DEVELOPMENTS IN THE SPECIFICATION OF CONCRETE SEGMENTAL PAVERS FOR AUSTRALIAN CONDITIONS

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ABSTRACT

The use of concrete segmental paving in Australia is amongst the highest in the world on a per capita basis. This has been reflected in the substantial research into the structural behaviour of segmental pavements undertaken within Australia during the last fifteen years. However, until recently, this research largely ignored the properties of the pavers themselves. This paper summarises research into those properties of pavers that are necessary to ensure good long-term performance. In particular, experimental studies have been undertaken of strength and abrasion wear. The studies included detailed critical evaluations of the test methodologies and the effects of factors such as mix design, aggregate type, use of pigments and curing regime. Laboratory investigations have been supplemented by limited observations of pavers in service. The data gained in these studies are summarised and their implications in the drafting of specifications for concrete pavers are discussed.

INTRODUCTION

1. Some 20 independent specifications or standards for concrete segmental paving units have been issued worldwide. The evolution of these specifications and their principal features have been extensively reviewed (Shackel 1990; Marais and Lane 1979; Houben et al 1984; Anon 1988; Vring 1992; Madrid 1992). In most European countries and in North America, South Africa and New Zealand the specifications have been published by independent national standards authorities. Elsewhere, in countries such as Japan and Australia, the specifications carry the imprimatur of concrete masonry manufacturing associations. Occasionally, as in the USA, both national and manufacturers' specifications are available. Recently, in Australia, the development of national draft standards for segmental paving has been initiated by Standards Australia. The new standards are scheduled for publication in 1994 and will be relevant to all segmental paving materials, including concrete, clay and stone.

2. Standards and specifications written in English fall into two groups. The first of these embraces specifications for pavers designed to perform in cold climates. This group emphasises freeze-thaw durability and includes the American, Canadian and British specifications (Shackel 1990; CSA 1982; BSI 1986). The second group of specifications issued in South Africa (SABS 1985), New Zealand (SANZ 1981) and Australia (CMAA 1986, 1993), are for temperate climates and, accordingly, place less emphasis on weathering resistance.

3. In evaluating quantitative specifications of paving units four areas are of interest, viz:

(i) Materials
(ii) Dimensional tolerances
(iii) Strength, and
(iv) Durability

Typical specification limits are summarised in Table 1 for both Australian and overseas conditions. Each of these factors is now considered in more detail.

EVALUATION OF SPECIFICATION FACTORS

MATERIALS

4. Most paver specifications include requirements for the materials to be used in paver manufacture (Anon 1988). These cover the types of cement that are permitted, the types and quantities of admixtures and pigments, and the grading of the coarse and fine aggregates. Usually, the specifications make reference to older, well-established but generalised standards for concrete manufacture. Often these specifications need to be adapted to the special requirements of paving. For example, in the British specifications (BSI 1986), limits have been placed on the proportions of acid-soluble fine aggregate to ensure that the paving units will have adequate skidding resistance. In Australia, moves towards performance based paver specifications have largely obviated the need for prescriptive materials specifications.

DIMENSIONAL TOLERANCES

5. Two important factors are influenced by the dimensional tolerances of the pavers. First, the ease and precision of both laying and repairing segmental paving is affected by the paver dimensions. Except where the pavers are to be layed in running (stretcher) bond, allowance must be made for the width of the joints between pavers. If the nominal ratio of the length, L, to the breadth, B, of a paver is n, it has been shown (Shackel 1990) that the true manufactured length of the paver is given by the relationship:

$$L = nB + (n\text{-}l)\,J \qquad (1)$$

where J is the average joint width and n is an integer. In Australia J is normally required to lie within the range 2 mm to 4 mm, with a target nominal width of 3 mm.

6. If equation 1 is not satisfied it is not possible to maintain unstaggered joint lines in the pavement. In other words, the dimensions and the tolerances on dimensions influence the ease of laying where the pavement appearance is important or where uniform joints widths are required. The control of horizontal dimensions is largely dictated by the amount of wear in the moulds used in paver manufacture. Most specifications call for tolerances between ±2.0 mm and ±3.0 mm (see Table 1).

