TECHNOLOGIES AND OPPORTUNITIES FOR PERMEABLE SEGMENTAL PAVING IN AUSTRALIA

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Abstract

Permeable segmental paving was first applied in Europe almost 20 years ago. Research into permeable paving began in Australia in the early 1990's, and was directed both to adapting permeable paving to suit Australian climates and rainfalls and to providing fundamental information for the design of permeable pavements to carry traffic. This work, taken in conjunction with overseas investigations, means that that there is now a substantial body of information that can be used in the design and application of permeable paving under Australian conditions.

The paper begins by summarizing the technology of permeable paving. The environmental advantages and utility of permeable paving in the Australian context is then discussed. This is illustrated by citing a series of case histories of the successful application of permeable paving both around Australia and overseas. The applications described range from landscaping to heavy duty container yard pavements. The need for Australian standards for permeable paving is discussed and progress towards formulating such standards is outlined.

Key Words: Permeable pavements, pavers, design, environment, sustainability, standards.

Introduction

Although permeable concrete segmental paving concepts only began to emerge in Germany and Austria some 25 years ago they have subsequently spread rapidly to become a viable option for sustainability in most developed countries worldwide. Originally in Europe, permeable paving was seen principally as a means of flood mitigation and control that minimised the very high land use costs associated with installing retention ponds and soaks by combining these with the paving already required on site. This concept remains a powerful argument for using permeable paving in highly urbanised societies such as Australia where government enforced urban consolidation is placing ever increasing demands on existing and often barely adequate stormwater infrastructure. However, it was soon demonstrated that permeable paving could also make significant contributions to trapping, removing and treating pollutants from stormwater "at source" and therefore at minimal cost to communities. This has been a strong incentive in the USA where the Environmental Protection Agency (EPA) places its main priority on controlling stormwater pollution. For more than 2 years the EPA has required developers of projects greater than 1 acre in size to apply for permits for stormwater management. Although in practice some projects smaller than 5 acres may receive waivers, almost 98% of all development now proceeds under EPA permits which must conform to recognised Best Management Practices (BMP). BMPs approved by the EPA include permeable paving.

The EPA's use of permits and BMPs for stormwater management is typical of the worldwide response to environmental challenges. Almost invariably, the uptake of permeable paving has been a response to national or local regulations for achieving sustainability and managing the environment. In Australia, the concept of Water Sensitive Urban Design (WSUD) aims to manage stormwater and pollution at either the site level or on a regional basis. WSUD is referenced by planning guidelines and drainage regulations and provides a rational framework for incorporating permeable paving into urban design. Permeable paving plays a major role in WSUD. Its benefits not only embrace stormwater management and pollution control but include economic advantages by minimising the costs of surface drainage works, reducing the demands on stormwater sewerage and optimising land use (Shackel, 1996).

To use permeable paving effectively pavement designers need to consider environmental and sustainability issues in addition to conventional pavement design requirements. The EPA has listed unfamiliarity by pavement engineers with the concepts of permeable paving as an obstacle to the wider adoption of such techniques. This paper seeks to demonstrate that a substantial technological base already exists for applying permeable paving in Australia. This technology is based on both local and overseas research and is reviewed below.

Choice of Permeable Pavement

Traditional pavements surfaced with asphalt or concrete are almost impermeable, allow very rapid stormwater runoff, have only a limited ability to assimilate contaminants, may clog and are difficult to clean when clogging occurs. Because conventional impermeable pavements rapidly remove water from a site they require expensive stormwater infrastructure to avoid flooding and act to concentrate pollutants into waterways where they cannot be completely broken down. Indirectly, impermeable pavements contribute to the destruction of riparian habitats. To overcome these disadvantages requires a Green Site Design approach. This treats as much water as possible on site, treats non-point source pollution and minimises stormwater infrastructure costs whilst maximising groundwater recharge. This tends to maximise the ecological value of streams and other waterways which ultimately receive the effluent. Permeable pavements provide the means to implement such an approach. Permeable pavements include porous asphalt or concrete with the fine materials left out of the mix, grid pavers filled with aggregate and/or grass and concrete segmental permeable paving (CSPP).

The sustainability of these different types of pavement has been assessed using green rating systems including:

1. **LEED** (Leadership in Energy and Environmental Design). LEED developed by the U S Dept of Energy but now administered by the US, Canadian and Australian Green Building Councils, is a points rating system for measuring sustainability. Points or credits are earned by showing evidence of compliance with the system.
2. **LCA** (Life Cycle Analysis). This is a more sophisticated analysis than LEED which accounts for the environmental loads created by a product or service from "the cradle to the grave" including the recycling and reuse of materials.

