Interlocking block paving in Australian residential streets

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Introduction

THE USE of concrete block pavements in Australia began in the mid 1970's. Initially the blocks used were rectangular and the interlock was developed by employing a herringbone laying pattern, but it was not long before the interlocking block was introduced mainly to cater for a demand based upon its aesthetic appeal in the landscaping of private properties. In fact this market has grown in recent times and still constitutes a major proportion of the estimated 2 million m^2 of units now laid each year.

This growth in the production of concrete blocks has seen a number of different block shapes introduced, many of these at the instigation of architects and landscape designers. The "unipave" shape, however, has dominated the "engineering" ie trafficked pavement market which, each year, is gradually increasing its share of the total market. This relatively slow growth has been caused by a number of factors, not the least of which has been the preoccupation of the block manufacturers with the lucrative "householder" market.

The lack of an acceptable (to conservative government authority engineers) design guide and the inertia associated with a new engineering process have also influenced this growth rate. On the other hand, especially with respect to residential street pavements, forces have operated to encourage the use of Interlocking Concrete Block Pavements (ICBPs). The recent lobbying - eg Thomas (1968) and Ministry for Conservation (1979) - for streets which are more compatible with the residential environment and the frequent jumps in the price of crude oil with its consequent repercussions in the flexible pavement industry are two examples of such forces.

The new decade has begun in Australia with results appearing from research by Shackel (1980) carried out with tne CSIR in South Africa. This large investment in 1CBP research has been directed towards providing a sound design guide. Although much research work remains to be carried out the C&CA (Aust) have seen fit to use these "preliminary" results in an "interim" design guide (Hodgkinson and Morrish (1980)). The background to this guide and its application to residential street pavements will be considered.

Residential streets in Australia

Road networks can take two basic forms - the grid pattern and the tributory layout. In Australian cities residential areas contain both types of network. The grid is common in inner suburban areas and the tributary is used in the newer, outer suburbs. Congestion problems in inner city areas have often resulted in traffic management measures (street closures, turning bans, etc) which have converted grid patterns into tributory layouts. Whichever network applies, it is obvious that in residential areas, some roads will have as their prime function the distribution of traffic while others will provide access to properties. It is the latter which will be called "residential streets" in this paper. The tortuous tributory layout at the residential street level precludes public transport (ie bus services) operating in these streets. It is possible, however, that future developments in demand-responsive bus services may see the introduction of mini-buses onto residential streets. Brindle (1979) considered the question of road classification and described two types of residential streets as detailed in Table 1. The criteria specified in this table provide a reasonable basis upon which to investigate the use of ICBP's in Australian residential streets.

Current pavement construction

Results of a survey of local government engineers throughout Australia were reported by. Holton and Pattinson (1976). Table 2 summaries the responses to questions on road pavements in residential areas.

It can be seen from this table that a crushed rock base with a bituminous concrete surfacing is the most popular pavement for residential streets. This pavement was also judged to be the most suitable for traffic volumes 200-1000 vpd. Below 200 vpd, 67% respondents agreed that crushed rock with a bituminous seal was more appropriate.

ICBP Materials

Sub-base

TN 34 suggests that "the sub-base material should have a CBR value of not less than 50%, a Plasticity Index not exceeding 8% . . ." and further requires the sub-base material to comply with requirements of the local highway authority. The high

TABLE 1. Planning and Design criteria for residential streets after Brindle(1979)

	Residential street type	
Criterion	*A*	*B*
Network role	Minor tributory	Housing access
Max desirable volume (vpd)	1000	200
Desirable max operating speed (kph)	20-30	20
Design speed (kph)	50 (minimum)	40 (minimum)
Public transport	Mini bus only	No
Parking	Additional parking strip	Parking bays
Minimum carriage-way width (m)	5.5	Variable 4.5 minimum

TABLE 2: Pavement bases and surfaces used in Australian residential streets

Layer	*Material*	*Thickness (mm)*	*Local Authorities %*
Surface	Bituminous concrete	20-50 (100 max)	60
	Flush seal	Up to 30	20
	Asphalt	Various	20
Base	Crushed rock	≤ 100 (16%) 101-150 (31%) 151-200 (38%) 201-300 (15%)	95
	Other eg fine crushed rock, wet mix, lime stabilisation		5

target CBR of 50% has been selected on the basis of work (eg Clark 1978) which related the stiffness of the block (layer) to that of the supporting layer. Providing such a high quality sub-base should then reduce deformation during "bedding-in", as long as the sand layer performs satisfactorily. This is a logical approach although the target figure may be unnecessarily high. Further research will reveal whether a cost saving reduction in sub-base quality may be possible. A further important factor in considering quality requirements must be the actual period of time during which the sub-base is called upon to provide this "extra" strength. If this "bedding-in" period can be reduced or if the pavement can be protected prior to "lock-up" occurring, then a lower quality sub-base may be feasible.

