THE LIFE CYCLE OF KING WILLIAM ROAD, ADELAIDE – AUSTRALIA'S LONGEST AND OLDEST CBP STREETSCAPE

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SUMMARY

King William Road was reconstructed in 1985. It is 2.2 km long and passes through five suburbs of Adelaide, South Australia. It is the longest and oldest length of urban arterial road in Australia to utilise concrete block paving (CBP). Much of the area traversed by the road has a Heritage Classification and as such the pavement and streetscape had to be designed in conformity with heritage and tourist requirements. Apart from the aesthetic and heritage considerations of pavers as a wearing course, the structural ability of the pavement to carry significant urban traffic loads has proven itself throughout the design life of this pavement. Twenty years on, the pavement has performed to maintain a good level of service throughout its design life with little maintenance and yet retains residual in-service capacity.

This paper begins by reviewing the factors that were considered in the design and construction of King William Road. The paper then looks at the performance, maintenance history and the asset value of this unique pavement over its design life. The study includes end-of-service-life testing and analysis, pavement evaluation and whole of life remedial options including recommendations for the future management of this asset.

1. INTRODUCTION

King William Road was constructed in its current form in 1985. It was one of the largest and most imaginative urban-street-renewal projects to have been undertaken outside Europe utilising concrete segmental paving. Whilst many other large municipal segmental paving projects have been built in Australia including the paving of Salamanca Place, Hobart, the construction of malls, plazas and bus termini in most major cities and the commissioning of many kilometres of residential streets (Pearson and Hodgkinson, 1993), it was not until the construction of the Sydney Olympic precinct in the late 1990's that a larger integrated urban paving project was undertaken (Mearing, 2003). Accordingly, as King William Road has now reached the end of its design life, albeit whilst retaining considerable residual service capacity, it is appropriate to look at the history and performance of this significant project.

2. PROJECT HISTORY

King William Road is an urban arterial road some 2.2 km long. It is located about 2 km South West of the Adelaide CBD, South Australia. Many of the buildings fronting the road were constructed in the 19th century and much of the area has a Heritage classification attracting both locals and tourists to its fashionable shops and restaurants. The road was originally paved with asphalt but, in the early 1980's, local traders urged Unley Council to rehabilitate and upgrade the road because the pavement was inadequate for the type and volume of traffic being carried. In 1983 a strategy was formulated to reconstruct the road (McCarthy, 1986). In December, 1984, the Council obtained a grant of $1,194,042 of which $779,226 was for labour through the Community Employment Program (CEP). Council matched this grant with the sum of $1,069,712 (McCarthy, 1986; Rourke, 1986; CACA, 1986). This enabled King William Road to be completely repaved using pavers. The paving work included the footpaths, intersections and turnouts to intersecting streets. This ensured that the whole area was repaved to a single master plan thereby avoiding the inconsistencies that had so often been a product of municipal paving. The project was completed in April, 1986.

3. PAVEMENT DESCRIPTION

The carriageway width of King William Road varies between about 11.2m and 15.5m within a road reserve varying between 15.5m and 22.5m. As shown in Figure 1, there are four lanes with the kerbside lanes generally reserved for parking. This means that through traffic is carried by just one lane in each direction (In 1987, AADT=8000 vehicles per day in one direction (Candy and Shackel, 1987). The footpaths are also paved using concrete pavers.

