

PE01 Permeable Interlocking Concrete Pavements -Design and Construction Guide



Concrete Pavements

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Concrete Pavements

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Contents

- **1 INTRODUCTION**
- **2 CONCEPTS OF PERMEABLE PAVING**
- **3 PERMEABLE PAVEMENT COMPONENTS**
- **4 BENEFITS OF PERMEABLE PAVING**
- 5 CIRCUMSTANCES FOR CHOOSING OR REJECTING PICP
- **6** APPLICATIONS OF PERMEABLE PAVING
- 7 DESIGN OF PERMEABLE PAVEMENTS
- 8 THICKNESS DESIGN
- 9 MATERIALS AND CONSTRUCTION SPECIFICATIONS
- **10 RETROFITTING**
- **11 MAINTENANCE**
- **12 REFERENCES**

Permeable Interlocking Concrete Pavements

by Dr Brian Shackel

Introduction

In urban catchments, road surfaces can account for up to 20% to 25% of impermeable surfaces ie roads are a major generator of runoff. In Australia, the control of this runoff is the prime objective in Water Sensitive Urban Design, WSUD. One way to achieve this is to use Permeable Interlocking Concrete Paving (PICP). PICP was first developed in Europe more than two decades ago and has been used in Australia since 1997. Because water infiltration is actively encouraged, a wide range of environmental and cost benefits can be achieved. This guide summarises the principal factors influencing the choice of pavement and the design, specification and construction of PICP.

The guide is intended to be used in conjunction with the CMAA software PERMPAVE for the hydraulic design and LOCKPAVE for the structural design of PICP. These programs can be downloaded from the CMAA website, www.cmaa.com.au and are regularly updated. The software is specific to Australian rainfall and other local conditions and is not suitable for use elsewhere.

This document is intended to be consistent and read with the following Australian guidelines for water and environmental management

- Water Sensitive Urban Design: Basic Procedures for 'Source Control of Stormwater A Handbook for Australian Practice. (ed Argue). Urban Water Resources Centre, University of South Australia (2004)
- 2. Australian Runoff Quality A Guide to Water Sensitive Urban Design. Engineers, Australia
- **3.** Australian Rainfall and Runoff a guide to flood estimation. 3rd Edition, Engineers Australia (2001)

2 CONCEPTS OF PERMEABLE PAVING

Permeable Interlocking Concrete Pavements (PICP) cover a wide range of applications ranging through landscaping, domestic paving and driveways, public spaces, residential roads and streets and heavy duty industrial pavements including container areas. They both carry traffic and act as a drainage facility which can reduce or eliminate runoff, trap pollutants and harvest water for future reuse. They combine these multiple roles with a reduction in overall project cost by eliminating much of the drainage infra-structure such as gulleys, sub-surface drains and sumps that is needed in conventional pavements (Ref 1).

Permeable pavements reduce runoff by infiltrating rainfall. Provided infiltration is fast enough, runoff can be minimised or eliminated. To keep infiltration high the entire system must be designed to have high permeability. This is of particular importance in Australia where rainfall is often more intense than in those countries where permeable paving was originally pioneered. Early research in Australia therefore examined whether PICP could adequately accept heavy Australia rainfall (Ref 2 – 5). This work has shown that rainfall intensities up to about 200 mm/hr can be accepted even after the pavements have been in service for many years.

Once water has entered the pavement sub-structure it can be drained to the subgrade. Where this is a highly permeable granular material such as gravelly soil, the rainfall from a typical storm can be directed to the water table. Where the subgrade is a relatively impermeable soil such as clay this is not possible. The function of the pavement is then temporarily to store ie detain the water and to allow it to flow to the storm water sewers at a rate that will not overload them. Here the only sub-surface drainage infra-structure required is an outlet connecting to the storm sewer. In this case the pavement also acts as a retention basin.







PERMEABLE PAVEMENT COMPONENTS

The essential components of a permeable pavement are shown in Figure 1.

