An initial study into concrete block paving

by K.G. Sharp
Australian Road Research Board, Australia

Introduction

INTERLOCKING concrete blocks were introduced into Australia in 1976. By 1979 sales figures had reached $2\,km^2$ per annum and are currently increasing rapidly.

Until recently, very little scientific investigation had been carried out into the performance of block paving under traffic and the design and construction of block pavements had been based on European experience or modifications of flexible pavement design procedures[1].

The first full-scale testing of block pavements of any significance in Australia began in 1977 at the University of New South Wales test track[2,3,4]. Shackel has continued his investigations at the National Institute for Traffic and Road Research (NITRR) in South Africa using a Heavy Vehicle Simulator[5,6]. Studies have also commenced at the University of Canterbury, New Zealand, test track[7].

The Australian Road Research Board (ARRB), in co-operation with a local manufacturer, will be monitoring a full-scale concrete block test pavement at its headquarters in Melbourne. This paper describes the test sections to be incorporated in the pavement, the reasons for these sections, and the programme of testing to be carried out.

The test pavement

The test pavement is 100 m long and 4 m wide, comprising ten 10 m test sections (Figure 1). The sections have been chosen to test the effects of varying block thickness, sub-base thickness, compaction level and (later) moisture content of the subgrade and sub-base on pavement performance. Some sections are duplicated, to allow assessment of performance variations due to extraneous factors.

Traffic

The pavement will operate as an access road between two car parks used by staff at ARRB; it will also be used by delivery vehicles. Heavy loads will only be applied on an irregular basis under normal trafficking conditions. Consequently, the road will operate as a minor residential street serving local traffic and although it is anticipated that accelerated trafficking will be introduced at a later date, initial coverage will consist only of traffic normally traversing the pavement.

Choice of block shape, laying pattern and block thickness

A survey of Australian manufacturers was carried out in 1979 to collect information on the types of