The sand bed

"The sand bedding layer shall be of uniform thickness and shall finish 30 mm ± 10 mm when the pavement has been compacted", suggests TN 34. Specification TN 35 (Hodgkinson (1980)) warns that "under no circumstances should the compacted thickness of the sand bedding exceed 40 mm".

The literature contains only one reference - Shackel (1979) and that relates to a single test - which indicates that a reduction in compacted sand thickness from 30 to 20 mm provides a "significant reduction in the vertical stresses" within the sub-base and subgrade. Other work reported by Shackel (1980a) employed a compacted thickness of 20 mm with some success so that this author concluded that "the layer of bedding sand contributed to the structural capacity of the pavement". Not all reports support this reduction in the sand bed. Simmons (1979) for instance warns that if the sand depth drops below 40 mm, movement of blocks under initial traffic cannot be accommodated by the sand since it is unable to move freely.

In fact, it would appear that if the sand is laid at the optimum (for maximum density) moisture content and to a uniform thickness; then this thickness is limited only by what can be achieved in practice. The accuracy of the sub-base finish then becomes important. With a 10 mm tolerance on the subbase a final sand depth of 30 mm ± 10 mm may be a reasonable target.

Pavement design

Traffic classification

The anticipated traffic loadings provided in TN 34 (see Table 3) for residential streets are 45-150 vpd over 3t gross; a max wheel load of 2.3t and 1.4 x 10^5 - 4.5 x 10^5 total equivalent standard axle repetitions after 20 years service. Even the "minor residential street" is listed as 15-45 vpd over 3t gross. This author considers that these figures are well in excess of any (even the most pessimistic) prediction of traffic on an Australian residential street in 20 years time. Collector streets, feeding residential areas may approach these figures, they would not handle the 150-450 "heavies" nominated for "minor through roads". It is suggested then that curve B (see Figure 1) is more suitable for residential street construction unless there is a regular bus service - a rarity

TABLE 3: Traffic classification and required paving units (adapted from Table 1 of TN 34)

	Anticipated traffic loading				*Required paving units*			
Traffic classification	*No of vehicles per day 3t gross*	*Max wheel load (t)*	*Total equivalent standard axle repetitions after 20 years' service*	*Examples-of usage*	*Shape type (1)*	*Min thickness (mm)*	*Laying pattern (2)*	*Strength grade (3)*
A	0-15	2.3	0-4.5 x 10^4	Multi-dwelling driveways, car parks, malls not accepting delivery traffic	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	150 - 450	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

(1) Shape type A - Interlock on all four faces eg unipave
B - Interlock on two faces
C - Rectangular units

(2) H - herringbone, S - Stretcher bond

(3) Strength grade - compressive strength m MPa

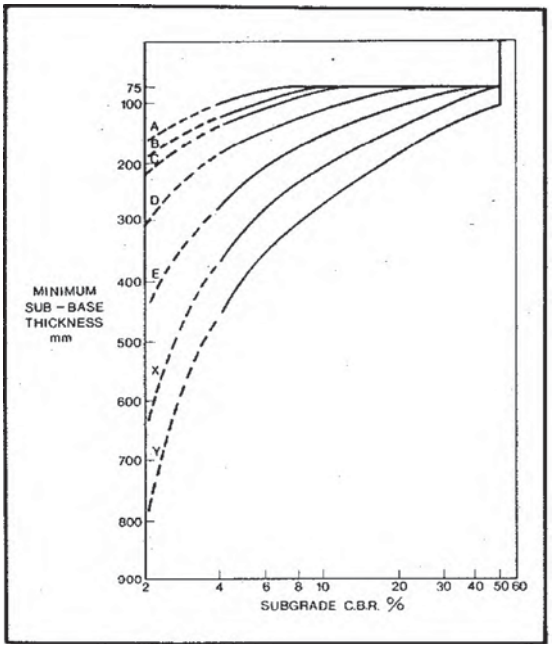


Figure 1: Minimum sub-base thickness recommended by TN 34

in Australian housing subdivisions. Any discussion of future traffic volumes is of critical importance in flexible pavement design. Shackel (1980b) however has suggested that this may not be so with ICBP's since "block pavements tend to lock up under traffic and attain a state in which the amount of traffic is no longer a relevant design parameter. In such circumstances it is generally extremely conservative to apply conventional pavement design wisdom to block paving." This conclusion was drawn from work which involved loading up to 70kN.