The elements of the pavement, which are described in detail in subsequent sections of this manual, comprise:

- 1. A surfacing of permeable pavers design to permit the rapid infiltration of rainfall (see Sections 7.1.1 and 9.1). Typically, the pavers will range in thickness between 60 and 80 mm.
- 2. The joints between the pavers must not be left empty but should be completely filled with a uniform aggregate (Section 9.2). Sand must not be used instead of aggregate as it slows water ingress.
- **3.** Depending on the degree of infiltration that can be achieved for a particular design storm it may be necessary to provide drainage at the perimeter of the paving to manage overflows. This can be achieved by using conventional gulley inlets to existing storm sewers or by constructing swales or bioretention areas adjacent to the pavement.
- 4. The permeable pavers are laid on a 20-40 mm bedding course of uniform aggregate typically 2-5 mm in size (Section 9.2). Sand is not suitable as a bedding course and should not be used in permeable pavements because it does not allow water to infiltrate rapidly enough to cope with Australian rainfall.
- 5. Beneath the bedding layer a permeable geotextile may be installed. This is optional and is only used when it is desired to mobilise biological controls of hydrocarbons etc. (Section 9.5).
- 6. A permeable basecourse normally consisting of compacted unbound granular materials provides the main load-bearing layer (See Section 9.3). The thickness of this layer must be sufficient both to resist traffic loads and to provide adequate water storage (Section 8).
- 7. On cohesive subgrades, a filter fabric must be provided under the basecourse to prevent clay migrating into the pavement (Section 9.5). This is not needed where the subgrade is granular ie a sandy or gravelly material.

- 8. Where the subgrade is contaminated, saline or expansive, an impermeable membrane must be provided under the basecourse to prevent water entering or leaving the pavement (Section 9.5). This membrane will normally be run up the sides of the pavements as shown in **Figure 1**.
- 9. For some pavements a drainage pipe is installed to remove water from the pavement (Section 7.1.2 and Figures 15, 17 and 18).
- 10. The in-situ soil at the pavement site is known as the subgrade. The type of subgrade determines what type of permeable pavement cross-section is feasible (Section 7.1.2) and how thick the pavement will need to be to resist traffic and to control stormwater (Section 8). The subgrade must always be compacted to a depth of at least 100 mm (Section 9.6).



Figure 1: Components of a typical permeable pavement

The benefits of permeable paving include:

- 1. Reducing the amount of rainfall runoff from pavement surfaces and, thereby, eliminating or minimising the extent of the stormwater drainage system needed. This can lead to substantial savings in the overall project costs (Ref 1).
- **2.** Reducing the size or need for rainwater retention facilities in roadworks by using the pavement itself for retention. This improves land use.
- 3. Reducing or avoiding downstream flooding.
- 4. Recharging and maintaining aquifers and the natural groundwater.
- **5.** Trapping and treating pollutants that would otherwise contaminate groundwater or drainage systems.
- 6. Assisting in the biological decomposition of hydrocarbon contaminants.

By infiltrating water permeable pavements reduce or avoid surface runoff and standing water and puddles on the surface are virtually eliminated. Importantly, PICPs reduce the peak flows directed to storm sewers. This means that new developments, for example due to urban consolidation, rather than requiring new and expensive storm drainage to be installed, can usually utilise the existing drainage infra-structure without overloading it. A further benefit of infiltrating water is that surface gradients can often be minimised or eliminated ie pavements can be laid level where this improves the amenity of the surface such as in car parks or for container stacking in port areas.

Permeable pavements also provide interception storage whereby water is absorbed into the pavement and thereafter evaporates only once the rain has stopped. The consequence of this is that, under Australian conditions, runoff during a storm does not occur until after the first 5 mm of rainfall (Ref 5).

An important function of permeable pavements is that they improve water quality by removing and treating the pollutants that are commonly found on road surfaces or which get washed on to roads from the roofs of adjoining properties. These pollutants are either trapped by the pavement acting as a filter or by sedimentation within the pavement. Pollutants are also broken down by biological and chemical action. This means that PICPs treat pollution "at source", an important concept in water sensitive urban design. By contrast, conventional pavements rapidly direct polluted rainfall into watercourses where it is difficult and expensive to remediate.