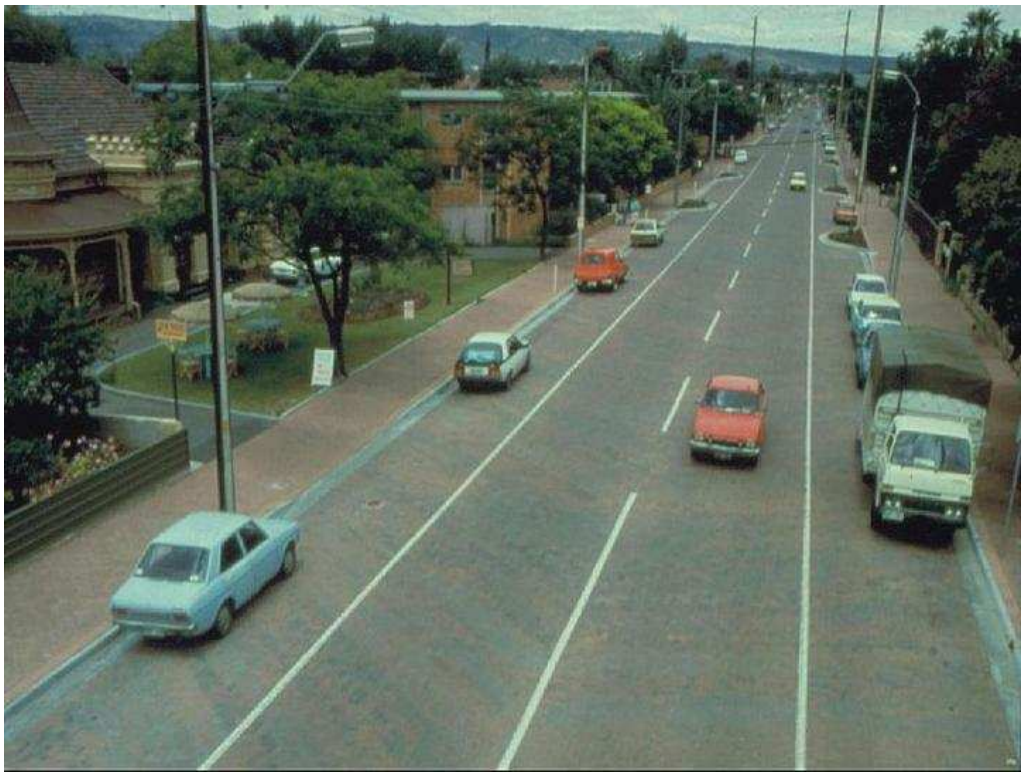


Figure 1. General View of King William Road

Multiple relocations and reconstructions of underground services were required along the road. This meant that it was not practical to retain the existing pavement as a foundation for the new construction. Rather, it was decided to completely rebuild the pavement. Such rebuilding needed to be consistent with the location of the underground services including one critical section of water main just 600 mm below the finished surface.

The subgrade soils along the road comprise clays having Soil Classifications of CH/CL with moisture contents between 25% and 41%. The Plasticity Index (PI) ranged from 40% to 65%. At the time of construction the subgrade was reported to exhibit soaked CBR values of 1% to 2% (5). However, recent soil testing has yielded three *in-situ* Dynamic Cone Penetration (DCP) CBR values of 6%, 8% and 12% in the upper 300mm of subgrade and two laboratory CBR values of 3% and 3.5%.

The roadway and pavements were designed by B.C. Tonkin and Associates. A typical cross-section is shown in Figure 2. From this figure it may be seen that, because of the disturbance caused by the extensive work on the buried services and the proximity of some of these services to the road surface, the subgrade was overlayed by a working platform of 150mm of 7 MPa lean concrete before the pavement itself was constructed. This had the twin benefits of overcoming the effects of subgrade disturbance and of reducing the thickness of pavement required.

