FACTORS INFLUENCING THE CHOICE OF CONCRETE BLOCKS AS A PAVEMENT SURFACE

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SUMMARY

This paper examines the factors affecting the safety and environmental impact of concrete block paving The paper begins by reviewing the surface characteristics of block pavements. In particular, surfaces colour and texture, pavement roughness, skid resistance and road noise are considered. The contributions made by these factors to the control of traffic, safety and the mitigation of adverse environmental impacts are then discussed. Inter-alia it is shown that block paving is exceptionally versatile in the control that it provides to designers and specifiers in the construction of safe and environmentally acceptable pavements.

1. INTRODUCTION

To date most research into concrete block paving has been directed towards both delineating the structural characteristics of this form of construction and developing design procedures (eg. 1-5). However, block paving offers designers and specifiers more than just structural advantages. In particular, the choice of concrete segmental paving can have significant implications in both safety and environmental engineering.

Because the safety and environmental effects of a block pavement relate almost entirely to the surfacing the paper begins with a review of the surface characteristics of small-element paving. The implications of these characteristics with respect to the comfort and safety of pedestrian and vehicular traffic are then assessed. Finally the environmental effects of block pavements are briefly discussed.

2. SURFACE CHARACTERISTICS OF BLOCK PAVING

In 1985 the OECD published a report (1) concerned with the comfort, safety and traffic noise characteristics of road surfaces. This report was confined to flexible asphalt pavements. It is therefore of interest to examine these features for segmental pavements. The following characteristics of a concrete block surface are now considered:

1) Colour
2) Roughness or riding quality
3) Skid resistance
4) Abrasion resistance
5) Noise generation.

2.1 Colour

Concrete blocks are unique amongst pavement surfacings in respect of the ease with which colour may be controlled. This allows the pavement designer to specify colour as a design element in both pedestrian and trafficked areas. In the latter case the choice of colour may have important implications for the visibility of the road surface by day and by night. For this reason it is important to quantify the effects of a change in the colour of paving blocks. This can be conveniently characterised in terms of the luminance factor. This is defined as the ratio of the luminance of a material to that of a perfect diffusing reflector illuminated and viewed under the same conditions. In other words, the luminance factor can be regarded as a measure of the amount of light reflected by the material.

Measurements were made in 1982 at the University of New South Wales (UNSW) of the luminance factors of concrete blocks manufactured by a single supplier. The blocks were studied using both CIE Illuminant C (a light source simulating average daylight) and CIE A (a light source representing artificial incandescent lighting). For each sample measurements were made at three points on the block surface. Each measurement point was about 20mm in diameter. These observations are summarised in Table 1.

TABLE 1

Luminance Factors for Concrete Paving Units

Paving Unit Colour	Luminance Factor [P(0,45)] (mean of 3 determinations)	
	Illuminant A	Illuminant C
Charcoal Grey	15	14
Light Grey	18	16
Dark Brown	18	16
Light Brown	29	27
Light Red	18	16
Sandy Yellow	29	27
Natural	23	23
Light Brick	24	22

From Table 1 it may be seen that the luminance factor typically ranged between 0.14 and 0.27 for daylight and between 0.14 and 0.29 for artificial lighting. Irrespective of the block colours, these values are higher than the luminance factors normally measured for asphaltic surfaces (0.07).

subsequently the effects of the colour of concrete paving units were studied at the Australian Road Research Board (ARRB) (6). Here it was concluded that the response of a driver to two specific block colours (yellowish brown and reddish brown) and a conventional asphalt surface depended on whether the surface was wet or dry.
Overall the UNSW and ARRB results show that, in the dry state, good contrast can be observed by a driver between blocks of different colour and between blocks and asphalt. However, in wet conditions, the contrast is severely diminished. At this stage the surface finish and presence of joints in a block pavement are likely to provide the principal visual cues to a driver.