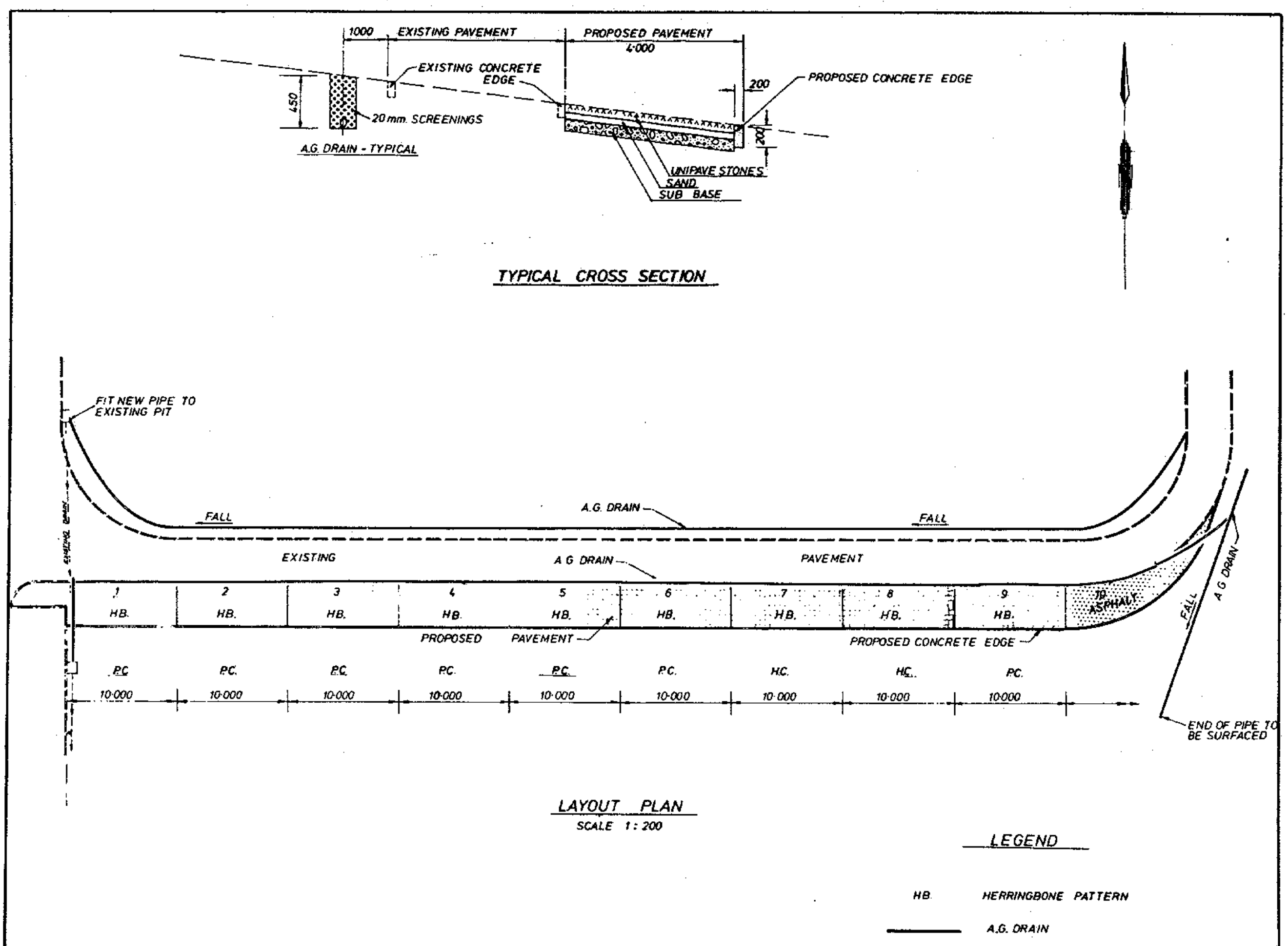


Figure 1: Plan of the Australian Road Research Board (ARRB) test section.

traffic classification. This is less than the figure recommended in Europe; the German manufacturing standard DIN 18501[10] recommends a compressive strength of 63.6 MPa for 80 mm blocks, a figure which cannot be achieved by some of the manufacturing plant in Australia. So far, the lower value has proved satisfactory under Australian conditions. No doubt the higher European figure relates to some extent to freeze/thaw conditions which are not encountered in Australia. Unfortunately, no data have been published from Europe to explain why such a high compressive stress was used. It is presumed that experience in service has led European designers to the conclusion that the extra strength is required.

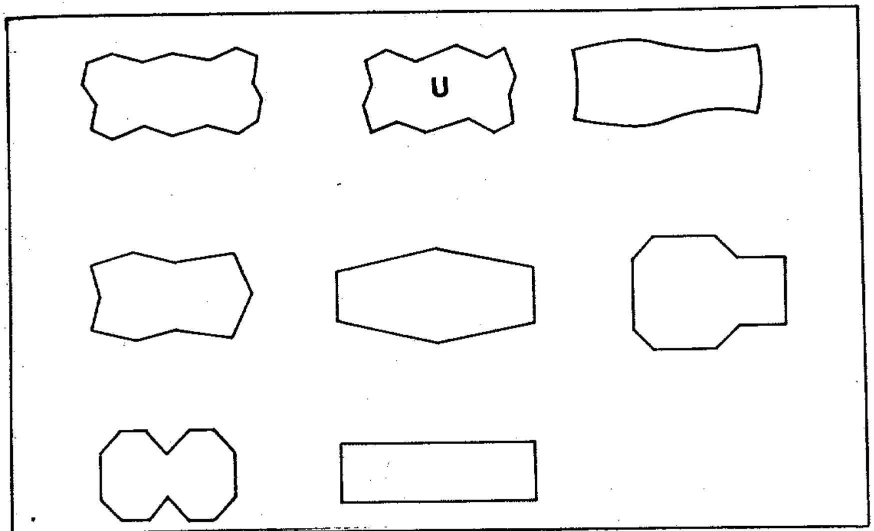


Figure 2: Block shapes manufactured in Australia (not to scale)

blocks manufactured and the costs associated with the construction and maintenance of a block pavement. The shapes manufactured in Australia are shown in Figure 2, and block shape "U" in this Figure (Unipave) was adopted for the test pavement. This shape conforms with the Concrete Masonry Association of Australia's (CMAA) specification[8] in that it is a shape which keys on all four sides and resists the spread of joints parallel to both the longitudinal and transverse axis of the units.