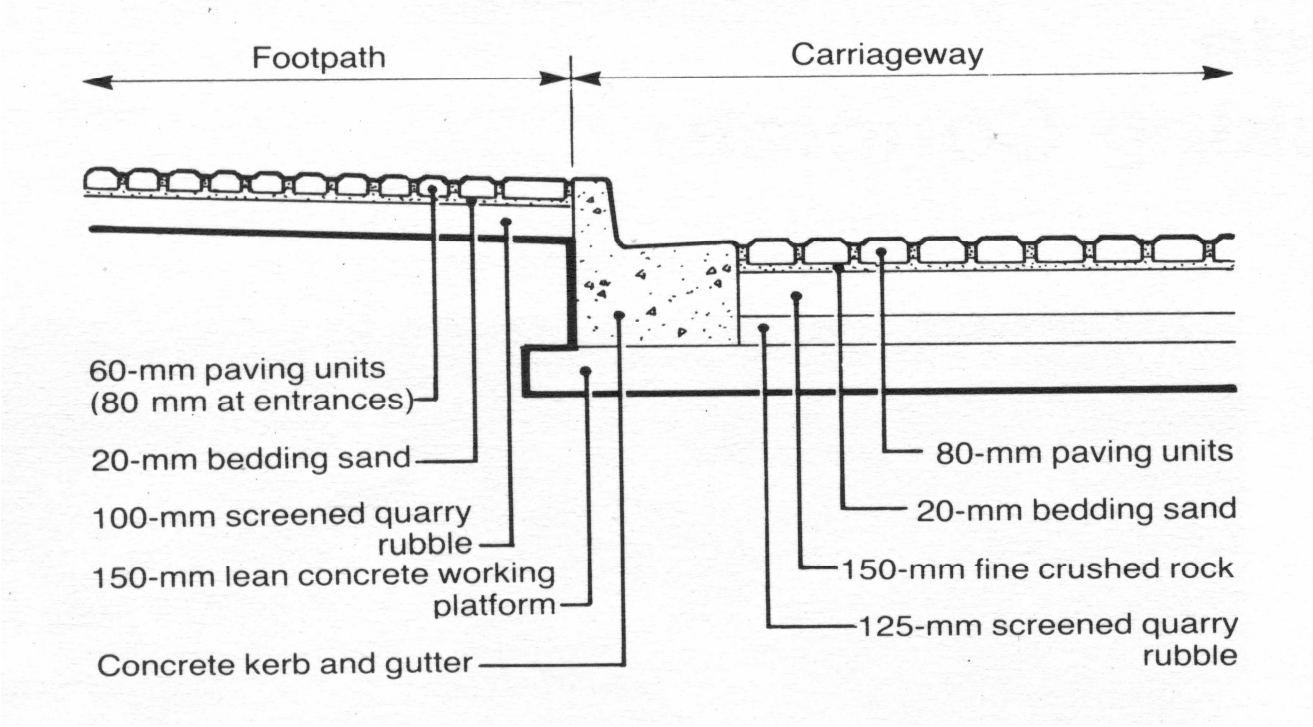


Figure 2. Typical Pavement Cross-section

For the carriageway, as shown in Figure 2, the pavement comprised 150mm of a 20mm crushed rock basecourse over 125mm of screened quarry rubble sub-base with a maximum particle size of 20mm. It has been commented that use of pavers and a lean concrete capping layer were crucial to the success of the project because, in places where services were close to the surface, the use of a conventional flexible pavement would have required surface levels to have been raised (Rourke, 1986).

The pavement was surfaced with 80mm concrete pavers having a Category A shape installed in herringbone bond on 20mm of bedding sand. The pavers were chosen to be a two-colour mix of

charcoal and red. This colour combination was selected to mask oil droppings. In the Heritage area and at intersections a single-coloured charcoal paver was used to provide contrast. The footpaths were surfaced with 60mm Shape A pavers laid in herringbone bond over 20mm of sand on 100mm of screened quarry rubble. At driveways and crossovers the paver thickness was increased to 80mm. The footpath paving was single-coloured terra-cotta or red to contrast with the roadway. Rectangular Shape C units were used for edge detailing. This is now the recommended standard detail for roads and footpaths (CMAA, 1987).

As shown in Figure 2, no subsoil drainage was installed to drain the base and the sand bedding layer. The lean mix base and full depth kerb also restrict natural subsurface drainage of the base. Experience gained since the construction of the road has established that it is crucial to drain the bedding sand of CBP and the Concrete Masonry Association of Australia has recommended details to achieve this (CMAA, 1987).

