PERMEABLE CONCRETE ECO-PAVING AS BEST MANAGEMENT PRACTICE IN AUSTRALIAN URBAN ROAD ENGINEERING

Dr Brian Shackel, University of New South Wales, Australia

Alan Pearson, Concrete Masonry Association of Australia, Australia

ABSTRACT

Research into the structural and hydraulic properties of permeable concrete segmental eco-paving has now been active in Australia for almost 10 years. Moreover, over the last six years a significant number of projects in Australia have successfully utilised this new form of construction. In this paper, the progress that has been made in the testing, evaluation, design and construction of permeable eco-paving is summarised and critically assessed and a state-of-the-art review is presented. The role and potential of permeable concrete segmental paving in best management practice in Australian urban road engineering is then assessed. This is illustrated by a series of case histories.

INTRODUCTION

In urban catchments, road surfaces can account for about 20% to 25% of impermeable surfaces i.e. roads are a major generator of runoff. The control of this runoff is a prime objective in Water Sensitive Urban Design. One way to achieve this is to use permeable eco-pavements.

Permeable eco-paving was first developed in Europe more than a decade ago and has been used in Australia since 1997. Eco-paving is designed to be permeable and water infiltration is actively encouraged. This enables eco-pavements to achieve a wide range of environmental benefits (1,2,3) including :

a) A reduction in the amount of rainfall runoff from pavement surfaces and, thereby, a decrease in the extent of the stormwater drainage necessary and a reduction in downstream flooding.

b) A decrease in the size or need for rainwater retention facilities in roadworks by using the pavement itself for retention.

c) Trapping pollutants that would otherwise contaminate groundwater or drainage systems and assistance in the biological decomposition of hydrocarbon contaminants i.e. effluent quality enhancement.

d) Recharging and maintaining aquifers and the natural groundwater.

In addition, eco-paving can reduce the cost of compliance with storm water regulations.

WARRANTS FOR USING ECO-PAVING

Worldwide, emerging regulations for new urban pavement developments typically include requirements for

- On-Site retention of rainwater
- Control of the discharge rate
- Control of the discharge Water Quality

- Limits of the extent of impermeable areas
- Measures to reduce sedimentation and/or pollution

To meet such requirements in the context of Water Sensitive Urban Design, Best Management Practices (BMP) include controls for reducing or managing pollutants, procedures for the proper disposal of waste and the use of flood management procedures which assess impacts on water quality.

Permeable eco-paving should be considered as an option when the stormwater sewerage is near or at capacity, when there are limitations on the extent of impermeable cover, when there is insufficient space for both vehicle use and detention ponds and when water quality and pollution control are primary design objectives. For these reasons, permeable eco-pavements provide an attractive option in Water Sensitive Urban Design that is relevant to urban roads and streets and especially to Local Government.

TECHNOLOGY

In Australia, research into permeable concrete eco-paving has been conducted at the University of New South Wales (UNSW) since 1994 and more recently has been initiated at the University of South Australia (UNISA). At UNSW the research has concentrated on laboratory studies of water infiltration through eco-pavement surfacings (1,4-6), the structural capacity of the paving (5-8) and the properties of base materials for permeable pavements (9). Recently this work has been extended to full-scale field studies with emphasis on water quality and pollution control (10). At UNISA both laboratory and field trials have been conducted with an emphasis on pollution management (11,12). These studies show that eco-pavers can accept rainfall intensities of up to about 600 l/sec/ha (11) whilst maintaining levels of structural capacity that are comparable with those exhibited by conventional paving (11). Moreover, there is good evidence that eco-paving can trap up to about 90% of particulate contaminants (11,12).

NATURE OF PERMEABLE ECO-PAVING

Permeable eco-pavements comprise a permeable surfacing overlying permeable base and sub-base materials. The surface is installed on a fully engineered sub-structure and such pavements provide a viable alternative to conventional paving (13).