7. The paver dimensions also influence the long-term riding quality of a segmental pavement. Dutch and local experience has shown that variations in the thicknesses of pavers can cause gradual loss of surface profile in segmental pavement under traffic. The mechanisms causing this have been described elsewhere (Shackel 1990).

8. There is no assurance that the requirements of equation 1 will be met in practice. In the case of paver thickness, the limits that can be achieved are controlled by the manufacturing method. Tolerances of ±0.5 mm are possible using modern plant. Worldwide permitted tolerances range between ±2 and ±5 mm. However, recent Australian standards (draft) specify a range of standard deviation (SD) from 2 to 3 mm (see Table 1). Because variations in paver thickness can cause surface roughness in a segmental pavement carrying traffic it appears desirable to tightly control thickness standards. At present, the tolerance on height of ±3.0 mm recommended in the UK and France and the SD of 3 mm in Australia are to be preferred to the value of ±5.0 mm permitted in Germany.

STRENGTH

9. Pavers must possess sufficient strength to resist handling, construction stresses and traffic. Most specifications require the pavers to exhibit compressive strengths in the order of 40 MPa or flexural strengths in the range of 3–4 MPa. However, data on strength should be treated with caution when comparing different specifications. Often comparisons are rendered meaningless because of differences in the test specimens (eg whole paver, or cube or cylinder extracted from paver) the definition of strength (single, mean or characteristic strength) the testing procedures and the age and number of specimens tested. No consensus exists on the most appropriate sampling, testing and reporting procedures for determining paver strength. Nevertheless, a survey of specifications worldwide suggests that, once the influence of test procedures is eliminated, the minimum compressive strength of a single paver should exceed 45 MPa to 50 MPa (Houben et al 1984).

10. Clearly a paver must possess sufficient strength to resist handling, construction and traffic stresses. To investigate the paver strength necessary to ensure good in-service performance the senior author conducted a series of accelerated trafficking trials of full-scale prototype segmental pavements. In these trials both rectangular and five different shaped pavers were used. The pavers were 60 mm thick and were manufactured to dry compressive strengths ranging between 31 MPa and 61 MPa (measured at the time of testing). The pavers were laid by hand. Depending on their shape some pavers could only be installed in stretcher bond. Others were installed in both stretcher and herringbone patterns. The trial pavements were subjected to accelerated trafficking under a full size single truck wheel applying loads ranging between 24 kN and 70 kN via a tyre inflated to 0.6 MPa. Each pavement received up to 45,000 wheel passes. Details of the test pavements and their structural performance under traffic have been given elsewhere (Shackel 1980).

11. The compressive and flexural strengths of the pavers were measured at the time of trafficking. In the case of compressive strength complete pavers were tested air-dry between two pieces of soft board 13 mm thick with the specimens aligned with their height in the vertical direction. To measure the flexural strength, complete pavers were subjected to a three-point bending test. The pavers were tested under a central line load whilst simply supported over a span of 150 mm. Fifteen separate batches of pavers were tested with 25 randomly selected pavers in each batch. Ten of these pavers were subject to compression testing and the balance was used for flexural tests. The data from these tests are summarised in Table 2.

12. The compressive strength of a paver, when measured as described above, is dependent upon the height of the paver. Generally, the thinner the paver the greater will be the measured compressive strength. No correction for height has been made in the work described. By contrast, the flexural (tensile) strength is not affected by paver thickness. For this reason, flexural strength is preferred as an index of strength.

13. To take product and test variability into account it is customary to use statistics such as the mean or the characteristic (mean - 1.65 standard deviations). The flexural and compressive strengths were linearly related in terms of both mean and characteristic values (see Table 2). The regression equations relating the tensile strengths, T (MPa) to the compressive strengths, C (MPa) together with the corresponding correlation coefficients, r, were:

a) For average values

$$T = 1.507 + 0.0865\,C \quad \text{with } r = 0.753 \tag{2}$$

b) For characteristic values

$$T = 1.947 + 0.0649\,C \quad \text{with } r = 0.762 \tag{3}$$

14. It was expected that, under traffic, the incidence of traffic-induced damage (ie cracking and spalling) would vary according to the paver strengths. However, irrespective of the compressive or flexural strengths of the pavers, all of the test pavements developed some paver damage under traffic. Typically this took the form of occasional hairline cracking through the pavers in directions which tended to extend the joint lines. The incidence of cracking was small and affected less than 1% of the pavers. The damage was similar in both nature and extend to the cracking which typically occurs during compaction of segmental pavements under a plate vibrator.