The Unipave block can be laid in three patterns: herringbone, stretcher and basketweave. The herringbone pattern is preferred for trafficked pavements because the right-angle orientation of adjacent blocks prevents pavement creep and block rotation which can occur if other patterns are used. Shackel's work at NITRR has confirmed that blocks achieving interlock on all four sides perform better than those achieving interlock on two sides only, or with no geometric interlock (Figure 3). He has also shown that blocks laid in the herringbone pattern performed best under load (Figure 4).

Block thicknesses of 60 mm and 80 mm are used in the pavement. Hodgkinson and Morrish[9] have produced a table relating traffic classifications and required block characteristics (shown here as Table 1). The amount of traffic expected on the pavement over its design life is in accordance with traffic classification "A" in this table and it is expected that 60 mm blocks will be satisfactory in most cases. However, as vehicles applying high point loads will occasionally traverse the pavement, as accelerated loading will be applied at a later date, and as some sections of the pavement have been constructed with no sub-base, it was decided to use 80 mm blocks in some sections.

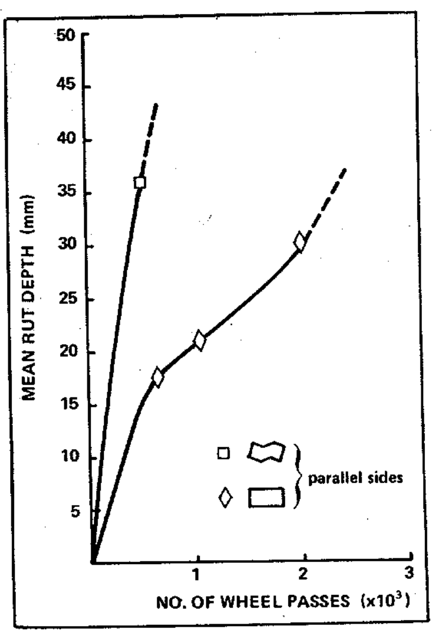
The blocks are manufactured in accordance with CMAA's Interim Specification for Interlocking Concrete Paving Units[8]. The characteristic compressive strength of the blocks is 35-45 MPa, depending on

Sand thickness

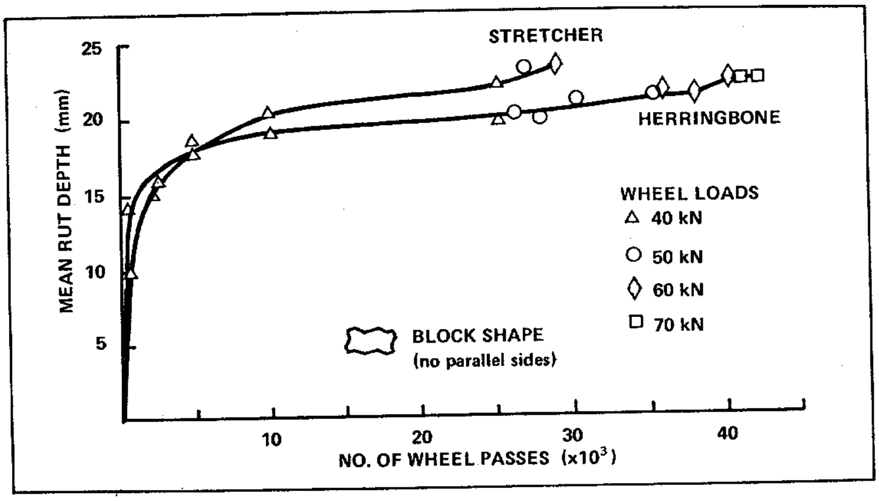
There is much debate as to the required thickness of the sand layer. Shackel[3] used loose thicknesses of 50 mm and 30 mm in his testing and found that the thickness of the sand layer should be kept as small as possible (Figure 5). In later tests[5], Shackel used a compacted depth of 20 mm. The need to reduce rutting must be compromised with practical construction tolerances and having a construction tolerance on the sub-base of ±10 mm could result in the practicality of using 20 mm of sand being questioned. Hodgkinson[11], in his specification for the construction of block pavements, has recommended that a compacted depth of 30 ± 10 mm be used, and this recommendation has been adopted in the test pavement (cf Auff[12] who showed that a standard deviation of 8 mm required very careful construction control on both the layer's surfaces).