2.2 Roughness

Only two sets of objective roughness measurements for block pavements appear to have been reported. The first of these, obtained in Britain, was made using a rolling straightedge and showed that satisfactory regularity could be achieved for urban road conditions (7). Moreover, the smoothness of the pavement appeared to increase under traffic. A more comprehensive study was reported by the Danish State Road Laboratory. This concerned trials of a series of block pavements installed as the climbing lane of a rural expressway (8). Here a test road about 1.3km long was constructed. This comprised four types of concrete block and two types of asphaltic surface. Profilometer and bump integrator measurements made immediately after construction showed that the riding qualities of the blocks were inferior to the asphaltic surface. Later measurements made once the pavements have been under traffic for two years showed an improvement in roughness. Generally the rougher pavements tended to become more even. However, the block pavements continued to exhibit higher bump integrator values than for the asphaltic surfaces. It was concluded that block paving was suitable for speeds up to 60km/h (8).
The adverse impression of pavement roughness conveyed by measurements of the type described above does not necessarily correlate with the ride comfort perceived by the travelling public. Block pavements do not appear to have attracted adverse comment from motorists. This suggests that block pavements are not perceived to offer inferior riding qualities. Support for this view comes from a public survey conducted in Japan (9). Here 46 per cent of respondents rated the riding qualities of an urban block pavement as good whilst 41 per cent believed that it was no different from a conventional asphalt surface. Only 13 per cent of the people interviewed rated the riding comfort of block paving as being inferior to asphalt.

2.3 Skid resistance

The skid resistance of concrete block pavements has been measured in 4 way, as

1) The stopping distance of test vehicles operating at or near the design speed of the road (10).
2) Friction/force parameters measured by special vehicles (eg. Stradograph, SCRIM) (2,8,11).
3) Pendulum test values (2,11,12,13).
4) Texture depth (7,8).

Measurements of the stopping distance of an actual test vehicle have been reported for interlocking concrete block and comparable asphalt pavements (10). High speed video equipment has been used to identify the precise point of wheel lock during sets of 6 panic-stops. In wet conditions the stopping distance of an average saloon vehicle from 60km/h was found to be reduced by 5m by replacing the asphalt surface with interlocking concrete (26.7m reduced to 21.3m). Reductions in stopping distance associated with block paving compared to asphalt were also measured at speeds of 20km/h and 40km/h. Ideally, skid resistance should be measured by test vehicles operating at or near the design speed of the pavement. In this respect, for six types of concrete block paver, brake force trailer measurements (BFC_{50}) ranging from 0.27 to 0.43 were observed in 1979 by the senior author (2). More comprehensive measurements were later reported by the Danish State Road Laboratory (8). Here a Stradograph was used to evaluate four types of block paving. This vehicle measured the skidding resistance continuously along the pavements at speeds of 20, 60 and 80 km/h. The measurements showed a fall in skid resistance during the first year of trafficking. However, the blocks maintained satisfactory skid resistance thereafter.
Measurements using the Sideways-Force-Coefficient-Routine-Investigation-Machine (SCRIM), have been made in South Africa (11). Here average values ranging between 63 and 74 were reported for travel speeds of 50km/h. The corresponding pendulum values ranged from 45 to 60. These values compare favourably with the values normally measured on an asphalt surface.
SCRIM values have also been obtained in the United Kingdom for a concrete block road surface in an indudstrial estate (7). Although the Sideways Force Coefficients (SFC) measured by this machine have not been reported it has been stated that the values did not depend on the orientation of the units to the direction of travel of SCRIM.
Pendulum tests (2,7.12) have been carried out to assess skid resistance. These do not provide as accurate an indicator of road safety as moving vehicle measurements. Typical pendulum values are summarised in Figure 1. It may be seen that the skid resistance values achieved for interlocking concrete block pavements tend to fulfill the requirements of even fast traffic and, in general, compare favourably with asphaltic surfacings. Several workers (8,12) have reported that concrete block pavements show a drop in skid resistance during construction, because of the polishing action of the plate vibrators commonly used to achieve initial compaction. Generally, it has been reported (12,13) that the skid resistance values tend to decline during the early stages of trafficking. Thereafter, the values either remain relatively constant (at levels similar to those measured for asphalt

