LIGHT REFLECTION BY CONCRETE BLOCKS

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1. INTRODUCTION

Figure 1 shows one particular type of lighting installation in combination with four different asphalt concrete road surfaces. In all four cases the illuminance on the road surface is the same, both regarding mean level and distribution of light. Yet the appearance of the road surfaces is quite different, both with regard to the mean level of lightness - officially the mean road surface luminance - as with regard to the brightness distribution or patchyness - officially the uniformity of luminance. The explanation of this phenomenon obviously is, that the road surfaces reflect the incident light in different manners towards the observer. Hence the reflection properties of road surfaces are an important factor in street lighting. This of course also holds for concrete block pavements. Reflection properties of road surfaces have been studied a lot in the past. One may say, however, exclusively for bituminous mixes and for cement concrete road surfaces. Recently, the Study Centre for Road Construction took the initiative to extend the investigation to the much used concrete blocks. The aim of this short contribution is to report on the first results in this respect, and in particular to see how concrete blocks compare with bituminous mixes, and above all with cement concrete road surfaces.

2. FUNDAMENTALS OF LIGHT REFLECTION

The basic notions regarding reflection properties of road surfaces may easily be explained with the help of figure 2. Here A denotes a lantern which emits light towards road surface element dS. This causes on dS a horizontal illuminance E_H and consequently dS obtains a luminance L perceived by observer O. Obviously L is proportional to E_H, so one may write:

$$L = q \cdot E_H$$

in which q is called luminance coefficient and is expressed in $cd.m^{-2}.lux^{-1}$.

q is not a mere material property of the road surface. It is to a large extent dependent upon the angle of illumination (γ), the angle of observation (α) and the angle (β) between the vertical planes containing the directions of respectively illumination and observation. In public lighting α may be taken as a constant ($1^{\circ}9'$), and so one gets:

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

For public lighting purpose q-values need be known at a large number of combinations of γ and β in order to have sufficient information about the reflection properties of the road surface under consideration. A way of handling such a set of q-values is to plot q at each direction of light incidence as a vector from dS as origin against the direction



Figure 1. Four differently reflecting road surfaces lit by one particular type of lighting installation.

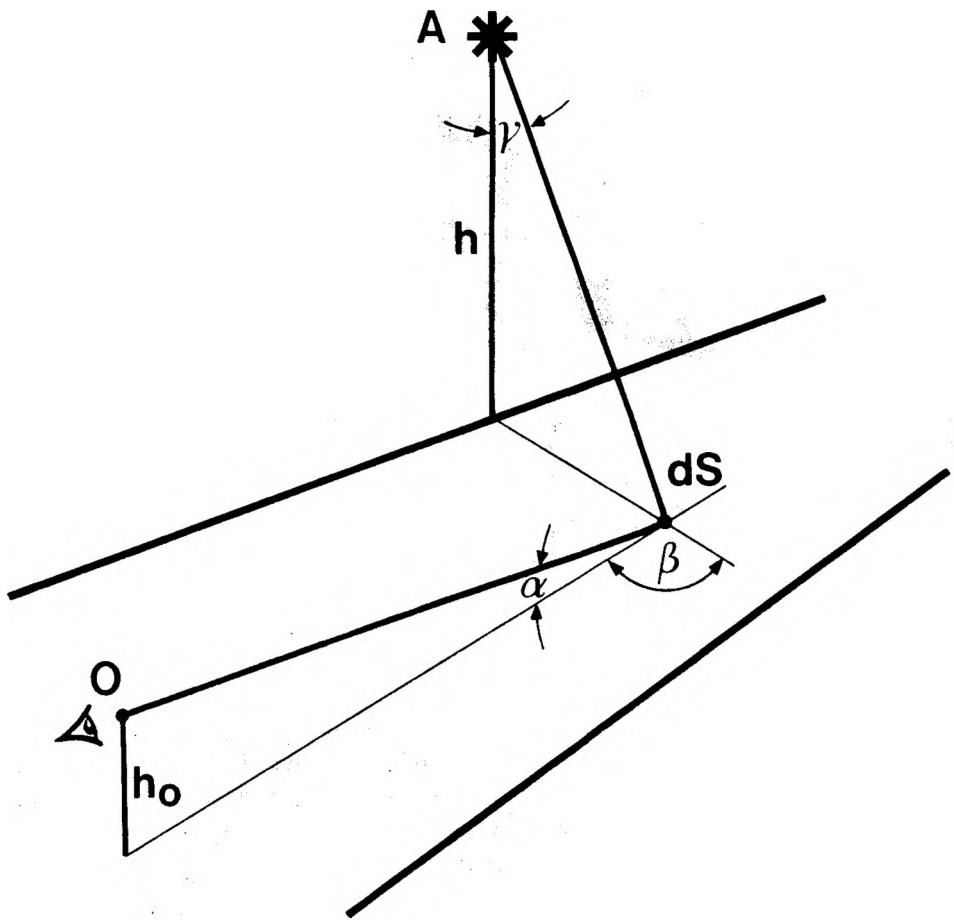


Figure 2. Basic geometry at reflection.