Sub-base thickness

The design recommendation for the depth of sub-base to be used under Australian conditions is shown in



Left. Figure 3: Comparison of the development of interlock for two block shapes (after Shackel[5])
Below. Figure 4: Development of deformation under traffic (after Shackel[5])



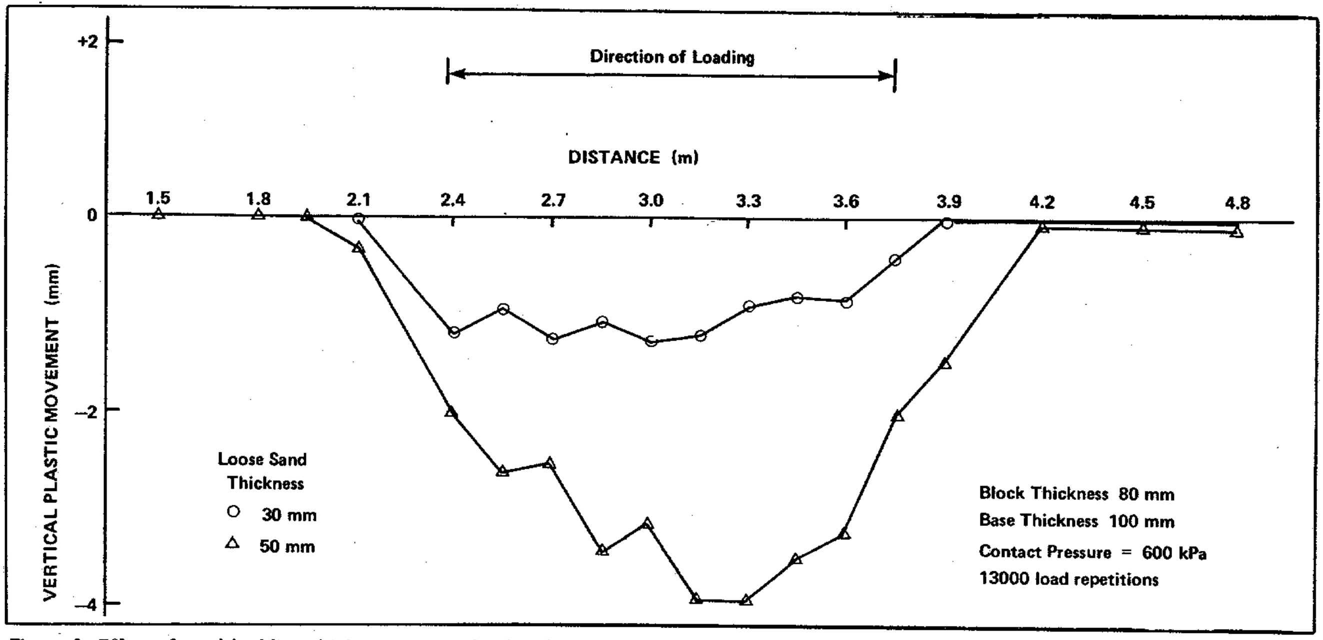


Figure 5: Effect of sand bedding thickness on rut depth (after Shackel[5])

Figure 6, the curves being based on the work of Shackel previously mentioned. Traffic classification "A" was chosen as appropriate to the expected traffic over the design life of the pavement.

Three important considerations in the design of the sub-base for the experimental section are:

(a) the CBR of the subgrade;

(b) the value from the research point of view of under-designing the pavement; and

(c) the need to construct a block pavement that would compete with other types of pavement on a cost basis.

SUBGRADE CBR

A preliminary investigation of the subgrade was made in October 1979 using a dynamic cone penetrometer with ten tests (five per wheelpath) in each section. CBRs were estimated from a correlation between dynamic cone penetration and CBR established by the Country Roads Board of Victoria[13]. Estimated CBRs were uniform across the sections and varied with depth from 10 at 90 mm to 3.5 at 200 mm. At this time of the year, the subgrade was considered to be in its weakest condition. A further series of tests was carried out in February 1980 (mid Summer) when the site was extremely dry. Estimated CBR had increased to 45 at all depths. In the interval between the two tests, an agricultural drain had been installed in the high side of the existing asphalt road as shown in Figure 1.

On the basis of these investigations it was decided to adopt the minimum sub-base thickness of 75 mm as specified in Figure 6 for $8 \leqslant CBR \leqslant 50$. Thus, although the sections would be under-designed for a CBR of 3.5, it was considered unlikely that this condition would be achieved after the installation of the drain and other subsequent measures (see later section on Progress with construction). Further, in order to obtain more performance differences in a reasonable period of time, under-designing was thought preferable to over-designing. Laboratory CBR testing of the subgrade material is to be carried out when the subgrade is compacted prior to the placement of the sub-base material. In addition, CBR testing in situ will be carried out during the course of the study.