LEED and LCA analyses have shown that, in terms of sustainability, concrete segmental permeable paving rates significantly better than conventional surfaces such as asphalt and in-situ concrete (e.g. Andersen et al, 2004). For this reason this paper concentrates solely on permeable segmental paving.

Types of CSPP

Essentially there are five types of concrete segmental permeable paver system:

1. Permeable pavers

2. Grass-pavers and grids

3. Systems using widened joints for grass growth

4. Systems using widened joints for drainage

5. Systems employing pavers with discrete drainage openings.

The use of these systems has been described elsewhere (Shackel, 1996). Potential application of these systems varies widely. For example, Table 1 shows an early assessment made in Germany (Borgwardt, 1997).

Table 1 represents a landscape architect's view of permeable paving. From the engineering standpoint the range of applications is much wider and more challenging. Proven applications include:

a) Pedestrian Areas in footpaths, malls and large public spaces. Successful examples include large areas at the Sydney Sports ground and in the Sydney Olympic precinct (Figure 1).

Figure 1. CSPP at Olympic Park, Sydney.

b) Private and Municipal Parking Areas. CSPP has been widely used in parking lots where it is often laid in conjunction with bio-swales. An early example of a parking area comprising approximately 38000 m^2 of machine-laid permeable pavers is to be found at the Ernst-Happel Stadium, Vienna. This is shown in Figure 2. This has regularly carried cars, buses and trucks without problem for more than 12 years.

c) Residential Streets. The best documented use of permeable residential paving in Australia is Smith Street, Manly, NSW - Figure 3 (Shackel, Ball and Mearing, 2003). Another example, a street in Kiama, NSW, is shown in Figure 4

Figure 2. Permeable Car and Bus Parking Area, Vienna

Figure 3. Permeable Residential Street, Manly, NSW.

Figure 4. Permeable Roadway, Kiama, NSW.

d) Bus Termini. About 80 000 m^2 of CSPP was used at the bus terminus, Expo-2000, Hanover, Germany. This is shown in Figure 5.

Figure 5. Permeable Bus Terminus, Hanover, Germany.

e) Ports & Container Yards. Permeable paving offers particular advantages in port and containers yards where drainage is often a problem and large crossfalls are not readily tolerated. Successful applications of permeable paving have been made in the Santos Container Terminal (150 000 m^2) in Brazil (Knapton and Cook, 2000) and at Howland Hook in the USA (ICPI, 2002) – figure 6. These pavements carry heavy industrial vehicles.

Figure 6. Permeable Container Yard, Port of New York and New Jersey.

At noted above, permeable pavers have the proven potential to serve in virtually all markets currently supplied by conventional pavers except airports. They should, therefore, be assessed by a full range of landscaping, engineering and environmental criteria. These include aesthetics, permeability, water retention, pollution removal, clogging potential, maintenance and the structural capacity to carry loads and traffic. Using these criteria a comparison of the common permeable paving systems is given in Table 2.

The Technology of CSPP

All of the paving systems shown in Table 2 have been used in Australia. Although there has been relatively little work on grassed joint paving most other systems have researched locally. Commencing at the University of New South Wales in the early 1990s, most research has concentrated on paving systems with widened joints or openings because, as noted in Table 2, these can accept high infiltration rates and are therefore well suited to Australian rainfall patterns where high intensity storms are often the norm. At least 7 different CSPP systems have been studied in Australia

Broadly, research into CSPP needs to address 4 main questions. These can be stated as

1. How much rainfall can the paving accept over time?

2. How much traffic (loads and repetitions) can the paving carry?

3. How effective is the paving in trapping or treating pollutants?

4. How quickly is the pavement likely to clog?

All of these questions have been researched both in Australia and overseas. A brief summary of the main conclusions of this work now follows.

Water Infiltration and Retention

Water infiltration and retention (or detention) form key parts of WSUD practice. The earliest work in the development of permeable paving concentrated on the infiltration of water into the surface layer of pavers and bedding materials (e.g. Muth, 1989, 1994). Such work included extensive studies at the Universities of New South Wales (Shackel et al, 1996, Shackel, 1997) and South Australia (Anon, 2002). In general such work showed that infiltration rates of around 600 l/sec.ha could be achieved for paving with drainage openings. Whilst this is adequate for European conditions where 2-year design storms are generally less than 275 l/sec.ha, it is important to note that in Australia such design storms occur much more frequently than in Europe. This means that it may not be possible for permeable paving to accept some design storm intensities expected in Northern Australia. Nor is this simply a matter of redesigning the pavers because the rate of infiltration is limited not only by the paver surface but also by the rate at which the pavement sub-structure can absorb, retain and drain water. In this respect, there have been only limited studies of the infiltration, retention and drainage capacities of the materials used in permeable pavement sub-structures (e.g. Shackel et al, 2001).