4. PAVEMENT CONSTRUCTION

A detailed description of the project has been given elsewhere (McCarthy, 1986). The key feature of the CEP funding was to provide jobs for the unemployed. At this time the construction of segmental paving was labour intensive which suited it to CEP requirements. Eighteen workers were engaged in laying pavers at any given time. They were trained on the job by the paver supplier. At that time, trained full-time paving installers were typically expected to achieve a finished output of about 50 m^2 per person per shift for the type of work involved in King William Road but the outputs achieved in the project were much lower. Nevertheless, the quality of work achieved was satisfactory. At about the same time that King William Road was constructed, the first full-scale trials in Australia of mechanical laying were being successfully conducted nearby in the construction of Stage 2 of the ANR Intermodal Facility at Islington. These trials together with experience gained elsewhere in Australia demonstrated that significant savings in both construction time and cost could be achieved where pavers were mechanically laid. Nowadays, construction of a project of the size of King William Road would normally utilise mechanical laying.

5. PAVEMENT CONDITION

After some 20 years of traffic the surface had lost much of its original colour due to wear. More significantly, there was evidence of rutting occurring in the wheel paths along much of the road although this was only visible after rain. Most pavement distress that was visible to the unaided eye consisted of a few small, highly localised areas in which the pavers had chipped because loss of jointing sand had allowed the pavers to come into direct contact with one another.

6. PAVEMENT CONDITION SURVEYS

6.1 Preliminary Investigation

To obtain a quantitative assessment of the current condition of the road a preliminary rutting survey was conducted in February, 2004, involving the following measurements:

1. Rutting under a 2 m straightedge measured to an accuracy of 1 mm
2. Rutting obtained by a profilometer to an accuracy of 0.5 mm

The measurements were made in the outer wheel path (OWP) at 5 locations selected to be representative of the road and including the most heavily trafficked areas and one bus stop. At each location 10 measurements, spaced at about 2m c/c along the roadway, were made. A few measurements were made on adjacent asphalt pavements although these were of different age and composition to the CBP. The rutting data are summarised in Table 1. Some straightedge measurements were also made in areas of localised failure. Here peak rutting deformations between 10mm and 30mm were observed. These data are not included in Table 1.

In the asphalt pavements ruts between 0 and 5mm were measured with an average of 3.2 mm. The maximum rut measured by the profilometer was 6mm. Interestingly, the profilometer plots showed that the ruts in the asphalt were wider than those in the CBP.

Table 1. Rutting Deformation Measurements in mm.

LOCATION		Rut under 2 m Straight Edge		Rut under Profilometer
		Range	Mean	Maximum
1	AC	0 - 5	3.2	6
	CBP	0 - 3	1.5	2.5
2	CBP	0 - 4	1.9	3
3	CBP	3 - 10	5.2	8
4	CBP	0 - 3	2.7	2.5 (OWP), 3.8 (IIWP)
5	CBP	3 - 13	5.6	6 (kerbside), 6 (centre lane)

In the CBP, no rutting could be measured at 7 of the 50 positions where straightedge measurements were taken. Elsewhere, as shown in Table 1, the rutting was generally less than 6 mm although in a few places individual deformations up to 13 mm were recorded. The rutting deformations in the paving averaged 3.4 mm according to the straightedge measurements and 4mm according to the profilometer results. Overall, this represents a good level of performance for a pavement that, at that time, had carried 18 years of urban arterial traffic without resurfacing.

As noted above, some loss of jointing sand had been observed in portions of the paving. For this reason, measurements of joint width were made at two locations. These were taken in serviceable areas of the paving and are reported as the mean of 10 randomly positioned readings in Table 2.

Table 2. Joint Widths.

LOCATION	JOINT WIDTH (mm)	
	Range	Average
3	2 - 4	3
4	2 - 4	2.7

From the table it may be seen that, at location 3, the mean joint width was 3 mm whilst at location 4 the average was 2.7 mm. In both cases the joint widths complied with customary requirements that joints should be within the range from 2 mm to 4 mm (Shackel, 1990). Thus in general there was no evidence of pavers coming together except where there was severe loss of sand from the joints.

6.2 Detailed Investigation

In 2004/2005 Tonkin Consulting undertook a full investigation of the road to assess:

* Unravelling (area - m^2)
* Cracking of pavers (number per 100 m^2)
* Chipping (no of chipped paver per 100 m^2)
* Jointing Sand Loss (depth from top of paver to top of sand - mm)
* Rutting under a 2m straight edge – mm

The measurements were compared to the threshold values given in Table 3. Other factors such as staining, edge condition, patches and depressions were also recorded.