of light incidence, the length of the vector being proportional to the numerical value of q. The envelope of all these vectors constitutes a surface in space which is called reflection indicatrix (figure 3). As a matter of fact each road surface has its own reflection indicatrix, which is characterized by its shape and its size.

Road surfaces which have reflection indicatrices of the same shape all have the same brightness distribution or uniformity in the same lighting installation. Those road surfaces essentially have the same appearance. Differences in size of these reflection indicatrices manifest themselves in differences in the mean luminance of the road surface. They make one road surface on the whole look brighter than another as the size of its indicatrix increases.

3. CHARACTERIZATION OF LIGHT REFLECTION

Research carried out on behalf of Working Group E2 "Road lighting and surface texture" of the Study Centre for Road Construction has shown that the reflection indicatrix of a road surface is fully characterized by the measurement of only three luminance coefficients. Figure 4 shows at which three directions of light incidence the luminance coefficients must be measured.

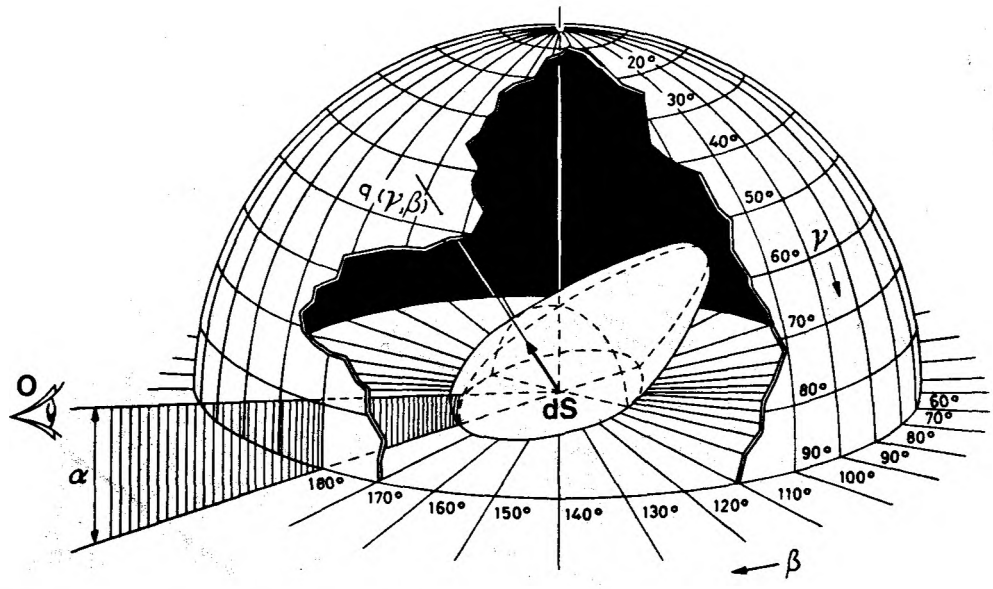


Figure 3. Reflection indicatrix.

From these luminance coefficients - denoted by q - two parameters may be derived, viz. P(2;0) and P(1;90). Their definition also follows from figure 4. They are characteristic of the shape of the indicatrix. The size of the indicatrix may be accounted for by q_p as scale factor.

4. CLASSIFICATION OF ROAD SURFACES

With regard to light reflection road surfaces may be represented in a P(2;0) - q_p diagram. Figure 5 shows such a diagram for bituminous mixes, e.g. cold asphalt and asphalt concrete, and cement concrete road surfaces. It appears that these road surfaces lie in a parabolic band within the diagram.