In the case of grass-blocks and grids and porous pavers it is doubtful whether such systems can play a major role in WSUD practice in Australia because of their limited infiltration rates and high tendencies to clog.

Structural Capacity

Landscapers and architects often prefer rectangular or square pavers to dentated shapes. However, dentated shapes generally offer performance advantages where the pavement is to carry traffic (Shackel et al 1993, 2000, Anon 2002) This principle remains true for permeable pavers. Structural tests of permeable pavers have shown that:

a) Shaped permeable pavers perform better than rectangular permeable pavers (e.g. Anon 2002, Shackel, 1999, Shackel et al, 2000).

b) Where permeable pavers have been derived by modifying conventional paver shapes to provide drainage openings along the joints the structural performance of both the permeable pavers and the conventional pavers has been similar (e.g. Anon 2002, Shackel et al, 2000).

c) Not all shaped permeable pavers give equal structural performance (e.g. Shackel et al, 1996, 2000).

Pollution Control

Trapping of heavy metals and hydrocarbons is much more effective in pavements using porous concrete pavers than where paving with drains or widened joints are used However, in general terms, most permeable paving systems using widened joints or drainage openings have been shown to be capable of removing up to about 90% of the total suspended solids (TSS). Even more TSS is removed by grass-blocks and grids with up to about 97% being caught (e.g. Dierkes et al 2002). Much of the TSS is trapped in the material filling the joints or drainage holes (James, 2002) but some is retained within the basecourse or sub-base (Dierkes et al 2002). Over time this reduces the infiltration capacity of the pavement. However, experience and laboratory tests indicate that service lives of 15 to 25 years can be expected before this is likely to become a problem (e.g. Anon 2002). Nevertheless, allowance for some reduction in infiltration must be made at the design stage.

Pavement Clogging and Maintenance

Many authorities including EPA have expressed concern about maintaining permeable pavement surfaces and several studies have assessed the need for regular maintenance. It is generally said that the worst problem with permeable pavements is clogging Experience over nearly 20 years in Europe suggests pavements show significant reductions in permeability due to clogging between 5 and 10 years after construction (Dierkes et al, 2002). One beneficial aspect to this is that pollutants are retained in the pavement. Because of the potential for clogging, cleaning and maintenance needs to be an integral part of any permeable paving system.

Sweeping is beneficial. This can be demonstrated in laboratory-scale tests (e.g. Anon 2002). Studies of full-scale pavements have been less common but long-term monitoring of prototype CSPPs (e.g. James, 2002) has confirmed that the infiltration capacity of test pavements decreases as the amount of oil and grease together with organic and fine matter within the gravel filling the drainage openings increases with increasing traffic. Importantly, the tests have shown that the infiltration capacity can be restored by removing and replacing the top 10 to 20 mm of the drainage material (James 2002). For systems with rectangular drainage openings this can be readily and economically achieved by using conventional street sweeping equipment.

By contrast, porous concrete pavers are very difficult to clean. Typically, this requires specialised cleaning equipment using vacuums and/or high pressure water jets. Maintenance of grass-blocks or grids is also expensive and involves mowing and maintaining the vegetation.

Design of CSPP

To effectively use CSPP a designer must calculate the pavement dimensions both to carry traffic and to manage stormwater. The first of these requirements can be achieved using the mechanistic design program LOCKPAVE version 15+ (Shackel, 2000) published by the Concrete Masonry Association of Australia (CMAA). Stormwater water management can be achieved using the EPA's public domain program SWMM. To facilitate the use of SWMM, CMAA is currently developing a version of this program specific to CSPP.

Australian Standards for CSPP

Work on developing draft Australian Standards for segmental and flag pavements is currently well advanced (Pearson and Shackel, 2005). The draft Standards form a suite of documents – see Figure 7. Draft AS 4960.5 will be available as a public review draft during 2006.

Summary and Conclusions

From the information presented here it can be concluded that no single paving system can fulfil all the roles required of permeable paving. However, CSPP rates much better than the alternatives in terms of sustainability. Some CSPP systems such as grass-pavers or grids and grassed joint paving are limited to landscaping and niche municipal markets. These products do not require very much technical support because traffic is limited to minor applications such as car parks or emergency vehicle access routes. However, because of their limited infiltration capacity they cannot address fully the demands of stormwater management in the Australian context

Overall, the most versatile CSPP systems are those using widened joints or discrete drainage openings. As noted above, such systems have already been studied for up to about 15 years in Australia. Research has embraced measurements of infiltration rates, structural capability, pollution trapping and clogging.

