REQUIREMENTS OF HIGH GRADE POLISHED PAVEMENTS

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ABSTRACT

The resultant aesthetic value of a large public pedestrian area paved in concrete segmental pavers is a collective effort between the landscape architect, builder, paviour and manufacturer. In architectural landscape pavement malls where the transition from vehicular to pedestrian traffic through to maintenance of flora, and the integration of the sections is to be seamless, the manufacturer needs to understand all stakeholders' requirements and incorporate these needs into each concrete segmental paver. When the pavement includes honed/polished product the hurdle for quality is raised to a new level.

1. INTRODUCTION

A major event can be the catalyst, which in turn ensures performance is lifted to a higher level of excellence. The Olympic Games is one such event for athletes. The winning of the 2000 Olympics in 1995 also provided Sydney with the opportunity to create within an urban environment sporting venues of world class. Utilising a disused industrial area, the Sydney Olympic Co-ordination Authority (OCA) was allowed a freedom of imagination that has resulted in urban environment that will stand head and shoulders above others for years to come.

The Olympic complex, situated at Homebush Bay, is a group of sporting venues inter-connected by plazas, thoroughfares and a 1.5 kilometre boulevard paved in concrete interlocking segmental pavers. The venues of the complex are: -

- Stadium Australia - main Olympic stadium
- Aquatic Centre - swimming
- Super Dome - basketball
- Olympic Boulevard
- Olympic Village
- Homebush Bay Rail Station & Bus Interchange

Other venues of the complex are tennis centre, hockey stadium, show ground, five star hotel, warm up track and water features.

This paper will focus on the development of the segmental concrete interlocking pavers used in the complex of which there is a total of 160,000 m^2 or 6,000,000 units.

2. PAVING SELECTION PROCESS

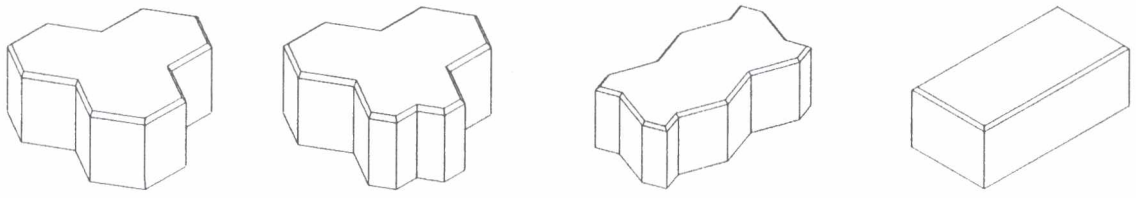
The selection of pavement materials commenced some 12 months prior to any paving being manufactured and involved numerous architects, designers, committees and builders, all requiring their needs to be incorporated in the specification.

The selection process for the hard wearing boulevard and plaza areas was based to a large extent of the following criteria:-

- Interlocking characteristics for the boulevard pavement
- Durability under very high volumes of pedestrian traffic
- Similar shape to an existing paver used around the aquatic centre
- Ecological properties to allow sustainability of the large shade trees
- High degree of polish without exceeding the slip resistance for pedestrians
- High strength to ensure minimal breakage in pavement.
- Seamless transition from thoroughfares to ecological pavements through to the boulevard, as no kerb and channel was to be used.

The paving units selected were Unipave for vehicular trafficked areas and Trihex for pedestrian thoroughfares and plazas (see Fig 1). Sustainability of shade trees was achieved using a permeable paver Eco-Trihex with specifically designed base material which allow the trees to breath as well as providing moisture to their root system. Edge detailing was accommodated in brick size, Trupave, units of 110mm x 220mm (see Figure 1).

Figure 1. Paver Shapes



Trihex **Eco-Trihex** **Unipave** **Trupave**

This selection of shapes allowed for seamless transition from vehicular trafficked boulevard to pedestrian thoroughfares through to permeable paved areas around the greened areas.