15. In no case was the hairline cracking of pavers detrimental to the performance of the pavements under traffic. In some trials structural failure of the pavements was induced. Large rotations then occurred between neighbouring pavers. This sometimes led to spalling and fracture of the pavers. Again the incidence and type of damage was independent of the paver strength. Overall, it was concluded that, within the range studied, the strength of the pavers did not have any significant influence on the performance of the trial pavements.

16. It may be concluded that provided the mean flexural strength exceeds 4.0 MPa or the characteristic flexural strength exceeds approximately 3.0 MPa, satisfactory performance would be expected in service. (The corresponding lower limit mean and characteristic compressive strengths are approximately 35 MPa and 25 MPa respectively). It would appear that such values could be confidently used as the basis for specifying the strength of pavers to be used under normal road traffic. As noted above, the use of the flexural strength is a more reliable indicator than compressive strength because it is not affected by the paver thickness. Accordingly the most recent

draft Australian industry specifications (CMAA 1993) nominate characteristic breaking load and characteristic flexural strength for strength testing as both these parameters are unaffected by the paver thickness.

ABRASION RESISTANCE AND DURABILITY

17. Two aspects of durability are of concern in segmental paving. These are the resistance to abrasion and the ability to withstand frost and the effects of de-icing salts. In Europe, where block paving originated, most emphasis on durability has been placed on freeze-thaw resistance. Indeed, in countries like Germany it has been argued that tests for wear resistance can be discarded provided adequate frost resistance is achieved (Meyer 1980).

18. In the early application of concrete segmental paving in countries with temperate climates such as Australia, New Zealand and South Africa it was assumed that, because frost was not a problem in pavement engineering, the specifications need not include durability tests. However, significant wear occurred in the surface of many segmental pavements laid in the 1970s and early 1980s in the southern hemisphere. In Australia, the industry specification for pavers issued in 1986 was amended to include abrasion testing (CMAA 1986, 1993). In the 1993 draft industry specification, the parameter for resistance to salt attack has been included specifically for residential applications around swimming pools.

19. Until recently it had been widely assumed that paver durability and strength were inter-related. Increasingly, however, evidence is available that factors such as cement content and water-cement ratio provide better indicators of durability than strength. Moreover, in several countries including Australia it has been observed that achieving characteristic compressive strengths (corrected for paver thickness) of 35 MPa or more have sometimes been associated with unacceptable levels of abrasion wear (Shackel and Pearson 1993). For these reasons considerable effort has recently been directed towards the abrasion testing of pavers.

20. As in the case of strength testing, there is little universal agreement on what constitutes an adequate or appropriate abrasion test for concrete paving units. In Europe, specialised test procedures for pavers have been developed (Vring 1992). Generally, however, existing procedures for evaluating concrete surfaces have been adapted to segmental paving. For example, American paver specifications (ASTM 1982) require the use of sand blasting in accordance with ASTM method C418 although it has been suggested that the use of a dressing wheel abrasion machine to ASTM C944 can provide a simpler and cheaper alternative (Rohn and Pfeiffenberger 1985).

21. In Australia, two disparate and incompatible procedures have been developed from overseas tests. The earliest procedure, developed by Perth City Council, represented a modified version of ASTM Test C779-82. This was incorporated into the MA20 paver specification published in 1986 (CMAA 1986). More recently, two developments of the procedure given in British Standard BS 5395: 1977 have emerged as alternatives to the MA20 test. The first of these was developed by Sydney City Council (Gabrawy 1986). This was later adopted in a modified form by the Clay Brick and Paver Institute (CBPI) (Zsembery et al 1989). Both of these procedures comprise rattler tests in which steel balls are tumbled against the paver surface. Abrasion wear is expressed as a volume of material knocked from the surface. Considerable discussion surrounds the relative merits of the MA20 and SCC/CBPI procedures. The two procedures do not correlate with one another except for individual batches of closely controlled pavers. Accordingly results or specifications expressed in terms of one test cannot be simply or reliably translated in terms of the other procedure (Shackel and Pearson 1993).