SURFACING

Broadly permeable paving can be divided into two categories:

1. Pavements using porous surfacings including porous asphalt, porous rigid concrete or porous pavers.

2. Pavements surfaced with concrete pavers which, although impermeable themselves, are provided with openings that permit the rapid ingress of water.

Porous surfaces often do not permit a sufficiently rapid infiltration of rainwater to suit Australian rainfall conditions, tend to clog within a relatively short time and are difficult to clean. For these reasons they are not considered further here.

Pavers which allow water to infiltrate through vertical opening or drains have been described in detail elsewhere (13) and comprise:

a) *Grass-stones or grids.* These comprise concrete slabs or plates with large openings within which grass is grown. These have a proven history of successful use in car parks (14) but, whilst effective in trapping pollutants, suffer the disadvantages of permitting only small water flows and of being unsuitable for sustained truck traffic.

b) *Widened Joint Paving Systems.* Here the pavers are provided with spacer lugs which hold them apart to provide much wider joints than those customarily specified for concrete segmental paving (2 to 5mm). These are normally proposed only for parking areas and very light traffic applications.

c) *Eco-Pavers.* Eco-paver surfaces give the highest infiltration of water amongst permeable pavements. Such paving is produced by modification of well-established concrete paver shapes so that, once laid, small openings are provided at intervals along the joints. As shown in **Figure 1**, these are filled with a uniformly graded 2-5mm aggregate to act as vertical drains through the pavement thereby permitting water to infiltrate the pavement. Because eco-pavers are based on well-proven conventional paver shapes, they provide a viable alternative to conventional segmental paving. As described below, such pavers have been successfully used in a wide spectrum of applications ranging from car parks, residential streets, and bus termini to container yards carrying heavy industrial loads.

BASE AND SUB-BASE

The basecourse and sub-base materials for permeable eco-pavements should meet the following criteria:

1. The materials should possess adequate water storage capacity and be able to drain water within a reasonable period of time without erosion or migration of fines.
2. The materials should possess adequate stiffness to carry the full spectrum of traffic loads and repetitions.
3. The materials should be capable of trapping and removing contaminants from water draining through the pavements
4. The materials should satisfy filter criteria which prevent movements of fines between the bedding and base, base and sub-base or base/sub-base and subgrade.

Each of these requirements is now considered in more detail.

Hydraulic and Load Spreading Properties

It is convenient to consider the hydraulic properties and stiffness (load-spreading) of the materials for permeable eco-pavements together. This is because a change in one of these properties tends to adversely impact the other e.g. an increase in permeability can often be achieved only at the cost of a reduction in modulus. The dilemma posed by this is illustrated in **Figure 2** based on data obtained at the University of New South Wales (9). It may be seen that materials exhibiting high resilient moduli do not necessarily achieve high permeablities.

A wide variety of free-draining, open-graded and rapid-draining granular base materials have been developed and used for conventional highway construction. Details have been summarised elsewhere (eg 15). The maximum size of such aggregates ranges up to about 50mm although many gradations stop at 20mm or 25mm. Free-draining materials exhibit gradations ranging between 0.075mm and the maximum size but rapid-draining and traditional open-graded materials typically exclude material finer than 2mm. Such materials may require filter layers or fabrics to protect them from the migration of fines. Traditionally, these materials have been used as drainage layers beneath full-depth asphalt or rigid concrete pavements but are less suitable for basecourses in flexible eco-pavements where traffic-induced stresses may be higher. In this respect, such materials typically exhibit resilient moduli below the values normally selected for pavement design (eg 9). Moreover, the materials are more difficult to lay and compact than conventional granular basecourse if segregation and rutting during construction are to be avoided (15).

For the reasons given above it is desirable to modify existing drainage base materials to improve their load-distribution and construction characteristics. This can be most conveniently accomplished by stabilising the material with the addition of small amounts of cement (15).