3. COLOUR

Prior to the specification being finalised the colour of the pavers had to be selected. Three colours were required: -

- Yellow
- Mauve/Lavender
- Bluestone

The colour selection process was long and involved with multiple committees putting forward their needs with Rocla trying to convert these into "manufacturable" criteria. Those involved were the Government Design Directorate, Hargraves Architects, Olympic Co-ordination Authority, Landscape Designs, Olympic Transport and Access Authority. From numerous colour samples three were selected that were closest to the committees needs. It was quickly found that each colour was either too deep or cold and had to be warmed.

After several modifications to the initial colour samples three were selected which were:-

- Sierra (yellow)
- Terracotta (earthy red)
- Charcoal (grey/blue)

As the plaza areas were large, designers initially wanted three shades of each colour laid randomly to hide potential colour variations of production over the three year period of construction. Through the discipline of quality assurance certification IS9002 [1], it was shown that control of small quantities of pigment was achievable and this requirement was removed.

Before manufacture could commence large pavement reference panels were laid including edge detailing with lighting and seating to monitor public feedback. As a result of strong public support and opinion the paver colour and shape used in the reference panels were specified.

4. SPECIFICATION

The specification for the project evolved over a two year period where issues learnt on the first contract were improved upon in the successive contracts. The contracts were broken into sections of the vast complex: -

- Railway Plaza
- Southern plaza and Boulevard
- Stadium Australia Plaza
- Super Dome Plaza

The specification for these pavers was complex in that overlapping properties were called up from ASNZ4455 "*Masonry Units & Segmental Pavers*"[2] and Concrete Masonry Association of Australia (CMAA) "*Guide To Specifying Concrete Segmental Pavements*"[3].

The major criteria of the specification was characteristic compressive strength whereas the mode of failure was more likely to be in flexure. The CMAA "*Guide to Specifying Concrete Segmental Pavements*"[3] gave no guidance on compressive strength but a characteristic value higher than any previous level was called for. The values of breaking load and flexural strength were also mandatory.

It was quickly recognised that certain properties may not be achievable in the time window between manufacture and delivery to the site, so a lower value was accepted for

delivery with follow up testing showing that specification properties were achieved by time of trafficking (see Table 1.). Abrasion was another property which increases with curing and time and this was adjusted on the same basis.

The finally agreed specification can be seen in Table 1.

Table 1 - Specification of Pavers

	Time of Trafficking	Time of Delivery	Test Method
Dimensional Accuracy	Work Size		
- Plan/Height	Mean ±2.00		ASNZ4456.3
	Std Dev 2mm		ASNZ4456.3
Compressive Strength	60MPa	55MPa	CMAA MA20
Breaking Load			
- Boulevard	10kN		ASNZ4456.5
- Plaza	5kN		ASNZ4456.5
Flexural Strength			
- Boulevard	4MPa		ASNZ4456.5
- Plaza	3MPa		ASNZ4456.5
Abrasion Resistance	3.5	<4.0	ASNZ4456.9
Slip Resistance	>0.4		ASNZ3661.1
Absorption	<5.0%		Custom
Surface Integrity	0.3gm/mm2		Custom
Chamfering	3 x 3 mm		

4.1 Surface Integrity [4]

The requirement of the Olympic Organising Authority was to achieve a carpet of paving to the entry of the venues. This carpet was to appear soft through colouring and smooth through surface integrity. The test procedure for achieving smoothness was a surface integrity test. This test required that 75 to 150micron sized sand be spread over the top surface of the paver so that no sand grains be above the nominal surface of the paver. The sand trapped in the indentations of the surface is then expressed as gms/mm^2 of surface area. To achieve the surface integrity and absorption values, the blending of specifically graded aggregates, cement and fillers were required to achieve a low void content on a dry cast compaction machine. The maximum size aggregate had a critical role in the surface integrity result as any stone trapped in a corner of the mould is difficult to force non-plastic paste around causing a bug hole. This was borne out in the Homebush Bay Rail Plaza where a 15mm decorative aggregate left "bug holes". Although the pavers had an absorption figure of 3.5 to 4.5% the "bug holes" at the surface and edges contributed to surface integrity values greater than 0.2gm/mm^2.

