THE AUSTRALIAN ROAD RESEARCH BOARD'S PROGRAM OF TESTING OF INTERLOCKING CONCRETE BLOCK PAVEMENTS

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ABSTRACT

This paper summarises the program of testing into the performance of interlocking concrete block pavements conducted by the Australian Road Research Board (ARRB) on test pavements at ARRB and the Shire of Flinders. The testing at ARRB was conducted in three stages, ranging from deliberately under-designed pavements to pavements of thickness and subgrade conditions corresponding to the T4 curve of the design charts for block pavements produced by the Cement and Concrete Association of Australia in 1982. The performance of the pavements was related to the observed in situ conditions, the traffic applied to the pavements, the results of laboratory testing, and to other related studies in order to make recommendations as to changes that should be considered to the existing design and construction guides. The performance of the paving block itself was also examined in detail, including strength, noise, colour and skid resistance. A short review of previous overseas and Australian research into the performance of block pavements is also included, as well as a discussion on costs and benefits compared to other types of pavement. It is noted that many of the changes suggested as a result of the ARRB study have been incorporated into the revised design and construction guides.

INTRODUCTION

The Australian Road Research Board (ARRB) conducted tests of full-scale interlocking concrete block pavements between 1980 and 1984. The findings of this research have been extensively reported both in Australia and overseas (e.g. Sharp and Armstrong 1984a and b; Sharp, Armstrong and Morris 1982). The final report of the project, which was produced in 1985, can be considered an adequate summary of most of the previous reports. The following is an edited version of the Executive Summary of Sharp and Armstrong (1985), which was divided into two parts: a state-of-the-art review, and a summary of the ARRB tests.

STATE-OF-THE-ART REVIEW

Part A of Sharp and Armstrong (1985) presents a state-of-the-art review of the design of interlocking concrete block pavements, with particular emphasis on their use in roads, in The Netherlands, the U.K., the U.S., Japan and Australia, though research in other countries (e.g. Denmark, New Zealand and South Africa) is also reviewed.

Design in The Netherlands was, until about 1980, based on experience with clay brick paving and no need was seen to carry out any fundamental research (e.g. van der Vlist 1982). Since 1980, testing in The Netherlands has been carried out on both in-service and full-scale test pavements for the purpose of deriving design charts. The major performance parameters modelled were surface rutting and surface deflection (mainly using the Failing Weight Deflectometer) and the results have generally been analysed using finite element analysis. The most important research so far published was probably that of Houben et al. (1984) and Molenaar, Moll and Houben (1984).

The earliest extensive research was carried out in the U.K. by Knapton (1976). The U.K. Cement and Concrete Association conducted research on both full-scale test pavements and laboratory-simulated pavements until the early 1980s; research has lately been continued by Interpave, the U.K. block manufactures Association, and by local government. The earlier research was aimed at deriving materials equivalency factors, in order that Road Note 29 (TRRL 1970) could be adapted for design purposes. Later research has investigated the possibility that design based on Road Note 29 was too conservative (e.g. Griffiths 1982).

Design in the U.S. is also based on adaptations of existing flexible pavement designs, using procedures adopted in the U.K. The

Traffic Classifications and Required Paving Units

Anticipated Traffic Loading				Required Paving Units			
Traffic Classification	No. of vehicles per day >3 t gross	Total Equivalent Standard Axle repetitions after 20 years' service	Examples of Usage	Shape Type	Minimum Thickness	Laying Pattern[1]	Strength Grade (MPa)
T1	0-15	$0\text{-}4.5\times10^4$	Multi-dwelling driveways, car parks, cul-de-sacs. Malls not accepting delivery vehicles[2]	A B C	60 mm 60 mm 75 mm	H or S S H or S	35 35 35
T2	15-45	$4.5\times10^4\text{-}1.4\times10^5$	Minor residential streets subject to garbage vehicles. Commercial carparks	A B C	60 mm 80 mm 80 mm	H or S S H	35 35 35
T3	45-150	$1.4\times10^5\text{-}4.5\times10^5$	Residential streets. Malls accepting vehicular traffic[2,3]	A B C	60 mm 80 mm 100 mm	H S H	35 35 35
T4	150-450	$4.5\times10^5\text{-}1.4\times10^6$	Minor through roads etc. in urban areas with 60 km/h limit. Industrial hardstandings[4]	A	80 mm	H	45
T5	450-1500	$1.4\times10^6\text{-}4.5\times10^6$	Major through roads in urban areas within 60 km/h limit. City streets, bus interchanges. Industrial hardstandings subject to truck traffic only[4]	A	80 mm	H	45

Notes:
(1) H = Herringbone
S = Stretcher bond or basket-weave.
(2) 80 mm units may be required to cope with high point loads associated with fire fighting equipment, etc.
(3) For malls laid over sound existing pavements 75 mm cobblestones or 60 mm Type B units may be suitable.
(4) Excluding areas where straddle carriers or fork lifts carrying shipping containers are in use.

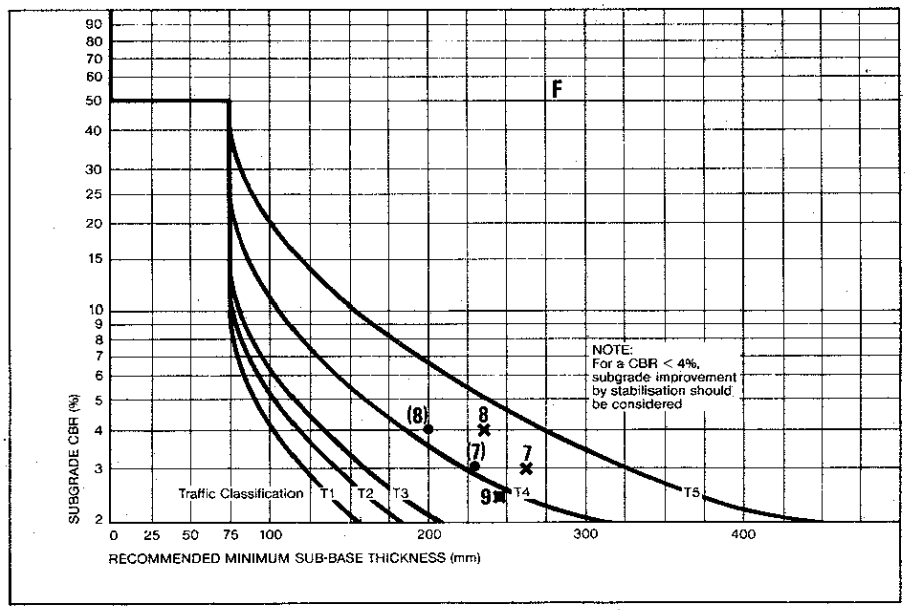


Fig. 1 - Design curves for concrete block pavements (Hodgkinson and Morrish 1982)

only major research reported in the literature was conducted by the U.S. Army Corps of Engineers in the early 1980s (e.g. Rollings 1983) and there appears to be a large potential market in that country which remains untapped.

Recent research in Japan has mainly been sponsored by cement companies and is continuing. Current design also appears to be based on existing flexible designs, with research concentrating on deriving materials equivalence factors between blocks, granular material and asphaltic concrete. Testing has been conducted on both full-scale test pavements and in-service pavements. Tests have also been carried out to investigate the potential use of block pavements to reduce traffic accidents.