Permeable pavements can harvest water for later re-use; an important function in the Australian context where water is often scarce and expensive. The harvested water is filtered largely free of debris and sediments and can be used for watering parks and gardens and similar non-potable purposes.

Because permeable pavements combine the functions of managing runoff, water quality and water harvesting within a single construction unit they make very efficient use of land because they do not require additional land to be dedicated for detention or retention ponds or for water treatment. This means that land take for new developments can be minimised.



CIRCUMSTANCES FOR CHOOSING OR REJECTING PICP

Permeable paving is of particular benefit when:

1. There is a need to maintain existing or green site runoff conditions when developing a site.

In many cases runoff can be totally eliminated using PICPs but, where this is not possible, it is usually feasible to control the volume of runoff to be similar to that flowing from a green-field (unimproved) site.

2. The stormwater sewer system is at or near capacity.

This situation will often be the case in older well established urban areas. Urban consolidation generally increases the extent of impermeable areas and runoff will increase. This will then overload the existing storm sewers. PICP provides a cost-effective means to circumvent this problem (Ref 1 and see Section 7.1 below)

3. There are limitations on the extent of Impermeable Cover that councils will allow for new developments.

Based on the maximum capacity of local storm drainage and to avoid flooding councils may regulate runoff by restricting the amount of impervious cover.

- **4.** There is insufficient land for both pavements and detention ponds. The use of PICP minimises the extent of land needed for pavements and drainage works.
- **5.** Where municipalities wish to control the pollution of local streams, wetlands and water supplies.

The amount of impervious cover influences the amount of pollutants washed off a site. PICPs both reduce the impervious cover and also remove or remediate pollutants.

6. Where there is a need to conserve and reuse water

Permeable pavements provide a cost and space efficient way to harvest and store filtered water for later non-potable reuse (see Section 7.1).

7. There is a need or requirement to recharge local aquifers. Depletion of aquifers is a widespread problem that needs to be addressed. PICPs should **not** be used when:

- 1. The site or paving requires slopes steeper than about 5%.
- 2. The Water Table is closer to the surface than about 0.5 m.
- 3. The stormwater sewer is less than about 1 m below the surface.
- 4. There is shallow bedrock.
- **5.** There is a risk of spillage of fuel, oil, detergents, pesticides or other hazardous liquids.
- **6.** There is the likelihood of a high sediment input (eg silt) being washed onto the paving and, thereby, causing clogging.
- 7. The pavement is subject to tidal Influence.



PAGE 5

6 APPLICATIONS OF PERMEABLE PAVING

For developers, local authorities and industrial facility designers addressing stormwater and associated water-quality guidelines and regulations, permeable pavements are very much at the forefront of planning issues. Worldwide research into permeable pavers has demonstrated that, structurally, their performance is similar to that of conventional segmental paving. This means that permeable pavers can be used in many types of application where conventional segmental paving has already become well established. Moreover both permeable and traditional segmental paving are often used side by side on the same project eg as at Olympics Park, Sydney (**Figure 6**).

Applications of permeable paving include

- 1. Landscaping
- 2. Domestic driveways, paths and patios
- 3. Car parks
- 4. Public space paving
- 5. Laneways, residential streets and roads
- 6. Factory and container yards

6.1 LANDSCAPING

In landscaping, care should be taken to design the area so that soil and mulch does not wash on to the surface of the paving as this will cause the pavement to clog.

6.2 DOMESTIC DRIVEWAYS AND PATHS

As shown in **Figure 2**, permeable paving makes very attractive domestic paving. Such paving also can confer significant environmental benefits. For example, a single car space 5m x 3m and 1m thick installed in PICP can store about 4000 L, i.e. as much as a typical above ground rainwater tank but at much lower cost and without taking up usable driveway space (Ref 25, 26). The stored water is suitable for grey water use and for watering gardens etc.



Figure 2: A domestic driveway

6.3 CARK PARKS

Car parks, often combined with bio-swales, have become a major application of permeable paving worldwide. **Figure 3** shows a car park in Sydney.