pavements) or else fluctuate seasonally (12). Most skid resistance measurements have been confined to a period of just one or two years after construction. However, the senior author was able to evaluate an interlocking concrete bus route in Durban, South Africa, after 17 years of traffic. Here, pendulum values having a mean of 61 and a standard deviation of 4.3 were obtained (Figure 1). This suggests that, subject to proper manufacturing controls, interlocking concrete pavements can maintain good values of skid resistance throughout the life of the pavement.

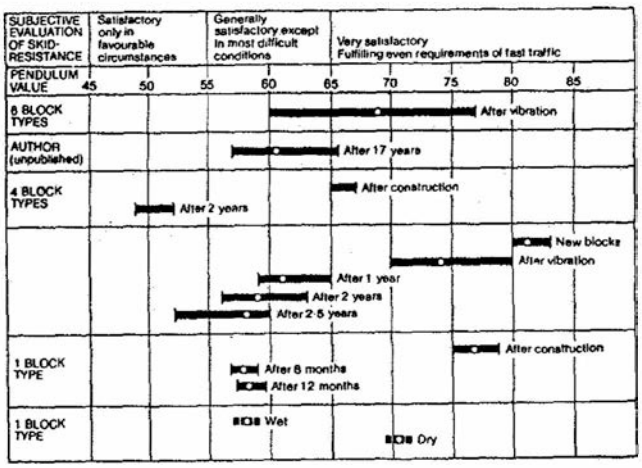


Fig. 1 Skid resistance values worldwide

In addition to the above methods of measurement texture depth has been used as a means of assessing skid resistance. This provides an indication of the extent to which the texture of the road surface contributes to skid resistance when water films are present. Two investigations of concrete block pavements have included measurements of texture depth (7,8). For the United Kingdom, texture depths measured using a hand-propelled laser texture depth meter ranged between 0.8 and 1.8mm. These results roughly correlated with the size of the chamfers on the units (8). In Denmark, measurements in accordance with Road Note 27 indicated texture depths between 0.6 and 0.7mm (8). These are less than the values for freshly laid asphalt surfaces but are similar to those observed in transversely grooved concrete pavements. Judged by this criterion the texture depths observed in block pavements are commensurate with satisfactory skidding performance.
The skid resistance of concrete pavement blocks depends, in part, on the mix design and also on factors such as efflorescence. For example, it is known that the use of siliceous aggregates serve to increase both the skid and wear resistance of concrete. By contrast, practical experience shows that excessive efflorescence may substantially reduce skid resistance in a block pavement. Excessive efflorescence may be attributed to the use of an unsuitable mix or curing regime during block manufacture. More commonly, however, in block paving it results from the use of unwashed bedding sands contaminated with soluble salts.

2.4 Abrasion resistance

By far the worst abrasive wear in municipal applications occurs on heavily used footpaths and malls in the vicinity of office buildings and shops. This consideration obviously extends to pedestrian crossings where both vehicles and pedestrians use the surface. Road surfaces in general are not subjected to such high levels of abrasion.
In Australia the Concrete Masonry Association, in conjunction with municipal authorities and the University of New South Wales has developed a simple and rapid abrasion test derived from ASTM Procedure C779-82 (4). Here, the penetration into a paver of a water-lubricated ballrace running at 1024 rpm under a load of 14kg measured as a function of the number of ballrace revolutions. Typical results are shown in Figure 2.