Pavement compaction

Two of the sections without any sub-base (Figure 1) will be compacted by a heavy roller as well as a plate vibrator. The object of using different compaction levels will be to determine if heavy rolling of the pavement promotes lock up and hence better performance. Shackel[5]

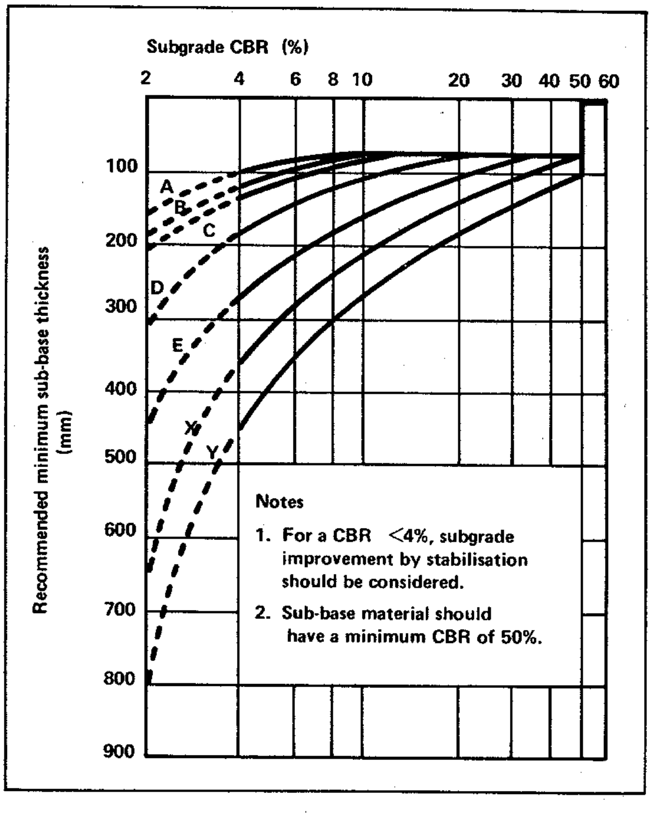


Figure 6: Design chart for interlocking concrete block pavements (after Hodgkinson and Morrish[9])

shown that about 90% of the rmation occurs in the initial ficking stage which is seen as the od of "lock up" of the pavement ure 4). This interlocking is umably enhanced by the action raffic forcing sand and detritus the joints and increasing friction levels. If this interlock can be encouraged before trafficking by the action of the roller, then the performance of sections with no sub-base under light traffic may be enhanced.

Control section

A control section consisting of fine crushed rock basecourse with a sprayed seal will be installed in the test pavement to compare its performance with the block sections. This section was designed in accordance with the National Association of Australian State Road Authority's (NAASRA) interim pavement

TABLE 1: Design table for interlocking concrete block pavements (see also Figure 6) (after Hodgkinson and Morrish 1980)

Traffic Classification	Anticipated Traffic Loading				Required Paving Units			
	No. of veh/day > 3 t gross	Max. wheel load (t)	Total Equivalent Standard Axle Repetitions After 20 years' service (NAASRA 1980)	Examples of Usage	Shape** Type	Minimum Thickness (mm)	Laying* Pattern	Strength Grade (MPa)
A	0-15	2.3	0-4.5 x 10^4	Multi-dwelling driveways, car parks, culs-de-sac. Malls† not accepting delivery vehicles.	A B C	60† 60† 75	H or S S H or S	35 35 35
B	15-45	2.3	4.5 x 10^4 - 1.4 x 10^5	Minor residential streets. Commercial car parks.	A B C	60 80 80	H or S S H	35 35 35
C	45-150	2.3	1.4 x 10^5 - 4.5 x 10^5	Residential streets. Malls†‡ accepting vehicular traffic.	A B C	60† 80‡ 100†‡	H S H	35 35 35
D	150-450	2.3 (on road) 5.0 (off road)	4.5 x 10^5 - 1.4 x 10^6	Minor through roads, etc. in urban areas within 60 km/h limit Industrial Hardstandings.§	A	80	H	45
E	450-1500	2.3 (on road) 5.0 (off road)	1.4 x 10^6 - 4.5 x 10^6	Major through roads in urban areas within 60 km/h limit. City streets, bus interchanges. Industrial Hardstandings.§	A	80	H	45
	Maximum contact (tyre) pressure	Max. wheel load (t)	Total Load Repetitions After 20 years' service					
X	$\not>$900 kPa	20	1 x 10^6 - 3.5 x 10^6 (Indicative only)	Heavy industrial hardstandings. Container yards handling straddle carriers.	A	80	H	45
Y	$\not>$900 kPa	45	1 x 10^6 - 3.5 x 10^6 (Indicative only)	Container yards handling transtainers.	A	80	H	45