Research carried out for the afore-mentioned Working Group has shown that two classes of road surfaces may be distinguished. These are denoted by CI and CII. Their boundary lies at P(2;0) = 0.4.
Road surfaces within CI are preferred over those in CII, because their level of reflection is on the whole 25-50% higher, whilst their uniformity of luminance in street lighting, again on the whole, is at least as good as the uniformity of the road surfaces which belong to CII.
The q_p-values of the road surfaces within CI show a normal distribution around a mean value of 0.08 $cd.m^{-2}.lux^{-1}$.
Since in street lighting the mean road surface luminance is proportional to q_p, it is obvious that a preferred area may be distinguished in the parameter diagram.
This is defined as follows:

$P(2;0) \leqslant 0.4$

$q_p \quad \geqslant 0.08\ cd.m^{-2}.lux^{-1}$

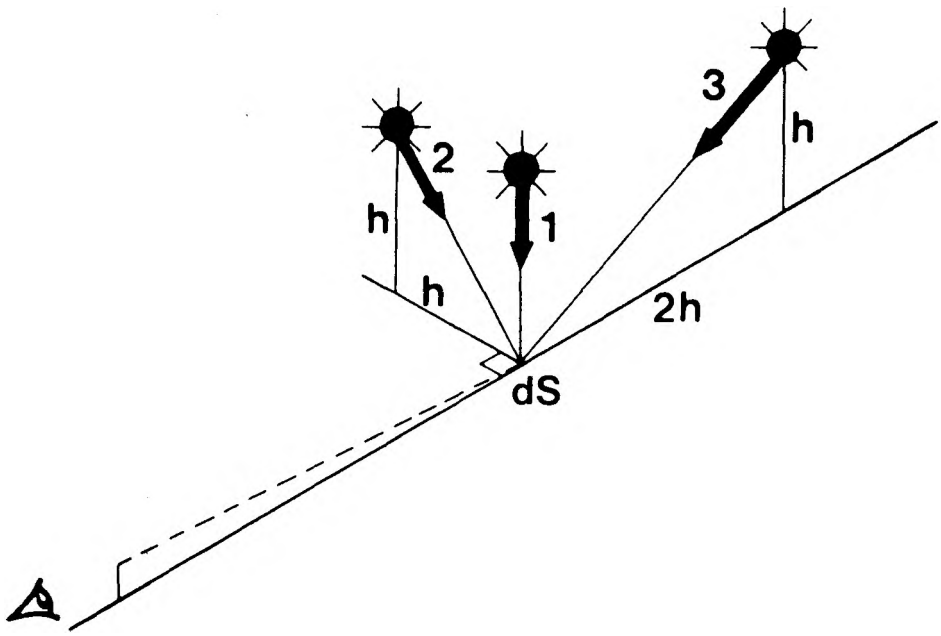


Figure 4. Schematic representation of the directions of light incidence 1, 2 and 3 for the measurement of resp. q_p, $q(\tan\gamma = 1, \beta = 90^o)$ and $q(\tan\gamma = 2, \beta = 0^o)$.
Note: From these measurements the characterizing parameters are calculated in the following manner:

$$P(2;0) = 8.95 \times 10^{-2} \times \frac{q(\tan\gamma = 2, \beta = 0^o)}{q_p}$$

$$P(1;90) = 3.54 \times 10^{-1} \times \frac{q(\tan\gamma = 1, \beta = 90^o)}{q_p}$$