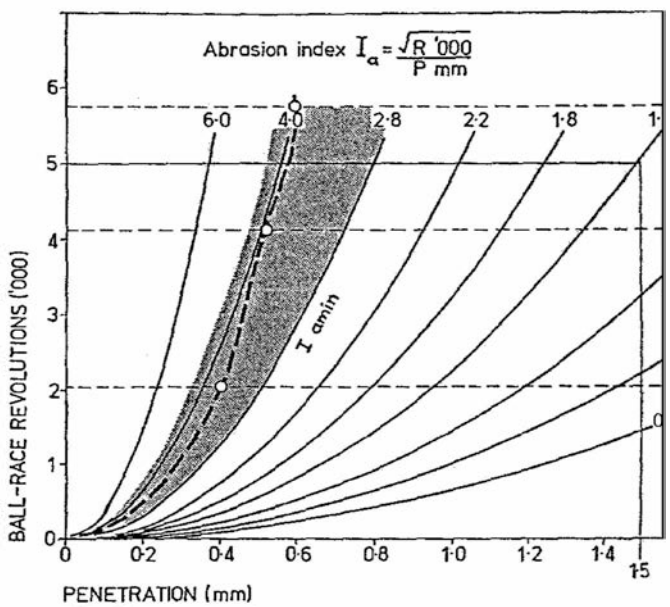


Fig. 2 Abrasion test results for a sample from a wear-resistant pavement

The CMAA test yields an Abrasion Index, I_{amin}, which is the lowest value from a sample of 5 specimens tested, representing a specified lot. Figure 2 illustrates the significance of I_{amin} values in relation to an actual footpath in service. Based on such tests minimum I_a values have been tentatively specified for general use (14). These range from 2.0 for busy pedestrian areas to 1.2 for lightly trafficked car parks.

2.5 Road noise

It has been claimed (15) that, at high traffic speeds, where tyre noise is the dominant noise generating mechanism, segmental pavements may be associated with noise levels from 5 to 8 dB(A), higher than for asphalt surfaces. However, in general, at vehicle speeds at or below 60km/h most studies show that the noise associated with block paving is either very similar to that generated by asphaltic roads (9,10) or else is lower (11) where the road surface is dry. For wet surface conditions the road noise associated

with block pavements has been reported to be about 8 db(A) lower than for asphalt pavements (9). This has been attributed to the fact that less water tends to remain on a block pavement than on an asphalt surface and that consequently the noise of the tyres forcing water across the surface is reduced (9). Most of the noise reduction occurs at frequencies over 1 kH (9). However, there is little reduction in noise at lower frequencies which may be regarded as more objectionable. Moreover, the roadside noise frequency spectrum normally shows a number of peaks which would be readily noticed by roadside observers (5). The road noise depends, in part, on the vehicle speed increases (9). Noise measurements made by the senior author in Adelaide (1982), Sydney (1983) and Hobart (1984) show that the effects of the size of the chamfers on the blocks influences the noise measured both at the kerb and within a moving vehicle. Overall, the block pavements showed increased road noise with increase in the size of the chamfers yielding increase of up to 4.4 dB(A) when the chamfers were 10mm x 10mm. Generally, for chamfers not exceeding about 5mm x 5mm the traffic noise measured at the kerb for a block pavement is little different to that generated on asphalt.

Although the noise levels observed for vehicles running on concrete block pavements are comparable to other forms of surface for an observer standing next to the roadway some increase in road noise may be apparent to a driver. Subjectively, in a recent study, about 80 per cent of drivers rated an urban block pavement as being either quieter or equal in noise level to asphalt surfaces (9). This is consistent with noise measurements made within a vehicle by the author and others (eg. 1) which show that, except in vehicles such as cars when the engine and transmission noise is low, no change in noise level is perceived for the vehicle running on either blocks or asphalt. In quiet vehicles block pavements may be associated with increases in the within-vehicle noise levels of between 2 and 4 dB(A) when compared to asphalt. Beneficial use of this effect has been made as a traffic control measure.

3. SAFETY ASPECTS OF BLOCK PAVING

Two aspects of safety need to be considered:

1) The control of traffic operations and signage
2) The comfort and safety of vehicle and pedestrian movements

These can then be evaluated against accident statistics for typical situations.