22. The procedures used to evaluate the abrasion tests have been published elsewhere (Shackel and Shi 1992; Shackel and Pearson 1993) and only a summary of those points relevant to the drafting of Australian specifications are given here. Full discussion of factors affecting the abrasion test results and the design of concrete mixes for concrete paver production have been reported elsewhere (Shackel 1993; Shackel and Pearson 1993). It was found that the reproducibility of the MA20 test was better than that reported for the ASTM C779 test from which it evolved. However, it was found that in order to adequately define the abrasion characteristics, statistical measures based on a minimum sample of 10 pavers needed to be used (Shackel, 1993). In the case of the tumbler test, similar conclusions have been reached except that the sample size is increased to 16 pavers (Zsembery, 1989). The tumbler test has been incorporated into the draft Australian Masonry and Paving Units Code and referenced in the draft Australian industry specifications (see Table 3).

23. The following factors thought likely to influence the abrasion resistance of pavers have been studied (Syahmansyah 1990; Lariba 1990; Shackel 1993):

i) Cement content
ii) Water-cement ratio
iii) Cement type
iv) Aggregate type
v) The use of pigments
vi) Curing regime

24. From the studies the following conclusions have been drawn:

a) The abrasion resistance increases with increased cement in the mix.

b) Increasing the water content or water/cement ratio to improve the workability of the mix led to a reduction in the abrasion resistance.

c) For pavers manufactured from off-white cements, the addition of up to 7% pigment produced no significant change in abrasion resistance.

d) Mixes incorporating crushed aggregate tended to exhibit higher abrasion indices than those manufactured using river gravel. Further study is needed in this area.

e) Some pigments significantly increased the abrasion resistance.

f) Moist curing yielded higher abrasion resistance and compressive strength than air curing of specimens. curing conditions affected abrasion more than strength.

g) Whilst it proved possible to obtain weak correlations between abrasion resistance, Schmidt Hammer Rebound Values and compressive strength, these relationships were significant at only relatively low levels of probability. In particular, compressive strength did not provide a reliable indicator of resistance to wear.

Based on these studies it does not appear necessary to impose major restrictions on factors such as cement type or pigment in a paver specification. However, it may be desirable to specify minimum cement contents and aggregate type.

25. Table 3 will be seen to include recommendations for abrasion resistance. some of the background research leading to the selection of these values has been discussed in detail elsewhere (Shackel 1993, Shackel and Pearson 1993).

APPEARANCE AND SURFACE FINISH

26. Although considerable emphasis is placed on the appearance of concrete paving units, few specifications adequately address this problem (Houben et al 1984). Usually, the uniformity, texture and colour of the paver surfaces are specified only in subjective terms. In other words, the specifications are qualitative rather than quantitative. Typically they require the absence of cracks, burrs, hollows, segregation etc and leave surface finishes and colour to non-specified agreements between manufacturers and end-users.

27. The current draft Australian specifications (CMAA 1993) do not impose any requirements on surface properties. It is, therefore, interesting to note that, at Cairns Airport where surface integrity of the pavers was a major concern, limits were placed on surface texture depth (Vroombout et al, 1992). Here a value of 0.11 mm was set as the maximum permissible average texture depth. In practice, texture depth measurements were found to be not sufficiently repeatable to control the paver quality. For this reason visual comparisons with acceptable samples were used for control purposes. In view of the increasing use of pavers in all forms of pavements in Australia greater attention needs to be paid to the specification of surface qualities.

CONCLUDING COMMENTS

28. Australian specifications for concrete segmental pavers were published in an interim form in mid 1980 (CMAA 1986). Following extensive research by both industry and university laboratories, sufficient data and user confidence have been documented to enable the publication of draft national standards to proceed. Whilst further development of these standards will no doubt occur, the authors believe that in their present form the draft specifications can be used with confidence by both specifiers and end-users alike.