CACA DESIGN CURVES

The design curves for concrete block pavements produced by the Cement and Concrete Association of Australia (CACA) in 1980 and 1982 (e.g. Hodgkinson and Morrish 1982) were less conservative than most overseas designs because they were not adaptations of existing flexible pavement design charts (see Fig. 1). The CACA curves were based on research carried out by Shackel in Australia and South Africa (e.g. Shackel 1979a, 1980a and 1982a). This research also led to the formulation of a hierarchy of block shapes which are related to expected performance. The major drawback of the design curves was that they had not been evaluated at subgrade CBR values less than 16; hence, the ARRB research was relevant, because the CBR of the expansive clay subgrade used in the tests was low, with soaked values ranging between about 2 and 4 per cent.

BLOCK SHAPE

It was also clear from the review that the choice of the most suitable block shape varies from country to country. Practice in The Netherlands and the U.K. is to use rectangular blocks. This is partly based on `tradition', but also from research findings in the U.K. that the performance of rectangular blocks is no worse than, and often superior to, shaped blocks. There is disagreement, then, between the findings of Shackel (1979a and 1980b) in Australia and South Africa and those of Knapton and Barber (1979 and 1982) in the U.K. On the other hand, Rollings (1983), in the U.S., tended towards the finding that increasing the block thickness was more beneficial to performance than changing the block shape. (Most research pointed to the advantages of increasing the block thickness.)

The testing at ARRB included an examination of the relative performance of two block shapes (one that keys on all four sides - Unipave - and one that keys on two sides only - Unidecor - see Fig. 2), and two block thicknesses (60 mm and 80 mm).

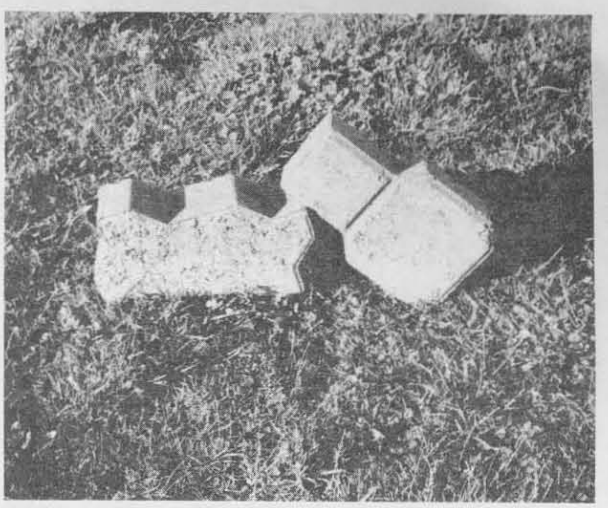


Fig. 2 - Block shapes tested by ARRB

IMPERMEABILITY OF THE JOINTS

A key parameter in the performance of concrete block pavements is the impermeability, or otherwise, of the joints of the pavement surface. There are obvious implications from the point of view of design and performance if water is able to find its way to the underlying pavement structure, having found its way into the pavement through the joints in the surface - or from anywhere else for that matter. While it has been traditionally claimed, and widely advertised, that the joints of a concrete block pavement surface seal, the only investigation to examine this behaviour (Clark 1979) suggested that, under simulated conditions of heavy rainfall, water penetration through the joints of the surface could be sufficient to damage the underlying pavement layers, especially if they were permeable base materials.

A major component of the tests at ARRB was the monitoring of the change in moisture content, and CBR and dry density, of the pavement layers over time and under trafficking. No other full-scale tests have examined these parameters to the extent of the ARRB tests; many tests did not consider this factor at all. Rainfall data at ARRB were also collected throughout the project.

CHARACTERISTICS OF PAVING BLOCKS

The characteristics of the paving blocks (compressive and/or flexural strength, dimensions, damage sustained under trafficking, etc.) were examined in some of the tests summarised in the review. All these characteristics were examined during the ARRB tests. Three properties of the block pavement surface, namely, their skid resistance and the differences in generated noise levels and in perceived colour from asphalt, are traditionally claimed advantages but little testing - especially of the latter two parameters - has been carried out. All three properties have implications for the potential use of concrete block pavements as a local area traffic management tool and the results of the ARRB tests are therefore important from this point of view.

MODELLING OF BLOCK PAVEMENTS

It is clear from the literature review that some difference of opinion exists as to the correct modulus value that should be assigned to the block layer when attempts are made to model the performance of concrete block pavements. Indeed, both finite element and elastic layer analysis have been used to model block pavements. Research from The Netherlands using finite element analysis (Houben et al. 1984) appeared to produce the best results, though their modelling was mainly restricted to block pavements laid over a sand sub-base. It appears that elastic layer models such as CIRCLY can be used to model block pavements, and elastic layer analysis forms the basis of the updated design guides (see Shackel 1986). The suggested modulus values varied from 415 MPa (Seddon 1980) to about 4500 MPa (Miura et al. 1984b) and clearly the value depends a great deal on test conditions. The work at ARRB was restricted in this area and certainly inconclusive. What was clear was that predicted performance, from the point of view of maximum surface deflection, was more dependent on a change in subgrade modulus than a change in block modulus (see Fig. 3). It is noted that, in many of the tests reviewed, the subgrade CBR was not accurately determined.

MATERIALS EQUIVALENCY

The materials equivalency between concrete blocks and AC was reported as being between 1.02 and 1.08 by Miura et al. (1984a) and 1.3 by Shackel (1979b). Rollings (1983) concluded that an equivalency between the blocks and granular material of one 1 lead to conservative results, Seddon's (1980) findings suggested a value of about 1, whilst Shackel (1979b) suggested a figure of 2.5. U.K. practice, on the other hand, was to assume that the

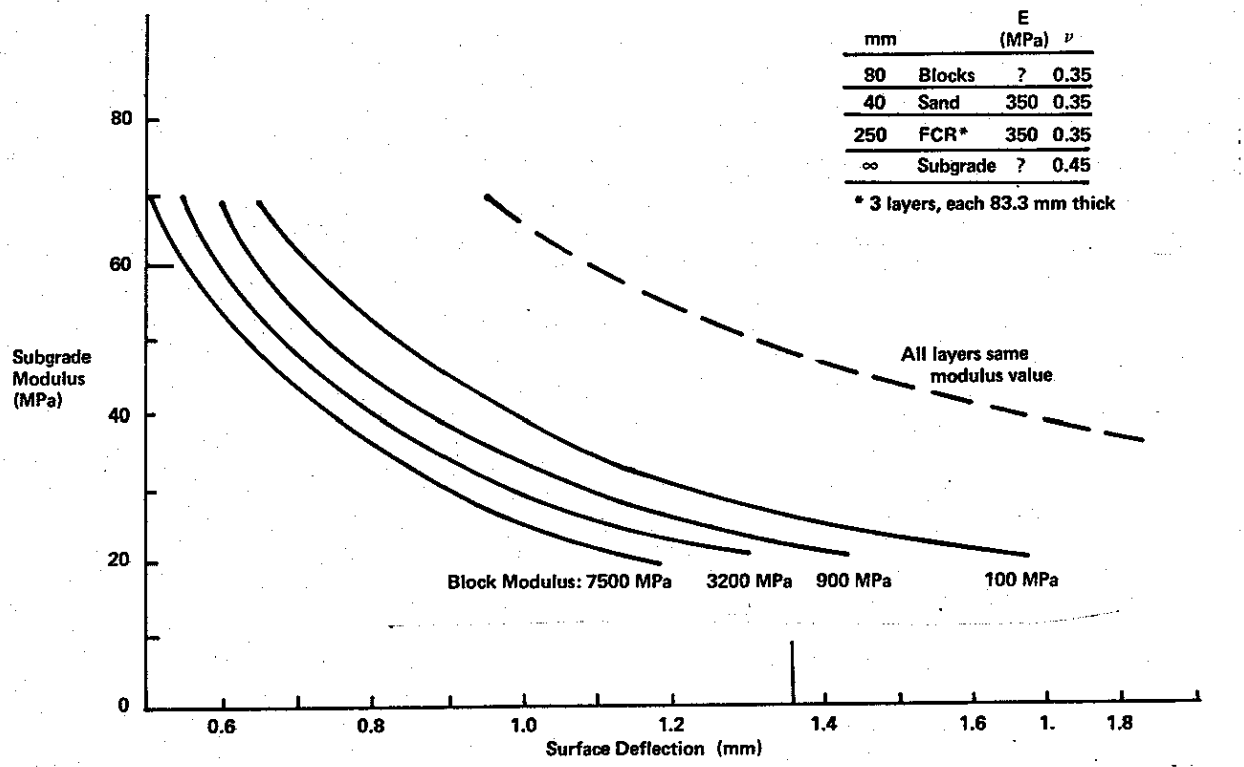


Fig. 3 - Attempts to model behaviour of block pavement at ARRB

blocks and sand are equivalent to 165 mm of the rolled asphalt roadbase, basecourse and wearing course used in flexible pavements, i.e. an approximate equivalency of 1.5.