Table 3. CBP Performance Threshold Values

DISTRESS	THRESHOLD VALUE
Rutting	15 mm
Cracking	2 pavers/100m^2
Chipping	3 pavers/100m^2
Jointing Sand loss from top of paver	10mm (max reading per lot)
Unravelling	5% of lot area

The cracking and chipping threshold values are considered to be very conservative and should be reviewed in the light of this study.

7. PAVEMENT EVALUATION

7.1 Rutting

There was little rutting in the parking lanes. In the traffic lanes 16% of the areas sampled had rutting in excess of the threshold value of 15mm and 11% was between 10 mm and 15 mm. The remaining 73% of the traffic lanes had rutting less than 10 mm.

At two test sites rutting was measured both of top of the pavers and again on the top of the base. Generally the ruts in the base were similar to those measured at the surface indicating that the rutting originated in the base rather than in the pavers and bedding sand. The thickness of the bedding sand was measured to be between approximately 20 mm and 30 mm in the traffic lanes.

7.2 Cracking

Cracking was expressed as the number of cracked pavers in an area of 100 m^2. 40% of areas sampled had rutting below the threshold values of 2 pavers/100 m^2 and 8% had cracking over 10 pavers/100 m^2. Cracking was significantly less in the parking lanes than in the traffic lanes and was more prominent near bus stops.

7.3 Chipping

Chipping was expressed as the number of damaged pavers in 100 m^2 of paving. Only 28% of areas had chipping below the threshold given in Table 3 with 8% of lots having chipping in excess of 20 pavers/100 m^2. High values of chipping were recorded adjacent to bus stops.

7.4 Jointing Sand Loss

Jointing sand loss was defined as the depth of the sand below the top of the pavers. Only 8.3% of lots showed jointing sand loss beyond the threshold value given in Table 3. Nearly 70% of the paving showed jointing sand loss less than 6 mm.

7.5 Unravelling

Unravelling is the loss of bond (interlock) between pavers. Overall, 7% of the areas sampled had ravelling in excess of the 5% threshold value and 61% showed no unravelling. The remainder showed unravelling below the threshold given in Table 3.

8. FWD SURVEY

In addition to the surface condition measurements described above a Falling Weight Deflectometer (FWD) survey was undertaken of the traffic lanes. The curvature functions obtained from this survey were used an indication of the pavement stiffness. FWD measurements were made both on the CBP surface and on exposed areas of the basecourse from which the pavers and bedding sand were removed. These showed that the pavers had a significant structural effect and contributed to absorbing and distributing loads horizontally. By contrast, the curvature on top of the basecourse alone was considered high

9. PAVEMENT EVALUATION

In this section of the paper the factors that may have contributed to the pavement performance are examined.

9.1 Pavement Design

The original pavement design is believed to have been based, at least in part, upon the empirical design curves published in 1982 by the Cement and Concrete Association of Australia (Hodgkinson and Morrish, 1982). Considerable advances in the technology of pavement design have been made since the construction of King William Road. It was therefore of interest to assess the adequacy of the as-constructed pavement according to current mechanistic design methodology for segmental pavements. To do this, the LOCKPAVE program published by the Concrete Masonry Association of Australia (Shackel, 2000) was used. Based on an estimated 20 year design traffic of 3.85×10^6 ESA, the LOCKPAVE analyses showed that the as-constructed design would be adequate for subgrade CBR values as low as 1% even under very poor drainage conditions. This showed that the pavement design was conservative. However, predicting the residual life of the pavement was difficult because there were no precedents to draw upon.

Overall, in assessing the in-service performance of the pavement, there was little scope for attributing defects to any lack of pavement thickness. As shown above the deformation performance of the pavement has generally been quite good and there is little evidence of structural failures or deficiencies. Distress tends to be localised. This suggests that these failures are most likely due to occasional local construction or materials deficiencies such as poor compaction. In this respect, based

on rutting measurements, Tonkin Consulting has reported that post-construction base compaction has occurred and is probably continuing in the wheel paths. This may be due to poor initial compaction and the high moisture contents observed in the base and subgrade.