In many cases it is feasible to control stormwater runoff without having to provide permeable paving across the full extent of a road or parking area. In this respect, PICP can be easily combined with other forms of construction including traditional non-porous surfaces such as asphalt or conventional segmental paving. For example, permeable paving is often used as parking bays adjacent to conventional asphalt pavements as shown in **Figure 4**. In such cases, it is often feasible to drain the conventional pavement onto the PICP. The PERMPAVE software (Section 8.1) facilitates this by including any impermeable areas contributing to the runoff in the design calculations.



Figure 3: Municipal car park, Camperdown, constructed in 1999.



Figure 4: Car parking along Karrabee Avenue, Sydney, constructed in 2000.



6.4 PUBLIC SPACE PAVING

Permeable paving has been widely used in public space paving in Australia. **Figure 5** shows the approaches to Sydney Sports Ground while **Figure 6** shows Olympic Park, Sydney, both constructed in 1998.



Figure 5: Approaches to Sydney Sports Ground



Figure 6: *Sydney Olympic Park*



6.5 LANEWAYS, RESIDENTIAL STREETS AND ROADS

Lanes, roadways and residential streets are also becoming a staple use of permeable paving in the UK, Europe and Australia. Design, construction and performance details have been given elsewhere (eg Ref 6). A laneway in Adelaide is shown in **Figure 7**, a residential street in the Sydney suburb of Manly in **Figure 8** and a road in Kiama, NSW in **Figure 9**.



Figure 8: A residential street, Smith Street, Manly, NSW, constructed in 2001



Figure 7: Rear access service laneway, Adelaide



Figure 9: Roadway, Kiama, NSW, constructed in 1997

PAGE 9

6 APPLICATIONS OF PERMEABLE PAVING (CONT...)

6.6 FACTORY AND CONTAINER YARDS

In Europe and North America, factory and truck loading areas increasingly use permeable paving to achieve both environmental and land use/cost benefits. For factory yards by combining the functions of water retention and hardstanding into a single unit makes the use of industrial land more cost-effective. A truck parking area in a factory yard is shown in **Figure 10**.

Overseas, permeable paving has been successfully used in container handling areas and ports subject to high wheel loads (Ref 7 and 8). The advantages of using PICP is that it can eliminate the need for pavement crossfalls, facilitate container stacking and reduce the extent and cost of sub-surface drainage infrastructure. An example of a container yard using PICP is shown in **Figure 11**.



Figure 10: A factory yard



Figure 11: Howland Hook Container Terminal

PAGE 10

The design process for permeable interlocking concrete pavements has been described in detail elsewhere (Ref 9-11) and is shown in **Figure 12**.

Permeable pavements must be designed not only to carry traffic but also to manage runoff, infiltration, pollutant treatment and, where appropriate, water harvesting. Essentially, as shown in **Figure 12**, designers need to go through three steps. These comprise:

- 1. The choice of the permeable pavers, cross-section and materials.
- **2.** A hydraulic analysis leading to the design of the thicknesses of materials needed for water management
- 3. A structural analysis of the pavement thicknesses needed to support traffic.

The first task of a designer is make the choices listed in step 1 above. **Steps 2** and **3** can then be quickly implemented using the PERMPAVE and LOCKPAVE software programs commissioned and distributed by CMAA.

Factors to be considered in implementing each of the steps above are now summarised.



Figure 12: The design process for permeable paving

7.1 PAVEMENT TYPE SELECTION

7.1.1 Choice of Permeable Pavers

Pavers should be specifically designed and manufactured for PICP. Conventional pavers are unsuitable for the levels of water infiltration required. Permeable pavers differ in their structural capacity and their ability to infiltrate water. In the case of structural capacity the prime determinants of performance are the paver shape, thickness and laying pattern.

a. Pavers and Structural Capacity

For structural performance pavers shapes are divided into the three categories shown schematically in Figure 13. These comprise:

- 1. Category A pavers Pavers having complex profiles which are dentated (not merely fitted with spacers or lugs). Such pavers fully interlock along all sides. For permeable pavers, the joints are usually within the range from 2 to 5 mm and openings are provided along the joints to permit water infiltration.
- 2. Category B pavers Pavers having complex profiles but which are typically dentated only along their long sides and are only partially interlocking. For permeable pavers water infiltrates via openings along narrow (2-5mm) joints or spacers are provided to increase portions of the joint width (<13mm).
- 3. Category C pavers Pavers which are not dentated and which generally have rectangular or square profiles. Permeable pavers are usually fitted with slots or spacers to increase the joint widths (<13mm) to facilitate water infiltration. Except for spacers or lugs there is no geometrical interlocking between pavers.

Loading and accelerated trafficking tests indicate that paver shapes can be ranked in order of performance under traffic as follows (best to worst):

- **1. Category A shapes**
- 2. Category B shapes
- 3. Category C shapes

Category A shapes

Dentated units that key into each other and by their plan geometry, interlock and resist the relative movement of joints parallel to both the longitudinal and transverse axes of the unit.

Category B shapes

Dentated units that key into each other and by their plan geometry, interlock and resist the relative movement of joints parallel to one axis.



Figure 13: *Classification of paver shape for performance under traffic*

The laying pattern also affects the performance of concrete segmental paving under traffic. The main laying patterns are shown in **Figure 14**.

In general, herringbone laying patterns tend to be associated with less rutting deformation than parquet or stretcher bonds. Where the pavement is to carry heavy road or industrial traffic the preferred laying pattern is normally herringbone. The laying pattern does not affect the thicknesses of base/sub-base required. However, it does affect resistance to horizontal creep (shunting).

The best in-service performance, in terms of both rutting and horizontal creep under traffic, is given by Category A pavers laid in herringbone bond or similar machine-layable patterns.

The thickness of pavers also influences performance under traffic. For landscaping purposes, where no vehicular traffic is to be carried, paver thicknesses between 40 and 60 mm are acceptable. However, in general, the thickness of paver needed depends on the traffic on the pavement. For light traffic a minimum thickness of 60 mm is required increasing to 80 mm once trucks or commercial vehicles have to be carried. For industrial pavements, thicknesses up to 100 mm may be necessary depending on the paver shape and laying pattern.

Amongst the permeable pavers categorised in **Table 1**, those utilising openings along the joints have received the most structural research. Such pavers exhibit levels of structural capacity that are comparable with those achieved by conventional paving (Ref 12).



Figure 14: Common laying patterns

PAVEMENT TYPE SELECTION (CONT...)

b. Pavers and Water Infiltration

Permeable pavers allow water to infiltrate the surface by using shapes that create drainage openings along the joints or by the use of oversized spacers which widen the joints. It is possible to classify permeable pavers in terms of infiltration and to rank their suitability for traffic into the five groups shown in **Table 1**.

For water infiltration there are substantial data acquired from both laboratory tests and in-situ infiltration measurements on PICPs that have been in service for periods of up to about 20 years (Ref 13-14). Pavers that have openings, widened joints or which are porous allow greater infiltration rates than grass-stones or pavers with enlarged grassed joints. Long term in-situ infiltration data for these three categories have been published and are incorporated into the design software, PERMPAVE (ref 14). Alternatively manufacturers' data can be used. To allow for clogging, infiltrations no more than 10% of manufacturers' laboratory based values should be used in design.

Table 1: Classification of pavers for PICP

	Paver Type	Description	Suitability to carry traffic	Example
	Pavers with openings along joints	Pavers have normal joints but openings are provided along these at intervals. The openings and joints are filled with 2-5 mm aggregate. Water flows only through openings and joints	General traffic	
	Pavers with widened joints	Pavers provided with slots or wider (< 10mm) joints than those customarily specified (2 to 5mm). Slots and joints are filled with aggregate. Water flows through slots or joints	General traffic	R
	Porous Pavers	Pavers made from porous concrete. Laid with 2-5 mm joints. Water flows primarily through pavers themselves	General traffic	
	Grass stones and grids	Pavers with large openings filled with soil within which grass is grown. These are effective in trapping pollutants but permit only small water flows. To increase flows, openings may be filled with aggregate instead of soil.	Light traffic with only occasional trucks	
	Paving systems with enlarged grass joints	Pavers are widely spaced using plastic or concrete spacers so that grass can grow between the pavers. Used primarily for landscaping.	Car parking only – No commercial vehicles	田