No materials equivalency could be determined from the ARRB tests, but an evaluation, independent of the tests, was made of the equivalencies between blocks and granular material inherent in the CACA design curves (see Fig. 4). It is stressed that the CACA design curves were not derived on the basis of materials equivalency; however, it was noted that no trend was evident in the curves and it was interesting that the equivalencies between the blocks and granular material were the highest in the range of traffic conditions and subgrade CBRs examined in the ARRB tests.

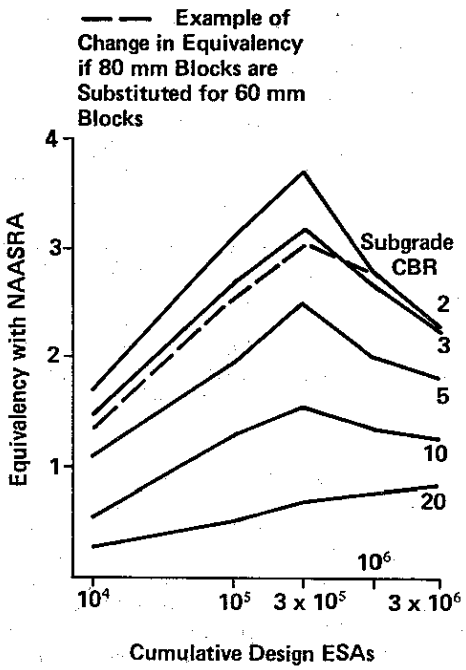


Fig. 4 - Layer equivalencies between blocks and crushed rock

BEDDING SAND LAYER

There is clearly some difference of opinion regarding both the desired grading and thickness of the bedding sand layer. Overseas practice tends to favour a compacted bedding sand thickness of at least 50 mm, but research (e.g. Shackel 1979a and 1980b) has suggested that pavement performance improves as tthe thickness of the bedding sand layer decreases. The figure of 50 mm suggested in the U.K. (Lilley 1982) is seen as a good `trade-off' between the need to install the bedding sand to a thickness as thin as possible and practical construction considerations. Generally, however, the trend is now to reduce the bedding sand thickness (see Hodgkinson 1986).

The gradings of the bedding sands tested also varied considerably, with the most extensive research in this area reported by Shackel (1980b). What was clearly demonstrated was that the grading suggested by CACA was `safe' and that users should strive to achieve this grading if possible. However, gradings outside the specification had also performed satisfactorily. Similar differences were evident regarding the desired moisture content of the bedding sand layer, with Shackel (1980b), for example, suggesting that performance was best if the moisture content of the sand was about 6 to 8 per cent, and Seddon (1980) suggesting that performance was best if the sand was either as dry as possible or saturated.

The role of the jointing sand has also assumed incraesed importance, and there is now a trend to specify a different (finer) grading for this sand than the bedding sand. Research in this area is continuing, and planned research by Clifford (1984b) and Mavin (1984) should cast more light on the role of this layer in the performance of block pavements.

The grading, moisture content and as-constructed thickness of the bedding sand was monitored during the ARRB tests and, at the Shire of Flinders, a different sand was used as the jointing medium to the bedding sand.

AS-CONSTRUCTED THICKNESSES

Most of the tests summarised in the review did not report any information regarding the thicknesses of the pavement layers achieved at construction, or changes in thicknesses after testing. If data were reported, they generally were confined to the thickness of the bedding sand layer at construction.

In order that the thicknesses of the pavement layers at ARRB could be accurately determined, levels were taken using an engineers' level and staff every 2 m at five transverse locations, including both wheelpaths. Levels were also taken at the end of testing of the final sections to determine which layers had deformed under loading. The results obtained were compared with those of Auff (1983) in order to assess if the standard of construction, with respect to final compacted thicknesses, were in line with normal construction

practice and also to check the practical relevance of the CACA suggested tolerances on thickness, i.e. were the CACA specifications in this respect 'achievable' in practice.

DESIGN TRAFFIC

The CACA design curves specified a range of traffic characteristics (applications, vehicles/day > 3 t gross and ESAs at the end of 20 years service) which were to be used for design purposes (see Fig. 1). Inherent in the design curves was the claim that block pavements will attain an equilibrium or `lock up' condition under trafficking, beyond which an increase in wheel load or the amount of trafficking will not affect performance. The traffic classifications were therefore included as a guide to designers only and were not intended to be used to calculate a `design traffic' per se.

This situation is obviously at variance with traditional flexible pavement design techniques. It was important, therefore, that the ARRB tests examined the relationship, if any, between observed performance and the amount of traffic applied to the pavement. Trafficking of the initial test sections at ARRB was deliberately accelerated, but the rate of application of traffic to the later sections was always within CACA requirements. The rate of application of loading was increased towards the end of testing of the final sections (though still within CACA requirements) in order to assess if increasing the rate of trafficking affected performance.

QUALITY OF CRUSHED ROCK MATERIAL

Of importance in any full-scale or laboratory test is the quality of the crushed rock materials installed in the pavement. In many of the tests reviewed, information of this nature was not adequately reported; on many occasions the crushed rock material was said to be of a certain standard, but little if any supporting test data were reported. An obvious exception was Rollings (1983).

The CACA design guide used the term `sub-base' to define its granular material, but specified that the quality of the material should comply with standards normally set for `base' materials by State Road and Local Government Authorities. An important part of the ARRB work was the investigation of the structural properties of the crushed rock materials installed in the test sections. Full laboratory analysis (Atterberg limits, compaction, gradings, Los Angeles values, etc.) was carried out, as well as field tests (in situ CBR, moisture content and dry density).

DESIGN SUBGRADE CBR

The design subgrade CBR could be determined, according to CACA, by any of five methods, the most reliable of which was in situ testing according to AS1289 (SAA 1977). The next most reliable method was laboratory soaked testing, followed by testing with the dynamic cone penetrometer (DCP) (see Hodgkinson 1982). The variation in subgrade moisture content and CBR (measured both in situ and with the DCP) was closely monitored throughout the ARRB tests in order to assess if the suggested methods of determining design CBR, and their order of reliability, were appropriate. Laboratory determination of the soaked CBR, Atterberg limits and compaction was also performed. In addition, the CBR values predicted using the in situ test were compared with those determined using the DCP, and the results compared with other Australian studies.

Where appropriate, results obtained were also compared with preliminary results from the ARRB local government sponsored project which has as one of its aims the derivation of design curves for residential street pavements.