3.1 Traffic operations

In addition to physical control measures such as speed humps, traffic islands, rumble bars etc, the pavement surface itself can play an important role in the control of traffic operations. This is accomplished by a designer using the surface to provide a variety of subtle visual, auditory and tactile stimuli to drivers and/or pedestrians.

The most widely used form of control is the use of the colour and texture of the pavement surface to delineate traffic lanes and the direction of traffic flow. Here, concrete block paving provides the designer with a choice of colour and surface finish that is unique amongst paving materials. Moreover, traffic delineators are permanent and maintenance free.

The mosaic nature of interlocking concrete pavements can be used to great effect in lieu of or to supplement signposts. Roundabouts in Britain have had striking safety treatment carried out along these lines (17). The use of pavers to indicate direction reduces the need for above ground signs which are expensive to construct and maintain and could themselves constitute a traffic hazard.

As noted above, drivers can perceive distinct differences between paving units of different colours and between interlocking concrete blocks and asphalt under both daylight and street light illumination provided the road surface is dry. However, once the surface becomes wet, these differences become much more difficult to see. Accordingly, there may be advantages in supplementing the use of colour with a change in the texture of the road surface. To be visible in wet weather this implies the use of units with either special surface relief, chamfers, or with false joints.

The use of surface relief serves two main functions. Firstly it modifies the visual cues given to both drivers and pedestrians. Secondly it provides an audible change in road noise once a vehicle moves on to the surface. These features have been used in traffic control for many years with successful examples existing in Adelaide dating back to 1976 and in Sydney dating back to 1979. In Adelaide the systematic use of concrete block paving at turnouts and intersections has led to a reduction in vehicle speeds and pedestrian knock-downs in the precinct. This is said to be because drivers instinctively slow down as the road noise perceived within the vehicle suddenly increases once the vehicle moves from an asphalt to a block surface.

Surface relief in suburban locations is often used in conjunction with other devices such as speed humps and constrictions. In Sweden these are used to good effect provided certain rules are observed (18). In particular, lengthy distances between such obstacles should be avoided since these lead to widely varying speed patterns and a deterioration in safety. Notional distances of between 50 and 100m are preferred to ensure uniform speed distribution.

The logical extension of this is to replace whole streets with interlocking concrete paving with or without other traffic control devices. This has been very successfully carried out in King William Road, Unley, South Australia where one lane each way carries approximately 8000 vehicles per 24 hour day on weekly average (16000 total). Third and fourth outside lanes are constricted to provide parking.

A "Catalogue of Ideas" is being prepared by the Danish Road Directorate to solve problems associated with highways through towns. Elements of this are reported (19) involving rumble strips as warning of pedestrian areas

which are themselves identified by changes in the surfacing.

3.2 Vehicle and pedestrian safety

Here the designer is concerned with the smoothness and slipperiness of the pavement surface. In respect of smoothness, as noted above, interlocking concrete pavements are generally inferior to asphalt surfaces. However, at the design speeds appropriate to this surface (60km/h), this is of little practical significance and is often used to advantage where speed restrictions of 60km/h are prone to being ignored.

In the case of pedestrian traffic the safe non-slip surface of segmental concrete paving has been a major factor in its use in pool surrounds, in footpaths and pedestrian malls and in pedestrian crossings on major roads. In Manhattan more than 1000 pedestrian crosswalks have already been installed in concrete block paving. In California, Caltrans has monitored the performance of pedestrian crossings carrying 25000 vehicles (AADT) with 2-6% trucks. Over a three and a half year period these pavements yielded an average friction factor of about 0.47. This compared favourably with the value of 0.3 required as a minimum standard. In Europe, concrete segmental paving has been widely used on rail platforms because of the need to maintain safe pedestrian surfaces in all weathers.

In the case of vehicular traffic the studies summarised above demonstrated that concrete block pavements typically exhibit skid resistance values that equal or better those associated with asphalt pavements of similar age. Moreover, as noted above the stopping distance of a light vehicle on block paving is normally less than on asphalt when the surfaces were wet (10).