4.2 Slip Resistance

A honed surface treatment was required predominantly to provide a smooth carpet affect with a degree of shine/reflection. This is contrary to the requirements of slip resistance where the rougher the surface, the greater the resistance to slipping. A compromise between density/void content and grit size of polishing was required. Void content of

the paver was measured by absorption values, and during manufacture it was established that absorption figures should not dip below 4.0% otherwise the dense surface gave a high glass like polish finish when honed. The honing media chosen was one that would remove scratches but not give a glass like finish.

4.3 Chamfering

Chamfers lower the potential for spalling of the edge of the paver under loading. Spacer nibs provide a similar affect and on this project spacer nibs were specified to come within 10mm of the top surface. In the Homebush complex chamfering was used for the reduction of lipping from one paver to the next when it was found that up to 2 mm occurred after construction of the Homebush Rail Plaza using non chamfered product. In successive contracts, an all round chamfer was specified.

5. MATERIALS

Material selection was critical in delivering the required properties. Initially 15mm maximum size aggregate was considered. This was found to cause problems with edge integrity, leading to failures of surface integrity. The aggregate used was 7mm crushed basalt blended with alluvial medium sand and fine sand. Aggregate gradings can be reviewed in table 2.

Table 2 - Aggregate Gradings

Percent Passing

Sieve Size	7mm Aggregate	Medium Sand	Fine Sand
9.6mm	100 %	100%	100%
6.7mm	100 to 98.0%	100%	100%
4.75mm	94.0 ± 3.5%	100 to 95.0%	100%
2.36mm	15.0 ± 5.0%	94.0 ± 1.5%	100%
1.18mm	3.0 ± 1.0%	75.0 ± 3.0%	100 to 95.0%
600 micron	2.0 ± 0.8%	50.0 ± 5.0%	97.0 ± 3.0%
300 micron	1.0 ± 0.5%	20.0 ± 4.0%	50.0 ± 6%
150 micron	1.0 ± 0.5%	6.0 ± 4.0%	15.0 ± 5%
75 micron	0.5 ± 0.25%	1.5 ± 0.5%	5.0 ± 1.0%

The cement used was a high early type as described in AS3972 [4] with the specification shown in Table 3.

Table 3 - Typical Cement Specification

Chemical Composition

C_3S	68%
C_2S	7%
C_3A	4%
C_4AF	14%
K_2O	0.53%
Na_2O	0.03%
SO_3	2.6%

Physical Composition

Fineness Index		$450m^2/kg$
Setting Time	- Initial	1hr 45min
	- Final	3hr

5.1 Mix Design

The mix design was based on minimum void content grading. The shape of the aggregate and particle distribution was most important in achieving low void content in the paver. The coarse aggregate had to be less than 10mm to achieve edge and surface integrity and generally less than 7mm to achieve the aggregate exposure after honing.

The final mix design used was: -

20% Cement + Filler
21% 7mm Aggregate
59% Combined Sands

6. MANUFACTURING TECHNIQUES

All pavers were manufactured on a Columbia C50 machine of a half-square metre pallet size with an automatic pallet transfer system, cuber and wrapper. The ancillary equipment is a Meridian automatic batching system with Hydronix moisture probes, supplied by Autocon Systems, and Granumat automatic oxide dosing system by Brockhues.

The polishing equipment was based around a Cassani four spindle head polishing machine with a calibrating head and two product turnovers.

To meet the deadlines of the desired opening dates, manufacture operated for two shifts 6 days a week, with maintenance on the third shift. Honing being a slower process was carried out three shifts, 6 days a week with maintenance on weekends.