q_p = scalefactor

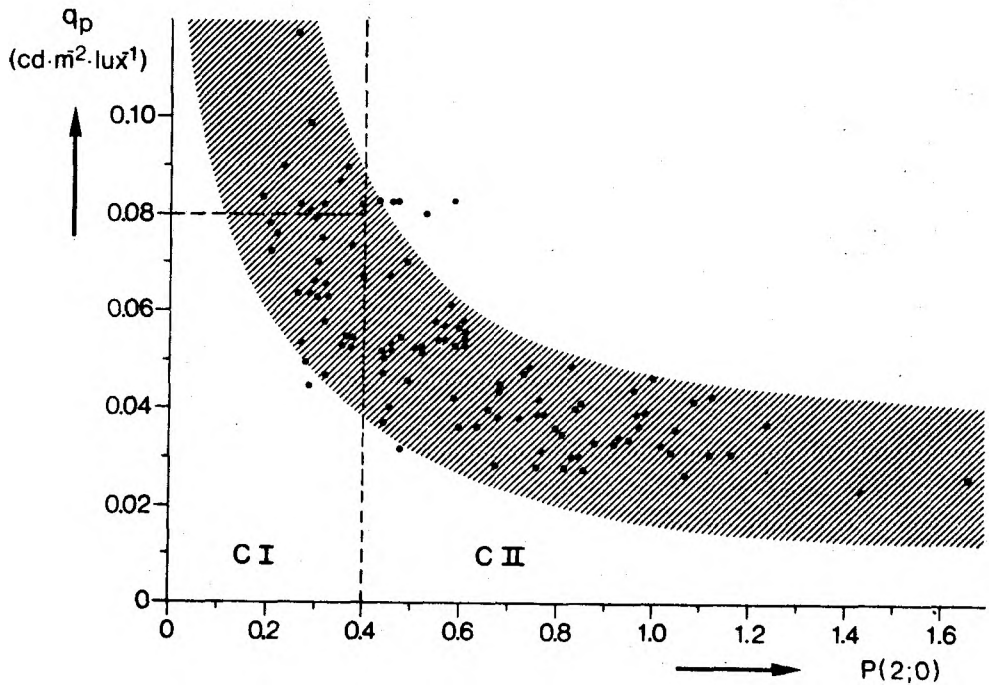
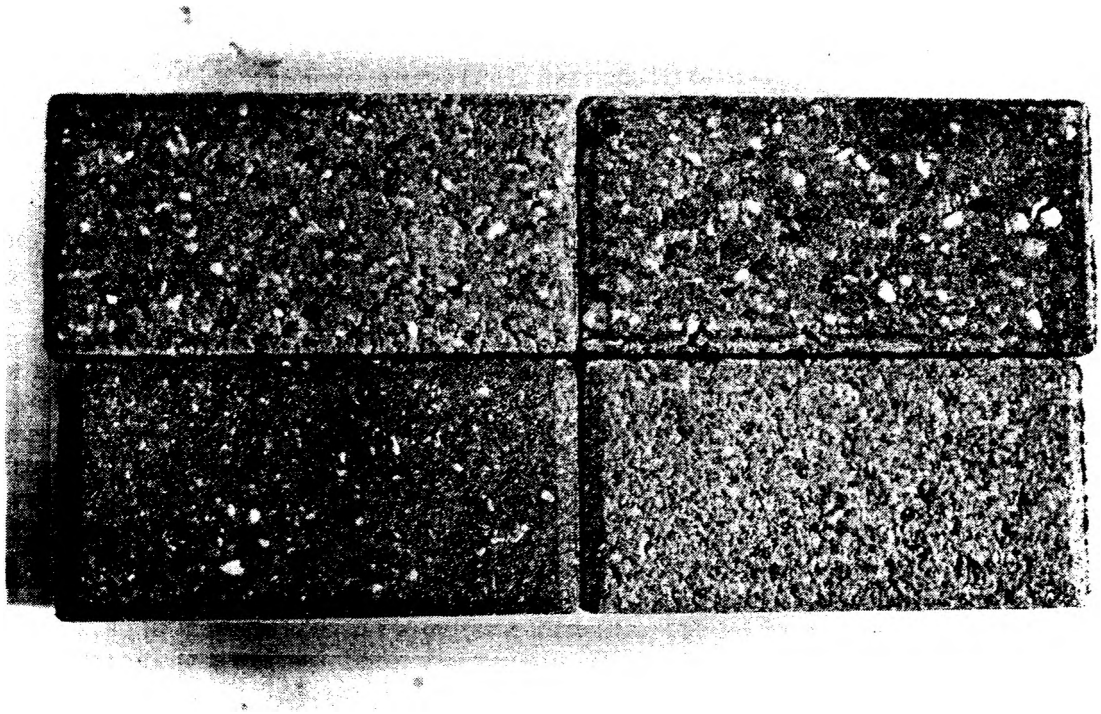


Figure 5. P(2;0) - q_p diagram for bituminous mixes and cement concrete road surfaces.

Cement concrete road surfaces were found to belong to CI where they lie around the lower border of the preferred area. An analysis of the relationship between the composition of bituminous mixes and reflection is summarized in the Appendix.

5. LIGHT REFLECTION BY CONCRETE BLOCKS

The afore-mentioned luminance coefficients have been measured on concrete blocks in order to learn how light reflection by these blocks compares with the reflection by bituminous mixes and concrete road surfaces.
Two types of concrete blocks were available, viz. grey ones and red coloured ones. Of each type there were 10 new blocks and 10 blocks which had been in use. The used blocks had been in use long enough to justify the expectation that they would no longer change with time. The new blocks - grey and red - were of one manufacturer, and the used blocks - also grey and red - were of another manufacturer. Therefore it is not possible to draw definite conclusions about ageing.
Figure 6 shows a representative block from each of the four categories.



above left: red used
above right: grey used
below left: red new
below right: grey new

Figure 6. Examples of the four types of concrete blocks.