In Australia accident statistics for "before" and after" conditions are now becoming available for block pavements. For example, data for intersections in Adelaide incorporating concrete block paving are shown in Figures 3 and 4 for accidents involving personal injury or more than $300 damage.

Whilst the data shown in Figures 3 and 4 are very limited they tend to indicate that there has been an appreciable reduction in accidents where intersections have been upgraded using block paving as a traffic control measure.

4. ENVIRONMENTAL ASPECTS OF BLOCK PAVING

It is widely recognised that block pavements can make a positive contribution to the built environment through their high aesthetic value and the wide range of choices open to the designer in terms of colour, texture, pattern and scale. In these areas few paving materials have proved so versatile in hard landscaping and in the integration of buildings with their surroundings. However, block pavements can make other, more subtle contributions to the environment. These include the control of rainfall runoff, the minimisation of erosion and the modification of micro-climates.

The increasing proportions of impervious pavements in urban areas has led to widespread

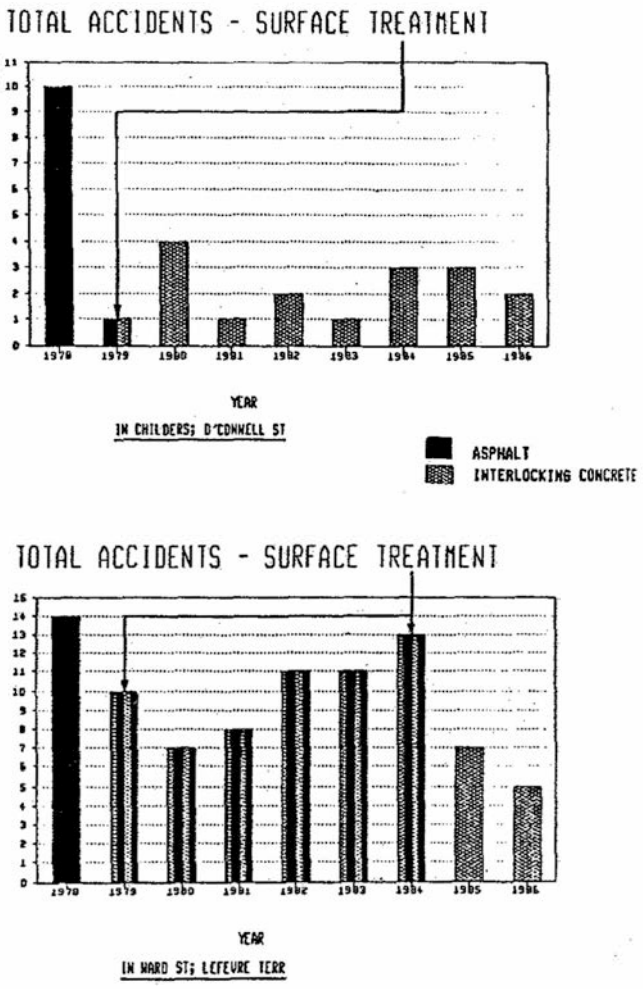


Fig. 3 Accident records as a function of surface type — Adelaide

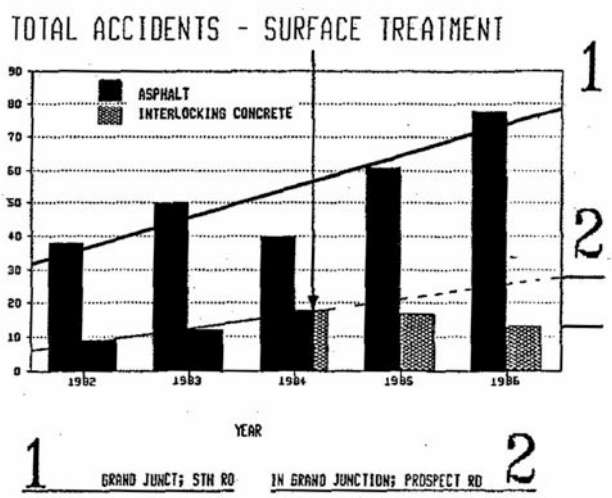


Fig. 4 Accident records on a major Adelaide arterial route as a function of surface type