Block shape, thickness, laying pattern and strength

As mentioned earlier, the Unipave shape dominates the Australian block pavement market. These blocks, manufactured in 60 and 80 mm thickness, are generally laid in a herringbone pattern. The blocks used in trafficked pavements so far have reached 50 MPa compressive strength and this can be compared with the minimum of 35 MPa required by TN 34 for residential streets.

Perhaps the most important feature of an 1CBP is the quality control which is possible for the surface material. No other type of pavement can match the consistency in terms of strength (in all its facets) of the interlocking concrete block.

Subgrade bearing capacity

A great variety of subgrade conditions exist in Australia ranging from the black soil of South Australia and the Northern Territory to expansive clays in Melbourne and the sandy subsoils of Perth. So far the research work which has been carried out has not attempted to cover this range. The guide is rightly cautious regarding low CBR subgrades where local failures could occur during "bedding-in" if water, penetrating the joints, flows through to the pavement formation. Within the range 2-4% CBR it is recommended by TN 34 that stabilisation may be employed to improve the subgrade bearing capacity. If a technique of speeding up the "bedding in" or of waterproofing the joints appears then this restriction may be eased.

Sub-base thickness

Tentative design curves for three levels of traffic intensity were published by Shackel (1978) following work at the University of New South Wales. The failure criteria on which these curves were based were rut depth and curvature ratio. The maximum thickness of sub-base is selected from the appropriate design chart by considering the subgrade CBR and the thickness of block to be used. The latest work (Shackel (1980a)) carried out by this researcher at the National Institute for Transport & Road Research in South Africa has contributed to the redrawing of these curves for a greater number of possible traffic loadings. These latter curves are presented in Figure 1.

Mavin (1980) discussed the question of failure criteria for ICBP's and provided the range of possible failure modes shown in Table 4. Rutting is the most likely problem leading to loss of riding quality with an ICBP. This type of failure, the basis for Figure I, may not be a valid design criterion for residential streets. If for instance, the "bedding-in" period is reduced to a minimum and control is exercised over heavy vehicle movements during construction and prior to "lock-up" then rutting will be negligible or even eliminated completely. It is more than likely that research in the near future will provide a means by which "lock-up" is expedited.

Edge Restraint

Standard kerb and channel profiles used on block paving work in lightly trafficked areas eg. car parks have provided adequate edge restraint. The latest specification (Hodgkinson (1980)) has suggested that this practice be maintained for areas not subjected to heavy industrial traffic. There is room for research here since the forces applied to an edge restraint in a block pavement are completely different to those existing with a flexible or rigid pavement.

Drainage

Australian ICBP work carried out, especially projects involving existing pavements, has been complicated by the fact that often the block laying contractor has been required to work with a second contractor responsible for sub-grade and sub-base preparation. This division of responsibilities has frequently produced drainage problems and in some cases these have contributed to local failures. It is to be hoped that block laying contractors now appreciate that accumulation of water anywhere within a pavement will lead to a loss of strength the most likely consequence of which will be a pavement failure.

The preparation of the formation

TABLE 4: Surface failure criteria for ICBP's after Mavin (1980)

Possible failure mode	*Comments*
Breaking of blocks	High block compressive strengths used in Australia - breaking unlikely
Loss of jointing sand	Local - but if water enters pavement, can be critical
Rutting	Where wheel tracks follow common alignment
Creep	Not recorded as a problem with interlocking blocks
Sinking of a block (relative to adjacent blocks)	Local - not common with interlocking blocks
Loss of skidding resistance	Unlikely to be critical in low speed residential streets