Pollution Control

Runoff from the initial part of a rainstorm has highest concentration of pollutants. Permeable eco-pavements captures this “First Flush”. In the USA, capture requirements vary State by State e.g. in New Jersey a BMP design must capture and treat the first 30mm (1.25 in) of rain over 2 hours whilst in neighbouring New York the capture requirement is just 13mm (0.5 inches). Capture requirements do not yet appear to have been regulated in Australia.

Concrete eco-pavement surfaces and base materials are inherently less polluting than asphaltic materials. Moreover, research has shown that surface runoff from concrete eco-paving can be cleaner than received rainfall (16). Eco-pavements reduce Total Suspended Solids (TSS) through filtration. As a result, pollutant outflow readings are much lower than those from traditional impermeable surfaces.

Eco-pavements reduce transport capacity i.e. less contaminant is transported to the catchment outlet, and, because they filter the infiltrated runoff, less contaminant gets to the ground water or to sub-surface collection systems. It may be seen, therefore, that eco-pavements provide control at the source of the problem rather than relying on downstream treatments. This can represent considerable cost savings.

Pollution removal mechanisms include filtration of solids, oxidation, cooling and bio-chemical reactions. Of these mechanisms, filtration is, perhaps the most important because it has been shown that most contaminants are particulates and that up to about 90% of these particulates can be filtered out of infiltrated water by eco-paving (11,16). Fine fractions including sand, silt and clay sizes of material are the most effective in performing this filtration task. As noted above, such fractions are largely absent from base materials that are intended to be free or rapid-draining (15) but are present in conventional base and sub-base materials.

As particulates are deposited in the pavements infiltration and hydraulic conductivity decrease but eventually achieve equilibrium. . Nevertheless, effective lives of 15 to 25 years are feasible allowing for clogging due to TSS retention i.e. similar to conventional pavements (11). However, designers should allow for reductions in the initial infiltration or conductivity measurements.

Filter Criteria

Where pavements incorporate open graded or rapid-draining materials there is an opportunity for fines to migrate into the base or sub-base or for erosion to occur. To minimise this it is necessary to ensure that the gradations of successive courses in the pavement meet recognised filter criteria (e.g. 15). If such criteria cannot be readily met then the obvious alternative is to use filter fabrics (geotextiles) between the layers or to encapsulate the base.

Choice of Material

To address the criteria listed above normally requires engineering compromises when choosing base and sub-base materials. For example, conventional unbound granular basecourses are well-graded, dense materials which exhibit relatively low permeabilities and water storage capacities. Changing the grading of such materials to increase permeability and storage by removing fines reduces their stiffness and, moreover, reduces the ability of the materials to trap pollutants. For these reasons, when using rapid-draining basecourses to provide water retention or detention it may also be desirable to employ conventional sub-base materials to provide filtration of contaminants.

DESIGN OF ECO-PAVEMENTS

The issues to be considered in designing permeable eco-pavements include the control of contaminants, the rapidity with which water can both infiltrate and drain from the pavement and the ability of the pavement to carry traffic. Separate structural and hydraulic analyses need to be performed. These will each yield different estimates of the thickness of base and/or sub-base required. The largest values of these thicknesses will be selected.

Structural Design

Structural tests of a wide range of eco-pavers have shown that they have similar load-spreading properties to conventional pavers i.e. they exhibit similar moduli (2-6). It follows that methods already established for the structural design of conventional segmental pavements can be used for permeable eco-paving. In Australia, the CMAA has published the LOCKPAVE® computer program for designing segmental pavements (17). This has been recently upgraded to include the design of permeable pavements.

In applying design programs such as LOCKPAVE®, particular care needs to be taken in the selection and modelling of unbound granular base and sub-base layers. In contrast to conventional pavements, it needs to be assumed that these materials will serve in wet or saturated conditions for much of their service life. Accordingly the moduli chosen for design should be much lower than for conventional pavements. In this respect, based on a survey of repeated loading triaxial test data, LOCKPAVE® assumes conservatively that the moduli of unbound permeable base and sub-base will just 40% of the values for conventional materials. For similar reasons, design should also be based on a soaked subgrade CBR or modulus.