9.2 Pavement Materials

Investigations conducted by Tonkin Consulting have revealed that the base materials generally complied with local Department of Transport (DoT) specifications of the time that the pavement was constructed in terms of grading and plasticity. Repeated loading triaxial tests gave resilient moduli between 380 MPa and 530 MPa. This meets current DoT requirements. These values are slightly higher than those used in the LOCKPAVE analyses.

There was also evidence that, in places, the bedding sand has been contaminated by fines pumping up from the basecourse. This tends to confirm the possibility that the basecourse degraded in service. This, coupled with the observation of high moisture contents in the base, indicated that the basecourse may require some form of stabilisation in the future.

In respect of the paving there was relatively little cracking or spalling breakage of the pavers except in a few localised areas. However, abrasion wear leading to fading of the original paver colours was widespread. In this respect, it is worth noting that, since the construction of the King William Road paving, considerable research has been conducted into the abrasion wear of concrete pavers and much better tests and standards for abrasion resistance in CBP are now in routine use (Shackel and Shi, 1992; Pearson and Shackel, 2003).

10. REHABILITATION STRATEGIES

An issue for ongoing maintenance or rehabilitation is that the various form of distress described above were not consistent in extent but were generally localised. Nevertheless, seven options have been identified for maintaining the road asset. Together with their approximate costs these options are to:

1. Remove the existing pavers, remove and replace the top 50 mm of base and then mechanically stabilise it to a depth of 150 mm and lay new pavers ($ 150/m^2).
2. Remove the pavers, replace the top 150 mm with Cement-treated base and lay new pavers ($165/$m^2$)
3. Remove the pavers and replace the top 150 mm of base with foamed asphalt and lay new pavers ($145/$m^2$).
4. Replace the existing pavers with new pavers on the existing base ($90/$m^2$).
5. Replace the pavers and upper base with 200mm of asphalt ($90/$m^2$).
6. Remove the pavers and upper base and replace with 200 mm of foamed asphalt with a 35mm asphalt wearing course ($87/$m^2$).
7. Remove the 80mm pavers and reprofile the base to allow replacement by 100mm pavers ($115/$m^2$).

11. CONCLUDING COMMENTS

King William Road has succeeded in its original aim of rehabilitating the urban areas through which it passes and must be considered a good example of urban renewal. As such, it remains a significant benchmark in Australian municipal engineering using CBP. The road has now successfully completed over 20 years of service with relatively little maintenance for a major urban road. In structural terms,

the existing pavements are capable of being rehabilitated for at least another 20 years without the need for major reconstruction. In these respects the use of concrete segmental paving has maximised the asset value of the roadway to the Unley municipality in addition to successfully acting as the catalyst for revitalising and renewing an area with strong heritage characteristics. The need for maintenance has only become evident in recent years. This is consistent with whole of life cost studies that show that concrete segmental paving offers significant economic advantages over conventional paving in downtown situations (Shackel and Pearson, 2001a).

Methods for rehabilitating or upgrading the pavement include:
1. Spot maintenance or repair of localised distress.
2. Reconstruction or rehabilitation of entire pavement sections.

In 2001, CMAA published a guide for maintaining concrete segmental paving in Australia (Shackel and Pearson, 2001b). The procedures detailed in this guide cover both surface and structural maintenance and are relevant to many of the problems now beginning to appear in King William Road. In the case of reconstruction, as noted above, seven options have been identified. The choice of option has yet to be made and a separate planning investigation is underway to establish future street scape needs for King William Road, which will assist in decision making for future rehabilitation treatments.

The project remains a milestone in applying concrete segmental paving in Australia. Recognising that, in the 20 years since King William Road was conceived, many advances have taken place in the manufacture and quality control of pavers and in the design, construction and maintenance of segmental paving the project reaffirms the importance and potential of concrete segmental paving in urban road engineering.

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