WHAT IS 'LOCK UP'

Throughout the review of overseas and Australian work, the term `lock up', or similar terms, was continually mentioned. It is generally agreed that block pavements gradually `stiffen', i.e. they commence life acting as individual units and gradually lock together and share the load. Many tests have been conducted to examine, in one form or another, the concept of `lock up'. Some researchers appeared to doubt Shackel's (1979a) conclusion that once `lock up' is achieved the performance of a block pavement will be independent of traffic; hence design need only be based on the amount of surface deformation a designer is prepared to tolerate before `lock up' occurs. Clifford (1984a) suggested that the term `settling in period' was more appropriate because the observed behaviour of the rate of accumulation of rutting over time and under traffic is not confined to block pavements.

Some testing (e.g. Barber and Knapton (1980) in the U.K.) concentrated on examining `lock up' by

monitoring the rate of accumulation of surface deformation. A fairly common finding was that the rate of accumulation of rutting did decrease, but that the amount of rutting required for `lock up' to occur was substantial (greater than 30 mm). Whether a pavement `locked up' was therefore dependent on whether the surface integrity of the pavement was retained under these large deformations.

Some difference was also apparent from the review as to the amount of traffic required for `lock up' to occur. For example, Shackel (1979a) concluded that `lock up' occurred after 5000-10 000 ESAs and that the pavement behaved flexibly up to this point. Houben et al. (1984) suggested that full interlock was achieved after about 10 ESAs and it was at that stage that the pavement behaved flexibly. Miura et al. (1984a) suggested a figure of about 50 000 ESAs.

`Lock up' has also been examined in terms of the change in vertical stresses or strains transmitted to the underlying layers (e.g. Shackel 1980b); Kellersmann et al. 1984) and by the use of `pull out' tests (Kellersmann et al. 1984; Mavin 1984; Clifford 1984b). The most comprehensive of these tests was that of Shackel (1980c), though both Mavin's and Clifford's tests are continuing.

Attempts to investigate this behaviour at ARRB were restricted to monitoring the rate of accumulation of rutting under traffic. Pressure cells were installed in the early test sections, but no useful data could be collected. The claim by Shackel (1980b) that block pavements could withstand surface deflections up to about 2 mm in magnitude without performance being affected was also examined at ARRB, though circumstances prevented a full investigation.

PROPERTIES OF PAVING BLOCKS

Several tests examined the skidding properties of concrete blocks (e.g. Shackel 1980a; Clifford 1984b; Mavin 1984; Garrett and Walsh 1984; Lekso 1982; Kanzaki et al. 1984). Generally the skidding properties of concrete blocks were found to be satisfactory, though not all of the studies compared the data collected on the blocks with those for an asphalt `control' section, and in some cases only data collected at construction were collected. The only data collected in Australia were reported by Mavin (1984), his data mainly pertaining to in-service car parks, etc.

As part of the ARRB study, skid testing was carried out on a heavily-trafficked block pavement at the Shire of Flinders and the results compared to two AC control sections. The pavement was subject to trucks of gross load up to about 40 t travelling down a slope and negotiating a bend. The test was important, therefore, because data were collected under severe conditions of loading and over a long period of time to allow for seasonal variations.

Two other properties of concrete block pavements that have potential application in local area traffic management schemes are noise generation and colour. The only noise testing reported in the literature was carried out in Japan and the tests were limited; no colour testing had been reported by the end of 1984.

Both parameters were examined by ARRB. Internal and external noise levels were measured as cars travelled over the block pavement, and the results were compared to those obtained on an asphalt control section. Laboratory tests were conducted to examine the colour differences betweem two concrete block samples of different colour and an asphalt sample. Tests were conducted in both the dry and wet state.

A review of the specifications for the manufacture of concrete paving blocks revealed that compressive strength was the major quality indicator, though flexural strength is also considered in some countries (Houben, Leewis and van der Kreeft 1984). Both compressive and flexural strength testing was carried out on samples of concrete blocks used in the ARRB tests. Dimensional tolerances were also examined.

THE ARRB TESTS

GENERAL

Part B of Sharp and Armstrong (1985) reports the program of testing of full-scale concrete block test sections carried out by ARRB at the Australian Road Research Centre in Melbourne, and the Shire of Flinders, Victoria.

The ARRB tests were co-sponsored by Monier Industries, who agreed to construct the test sections, whilst ARRB was to be responsible for their testing. The original aim of the project was to test pavements that could find application as minor residential streets. Therefore, the initial sections were deliberately under-designed and expected to fail under traffic. The plan was to

gradually strengthen the pavements in order to arrive at an optimum design situation. It can be argued that, because Monier were responsible for the construction of the pavements, the quality of construction would be at least in line with normal practice given Monier's expertise in the field and the nature of the tests.

The testing at ARRB was divided into three stages as follows (see Fig. 5).

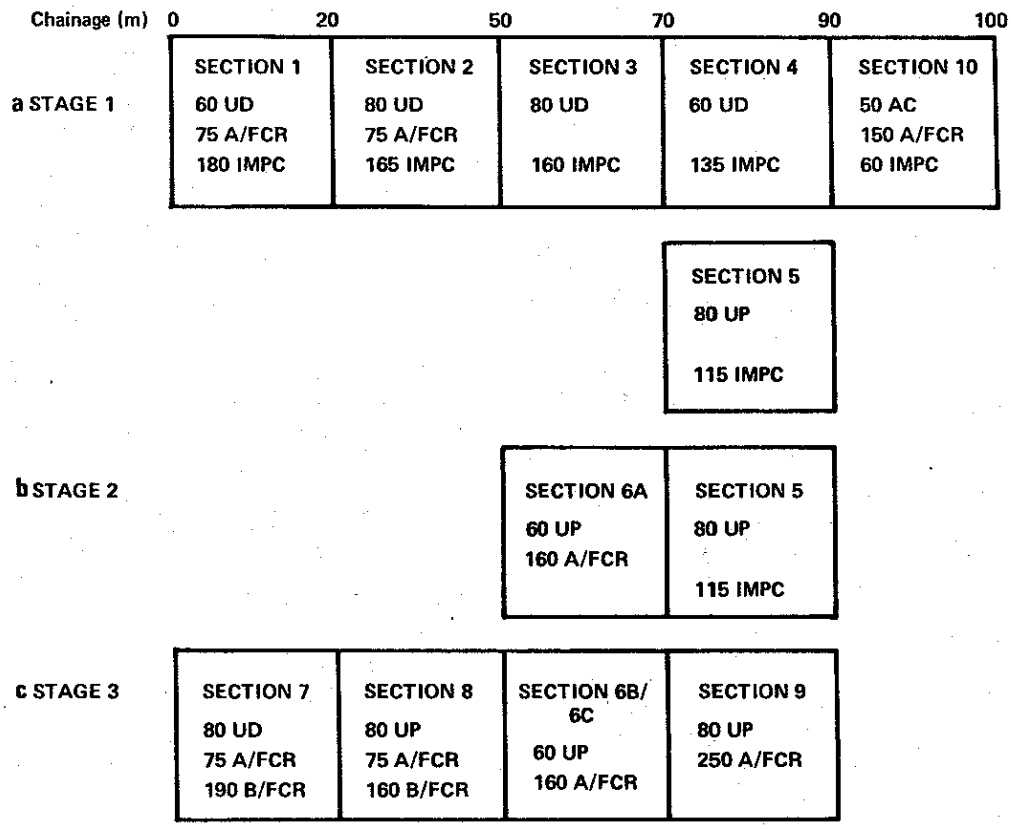
(1) Sections 1 to 5 and 10: under-designed pavements expected to fail under traffic. The object was to quickly assess the relative performance of Unipave and Unidecor blocks (Fig. 2) and 60 mm and 80 mm blocks. A section of AC laid over a granular base was also tested.

(2) Sections 5 and 6A: continued testing of Section 5, plus a section of thickness and subgrade CBR corresponding approximately to the T2 curve of the CACA design charts (see Fig. 1).