Hydraulic Design

The first step in the hydraulic design is to determine how the water will be controlled and managed within the pavement system i.e. to choose a cross-section and the materials. **Figure 3** shows three typical cross-sections. In Figure 3c water is allowed to percolate directly to the subgrade and water table. Figure 3b shows a system for collection of and disposal of the infiltration whilst Figure 3c illustrates how contaminated outflows can be handled.

Once a cross-section has been selected it is necessary to determine how much water flows into the pavement system (capacity**)**. This can be done using normal drainage equations (e.g.15). Typical values for the design parameters are illustrated in **Figure 4**. A more convenient way to perform the analyses is to use the well-known public domain drainage program SWMM or versions of it specifically adapted to eco-paving (16). These enable the hydraulic performance of the pavement to be conveniently assessed for a variety of storms and drainage conditions using site-specific data.

APPLICATIONS OF PERMEABLE ECO-PAVING

Around the world eco-paving has been used for more than a decade. In Australia, by far the biggest use to date has been in landscaping, car parks and pedestrian areas. **Figure 5** shows a good example of this adjacent to the Olympic Boulevard at the Homebush Olympics site, Sydney, constructed in 1999. However, roads have also been installed since 1998. **Figure 6** and **Figure 7** show a road in Kiama and Smith Street, Manly respectively. The latter is a demonstration project designed and monitored by UNSW which is described in detail elsewhere (9). Overseas, eco-paving has been successfully used in bus termini in Germany and Austria including about 100000 m^2 of paving for bus use at the 2000 World Fair, Hannover, as shown in **Figure 8**. In the Americas eco-paving has been successfully used in port pavements carrying heavy containers and their handling vehicles (17,18) – a typical example is shown in **Figure 9**.

CONCLUDING COMMENTS

Increasingly engineers are being challenged to address the environmental impacts of roadworks. In particular, the impacts of runoff, infiltration and water quality need to be considered in urban pavement design. Permeable concrete eco-pavements give the designer the opportunity to minimise runoff and to trap pollutants whilst achieving a high standard of structural behaviour and good aesthetics. The use of this technology is underpinned by research relevant to Australian conditions and by design programs that specifically address permeable paving. Once the environmental and economic benefits of using permeable paving are recognised it is to be expected that wider use of this type of paving will occur in Australian cities.

REFERENCES

1. Shackel B. Permeable Eco-paving - An Environmental Option for Stormwater Management. Proc 4th Annual Conf. Soil and Water - Management for Urban Development. (1996), pp97-105

2. Shackel B. Innovative Forms of Environmentally-Sensitive Precast Concrete Paving. *Radical Design and Concrete Practices* ed, Dhir K and Paine K A Thomas Telford, London. 1999. pp37-46

3. Shackel, B. and Pearson, A.R. Environmentally Sensitive Concrete Segmental Pavements Betonwerk + Fertigteiltechnik, Vol 62 No 10, October, 1996 pp 99-106 ISSN 0373-4331

4. Shackel B. Water Penetration and Structural Evaluations of Permeable Eco-paving. Betonwerk und Fertigteil-technik Vol 63, No3, March (1997), pp110-119 ISBN 0373-4331

5. Shackel B, O'Keeffe L, Gwynne P. W and Arisdianto I. Environmentally Sensitive Articulated Concrete Pavement. Proc. 6th Int. Conf. On Concrete Pavements, Indianapolis, 1997

6. Shackel, B., Kaligis, S., Muktiarto and Pamudji. Structural and Infiltration Tests of Permeable Eco-Pavers. Proc. 5th Int. Conf. on Concrete Block Paving, Tel Aviv, 1996

7. Shackel B, Litzka J. and Zieger M. Loading Tests Of Conventional And Ecological Concrete Block Paving. Proc. 6th Int. Conference on Conc. Block Paving. Tokyo, 2000

8. Shackel B. Laboruntersuchungen An Pflastersteinen fur Bemessungszweike und Verleichende Analysen. Festschrift, Institut fur Strassenbau und Strassenerhaltung., Technische Universitat, Wien Heft Nr 12, Oct, 2001 pp116-129. ISBN 3-901912-11-8.