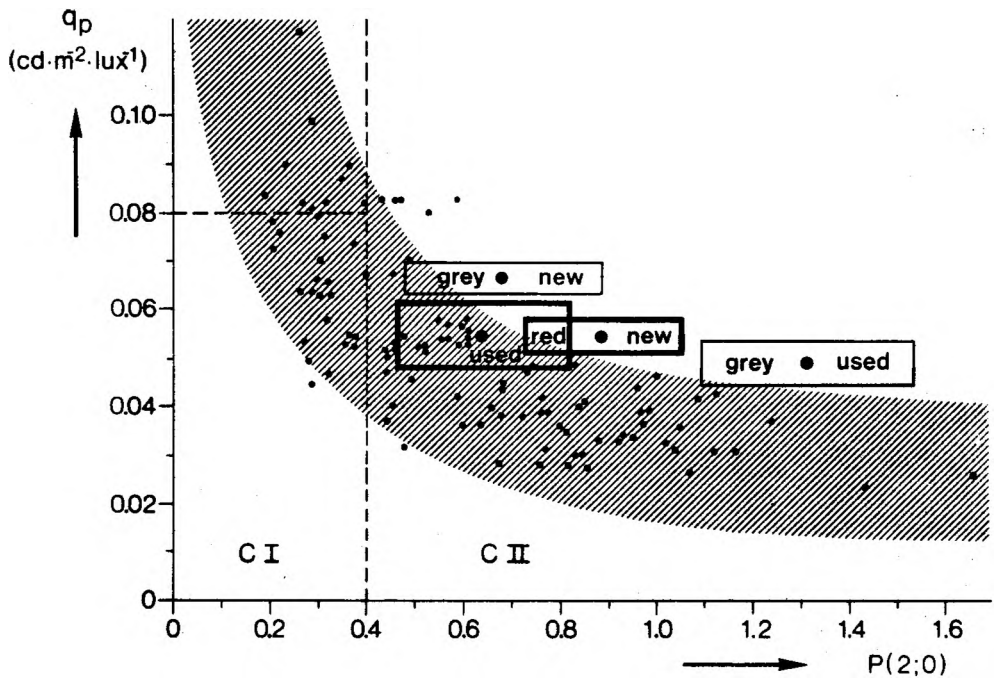
Table 1 contains the mean values of the parameters P(2;0) and P(1;90), and of the luminance coefficient q_p together with the standard deviations.

Manufac-turer	Type	q_p (cd.m^{-2}.lux^{-1})	P(2;0)	P(1;90)
1	red used	0.055 (0.003)	0.64 (0.09)	0.39 (0.01)
1	grey used	0.050 (0.002)	1.31 (0.11)	0.39 (0.00)
2	red new	0.054 (0.001)	0.89 (0.008)	0.41 (0.00)
2	grey new	0.066 (0.002)	0.68 (0.10)	0.38 (0.01)

Note: data between brackets are standard deviations

Table 1. Photometric data measured on concrete blocks.

The concrete blocks have also been plotted in the P(2;0) - q_p diagram for bituminous mixes and cement concrete road surfaces (figure 7). The data have been plotted together with the 2s-limits, i.e. in 95% of the cases the q_p and P(2;0) values of the type of blocks concrened will lie within the rectangles about the data points.



Note: new blocks and used blocks are of different manufacturers.

Figure 7. Plot of concrete blocks in the diagram of figure 5 together with 2s-limits.

Figure 7 shows that concrete blocks by and large conform to the band which was found for the road surfaces investigated earlier. It may be remarked, however, that the concrete blocks are on the whole more

specular than the other road surfaces owing to their relatively large P(2;0) values.
For practical purposes it is more interesting to take a look at the used blocks. Here one sees that the particular type of grey blocks is not well suited for public lighting because of its high P(2;0) value which would lead to too shiny road surfaces.
The particular type of red blocks, however, behaves fairly well and a pavement of such blocks may be compared with some of the bituminous mixes one may come across. It must be remembered that the used grey and red blocks are of different manufacturers, therefore it may not be concluded that red blocks are better than grey ones.
It is not possible to draw any conclusions regarding the effect of ageing since the grey new and grey used blocks are of different manufacturers. The same holds for the red blocks. Neglecting this, the grey blocks show increasing specularity with time as one would expect. The red blocks, however, show the contrary effect. But here the rectangles overlap so the difference between old and new is relatively small.

From the present random samples it must be concluded that from a light reflection point of view concrete blocks behave less favourably than bituminous mixes and - which is here more relevant - cement concrete road surfaces. It may be held well possible, however, that means can be found to shift concrete blocks into CI and possibly to raise their q_p-value. One of the means to this end would be to provide the blocks with a textured surface.

