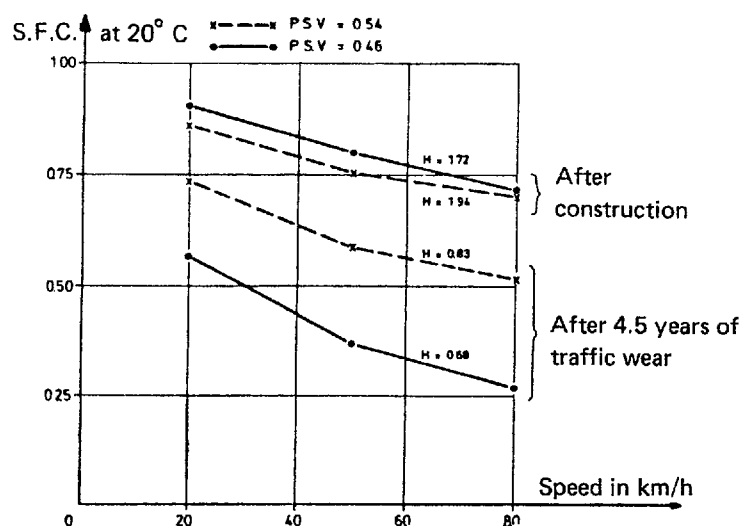


Figure 2.9. — Influence of the polishing of surface aggregates (P.S.V.) on the evolution of skid resistance (S.F.C.) with time (Leyder, Reichert, 1974).

c) Skid resistance

The skid resistance of a cement concrete pavement at any given moment depends upon the existing microtexture or macrotexture. It drops with use according to the evolution of both of these textures.

d) Evenness

No special observations.

e) Surface drainage

Transverse brushing and, above all, transverse grooving, are treatments which are particularly useful for improving the drainage of rainwater from the surface.

f) Lightness

The lightness of the pavement, traditionally high with cement concrete pavements, depends on the tint of the materials making up the surface. For new roads, whose surface has been left untreated or has been brushed or grooved, the surface of the pavement being rich in mortar, the tint of the sand and cement used determine the tint of the pavement. As the mortar is progressively worn away by traffic, the influence of the tint of the stones will increase.

With stripped concrete, the tint of the stones is the major influence from the beginning. Finally, for chipped cement concrete the tint is determined both by the chipping stones and by the mortar in which they are set.

It is worth noting here that the dirtying effect of fuel spill, oil patches and so forth caused by motorcars should not be neglected, especially on the slow traffic lanes.

g) Rolling noise level

Smooth or brushed concrete surfaces have the lowest rolling noise level, followed by stripped or chipped concrete pavements : rolling noise levels on concrete with deep transverse grooves may be fairly high (figure 2.3.).

2.2.2. Asphaltic pavements (Elsenaar, Reichert, Sauterey, 1977 ; PIARC, 1971 ; PIARC, 1975 ; PIARC, 1979 ; Van Heystraeten, Decoene, 1978).

Composition

The composition of the wearing course of asphaltic pavements varies considerably from country to country : in one single country, there are often differences associated with region, climate, importance of the road, legal maximum axle weight and so forth. There are, in effect, important differences regarding :

- the content (*) and properties of the components (stones, sand, filler and binder) of the mix,
- the maximum size (often related to the thickness of the layer), of the stones in the mix,
- the grading - grain size distribution - (gap or continuous) and the voids ratio of the mixture,
- the characteristics, the spreading rate and the size of the chipping stones, insofar as this surface finishing is applied.

The bituminous (or asphaltic) concretes, chipped or unchipped, hot rolled asphalt, topeka and mastic bituminous concretes of the gussasphalt type are all types of dense bituminous mixtures. They have less than 5 % voids after compaction and the stone content is between 25 and 60 %.

The semi-granular bituminous mixes contain 55 to 70 % stones and have a voids content of roughly 5 to 8 %.

The porous mixtures (roughly 20 % voids) are the most granular (80 to 90 % stones) and include the porous concretes, also called draining or porous mixes (Studie Centrum Wegenbouw, 1977), and the macadams.

Finally, it should be noted that mixtures with a high stone content hold little sand nor do they contain much filler or binder. The opposite goes for the low granularity mixes. The bitumen content thus varies between limiting values of 4 % (porous mixes having the least) and 9 % (some topekas and gussasphalt).