(3) Sections 6B, 6C and 7 to 9: further testing of Section 6A, plus three sections of thickness and subgrade CBR approximating the T4 curve of the CACA design charts.

The pavements tested in Stage 3 did not meet the original aim of the Project in that their application was, according to CACA, more heavily-trafficked roads than minor residential streets. The aim of the ARRB tests was not to specifically evaluate a particular design curve in the CACA design charts. Rather, and especially in Stage 3 of testing, the aim was to compare the observed performance with the known soaked subgrade CBR conditions, the amount of traffic applied, and the total thickness of the pavements.

Except for Section 6B, all of the test sections were either 20 m or 30 m long, and all sections were 4 m wide (see Fig. 6). The results obtained in the end 2 m of all sections were ignored to allow for 'end effects'. It was noted in the



All layer thicknesses are in mm.

Design compacted sand thickness in Sections 1-9 = 30 mm.

UD = Unidecor blocks; UP = Unipave blocks; AC = asphaltic concrete.

A/FCR, B/FCR = A Grade and B Grade fine crushed rock.

IMPC = Imported Clay Subgrade

Fig. 5 - Three stages of ARRB testing

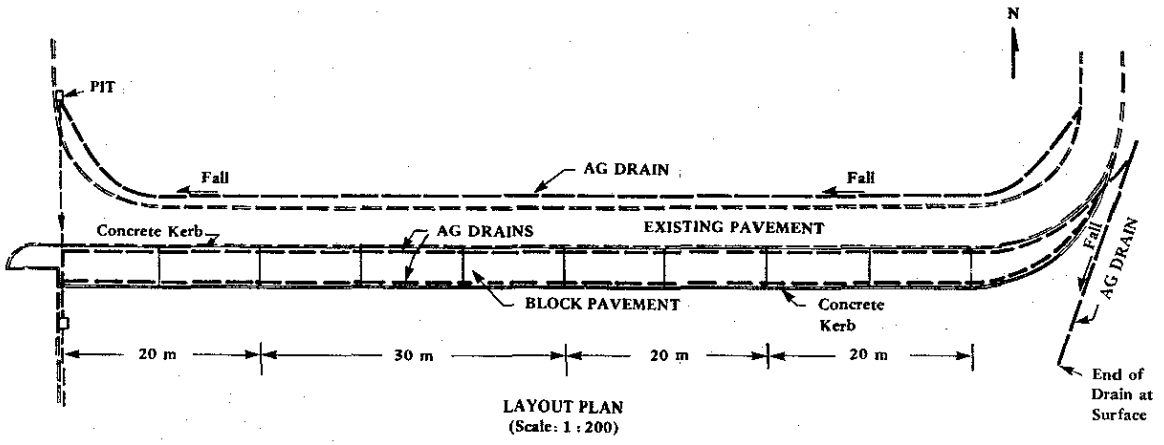
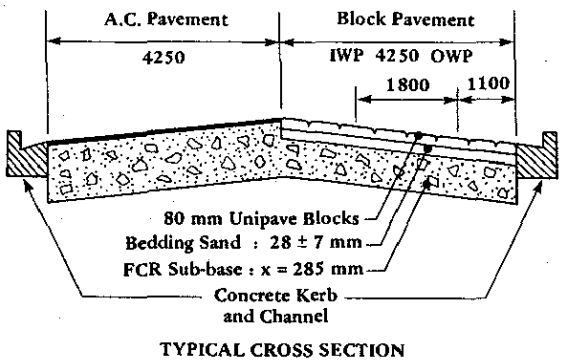


Fig. 6 - Plan and cross-section of test pavement at ARRB

review that many of the sections tested overseas were very short and doubts were expressed regarding the relevance of some of the findings reported.

The other pavement tested was part of an access road at the Shire of Flinders, Victoria (see Fig. 7). This pavement carried heavily-laden trucks and was over-designed according to the CACA design charts (see point 'F' on Fig. 1). As already mentioned, the main purpose of this test was to monitor the change in skid resistance over time and under loading and to generally assess the suitability of concrete paving blocks as a surface suitable for this type of traffic.

The major performance criterion at ARRB was the accumulation of surface deformation over time and under trafficking. The CACA design guide specified that the maximum allowable deformation was 10 mm. Rutting was monitored every 2 m in



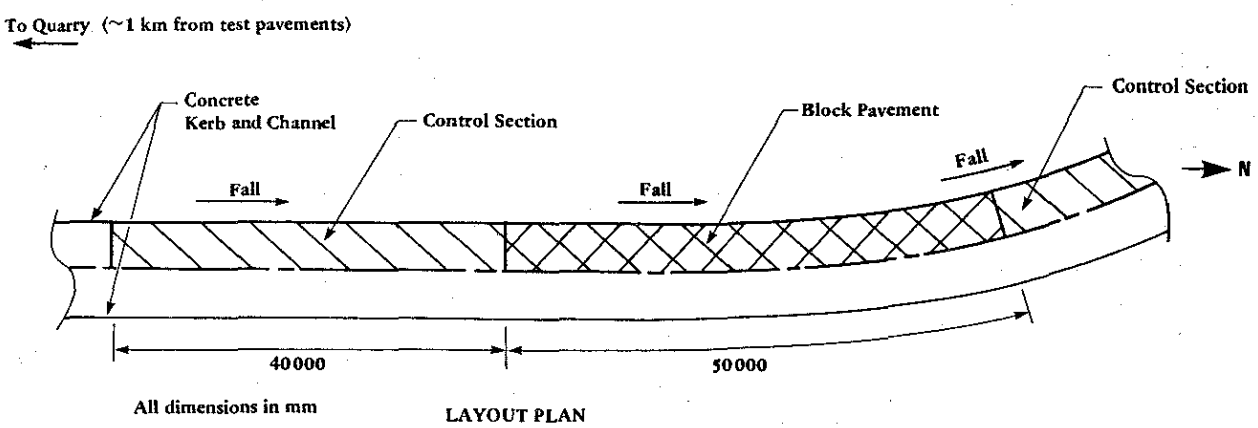


Fig. 7 - Plan and cross-section of test pavement at Flinders

both wheelpaths with a 1.2 m straight edge and generally trafficking continued until the mean rut depth in a test section reached, or exceeded, 20 mm. The relationship between surface deformation and traffic (in ESAs) for all sections tested is given in Fig. 8.

MAJOR CONCLUSIONS OF ARRB STUDY

As a result of the testing at ARRB, the following major conclusions were offered.

(a) Changes needed to be considered to the current CACA design and construction guides for concrete block pavements. These changes should recognise the following.

(i) The laboratory soaked CBR should be stipulated for design purposes if the subgrade is an expansive clay material and unbound granular material is to be placed over it. This conclusion was based on the evaluation of changes in subgrade moisture content and CBR observed over time and under traffic (Fig. 9), and a comparison of these data with findings from the local government sponsored project being undertaken by ARRB (e.g. Morris 1984). Comparisons between subgrade CBR recorded both in situ and with the DCP showed similar trends to those observed in the residential street project and to previous studies.

(ii) A minimum thickness of 'base' material (100 m) should be installed over the sub-base and required material characteristics should correspond with those normally accepted for base materials.

(iii) The thickness of granular material should be increased, at least for a range of subgrade CBR values 2 to 4. This finding was based on the fact that, although the pavements monitored in Stage 3 of testing had a thickness and soaked CBR corresponding to the T4 curve of the CACA design charts, the observed performance - based on the accumulation of surface rutting - was in line with the T1 curve (see Fig. 1).

(iv) Design traffic should be characterised in terms of ESAs or vehicles/day > 3 t gross.