9. Shackel B, Jitakeekul P. and Prasetyo S.B. An Experimental Study of Unbound Base Material for Use in Permeable Pavements. Proc. 16th Conf. Australian Road Research, Melbourne Jan, 2001

10. Shackel B, Ball J and Mearing M. Using permeable eco-paving to achieve improved water quality for urban pavements. Proc 8th Int Conf on Concrete Block Paving - Pave Africa, 2003 – in press

11. Anon. Research into “Effective Life” of Permeable Pavement Source Control Installations. Urban Water Research Centre, Division of IT, Engineering and the Environment, University of South Australia. Final Rpt Project 07 67680. June 2002.

12. Rommel M, Rus M, Argue J, Johnston L and Pezzaniti D. Carpark with “1 to 1” (Impervious/permeable) Paving: Performance of “Formpave” Blocks” UNISA

13. Shackel B. Handbuch Betonsteinpflaster. Beton-Verlag, Dusseldorf (1996) 216pp

14. Smith D. R. Evaluations of Concrete Grid Pavements in the United States. Proc 2nd Int. Conf on Conc. Block Paving, Delft pp330-336 1984.

15 Allen W.L. Subsurface Drainage of Pavement Structures: Current Corps of Engineers and Industry Practice. U.S. Dept of Transportation, Federal Aviation Admin. DOT/FAA/RD-91/24. December, 1991.

16. James W. Green Roads: Research into Permeable Pavers. Stormwater. March/April 2002.

17. Shackel B. Computer-Based Mechanistic Methods For Concrete Block Pavement Design. Proc. 6th Int. Conference on Conc. Block Paving. Tokyo, 2000

18. Knapton J., I.D. Cook Permeable Paving for a New Container Handling Area at Santos Container Port, Brazil. Proc 6th Int. Conf. on Concrete Block Paving, Tokyo, 2002

19. Anon. Permeable Pavements Now in First Port Application. Interlocking Concrete Pavement Magazine. August 2002, pp 6-9

BIOGRAPHIES

Brian Shackel graduated in Civil Engineering from the University of Sheffield, Britain, in 1962 and immediately thereafter joined the Department of Main Roads, New South Wales. In 1964 he was appointed Shire Engineer to Central Darling Shire, NSW. He left municipal engineering in 1966 to accept a Teaching Fellowship at the University of New South Wales, and subsequently joined that university taking the degrees of M.Eng.Sc. and Ph.D. He has published more than one hundred research papers dealing with geomechanics and pavement engineering and has been invited to lecture on pavement design and construction in 23 countries worldwide. In addition, he has been retained as a consultant for a variety of road, airport and industrial pavement projects around the world. Professor Shackel's book "The Design and Construction of Interlocking Concrete Block Pavements" was published by Elsevier Science Publishers, London and New York, in 1990 and, has subsequently been republished in Japanese, German and Hungarian editions.

Alan Pearson, a Fellow of the Institution of Engineers of Australia, is a graduate in Civil Engineering from the University of New South Wales. After working in local government in Sydney, he worked overseas in England, Saudi Arabia and West Africa, returning to Australia in the mid 80s. In 1985 he was appointed Regional Engineer in the NSW office of the Cement and Concrete Association of Australia. In 1990 he was appointed Executive Director of the Concrete Masonry Association of Australia. He is the author and co-author of many published papers addressing new technology and developments including concrete segmental pavements. He is a leading representative on numerous Standards Australia committees encompassing masonry design, construction, testing and specifications.