Some of these sorts of pavements, for example the bituminous concretes, can be laid in both thin (approximately 2 to 3 cm) and thick layers (5 to 8 cm). This last choice often determines the maximum size of the stones in the mix, which may vary from 4 to 6 mm for the microconcretes to an approximate maximum of 22 mm.

Surface characteristics

a) Macrotexture

Only the mixtures of < 60 % stones can be chipped, above this limit, the mix, already highly granular, will not accept more stones. However, even without chipping, their strong mineral mosaic ensures that these mixes have a rough macrotexture after construction.

This rough macrotexture is often achieved for other bituminous mixes, by a surface treatment carried out when laying the mix and consisting of : chipping with small size stones (1/3 - 2/5 or 4/7 mm) at the rate of 2 to 3 kg/sq m. Such a treatment, applied particularly in Germany on gussasphalt and in Belgium and the Netherlands on bituminous concrete having about 50 to 60 % stones, gives the new pavement a high skid resistance. The macrotexture achieved by this method is however not durable because the wear under traffic causes loss or punches the chippings into the mix (figure 2.10.).

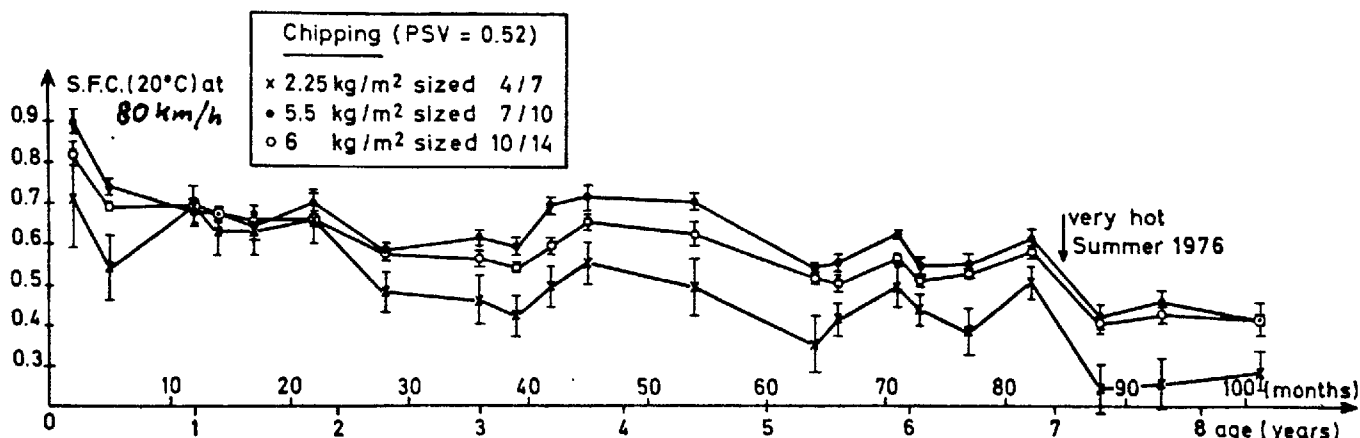


Figure 2.10. — Evolution of the S.F.C. at 80 km/h of 3 asphaltic concretes (45 % stones in the bulk) chipped with different sizes, showing that the size 4/7 is the least efficient one (Van Heystraeten, Decoene, 1978).

On the other hand, chipping with larger stones can create a rougher and, above all, a more durable macrotexture. This is carried out with 7/10, 10/14 and even larger chippings with a size up to 14/20 mm (figure 2.11.). If the macrotexture is to be rough, it is important that the chipping rate is high enough to create sufficient protrusions on the surface.