To manufacture a paver with 97% confidence of meeting the specification, statistical process control techniques were needed on the green product. These were based on: -

- Green weight to achieve a density between 2200 and 2300kg/m^3.
- Product height monitoring of 80 ± 1.0mm
- Batch weights ±1% of master mix design
- Moisture content 7.0±0.3%

These parameters were found to be critical for maintaining the high confidence level for the physical properties and also aesthetic values.

Attaining a characteristic compressive value of 60 MPa for a total population on a dry cast machine with less than 5% void value is not easy to maintain. As strength and density are closely related, increasing the density produces very high strengths, increasing the overall standard deviation which in turn lowers the overall population characteristic value.

Not only are physical properties affected in this way but colour changes occur with low density product as the voids trap light rather than reflecting it causing the product to appear dull or faded. When polishing lower density product the sand particles are not as well encapsulated within the matrix and are plucked from the surface, rather than polished, giving a pock marked finish to the power. A high density product will polish to a glass like finish which becomes slippery.

Where pavers have spacer nibs it became necessary to have three moulds rotating between production runs rather than run one mould continuously until worn out. This overcame the problem of product size creep, due to nib wear. To ensure nibs were always present on the green product the nibs within the mould had to be continually checked and cleaned.

6.1 Curing Regime

A curing regime of approximately 16 hours at temperatures of 50 to 60°C and humidity of 60 to 80% was used. Humidity greater than these formed water droplets on the surface during the cool down period which created efflorescence. With a two shift operation and a restricted number of kiln capacity, product was turned around in 16 hours and post cured in the stockyard. The months of October to February in Australia are hot and dry with little appreciable humidity, which tends to dry product rather than induce post curing. Product polished within 1 month of manufacture was found to pluck sand rather than polish the paver. The strength of such a paver was found to have stagnated around 45MPa. This problem was overcome by calibrating the product within one or two weeks of manufacture, thereby soaking it and continuing curing. Honing was carried out two weeks later.

6.2 Honing

Honing was carried out on a four spindle head Cassani bed grinder with an initial calibrating head. The product had the back calibrated at one to two weeks and left to post cure for a further two weeks prior to final honing. Final honing incorporated a diamond wheel followed by successive carborundum wheels to remove scratches but not provide a glass like polish.

Product heights were critical for a successful honing. Although the specification allowed 80 ±2.0mm tolerance, this could not be accommodated through the grinder. Product had to be within 80±1.0mm and optimally ±0.5mm was desired. Product outside these tolerances was either not calibrated which would not guarantee their flatness or ground too much off the paver slowing the process considerably. As the specification was 80.0 ±2.0mm the final height of the product was between 78 and 79mm as 1.5 to 2.0mm was ground away in the honing process.

7. TEST RESULTS

As stated earlier the major requirement of the physical properties was the compressive strength. The new test procedure detailed in ASNZ4456.4 "*Determining compressive strength of masonry units*"[5] is not applicable to pavers as the height to thickness ratios for unconfined values were not compatible with the characteristic value which was taken from the old CMAA MA20 "*Specification for Concrete Segmental Paving Units*"[6]. To accommodate the specifiers desires, the height to thickness ratio of MA20 were used in the calculation of characteristic compressive strengths.

Physical Properties are summarised in Table 4. The bottom line of the specification was that the total population of tests had to meet and exceed the specification. This required

special attention to keep green product properties within the parameters detailed in clause 6 otherwise the standard deviation became too wide causing the characteristic value to dip below the values of the specification.