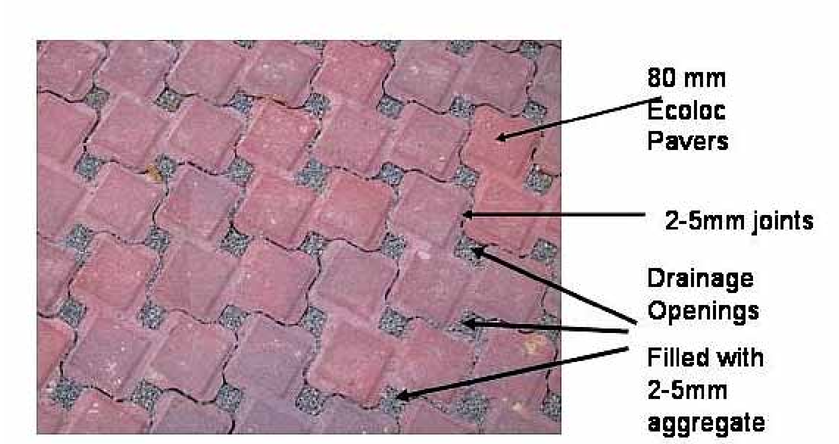

Figure 1. Typical Surface of a Permeable Eco-pavement (Smith Street, Manly)