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TABLE 1

PAVER SPECIFICATIONS

Property		Worldwide Range	CMAA Draft Specifications, 1993
a) Dimensions			
- aspect ratio		1.5 - 2.3	-
- width		68 mm – 160 mm	-
- length		200 mm – 280 mm	-
- thickness		60 mm – 140 mm	-
b) Dimensional Tolerances			
- plan dimensions		± 1.6 mm – ± 3 mm	2–3 mm (SD)
- thickness		± 3 mm – ± 5 mm	3 mm (SD)
c) Strength			
- Compressive:	- mean	25 MPa – 60 MPa	no
	- single	20 MPa – 54 MPa	longer
	- characteristic	< 40 MPa	specified
- Flexural:	- mean	< 5 MPa	-
	- characteristic	< 5.9 MPa	2–4 MPa
- Splitting:	- mean	< 4 MPa – 5 MPa	-
	- single	< 3.2 MPa	-
- Breaking Load:	- characteristic	-	2–10 kN

SD = Standard Deviation

TABLE 2

COMPRESSIVE AND FLEXURAL STRENGTHS OF RANDOMLY SELECTED PAVERS

Paver	Compression Strength (MPa)				Flexural Strength (MPa)			
Type	no	mean	std dev	characteristic	no	mean	std dev	characteristic
Shaped	10	49.5	5.51	40.41	15	4.19	0.40	3.53
Rectangular	10	53.0	5.31	44.24	13	5.45	0.79	4.14
Shaped	10	51.5	6.99	42.41	15	7.05	1.57	4.46
"	10	71.5	7.58	58.99	15	7.34	0.87	5.90
"	10	31.0	5.2	22.42	14	4.21	0.52	3.35
"	10	54.0	3.53	48.18	15	7.06	0.93	5.53
Rectangular	10	54.0	5.58	44.79	15	6.90	0.61	5.89
Shaped	10	41.5	5.58	32.29	15	4.43	0.57	3.49
"	10	44.9	8.05	31.62	15	4.85	0.48	4.06
"	10	31.0	8.99	16.17	15	4.88	0.78	3.59
"	10	61.0	11.58	41.89	15	7.94	1.47	5.51
"	10	47.0	4.14	40.17	15	5.87	1.05	4.14
"	10	46.0	3.17	40.77	15	5.58	0.64	4.52
Rectangular	10	59.5	9.42	43.96	15	6.06	0.64	5.00
Shaped	10	50.5	6.72	39.45	15	5.30	0.61	4.29

TABLE 3 – CMAA DRAFT GUIDE REQUIREMENTS FOR CONCRETE SEGMENTAL PAVING UNITS – MA34 1993

APPLICATIONS	ASXXXX Characteristic Breaking Load (kN)	ASXXXX Characteristic Flexural Strength (MPa)	Minimum Thickness (mm)	Shape □	ASXXXX Dimensional Deviations + Plan SD (mm)	ASXXXX Dimensional Deviations + Thickness SD (mm)	Chamfers	Abrasion Resistance ASXXXX Tumbler Index No.	ASXXXX Skid Resistance (Co-efficient of Friction)	ASXXXX Salt Resistance (Cycles)
1 Residential Pedestrian										
Not around pools	2	2		Any	3	3	Opt		0.4	
Around pools	2	2		Any	3	3	Opt		0.4	40
2 Residential Driveway										
Light Traffic	3	2		Any	3	3	Opt		0.4	
Medium Traffic *	5	3		Any	3	3	Opt	7	0.4	
3 Public Footpaths										
Low Volume *	5	3		Any	2	3	Opt	5	0.4	
High Volume *	5	3		Any	2	3	Opt		0.4	
4 Pedestrian Malls * +	5	3		Any	2	3	Opt	3.5	0.4	
5 Roadways □ +										
Minor	5	3	60	Any	2	3	Yes	5	0.4	
Local, Collector, Distributor	5	3	80	Any	2	3	Yes		0.4	
6 Industrial Pavements +										
No containers	10	4	80	A	2	3	Yes	5	0.4	
Containers	10	4	80	A	2	3	Yes		0.4	

* Capable of taking occasional 8.2 tonne axle loads provided that design, detailing and construction, and maintenance is carried out according to CMAA recommendations.

\+ The resultant joint variation is a combination of unit tolerance and laying procedures – for special applications manufacturer's advice should be sought.

□ Some shapes offer superior performance in Roadway applications – appropriate design approaches should be considered.