*H = Herringbone; S = Stretcher bond and Basketweave

†80 mm units may be required to cope with high point loads imposed by fire-fighting equipment, etc.

‡For malls laid over sound established pavements, 75 mm cobblestones or 60 mm shape Type B units may be suitable.

§Excluding areas where straddle carriers are in use or where vehicles operate on common alignments.

** Shape type A: dentated units which key on all four sides.
B: dentated units which key on two sides only.
C: rectangular units.

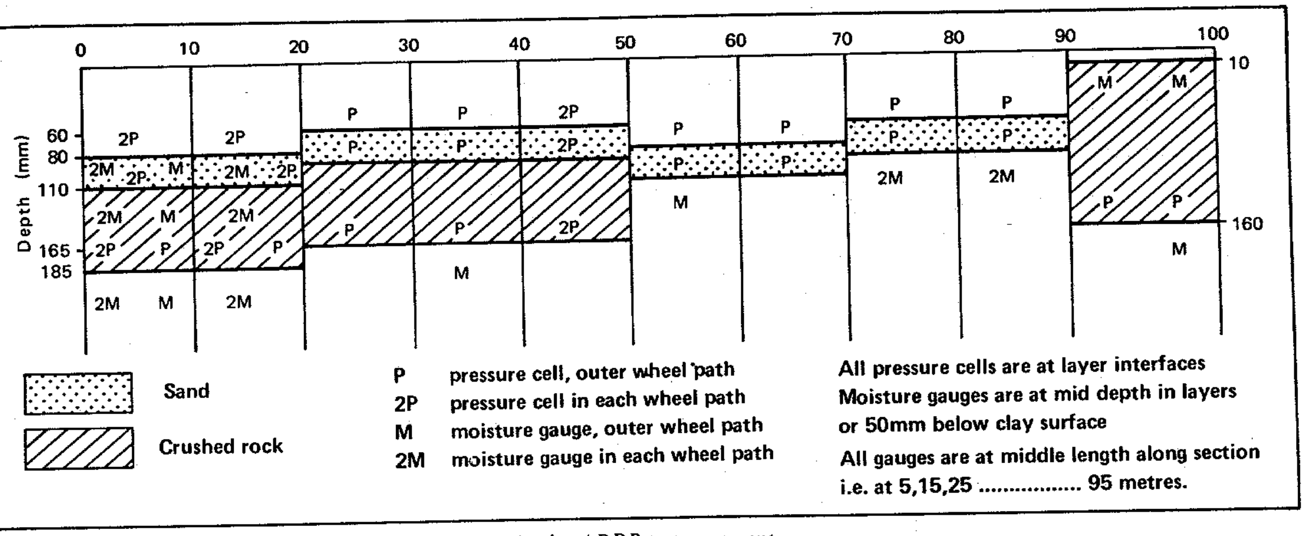
TABLE 2: Design thicknesses of three types of pavement (mm)

Traffic Classification (ESAs)	Asphalt Surfacing				Sprayed Seal			Blocks		
	Asphalt	Base	Sub-base	Total	Base	Sub-base	Total	Block and Sand	Sub-base	Total
(i) 10^3										
CBR 3	25	100	75	200	100	50	150	90	90	180
CBR 8	25	100	75	200	100	0	100	90	75	165
CBR 20	25	100	75	200	100	0	100	90	75	165
(ii) 10^4										
CBR 3	25	100	135	260	100	170	270	90	110	200
CBR 8	25	100	75	200	120	0	120	90	75	165
CBR 20	25	100	75	200	110	0	110	90	75	165
(iii) 10^5										
CBR 3	25	100	265	300	100	290	390	90	140	230
CBR 8	25	100	135	260	100	130	230	90	85	175
CBR 20	25	100	115	240	100	40	140	90	75	165
(iv) 10^7										
CBR 3	100	235	300	635	210	430	640	110	390	500
CBR 8	100	235	155	490	210	130	340	110	220	330
CBR 20	100	235	155	490	210	30	240	110	125	235