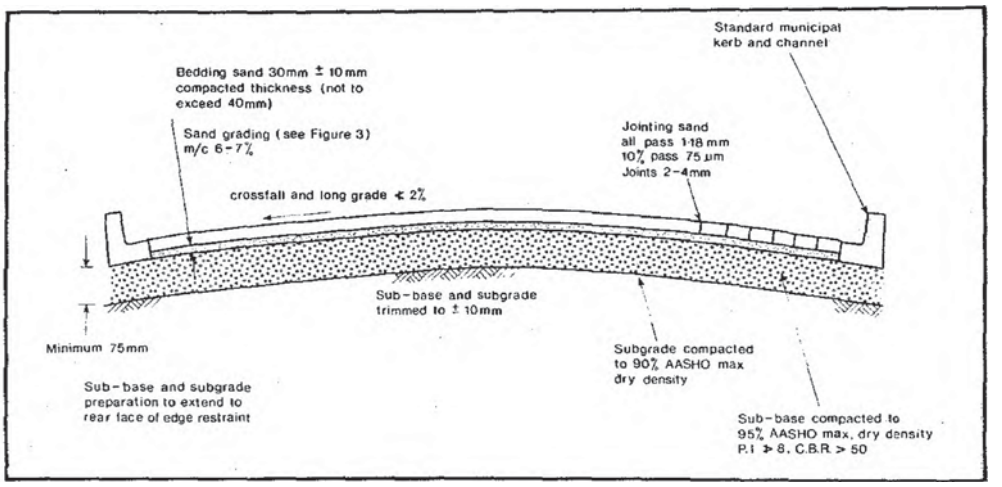


Figure 2: Pavement details specified in TN 35

and the sub-base-bedding sand interface are considered to be of utmost importance, more so than with other pavements. In order to facilitate drainage it is suggested that both of these surfaces be carefully shaped. Hodgkinson (1980) suggests trimming to within ± 10 mm of the sub-grade and sub-base design levels. Adequate surface water drainage is provided by maintaining a minimum longitudinal grade and crossfall of *2%*. This specification further allows a one-way crossfall if the pavement-is less than 6 m wide.

Skidding resistance

The skidding resistance of concrete roads has (generally) not been a problem where vehicle speeds are low. ICBP's have been used, and will be employed in the future, for low-speed situations. Work carried out by the author in the Melbourne area indicates that the skidding resistance of the blocks (measured by the pendulum test) reduces gradually with time as shown in Table 5. The pendulum test does not provide a valid representation of the skidding Resistance of the pavement; however it does indicate the rate of surface breakdown. This measure is of importance since it is recognised that the level of skidding resistance of a concrete surface is determined by the hardness and resistance to polishing of the fine aggregate. Future work in this area must include measurements of pavement skidding resistance using scrim or similar techniques. Knapton and Barber (1979) have suggested that the riding quality of a block pavement is acceptable for speeds less than 50 kph. The desirable maximum operating speed for Australian residential streets from Table 1 is 20 - 30 kph, well below the speeds at which skidding resistance and riding quality problems may occur.

Noise

One of the major problems with concrete road surfaces has been concerned .with the trade off between skidding resistance and noise. Achieving a suitable balance between the two for ICBP's will be complicated by the permanent network of joints. The only manoeuvring which may be possible would involve changes in the alignment of the joints with respect to vehicle wheel paths and, to a lesser extent, the use of different laying patterns.

The benefits to be gained by improved aesthetics in residential areas may not be appreciated by non-users subjected to disturbing traffic noise. Again the argument that vehicles will be travelling slowly applies although further research is necessary to determine the extent of possible noise pollution.

Conclusions

Now that a design guide is available which is based upon a reasonable amount of research and site observations it can be anticipated that the use of ICBP's in Australia will increase. Their use in residential streets, a small proportion of the market at present, will most likely outgrow all other areas of use. This prediction is based upon a direct comparison with flexible pavements, which have been employed exclusively for this purpose in the past. It is expected that the rising price of Middle East crude oil will create frequent jumps in the cost of bituminous pavements. On the other hand, the cost of ICBP's will remain stable or even reduce in real terms as further research and development produce a more refined design. In the short-term this research will be directed towards reducing the time which elapses before "lock-up" occurs.

TABLE 5: Mean (pendulum) skid resistance values, Melbourne, November 1979

Site	Date laid	*Mean skid resistance	Range
New Blocks		81	80-83
After vibration		74	70-80
I	Late 1978	61	59-65
2	Early 1978	59	56-63
3	Mid 1977	56	52-60

* 5 blocks, 5 measurements at each block

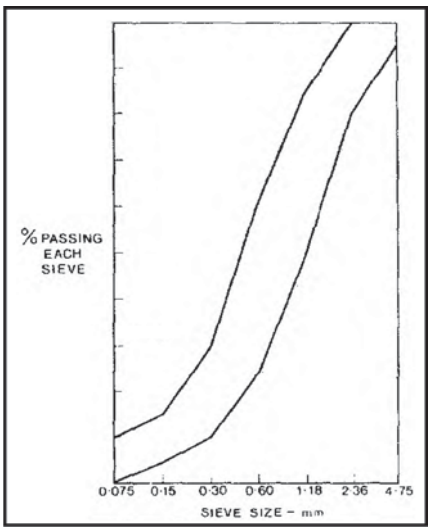


Figure 3: Grading envelope specified by TN 35 for bedding sand

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