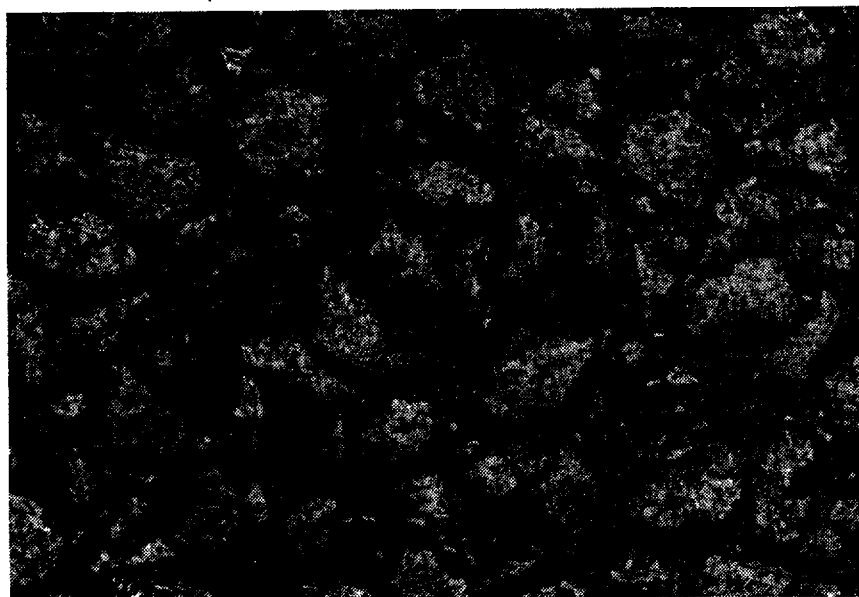


Figure 2.11. — Appearance of bituminous concrete, chipped at a rate of 7 kg of 10/14 mm stones per sq.m, after 4 years of traffic.

In order to provide an equivalent covering, a higher sprinkling rate has to be adopted for the larger stones. The rates then vary from 5 kg/sq m (for 7/10 size) to 11 kg/sq m (for 14/20 size). These chipped pavements are currently in use in Belgium (type II), in the Jura and Northern France (enrobé clouté), in Great Britain (hot rolled asphalt) and in Sweden (topeka).

The stones used when chipping are generally precoated with bitumen, with a view to assisting their integration with the mix into which they are rolled. Traffic wear and weather conditions remove the bitumen coating from the top of the chippings. The chipping stones should be cube shaped and be able to withstand abrasion, wear and polishing.

Figure 2.12. gives a general view of the laying of chipped asphalt, with finisher and chipping machines.

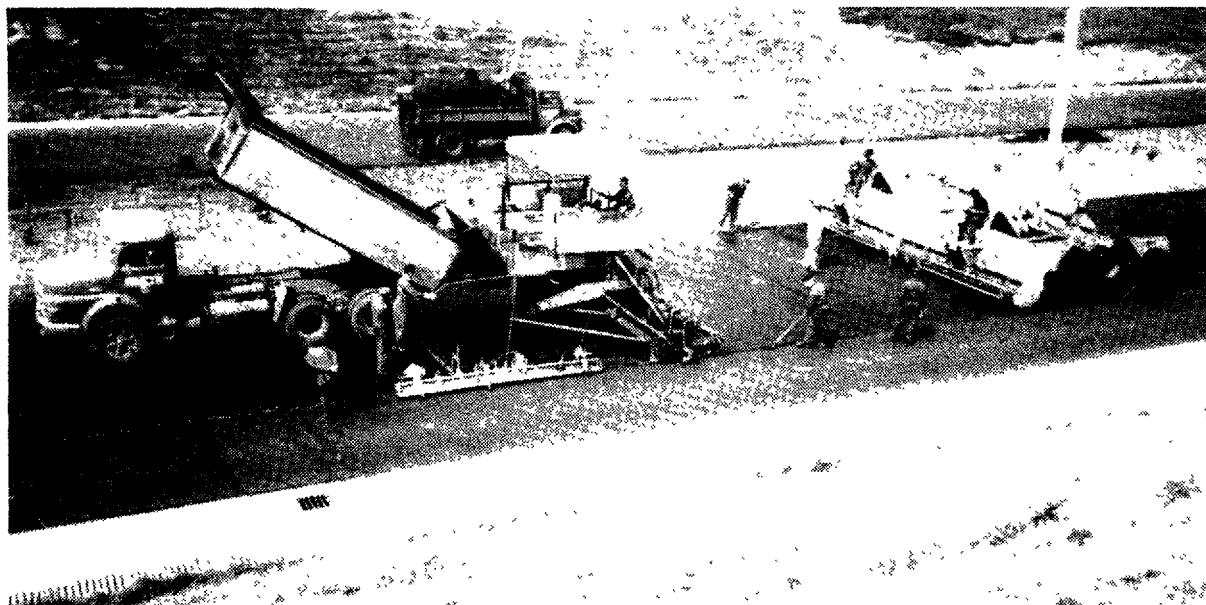


Figure 2.12. — General view of the laying of chipped asphalt, with finisher and the chipping machines.

b) Microtexture

With regard to the use of polishable aggregates as in cement concrete, restrictions are often applicable to roads with a high volume of traffic. Only the chip-sprinkling technique with large stones allows the use of polishable aggregates in the mix (cfr. cement concrete).