TABLE 3: Costs of flexible and block pavements ($\$/m^2$)

Traffic Classification (ESAs)	Asphalt Surfacing				Sprayed Seal				Interlocking Blocks			
	In'l Const Costs	Annual Ave Costs			In'l Const Costs	Annual Ave Costs			In'l Const Costs	Annual Ave Costs		
		Const	Maint	Total		Const	Maint	Total		Const	Maint	Total
10^3												
CBR 3	7.50	4.10	0.15	4.25	6.10	3.30	0.15	3.45	14.45	7.85	-	7.85
CBR 8	7.50	4.10	0.15	4.25	4.70	2.55	0.15	3.70	14.05	7.65	-	7.65
CBR 20	7.50	4.10	0.15	4.25	4.70	2.55	0.15	3.70	14.05	7.65	-	7.65
10^4												
CBR 3	9.15	5.00	0.20	5.20	9.35	5.10	0.95	6.05	15.00	8.15	-	8.15
CBR 8	7.50	4.10	0.20	4.30	5.35	2.90	0.95	3.85	14.05	7.65	-	7.65
CBR 20	7.50	4.10	0.20	4.30	4.70	2.55	0.95	3.50	14.05	7.65	-	7.65
10^5												
CBR 3	12.70	6.90	0.55	7.45	12.65	6.85	1.55	8.40	15.80	8.60	-	8.60
CBR 8	9.15	5.00	0.55	5.55	8.25	4.50	1.55	6.05	14.30	7.80	-	7.80
CBR 20	8.60	4.70	0.55	5.25	5.80	3.15	1.55	4.70	14.05	7.65	-	7.65
10^7												
CBR 3	22.90	12.45	2.65	15.10	20.00	10.85	6.80	17.65	23.65	12.85	-	12.85
CBR 8	18.95	10.30	2.65	12.95	11.80	6.40	6.10	12.50	19.00	10.35	-	10.35
CBR 20	18.95	10.30	2.65	12.95	9.10	4.95	5.70	10.65	16.40	8.90	-	8.90

Note: The annual average cost is the yearly cost over 40 years had the money been invested at 8% per annum.



igure 7: Location of pressure cells and moisture gauges in the ARRB test pavement

hickness design guide[14], using a sub-grade CBR of 10 and total traffic of 2.5 x 10^4 ESAs, i.e. in the middle of he range of traffic classification "A" n Table 1. The thickness designed was 150 mm.

Costs of block pavements
The sections having no sub-base will be monitored closely to establish the feasibility of constructing block pavements in this way for light traffic conditions.

Subgrade and traffic conditions were considered for two types of flexible pavements – sprayed seal and asphalt – and for block pavements. Their design thicknesses and costs of construction and maintenance are given in Tables 2 and 3. The costs data for block pavements were obtained from the survey of Australian manufacturers mentioned earlier. The other costs were obtained from local road authorities, suppliers and the Australian constructions costs as published by the Australian Institute of Quantity Surveyors[15]. Maintenance costs were taken from Lu and Seddon[16] and adjusted for Australian conditions. A discount rate of 8% per annum was used when bringing the costs to annual average costs over 40 years. The construction costs include only the supply and placement of materials.

Tests to be performed on the pavement

Road user aspects
Two important properties of blocks are the noise levels generated by traffic and the change in driver comfort at speed compared to a conventional asphalt pavement. The use of blocks at intersections, for example, has aesthetic advantages; the colour variation compared to an asphalt pavement serves to mark the intersection. Noise levels generated and change in riding comfort could act as an arousal mechanism to the driver. The noise levels generated at various speeds will be measured and reflectivity tests will be performed.

Pavement monitoring
The monitoring programme has been designed to assess both changes in pavement conditions and changes in pavement behaviour (response to load) with time (traffic). Pavement condition parameters to be monitored are rutting, skid resistance, surface permeability and moisture condition under the pavement. Pavement behaviour will be monitored in terms of surface deflection and vertical stress within the pavement structure under a Standard Axle (81 kN on a dual wheel).