(v) It should be recognised that the current requirements for the final thickness of the crushed rock layers are probably unachievable in practice. This finding was based on a comparison of the

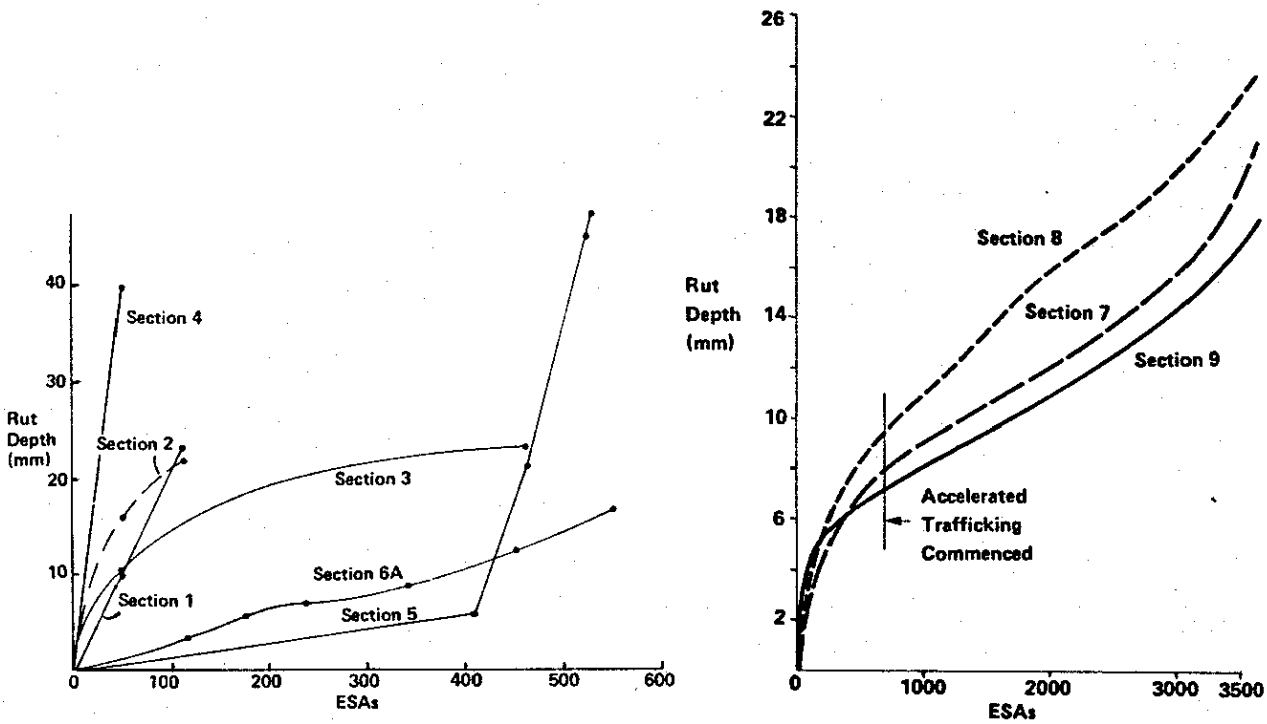


Fig. 8 - Rut depth v. ESAs at ARRB

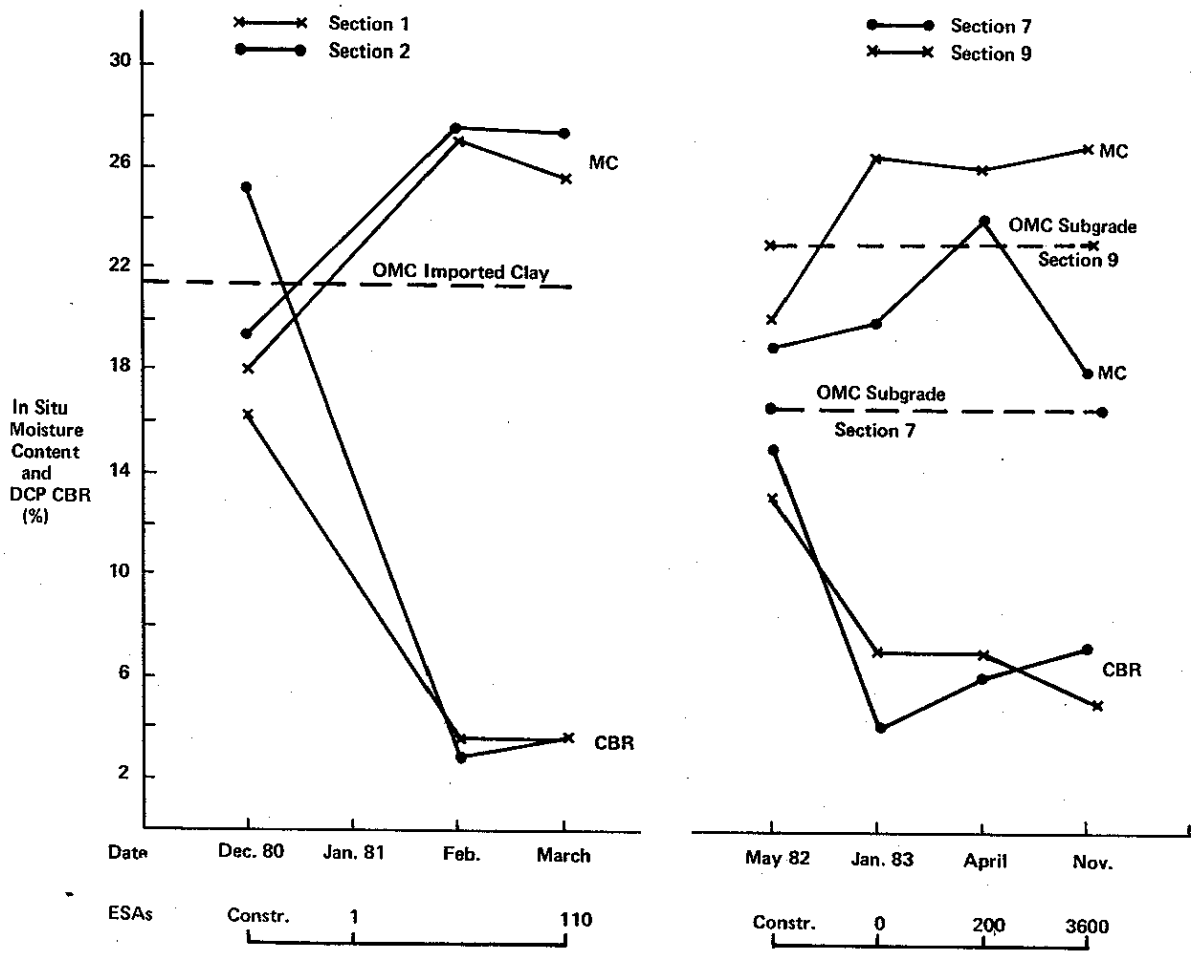


Fig. 9 - Typical variation in subgrade moisture content and CBR at ARRB

levels achieved at ARRB at construction with those of Auff (1983) on tests on about 50 pavements constructed by State Road and Local Government Authorities. The CACA suggestions could not be achieved even if an autograde was used in construction, and the levels achieved at ARRB with within the range found by Auff to be in line with normal construction practice for that type of pavement.

(vi) Consideration should be given to suggesting that a primer seal be placed over the crushed rock layers in order to inhibit the entry of water into the underlying layers.

(vii) Stabilisation of the subgrade should be mandatory if the soaked CBR values is < 4.

(b) An increase in thickness of a concrete block pavement for a range of subgrade CBRs 2 to 4 will result in designs more in line with those recommended by NAASRA (1979) but less conservative than those suggested by preliminary results from the ARRB and local government sponsored project for residential street pavements (see Table 1).