The microtexture deteriorates as a result of aggregate polishing by traffic, rubber or oil deposits and, in some cases, bleeding of bitumen binder in periods of hot weather.

c) Skid resistance

Same observations as with cement concrete and with the example of figure 2.10.

d) Evenness

Figure 2.13. shows an example of ruts in a heavily trafficked asphalt road. Water stagnancy in these ruts completely ruins the skid resistance of the pavement, whatever the quality of the existing microtexture or macrotexture.

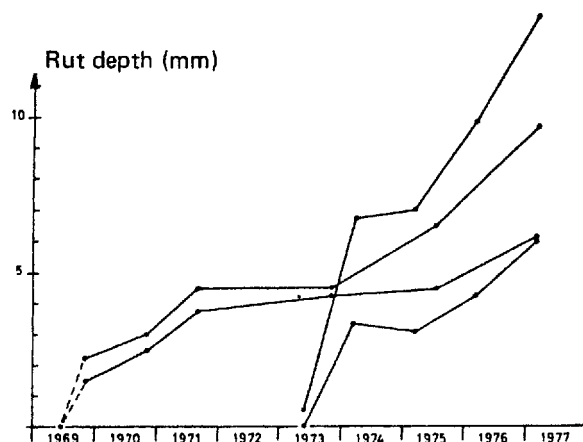


Figure 2.13. — Development of ruts in 2×2 chipped bituminous concretes constructed in Belgium in 1969 and 1973 showing the effects of the hot summer of 1975 and the very hot summer of 1976.

e) Surface drainage

The drainage of rainwater occurs at the surface of the dense bituminous mixtures. Only with the porous mixes does drainage take place through the layer itself (for this reason, it is called draining mix). Thanks to this internal drainage, porous surfaces show a very good skid resistance and give rise to little splash and spray.

f) Lightness

An asphalt pavement is extremely dark immediately after laying. Traffic wear and weather conditions cause a gradual stripping away of the bituminous mortar at the surface and expose the aggregates. In the case of chip-sprinkling, it is the original tint of the chippings which, in the first place, determines the tint of the pavement once the film of bituminous coating has worn away. Generally, this takes a few months depending upon the type of stones, weather conditions and traffic volume.

In order to make asphalt pavements lighter, some countries (e.g. Denmark) stipulate the inclusion of a proportion of white stones in the bituminous concrete. In Belgium, the use of light coloured stones for type II chip-sprinkling (comparable to hot rolled asphalt in the United Kingdom) is obligatory on the major roads of the State network (figure 2.14.). Provision is made for leucometer tests (Centre de Recherches routières, 1979) to determine the tint of chipping stones. A minimum reflection value of 45 % is required.

As for cement concrete pavements, the dirtying effect of fuel spill and oil patches is to be noted.

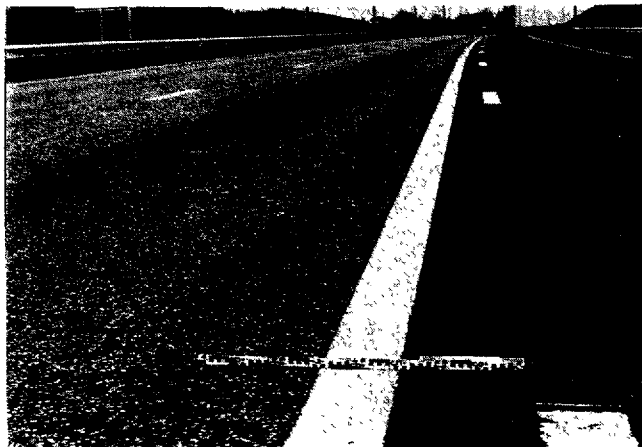


Figure 2.14. – Contrast between the traffic lane, which has been chip-sprinkled with light coloured stones and the dark shoulder for emergency stop (Belgium).

g) Rolling noise level

Asphalt roads produce less rolling noise than cement concrete roads with the same texture (figure 2.15.). Porous asphalt mixes have the lowest rolling noise level, followed by unchipped and chipped asphaltic concrete. Rolling noise levels on very prominent macrotexture (e.g. on some types of surface dressings) may be fairly high (figure 2.3.).