APPENDIX

Summary of the analysis of the relationship between reflection and composition of bituminous mixes

The investigation of the Working Group has led to the following conclusions with regard to bituminous mixes:

A1. As far as bituminous mixes are concerned no systematic relationship could be found between P(2;0) and q_p on the one hand and the type of bituminous mix - e.g. cold asphalt or concrete - on the other. It may therefore be concluded that the relationship between reflection and composition is determined only by the applied chippings.

A2. Bituminous mixes which contain the usual chippings may appear anywhere in the diagram: as well in CI as in CII, however, not in the preferred area.

A3. With bituminous mixes in which usual chippings have been replaced by white chippings, e.g. Luxovite or Synopal, it has been found that, if 30% or more of the total mineral aggregate consists of white chippings, the surfaces fall within the preferred area. Surfaces containing less than 30% white chippings will belong to class CII.

A4. Also in case of surface dressings or surfaces containing precoated chippings (e.g. hot rolled asphalt, topeca), the application of white chippings leads to surfaces within the preferred area.

CONCLUSIONS

In the Symposium it was emphasized that internal production control has a positive effect on the quality of the blocks and that therefore internal production control is necessary to present high-quality blocks to the user. Many developments will be co-determined by the demand, the availability of proper raw-materials, the need for exactness in size-tolerances and the need for mechanisation of block laying.
By further improvements in automation production volumes may well be significantly increased.
In view of the applications of concrete paving blocks it is desirable to aim at uniformity in block shape and block dimensions, on the other hand variation in block shape will stay with us if only with an eye on the visual aspect.
Of course for developing countries the consequences of production, quality and laying techniques will be different.

The results based on the papers presented during the Conference can be summarized as follows:

DESIGN

Four types of design methods can be distinguished, namely:
1. Design methods based on full scale testing of block pavements.
2. Modified asphalt design methods, based on CBR design philosophy.
3. Design methods based on linear-elastic multi-layer calculations, using elastic moduli for the various pavement layers.
4. Design methods based on finite element calculations.
   This approach has the best potential to analyse what is really happening in a block pavement under loading conditions.

On this Conference the theoretical design methods were emphasized, which might have been a bit disappointing for the practical engineers. In the next conference special attention should be paid to the verification of the theoretical design methods.
However, it became clear that the behaviour of block pavements ('progressive stiffening') is different from that of asphalt and concrete pavements.

CONSIDERATIONS ON THE CHOICE OF CONCRETE BLOCK PAVING

It was made clear that there are two main applications of concrete block paving, namely built-up areas and heavily loaded industrial areas like terminals.
However, adequate physical properties of the blocks are required to be sure that the durability of the pavement structure is sufficient.

CONSTRUCTION PRACTICE

In this Conference much attention was paid to mechanical block laying, which is gaining ground because of costs and, in some countries, for protecting the health of the paviors.

Mechanical laying has its influence on the concrete block manufacturing. Furthermore it should be noted that the performance of the pavement under traffic in the case of mechanical laying is not always as good as when the blocks are laid by hand. One of the reasons for this is that on this moment by machine not every laying pattern can be realized.

PAVEMENT MANAGEMENT

In the Conference low attention was paid to block pavement management. However, experience in this field with asphalt and concrete pavements is coming to block pavements.
Condition rating is only possible and useful if we appropriate a modified detection system.
It became clear that there is no unique performance standard, for example the acceptable rut depth, because subgrade conditions and maintenance costs are different in the various countries.

MATERIALS

With respect to materials, it is felt that an increase of the abrasion resistance is the most important condition for an increasing application of concrete blocks. Possible the use of waste materials and by-products can be increased.