(c) The joints of a block pavement surface do not seal, at least in the short to medium term.

(d) Eighty millimetre block outperform 60 mm blocks, irrespective of shape.

(e) Blocks that key on all four side performed better than blocks that key on two sides only in the short term. However, in the longer term, there was no difference in performance and increasing the block thickness was more beneficial than changing the block shape.

(f) The failure of Sections 7 to 9 appeared to be related to an increase in the rate of application of traffic (see Fig. 8).

TABLE 1

TOTAL THICKNESS OF PAVEMENT (mm) SPECIFIED BY T4 CURVE OF TN40, NAASRA (1979) AND ARRB PROJECT 392 FOR 45,000 ESAs

Section	Design CBR	TN40 (T4 Curve)	NAASRA	P392
7	3	335	340	375
8	4	295	285	330
9	2.5	360	375	420

(g) The concrete paving blocks were of a high quality with respect to their compressive and flexural strength, dimensional tolerance, skid resistance and damage sustained under loading. The skid data were collected at the Shire of Flinders for two years and 150,000 ESAs of trafficking (see Fig. 10). This is the most comprehensive test of its type ever conducted on a block pavement, and evaluation is continuing (Sharp et al. 1984).

(h) External noise levels generated by the concrete block surface were similar to those generated by an asphalt surface at low speeds (up to 40 km/h). However, the wavelenghts of the noise frequency spectra differed, with the wavelengths of the noise generated on the block pavement being longer than those generated on the asphalt. Internal noise levels were also similar, with most of the low frequency component generated by the concrete blocks being masked by engine and exhaust noise (see Samuels and Sharp 1984).

(i) Laboratory testing of samples of light- and dark-coloured blocks, and an asphalt sample, conducted in both the dry and wet states, showed that the light-coloured blocks could be distinguished from both the dark-coloured blocks and the asphalt in the dry state. In the wet state, a driver's ability to distinguish between the blocks and the asphalt could be dependent on his ability to discerne the joints of the block pavement surface (see Jenkins and Sharp 1985).

(j) The quality of the base and sub-base materials with respect to grading, Atterberg limits and field compaction at construction was satisfactory compared with State Road Authority specifications. The in situ CBR of the sub-base material at construction was also

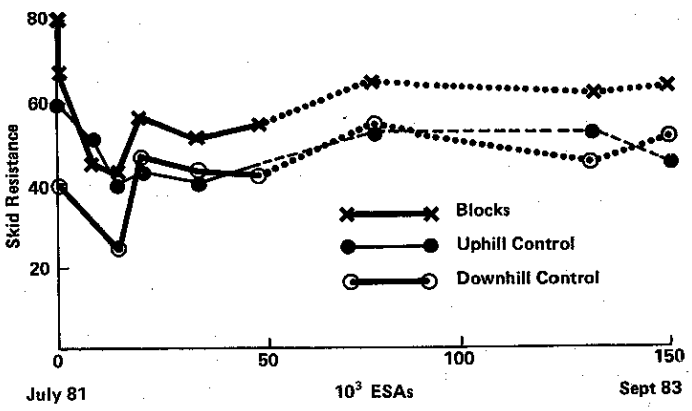


Fig. 10 - Skid resistance data at Shire of Flinders

satisfactory. However, the in situ CBR of the base material in Stage 3 of testing at construction was very variable and in some cases not up to acceptable limits.

(k) The grading of the bedding sand used at ARRB was not within the CACA recommended limits, being too single-sized. The grading of the bedding and jointing sands used at the Shire of Flinders was satisfactory.

(l) A comparison of level measurements taken on all layers before and after testing suggested that deformation had taken place in all layers, including the subgrade, in both wheelpaths.

CONCLUDING COMMENTS

This paper has briefly summarised the program of testing carried out by ARRB on full-scale interlocking concrete block pavements at ARRB and the Shire of Flinders. The performance of the test pavements was compared to the existing CACA design charts, to the results of laboratory testing of the pavement materials, to the observed in situ conditions, and to other studies. The performance of the concrete block paver itself was also examined in terms of strength, dimensions, colour, noise, skid resistance and damage under load.

It is noted that many of the findings of the ARRB research - which concluded in 1984 - have been incorporated into the revised design and construction guides for interlocking concrete pavements (see Hodgkinson 1986).

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APPENDIX

SOME FURTHER TESTING OF THE COLOUR DIFFERENCE BETWEEN CONCRETE PAVERS AND ASPHALT

INTRODUCTION

Jenkins and Sharp (1985) described a laboratory test in which the colour of three concrete pavers ('yellowish-brown' and two samples of 'reddish-brown') was examined, as well as the colour difference between the pavers and an asphalt sample. The tests were done in both the wet and dry state.

The definition and measurement of 'colour' was described in Jenkins and Sharp (1985) and will not be repeated here.

In the first series of tests it was concluded that, in the dry state, a driver should be able to distinguish between the two paver colours, and between the lighter-coloured paver and the asphalt. In the wet state, however, a driver would find it much harder to distinguish between both the two paver colours, and the pavers and the asphalt. This was explained in terms of the pavers absorbing water, with the result that their colour became far more desaturated, whilst asphalt tended to reflect water, because little water was absorbed.

All three paver samples had been provided by the one manufacturer. The surface appearance of these pavers can be loosely described as 'rough', and some interest has been expressed as to how pavers of nominally the same colour, but with a surface appearance that can be loosely described as 'smooth', would compare both with the 'rough' pavers and with asphalt.

This note reports the results of testing of four more paver samples. The results are compared with those obtained in the previous tests.

PROCEDURE

The procedure adopted was the same as in the previous tests, with the colour measured using a Spectra-Pritchard telephotometer in the laboratory with the samples both wet and dry.

In order that a valid comparison could be made with the previous results, one of the `reddish-brown' pavers previously tested was re-tested in this second series of tests. The five pavers tested are described as follows:

(1) reddish-brown (rough surface) tested previously;

(2) grey (rough surface);

(3) blue (smooth surface);

(4) red-grey (rough surface); and

(5) orange-grey (smooth surface).

Samples (2) and (3) and samples (4) and (5) could be described as having nominally similar colours.

RESULTS

COLOUR DIFFERENCE BETWEEN PAVERS

Colour differences are made up of two components - a difference in chromaticity (x,y) and a difference in reflectances (Y%). The formula used to calculate colour differences is strictly for small differences only; the results here should therefore only be seen as an approximation.

The chromaticity co-ordinates derived from both series of tests are

TABLE 2

Mean Values of Chromaticity Co-Ordinates (x,y) and the Diffuse Reflectance (Y%) for Concete Pavers

Sample	Dry			Wet		
	x	y	Y%	x	y	Y%
First Tests						
yellow-brown (R)	0.428	0.411	24	0.437	0.417	12
red-brown(1) (R)	0.417	0.403	15	0.428	0.403	09
red-brown(2) (R)	0.421	0.398	16	0.424	0.398	08
asphalt	0.402	0.401	11	0.395	0.400	06
Second Tests						
red-brown(2) (R)	0.425	0.399	16	0.430	0.404	07
grey (R)	0.405	0.393	15	0.407	0.397	07
blue (S)	0.383	0.377	21	0.393	0.385	06
red-grey (R)	0.443	0.400	16	0.466	0.406	08
orange-grey (S)	0.426	0.388	19	0.460	0.400	08

(S) = 'smooth'; (R) = 'rough'.

shown in Table 2 and plotted in Fig. 11, together with indications of the hue regions.