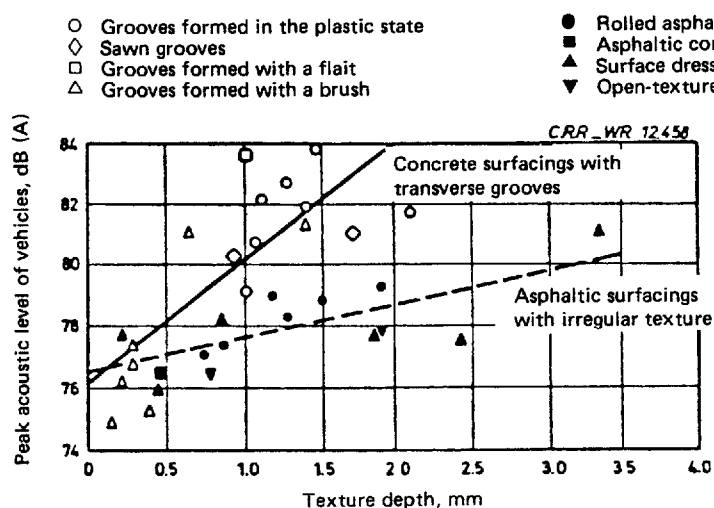


Figure 2.15. – Relations between the texture depth and the noise of light vehicles at 70 km/h for various bituminous and concrete surfacings (PIARC, 1979).

2.2.3. Maintenance and strengthening of roads

The main factors in the wear and deterioration of a road are traffic, climatic conditions and errors of design and execution.

Deterioration can appear :

- gradually with time and causing a loss of skid resistance, ruts, cracking ...,
- rapidly, and sometimes even suddenly at localised points, giving rise to potholes, bumps, subsidence ...,

For deficiencies affecting the structure of a road, the solution often consists of the reconstitution or replacement of the existing road by a thick layer. In such cases, the existing pavement may very well be replaced by a completely different structure.

For surface deficiencies, recourse is made to an appropriate maintenance technique for restoring skid resistance, evenness or impermeability, for example :

- mechanical, chemical or heat based processes (Leyder, Van Heystraeten, 1975) for restoring skid resistance, such as the transverse or longitudinal grooving (figure 2.16.) of cement concrete roads,
- planing rutted asphaltic pavements in order to restore evenness and the good drainage of surface water,
- the application of a surface dressing (figure 2.17.) on cement concrete or asphaltic pavements which waterproofs the surface and gives it a high skid resistance. A surface dressing consists

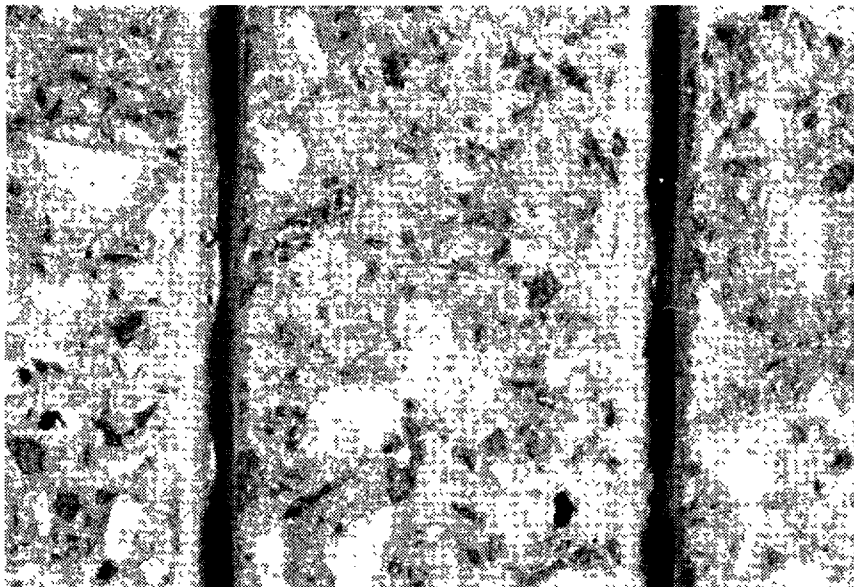


Figure 2.16. — Appearance of cement concrete after grooving with diamond disks (scale 1/1).