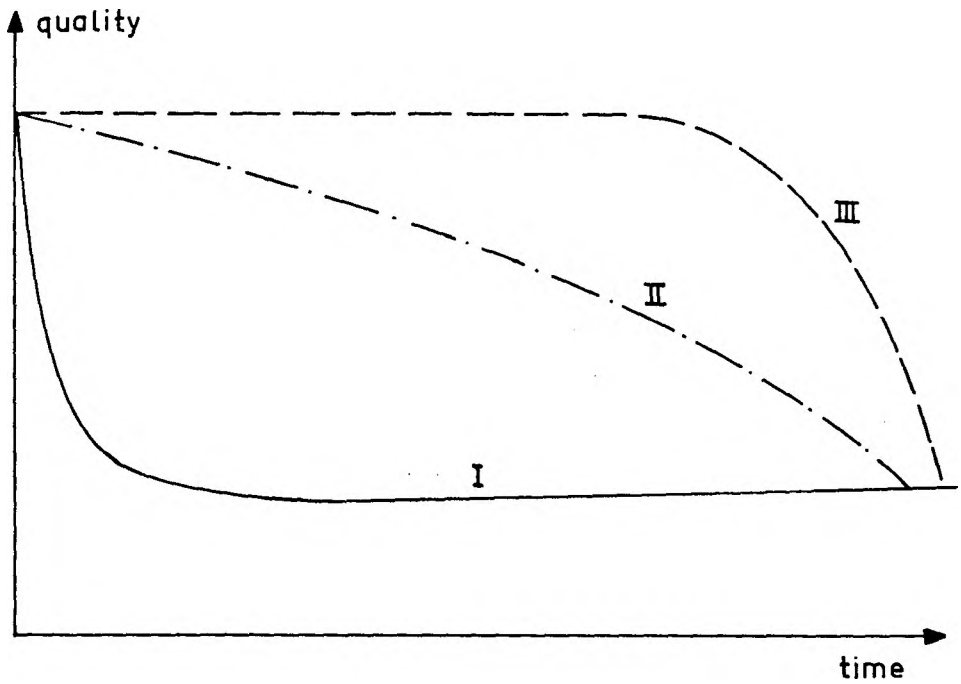
STANDARDS, SPECIFICATIONS AND TEST METHODS

It was shown that world-wide there is no uniformity in the judgement of concrete blocks.
However, it is to be wished that some day there will be one strength test procedure for comparison of test results.
The strength requirements are dependent on local conditions, like frost-thaw regime, if any, and the magnitude of the loads.



RECOMMENDATIONS

1. Judging from the papers offered for this Conference, it is felt that there are some 'blank areas' with respect to the application of concrete block paving and that some kind of information is lacking.
   It is clear that the themes deserving emphasis in a next conference are: test methods related to concrete block pavements, performance models, verification of design methods and pavement management and maintenance.
   The next figure, showing the deterioration of a pavement structure as a function of time, summarizes the foregoing: which curve is valid for the block pavement under consideration and where is it at present?



   Deterioration as a function of time for three different pavement structures

2. The main developments in a wide area of applied research and quality control of 'open' pavements are found in the countries that provided the strongest response at this Conference: Japan, Australia, South Africa, United Kingdom, United States of America and The Netherlands.