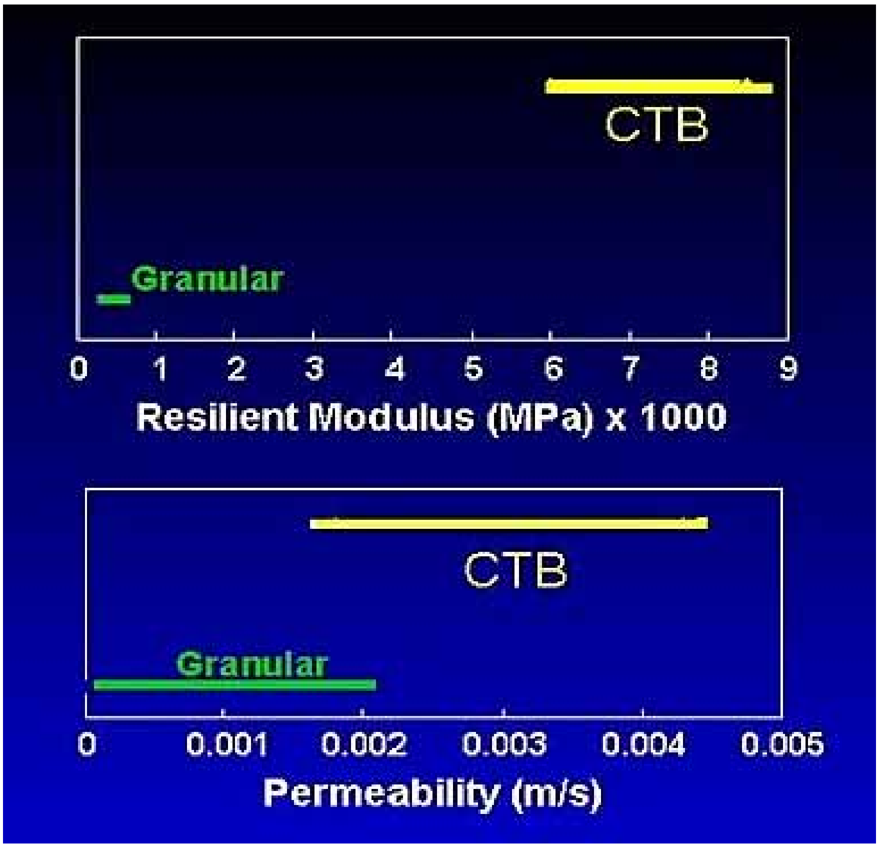

Figure 2. Permeability and Resilient Moduli for Granular and Cement Treated Base

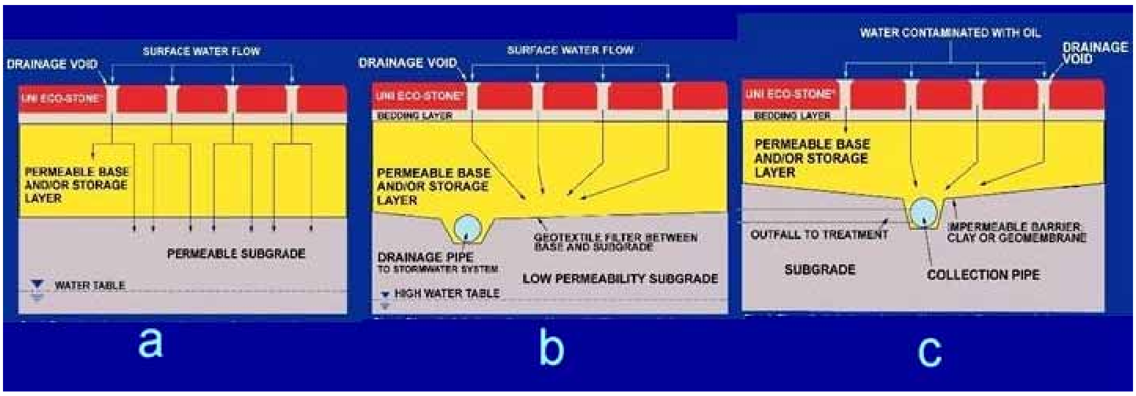

Figure 3. Recommended Cross-sections for Permeable Eco-pavements (after Rocla)