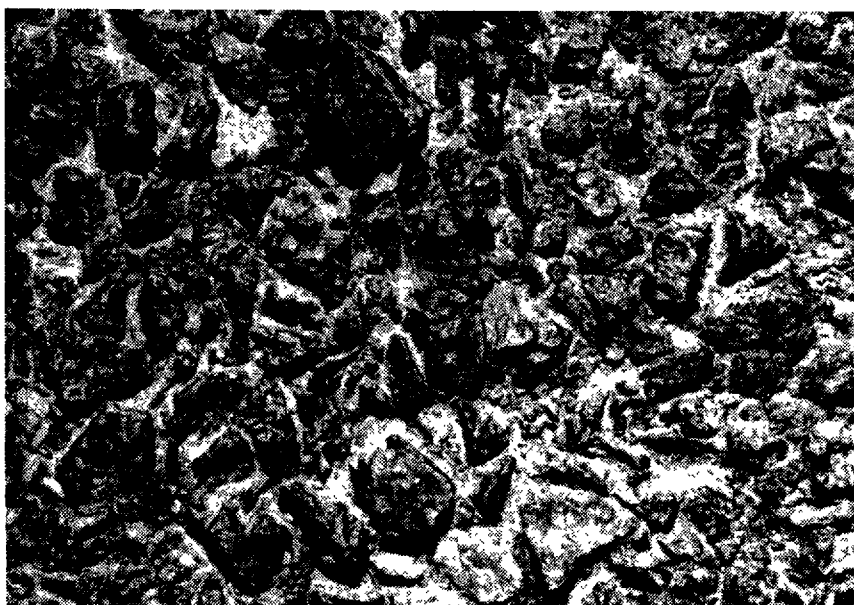


Figure 2.17. — Appearance of a single layer dressing with 6/10 mm sized chippings (scale 1/1).

in a single layer of gravel stones placed side by side and fixed to the base by the preliminary spreading of a binder. Surface dressings have been used for many years as a maintenance technique for small roads and, more recently, also for heavily trafficked roads (France). By their very apparent macrotexture, dressings provide the road with a rapidly drained surface.

During the life of a road surface, those characteristics (lightness, texture, ...) which influence its photometric and reflectometric characteristics, change as time goes by and maintenance or recovering works are carried out.

2.3 - Classification of road pavements (macrotexture)

The establishment of a general classification of road pavements is possible only for macrotextures, and not for other characteristics such as microtexture, colour, skid resistance, etc... for the reasons stated in the sections above. Even with macrotexture, limitations arise because :

- certain types of surface treatment (chip-sprinkling, grooving, etc...) can be carried out in different ways (degree of depth) depending on the worksite,
- the development of the macrotexture varies, in particular with the composition of the pavement and the intensity and the type of traffic carried by the road.

Given these limitations, table 2.18. shows a classification of pavement types in relation to the macrotexture most likely to be achieved on completion. All conditions remaining the same, this classification holds during the further life of these pavement types.

Macrotexture	Concrete pavements	Asphaltic pavements
Very rough	Chipping with large stones, Deep grooving, Stripping.	Surface dressings, Porous pavements, and Macadams. Chip-sprinkling with large stones (e.g. hot rolled asphalt, topeka).
Rough		Granular and semi- granular mixes, Gussasphalt (chipped with small stones and waffled).
Smooth	Light brushing	Dense concrete, chipped with small stones.
Very smooth	Untreated cement	Unchipped dense concrete.

Table 2.18.

3. CHARACTERISATION OF REFLECTION PROPERTIES

3.1 - Reflection properties for road lighting

A fundamental, physical approach to the study of the reflection properties of road surfaces has lead to a better understanding of the mechanisms of light reflection from road surfaces, but not to a workable system for road lighting design purposes. For the latter purpose it has been found possible to work with a simplified, empirical description system for the reflection properties of road surfaces (Van Bommel, de Boer, 1980). A reflection classification system for all dry road surfaces, based on such a description system, can be used as a basis for all the dry-weather luminance calculations for road lighting. This dry-weather classification system will therefore be described in detail. An extension of the system, which makes it valid for wet weather conditions will also be briefly considered.

3.1.1. Conventions

The complete reflection properties of a road surface are specified by means of a set of luminance coefficients. The luminance coefficient, q , is defined as the ratio between the luminance, L , at a point on the road surface to the horizontal illuminance, E , at the same point, caused by a single light source.

$$q = L/E$$

The luminance coefficient depends on the nature of the road surface material and on the positions of the observer and the light source relative to the point under consideration. This dependency can be described by the angles illustrated in figure 3.1. in which :

- γ : indicates the angle between the direction of light incidence and the upward vertical (angle of incidence),
- α : indicates the angle, in a vertical plane, relative to the horizontal, at which the light has to leave the point of reflection in order to reach the eye of the observer (angle of observation),
- β : indicates the angle through which the incident light has to be turned, away from its original direction, in order for the reflected light to enter the plane of observation (angle between vertical planes containing the directions of light incidence and observation),
- δ : indicates the angle between the vertical plane of observation and the road axis.