problems caused by excessive stormwater runoff with increasing amounts of pollutants being washed into rivers and streams. One solution to this problem is to make more use of pervious pavements. Caution should be exercised in the choice of pavement. Some designers have, in the past, erroneously assumed that all segmental pavements are permeable and remain so throughout their service lives. However, in a block pavement carrying traffic there is a tendency for the joints to clog within a few months of construction. Such pavements offer only a short-term solution to the problem of absorbing or delaying runoff. By contrast grass blocks and grid pavements provide an ideal solution (20,21). Such paving must fulfill the following functions:

a) A reduction in stormwater runoff.

b) Reduction in the pollutants reaching stormwater drainage systems.

c) Improved aesthetics with paved areas assuming a park-like appearance.

d) An improved micro-climate. In this respect lower air temperatures have been measured over grid pavements than over continuous concrete or asphalt (14). This results from lower heat radiation from the pavement surface and from the pavement surface and from the cooling effects of evapotranspiration from trees and vegetation watered by infiltration through the pavement.

e) Low maintenance costs.

For these reasons grass blocks and grid pavements have been used in many landscaping applications ranging from overflow carparks to revetments and fire engine access routes to home unit and town house developments. Studies conducted in the USA have established that, although grid pavements may involve a higher initial cost than alternative forms of paving, this is more than offset by the advantages gained (20,21).
As well as being used to pave flat areas both solid and grid pavers have been widely utilised in slope paving. Applications include erosion control (slope protection), the mitigation of wave action on coastal protection works and the control of scour on river and Canal banks (22).

5. SUMMARY AND CONCLUSIONS

This paper has shown that concrete segmental paving can facilitate the construction of safe pavements which guide and control vehicular and pedestrian traffic by the use of visual, auditory and tactile stimuli or cues and which provide good non-slip surfaces. In addition block pavements can make a positive contribution to environmental engineering in the control of runoff, the trapping of pollutants, the improvement of micro-climates and the control of scour and erosion.
Based on a survey of work done in Australia and overseas the following specific conclusions are drawn.

a) Block pavements exhibit much higher luminance factors under both daylight and artificial light than asphaltic surfaces.

b) Different block colours can be readily distinguished both from one another and from asphalt provided the road surface is dry.

c) At speeds below about 60km/h block pavements are perceived to provide a ride quality equal to that of alternative types of road surface.

d) Block pavements have been shown to maintain satisfactory levels of skid resistance in service. The skid resistance tends to be equal to that associated with grooved rigid pavements and usually equals or exceeds that associated with asphaltic surfaces.

e) Some loss in the skid resistance of concrete pavers occurs during construction but this trend does not continue in service.

f) The roadside traffic noise associated with block pavements is similar to or less than that associated with asphalt pavements where the surfaces are dry. However, in wet conditions, block pavements have been reported to be quieter overall than asphalt surfaces.

g) For light vehicles concrete block pavements lead to an increase of within-vehicle noise of between 2 and 4 dB(A).

h) Limited data suggest that, where urban streets and intersections incorporate concrete block pavements, there is a reduction in the number of pedestrian and vehicle accidents.

i) The abrasive wear of segmental concrete roads and footpaths can be successfully controlled using a standard abrasion test provided care is taken to correlate the laboratory measurements with in-service performance.

j) Grass blocks or grids mitigate storm water runoff and the entry of pollutants into rivers and streams. By reducing surface heat radiation and by facilitating increased evapotranspiration from plants and trees, pervious grass blocks and grids promote a cooler micro-climate than conventional pavements.

Overall, concrete block paving provides the designer and specifier with more options for building safe and environmentally acceptable pavements than most alternative forms of construction. Accordingly the use of segmental paving to satisfy the requirements of safety and the environment is likely to increase as designer become more familiar with these advantages.

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