8. CONSTRUCTION DETAIL

Construction was constrained by the official opening dates of certain sections of the complex and these dates could not be modified. The paving contractor, Sam The Paving Man Pty Ltd, had to break new ground as well as meet the deadlines:-

- The base course for the pavement was a heavily bound crushed rock. Base levels had to be ±5mm over 3 lineal metres. Purpose designed undulations and crowns in the plazas pavements were not allowed to be joint line ridged or valleyed. Final levels were cut immediately after forming the base course as it was not possible to carry it out later.
- Bedding material under the ecological pavers, that provided drainage, was a single sized 5mm crushed rock that required special screeding techniques as it did not compact in the same manner as traditional bedding sand. Even the compaction with a bed plate vibrator was different in that a circular technique was required to overcome rutting in the traditional straight up and down method. The single sized 5mm aggregate for the ecological pavers drainage holes was swept in with a 2.5 metre broom mounted on an all-terrain fork lift.
- No kerb and channel is used at the boundary of the boulevard (all boulevard drainage is through manholes and grates in the centre of the traffic way) as the demarcation line between boulevard and plaza does not exist. This meant that paving joint lines extended for 300 metres across the plazas and up to 1.5 kilometres along the boulevard. Joint lines had to be straight to achieve the defined layout. Pavers sizing, particularly spacer nib sizing, was critical in achieving this desired outcome.
- Lipping between pavers had to be kept to a minimum (less than 1mm) and this required that all pavers have a full chamfer.
- The desired result was for the plazas to appear like carpet as they led up to the entrances of the venues. Machine laying was not allowed in that it left cluster lines throughout the pavement detracting from the carpet effect. All pavers were laid by hand and up to 50 paviors were operating on the project 24 hours a day just prior to strategic opening dates.
- Final profiles at paver colour intersections could not be cut in once laid. A purpose designed intersection piece of paver had to be hand cut to ensure it was the major portion of a paver. This required approximately 10 diamond brick saws on site at all times.
- Inspection and acceptance of paved areas was mandatory prior to final sanding and tamping. Unacceptable pavers and areas were sprayed in iridescent paint and removed before proceeding to final joint filling and compaction.

9. CONCLUSION

All sections of the Homebush complex paving are now in service and have stood up well to the test events that are evaluating the ability of the complex to achieve the desired goals prior to the September 2000 Olympic Games.

Without the involvement of all stakeholders in the planning and specification stage it is unlikely that the complex would have been completed on time or achieved the high standard of excellence of functionality and aesthetic presence.

REFERENCES

1. AS/NZS ISO9002, Quality systems – Model for quality assurance in production, installation and servicing, Standards Australia, 1994

2. AS/NZS 4455 Masonry units and segmental pavers, Standards Australia, 1997

3. Guide to Specifying Concrete Segmental Pavements, T44, Concrete Masonry Association of Australia, 1997

4. AS3972, Portland and blended cements, Standards Australia, 1997

5. AS/NZS 4456.4, Determining compressive strength of masonry units, Masonry units and segmental pavers – Method of test, Standards Australia, 1997

6. Specification for Concrete Segmental Paving Units, MA20, Concrete Masonry Association of Australia, 1986, pp 11-13

Table 4 - Summary Of All Test Results

	Dimensions			Characteristic Value			Abrasion	Slip	Surface	Absorption	Density
	Length	Width	Height	Compressive F'uc	Break Load	Flexural F'uf	Index	Resistance Index	Integrity		
	mm	mm	Mm	MPa	kN	MPa			gm/mm2	%	kg/m3
Eco Trihex	188.4	93.4	79.1	67.5	14.3	4.7	3.3	0.65	0.073	4.38	2270
TriHex	188.1	93.1	79.0	62.4	12.0	4.3	3.3	0.63	0.092	5.00	2260
Unipave	242.1	106.1	80.2	57.7	11.0	4.6	3.8	0.65	0.093	4.74	2190
Trupave	222.0	110.0	79.7	61.9	11.9	4.4	3.3	0.66	0.087	5.14	2210
Population			**79.3**	**62.4**	**12.2**	**4.4**	**3.3**	**0.64**	**0.089**	**4.90**	**2240**
Std Dev			0.05	5.66	1.78	0.65					