Thus : $q = q(\alpha, \beta, \gamma, \delta)$

Since most road surfaces are almost completely isotropic, the influence of the angle δ can generally be neglected, particularly since for road widths up to as much as 25 m and for observation distances greater than 60 m the value of δ only ranges from 0 to 20 degrees.

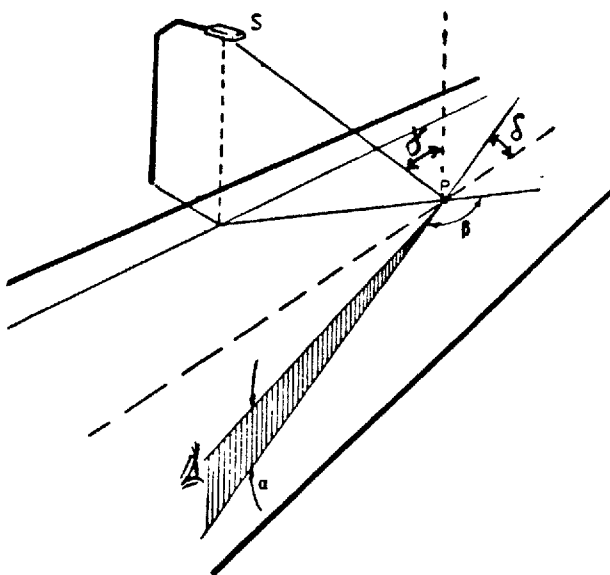


Figure 3.1. — Angles upon which the luminance coefficient is dependent.

- α : angle of observation (from the horizontal)
- β : angle between vertical plane of incidence and vertical plane of observation
- γ : angle of incidence (from the upward vertical)
- δ : angle between vertical plane of observation and road axis.

For the standardised area of road between 60 - 160 m ahead of a driver, (which can be considered as the area against which a car driver should be able to see obstacles) and for the standardised observation height of 1.5 m (which can be considered as the average eye height for drivers of motor vehicles) the observation angle α only varies between 0.5 and 1.5 degrees. Measurements have shown that within this range, the dependency of q can be neglected (de Boer, Onate, Oostrijk, 1952). Measurements of the luminance coefficients should be made for $\alpha = 1$ degree, which lies roughly in the middle of the region considered. For road lighting, therefore, the luminance coefficient will be treated as being dependent on the values of only two angles : β and γ .

Thus : $q = q(\beta, \gamma)$

When using luminance coefficients for specifying road reflection properties, one should bear in mind that for very specular reflecting surfaces the concept of luminance coefficient is no longer valid. In this case the luminance of the light source that illuminates a road surface element also determines the luminance of that element. In practice the concept of luminance coefficient as defined above can be used as long as the road surface is not flooded (de Boer, et al, 1967).

3.1.2. Description by means of reflection tables

For road lighting purposes, the complete reflection properties for any road surface condition other than flooded can be given in a (two dimensional) table in which the luminance coefficient value q is given for a number of β and γ combinations.

For convenience of use when performing luminance calculations, these tables are normally given in terms of the reduced luminance coefficient, r , where :

$$r = q \cdot \cos^3 \gamma$$

the luminance at a point can now be written as follows :

$$L = q \cdot E = q \cdot I \cdot \cos \gamma / (SP) \\ \text{(inverse square law and cosine law)}$$

however, $(SP) = h / \cos \gamma$, which leads to :

$$L = (q \cdot I / h^2) \cos^3 \gamma = r \cdot I / h^2$$

where

L = luminance at a specified point on the road (cd/sq m)

r = reduced luminance coefficient of the road surface for the angles β and γ corresponding to light incidence and observation direction relative to the point considered (cd/sq m/lx).

I = luminous intensity of luminaire in the direction of point P.

h = mounting height of luminaire (m).

An example of a reduced luminance coefficient table - also called a reflection table (or r-table) - is given in table 3.2. The r -values should be given for the standardised β and γ combinations specified in table 3.2.