RUT DEPTH
The main performance criterion will be the development of rutting. Shackel[5] recommended that a rut depth of 20 mm should not be exceeded for light traffic conditions under a maximum tyre pressure of 600 kPa. Rutting will be monitored by both straight edge and levelling.

SKID RESISTANCE
The skid resistance of the pavement will be monitored by using a British pendulum tester over the centre of selected blocks. The only skid resistance testing reported was by Shackel[5] who found that levels were well within minimum standards. Skid resistance will be monitored at regular intervals to establish the effect of trafficking and weather and also to examine change in skid resistance values between various points on the pavement, which could be of more relevance from the road safety aspect.

SURFACE PERMEABILITY
Tests will be made periodically with a surface permeameter (Gerke[17]) to assess the rate and extent of "waterproofing". The permeameter test consists of measuring the time required for a specified volume of water (under a hydraulic head of approximately 600 mm) to pass into a specified area of pavement.

PAVEMENT MOISTURE CONDITION
Moisture conditions in the sand bedding, the sub-base and the subgrade will be measured in-situ using 4-element electrical resistivity gauges described by McInnes[18]. Intended gauge positions are indicated in Figure 7. These gauges are suitable for monitoring the progress of a wetting front, and are sufficiently accurate that situations of suspect strength conditions due to gross wetting can be determined.

Waters and Merritt[19] carried out laboratory tests on the McInnes gauge in two soil samples: a crushed rock and a decomposed granite.

The investigation was similar to that described by McInnes, except that conductivity rather than resistivity was adopted as a measure of the moisture content. Throughout a series of wetting and drying cycles, the moisture content could be estimated to an accuracy of ±0.5%. Preliminary tests on the effects of dissolved salts on the conductivity of the soil were inconclusive. Twenty-nine gauges have been manufactured for the test pavement.

For each soil type, calibration will be established for two representative gauges by embedding the gauges in laboratory compacted soil samples at a range of known moisture contents and recording their resistivity. The gauges have been tested for uniformity by recording their outputs when immersed in two aqueous solutions whose salinities were adjusted to give resistivity values representative of the resistivity range anticipated in the test pavement. This range was determined from the resistivity values determined during the uniformity tests.

SURFACE DEFLECTIONS
Surface deflection measurement is widely accepted as an indicator of the structure adequacy of a flexible pavement. Surface deflection under a Standard Axle (8.2 t on a dual-tyre single axle) will be measured using the Benkelmen beam. Both maximum surface deflection and deflection bowl shape will be recorded.

VERTICAL STRESS
Vertical stress in the pavement subject to loading by a Standard Axle will be measured directly beneath the blocks, at the sand-sub-base interface and at the sub-base-subgrade interface (Figure 7) by means of in situ electrical resistance diaphragm pressure cells (Lee and Morgan[20]).

Calibration will be carried out by embedding representative cells in triaxial specimens and recording responses at stress levels anticipated to occur in the pavement.

Progress with construction

Construction of the pavement has been delayed owing to inclement weather and the presence of water under the existing asphalt road. A second agricultural drain has been installed on the low (south) side of the existing road, i.e. underneath the first half-meter width of the block pavement.

It is imperative that the subgrade be properly compacted before the sub-base and sand is laid. Obviously, if the pavement were being constructed under normal conditions, the subgrade could be stabilised or "soft" areas could be removed and crushed rock incorporated. However, it is important that the minimum design criteria already specified be incorporated so that the data collected will truly represent the performance of the pavement.

Conclusions

This paper has described the make-up of the test pavement to be installed at ARRB. The reasons for the choice of sections are: the light traffic volume and loading that will use the pavement, the advantage from the research point of view of under-designing rather than over-designing the pavement, the desirability of duplicating some sections and incorporating a control section and the possible cost savings associated with constructing pavements with no sub-base incorporated. The programme of testing to be performed is outlined. The pavement will initially operate as a minor residential street and some sections have been deliberately under-designed in an effort to exaggerate performance differences. The study will provide data on the performance of block pavements under light traffic. Sections having no sub-base will be closely monitored, especially to assess the effect of heavy compaction on performance. Studies of noise levels generated by traffic and the effects of traffic on skid resistance will be important.

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