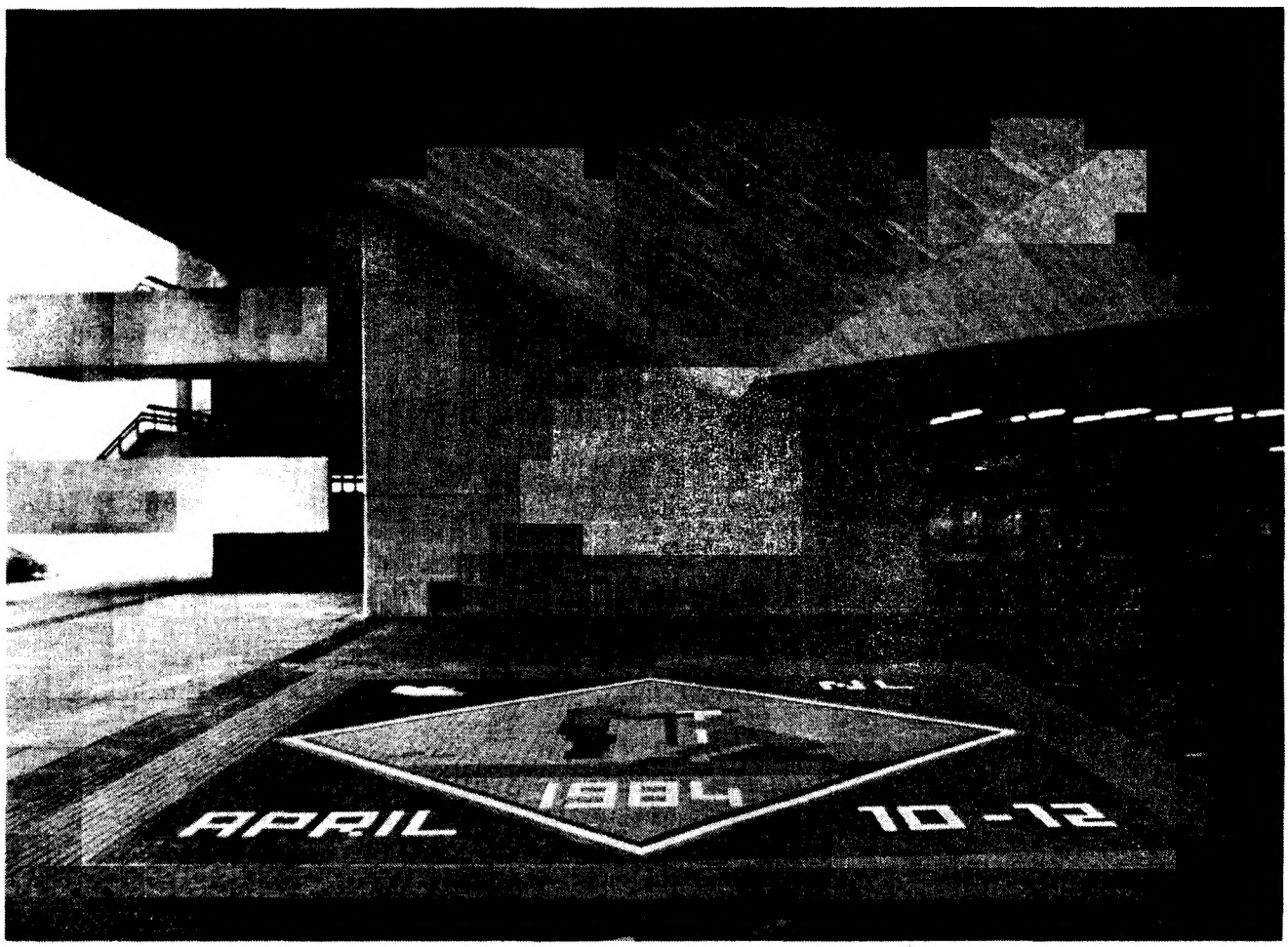
3. The broad participation and attention in this Conference on Concrete Block Paving (technical sessions, exhibition, manufacturing symposium, excursion) indicates that it is a proper basis for a beneficial exchange of know-how between principals, users, road authorities, researchers and manufacturers.
   It should be considered, however, to widen the title to 'International Conference on Small Element Paving'.
   Therefore it may be desirable to set up an international 'Steering Committee' with representatives from Asia, Australia, Europe, South

Africa and North America. The objectives of this Committee could be:
- formulation of the scope of the international conference in relation to small element paving
- stimulation of developments for test methods (strength, durability) and standardisation
- pavement management and verification of design methods.

A general conclusion of this Conference might be that it has been shown that the construction of adequately performing concrete block pavements is a reality, noting that quality and performance are strongly influenced by the quality and construction of the underlying materials. Concrete block paving has proven itself as a structure with many possibilities for application.

See you all at the next Conference (in 1988?).
There will always be a 'concrete' reason to remain 'locked-up' in contact.

Prof. Wim van Dijk



A remaining memory to the Second International Conference on Concrete Block Paving 1984 near the entrance of the Main Auditorium of the Delft University of Technology

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Delft — De straatklinkers moeten lichter worden. P materiaal waarmee straatmakers nu moeten werke veel te zwaar. Grote oorzaak van het hoge ziekt zuim onder de 5500 straatmakers in Nederland ook dat straatmakers zich letterlijk aan hun we

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opdrachtgevers, vaak nam overheidslichamen en o werpers — worden bij het treden van de aula d FNV'ers staande gehou om een stencil in ontvangs nemen.

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Tweede Internationale Betonstraatstenen Congres. Op het driedaagse congres (van 10 t/m 12 april) zullen 43 papers uit 13 landen worden gepresenteerd, waaronder Japan, Nieuw Zeeland, Australië, de Verenigde Staten, Canada en Israël.

Het gebruik van stenen voor het verharden van wegen is letterlijk al zo oud als de weg naar Rome. De toepassing van cementbeton als grondstof voor die stenen is recentere datum, maar bestaa ook al zo'n dertig jaar. Vreemd is het wetenschappelijk onderzo naar het verharden met betonstraatstenen echter pas een já geleden op gang gekomen. Een gespr met twee van de organisatoren van h Congres, prof. drs. W. van Dijk L.M.J. Houben, beiden akgroep Verha delin

uit betonstraatsteen", zo weet Houben te vertellen. Van Dijk somt nog wat ande getallen op: „Nederland heeft volg cijfers van 1980 92.000 kilomete weg. 40.000 km. daarvan bebouwde kom en zo Daarnaast is er d onverharde kom". Maar to

„the conference may serve to bridge the gap between theoretical knowledge and ...ice"



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