Having such a reflection table giving the complete reflection properties of a particular road surface, luminance calculations can be made for that surface for each point on the road with the formula given above.

The exact determination of the reflection table values for a particular road surface is possible only by performing laboratory measurements on a sample of the actual road surface - as described in section 4.1. of this report.

However, for the purposes of dry weather road lighting design, a reflection table can be selected via a classification system that groups road surfaces according to a simplified description system.

beta tan gamma	0	2	5	10	15	20	25	30	35	40	45	60	75	90	105	120	135	150	165	180
0	655	655	655	655	655	655	655	655	655	655	655	655	655	655	655	655	655	655	655	655
0,25	619	619	619	619	610	610	610	610	610	610	610	610	610	601	601	601	601	601	601	601
0,5	539	539	539	539	539	539	521	521	521	521	521	503	503	503	503	503	503	503	503	503
0,75	431	431	431	431	431	431	431	431	431	431	395	386	371	371	371	371	371	386	395	395
1	341	341	341	341	323	323	305	296	287	287	278	269	269	269	269	269	269	278	278	278
1,25	269	269	269	260	251	242	224	207	198	189	189	180	180	180	180	180	189	198	207	224
1,5	224	224	224	215	198	180	171	162	153	148	144	144	139	139	139	144	148	153	162	180
1,75	189	189	189	171	153	139	130	121	117	112	108	103	99	99	103	108	112	121	130	139
2	162	162	157	135	117	108	99	94	90	85	83	84	84	86	90	94	99	103	111	
2,5	121	121	117	95	79	66	60	57	54	52	51	50	51	52	54	58	61	65	69	75
3	94	94	86	66	49	41	38	36	34	33	32	31	31	33	35	38	40	43	47	51
3,5	81	80	66	46	33	28	25	23	22	21	21	21	22	22	24	27	29	31	34	38
4	71	69	55	32	23	20	18	16	15	14	14	14	15	17	19	20	22	23	25	27
4,5	63	59	43	24	17	14	13	12	12	11	11	11	12	13	14	14	16	17	19	21
5	57	52	36	19	14	12	10	9,0	9,0	8,8	8,7	8,7	9,0	10	11	13	14	15	16	16
5,5	51	47	31	15	11	9,0	8,1	7,8	7,7	7,7										
6	47	42	25	12	8,5	7,2	6,5	6,3	6,2											
6,5	43	38	22	10	6,7	5,8	5,2	5,0												
7	40	34	18	8,1	5,6	4,8	4,4	4,2												
7,5	37	31	15	6,9	4,7	4,0	3,8													
8	35	28	14	5,7	4,0	3,6	3,2													
8,5	33	25	12	4,8	3,6	3,1	2,9													
9	31	23	10	4,1	3,2	2,8														
9,5	30	22	9,0	3,7	2,8	2,5														
10	29	20	8,2	3,2	2,4	2,2														
10,5	28	18	7,3	3,0	2,2	1,9														
11	27	16	6,6	2,7	1,9	1,7														
11,5	26	15	6,1	2,4	1,7															
12	25	14	5,6	2,2	1,6															

Table 3.2. — Reduced luminance coefficient table for standard surface R1
(r-values have been multiplied by 10 000).

3.1.3. Simplified description system

The choice of the parameters used to describe the complete reflection properties of a road surface is based on the consideration that most surfaces can be reasonably well characterised by their specularly (or shininess) and their lightness (or degree of whiteness or blackness). The parameters adopted for use by the CIE in its description system are :

a) for the degree of lightness : the average luminance coefficient Q_0 , where :

$$Q_0 = \frac{\int_{\Omega_0} q \, d\Omega}{\Omega_0}$$

b) for the degree of specularly : the specular factors S1 and S2,

where $S1 = r(0,2) / r(0,0)$

and $S2 = Q_0 / r(0,0)$ (being equal to 10^{xp} , where xp is a specular factor used in older systems).

Where :

q = luminance coefficient (dependent on β and γ)

Ω_0 = solid angle containing all those directions of light incidence at the point on the road under consideration that are taken into account in the averaging process (as defined according to straight borderlines of figure 3.3.)

$r(0,2)$ = reduced luminance coefficient for $\beta = 0$ and $\tan \gamma = 2$ (figure 3.3.).

$r(0,0)$ = reduced luminance coefficient for $\beta = 0$ and $\tan \gamma = 0$ (figure 3.3.).