As noted above, an Australian Standard for using CSPP is currently under development. This is being drafted to accord with both Australian and overseas research and attempts to provide a state of the art review of current best practice worldwide. Thereby, it is hoped that the standard will facilitate the wider use of permeable paving and assist in achieving more sustainable pavements in Australia.

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Table 1. Applications for Concrete Segmental Permeable Pavements

(after Borgwardt, 1997).

PAVEMENT TYPE	**Paving stones with openings**	**Paving stones with enlarged open-jointed joints**	**Paving Stones made of porous concrete**	**Paving Stones with enlarged grass joints but not grid pavers!**
Infiltration	+	o	-	-
Retention	o	o	-	-
Moving traffic i.e. roads	o	-	-	-
Static traffic e.g.parking lots,	+	+	o	+
Bike paths, sidewalks, pedestrian areas	o	o	-	o

\+ Good
o Acceptable
\- Not recommended

Table 2. Comparison of Concrete Segmental Permeable Paving Systems

PAVER TYPE	**Pavement Aesthetics**	**Water Infiltration**	**Water Retention**	**Pollution Trapping**	**Clogging Potential**	**Drainage Maintenance**	**Structural Capacity**
Grass stones & grids	Good	Low	Moderate	Very good	Moderate	Difficult	Poor
Paving systems with enlarged grass joints	Good	Low	Moderate	Very good	Moderate	Difficult	Low
Porous Pavers	Poor (staining)	Medium	Low	Very good	Very high (c.5 years)	Very difficult	Satisfactory to good
Rectangular or square pavers with widened joints	Very good	High	High	Good	Low (15-20 yrs)	Difficult – untested In field	Satisfactory
Rectangular pavers with openings	Very good	High	High	Good	Low (15-20 yrs)	Easy but untested In field	Good
Shaped pavers with openings	Satisfactory To Good	High	High	Good	Low (15-25 yrs)	Proven to be easy by field trials	Excellent

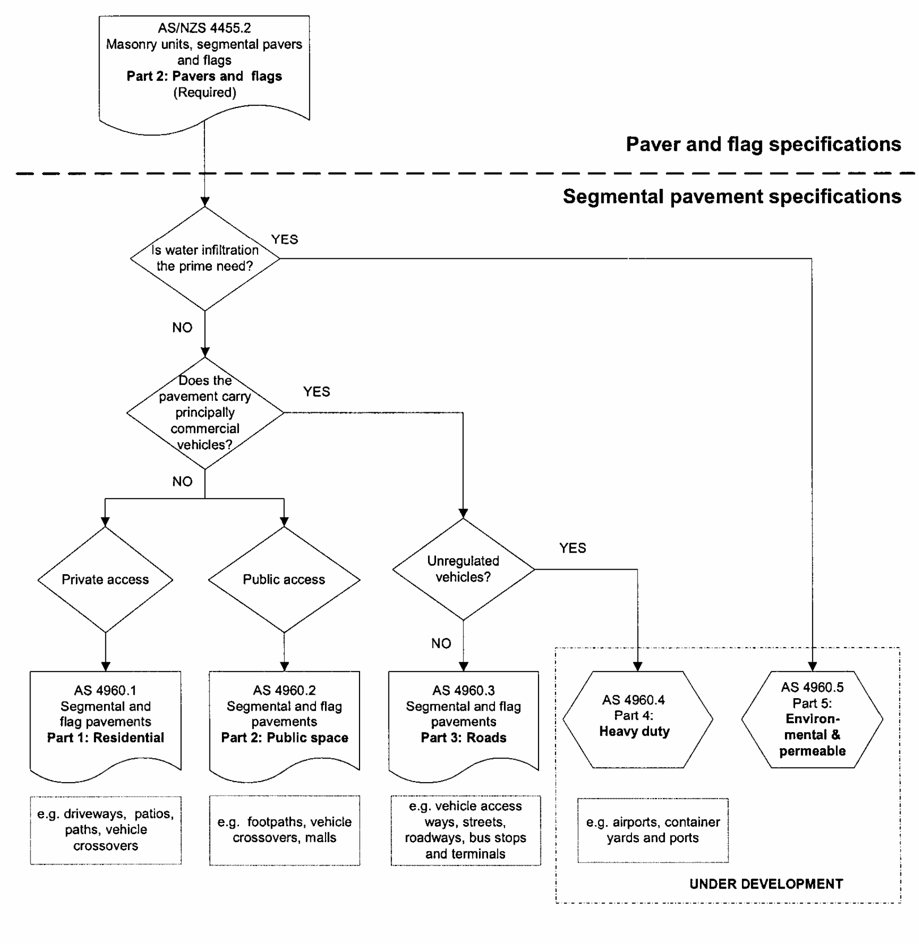

Figure 7. Flow Chart – Draft Standard Pathway