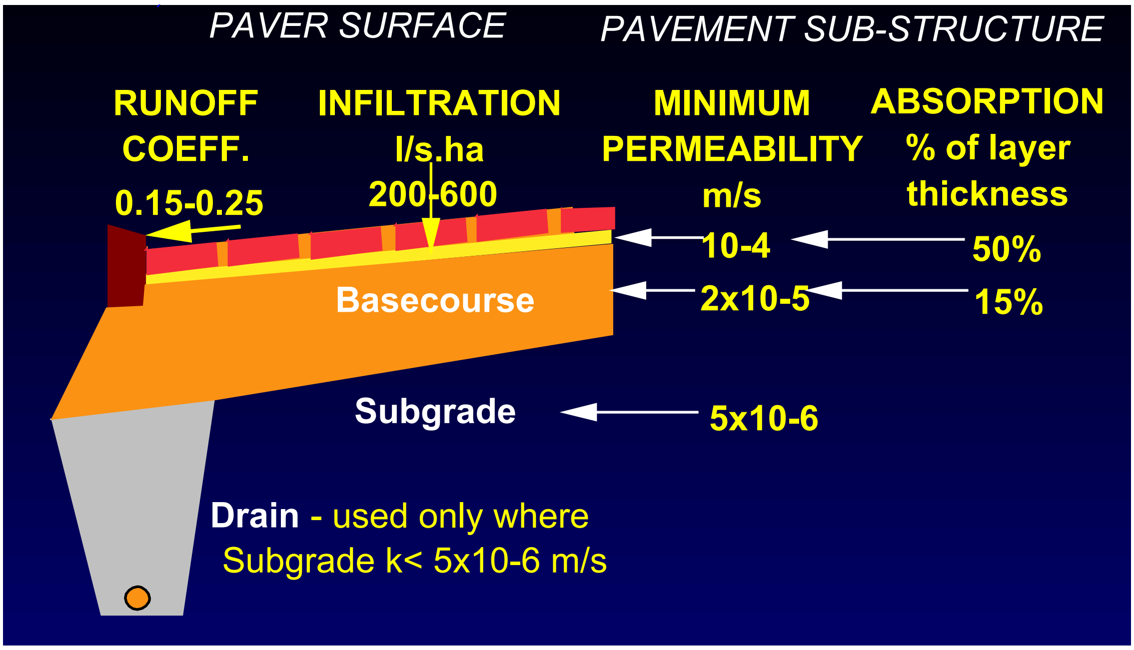

Figure 4. Typical Requirements and Design Parameters for Permeable Eco-paving

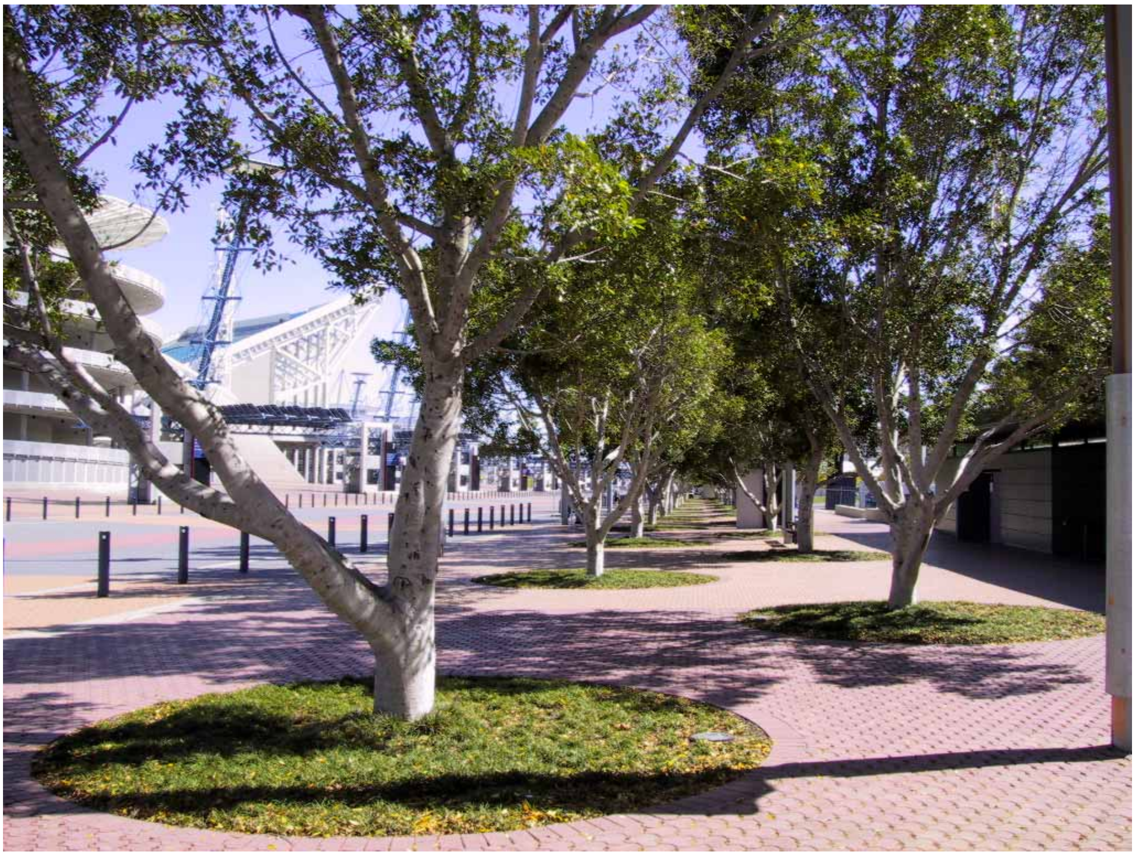

Figure 5. Permeable Eco-paving at the Homebush Olympics site

Figure 6. Roadway at Kiama constructed in 1998

Figure 7. Smith Street Manly (See Ref. 10)

Figure 8. Bus Terminus at Hannover 2000 World Fair

Figure 9. Howland Hook Marine Terminal, New York