As in the previous experiment, the pavers became more saturated in colour and darker when wet (refer Y% 'wet' data in Table 2), with the exception of the 'blue' paver, which became far less saturated. This indicates that it would be difficult for a driver to discern different colours in the wet state. In the dry state, the grey (smooth) paver would be seen as the most distinguishable from the reddish-brown (rough) paver used in the first series of tests. Also, the 'yellowish-brown' (rough) paver tested initially has the largest colour difference from the grey (rough) and red-grey (rough) pavers.

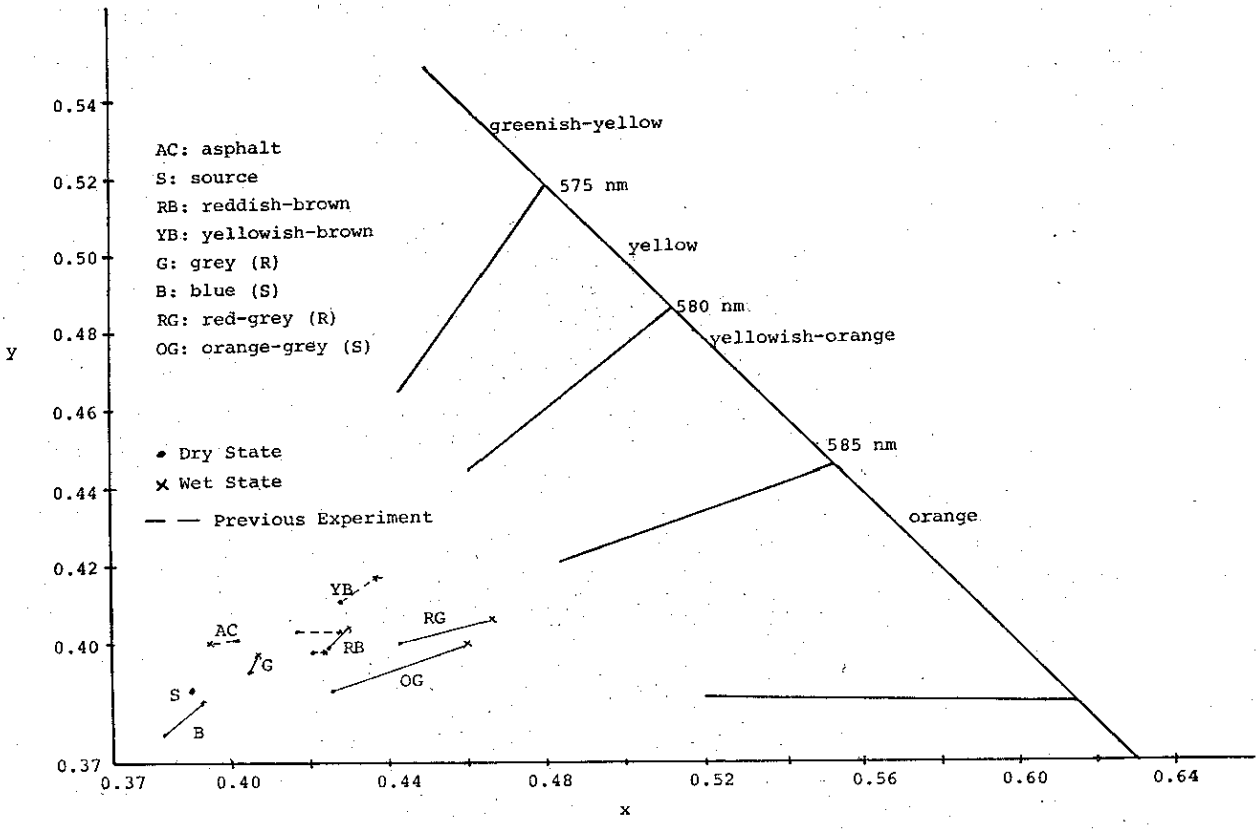


Fig. 11 - Chromaticity diagram for pavers and AC

Good repeatability of the results was obtained between the two tests. This is confirmed by comparing the chromaticity co-ordinates of the reddish-brown paver obtained in the two tests. The values in the dry state are within measurement errors.

COLOUR DIFFERENCE BETWEEN PAVERS AND ASPHALT

The colour difference between the pavers and asphalt was also determined. The colour difference between pavers and AC depends on the relative chromaticities and the relative reflectances. Unfortunately, the asphalt sample used in the first tests was unavailable for the second tests. Nevertheless, the results obtained with the reddish-brown paver in the two tests were in such good agreement that it was deemed valid to compare the results obtained on the pavers in the second tests with those obtained on the asphalt in the previous tests.

The colour differences obtained in both series of tests are shown in Table 3. The colour difference for the reddish-brown paver in the second tests (9.9 dry and 7.5 wet) were in excellent agreement with those obtained in the first tests (9.4 dry and 8.2 wet), which confirms the validity of re-using the results for the asphalt sample.

The grey (rough) paver, while having a sufficient colour difference from asphalt in the dry state, became much darker and almost indistinguishable from the asphalt in the wet state. This trend is even more marked for the grey (smooth) paver, which has an excellent colour contrast with the asphalt in the dry state, but not in the wet state (the lower the number in Table 3, the less is the contrast to asphalt). It is significant, however, that both the red-grey (rough) and orange-grey (smooth) pavers have excellent colour contrast with asphalt in the dry state and maintain (actually improve the contrast) in the wet state. An explanation for this behaviour follows.

TABLE 3

COLOUR DIFFERENCE BETWEEN PAVERS AND ASPHALT

Sample	Dry	Wet
First Tests		
yellow-brown(R)/AC	19.7	17.8
red-brown(1)(R)/AC	7.6	10.7
red-brown(2)(R)/AC	9.4	8.2
Second Tests		
red-brown(2)(R)/AC	9.9	7.5
grey (R)/AC	6.8	2.9
blue(S)/AC	15.6	3.7
red-grey(R)/AC	13.8	17.5
orange-grey(S)/AC	14.4	15.5

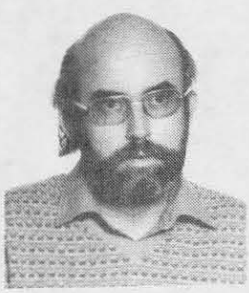
(R) = rough; (S) = smooth.

In most cases, as the pavers become wet their chromaticity moves away from that of the wet AC (see Fig. 11), thus increasing the colour difference. However, the reflectance (Y%) falls to a value close to that of the AC. The increase in chromaticity difference is not sufficient to balance the drop in reflectance difference. Therefore the overall result is usually that there is a smaller colour difference when the blocks are wet than when they are dry.

For the red-grey and orange-grey pavers, however, the increase in saturation is large and in a direction away from the AC chromaticity (Fig. 11). Thus the chromaticity difference when wet is the dominant component and it is large enough to more then compensate for the decrease in the reflectance difference. The overall result, therefore, is a small increase in colour difference when the two pavers are wet.

The contrast between the pavers and asphalt is seen, therefore, to be more dependent on colour than on surface appearance (i.e. rough or smooth), with the red-grey and orange-grey pavers appearing to be the most satisfactory for use in concert with asphalt in traffic treatments. It is stressed that only one sample of each colour of paver was tested and the range of colours possible in a red-grey block is large, with the grey or red possibly dominating in some cases. Intuitively, the red or orange component of such a paver would be the reason for the good colour difference compared with AC rather than the grey component.

It is also noted that the blocks tested were new and no conclusion can be drawn regarding colour differences of in-service pavers subject to traffic and environmental factors.



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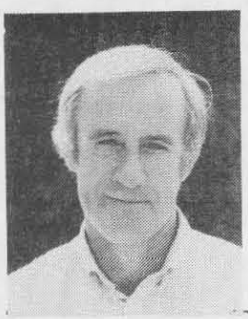

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