7.1.2 Subgrade Conditions and the Choice of Cross-section

The subgrade strength expressed as a CBR or Modulus value will determine how thick the pavement must be to resist traffic loads whilst the permeability will determine the amount of water storage that the basecourse must provide to ensure adequate water management. Suggested default values for different subgrade soil types are provided in the design software, LOCKPAVE and PERMPAVE.

PICP can be successfully constructed over all types of subgrade not just over granular materials. The subgrade soil determines the type of pavement cross-section that is required to manage both the structural response to traffic and water management requirements. The possible cross-sections are shown schematically in **Figure 15**.

In the cases of either partial or no infiltration, the pavement's main function is to detain the water temporarily and then to allow it to efflux via a carefully sized outlet pipe to the stormwater sewers at a rate chosen not to overload these facilities. Here, both the storage volumes of the permeable basecourse and bedding materials and the size of the drainage outlet must be designed together.

An important alternative use of the no infiltration cross-section is water harvesting. Here the water is retained for future reuse and only overflows are directed to the storm sewer.



Figure 15: Types of cross-section for permeable pavements (schematic only)

a. Full Infiltration

Where the subgrade is a non-cohesive granular material it is usually possible to infiltrate all the design rainfall and allow it to flow into the subgrade and thence to the water table. Here subsurface drains are usually omitted. Some local authorities will not permit water to infiltrate the subgrade and it is only feasible on permeable gravelly or sandy soils. Essentially this is a zero discharge system as no water is discharged into traditional drainage systems and there is no need for pipes etc. to be installed. Details of a typical cross-section are shown in **Figure 16**.

b. Partial Infiltration

Where the PICP is founded on a clay subgrade only a small fraction of the stormwater runoff will infiltrate the soil ie only partial infiltration is feasible. Provision must then be made to drain the water from the site using a drainage pipe. A filter fabric must be used to prevent clay fines contaminating the base and, if present, sub-base (see Section 9.5). Here the prime function of the pavement is temporarily to store (detain) the water that does not infiltrate the subgrade for later release to the stormwater system. The discharge rate must be designed not to overload an existing sewer or, alternatively, to minimise the size and cost of any new drainage system. Details of a typical cross-section are given in **Figure 17**.



Figure 16: Typical cross-section for pavements with full infiltration



Figure 17: Typical cross-section for pavements with partial infiltration

c. No Infiltration

In some cases, such as where the subgrade soil is contaminated, expansive or saline or where local regulations do not permit infiltration, an impermeable liner (Section 9.5) must be placed between the pavement and subgrade so that no infiltration is possible. Drainage pipes are required to remove infiltration. Here the function of the pavement is temporarily to store (detain) all water for subsequent controlled release to the stormwater system. Details of a typical cross-section are shown in **Figure 18**.

The cross-section shown in **Figure 18** is also used when water harvesting is one of the functions required of the pavement.

A cross-section similar to **Figure 18** is used for water harvesting except that the outlet pipe leads to a sump rather than directly to the storm sewer. Water can then be pumped from the sump as required. An overflow connection from the sump to the sewer may also be needed.

7.1.4 Choice of Pavement Materials

Base and sub-base materials suitable for permeable pavements include unbound granular base, cement-treated base, porous lean concrete and porous asphalt. Most permeable pavements constructed to date have used open graded permeable base, sub-base or drainage layer materials developed by State or Municipal authorities for conventional pavements. The most widely used bases for permeable pavements have been unbound granular materials although recent Australian research has shown that special cement-bound mixes can offer promising alternatives. Whilst research into permeable base materials is ongoing, working specifications for the materials are given below in Section 9.3. Designers and specifiers are advised to check periodically the CMAA web site (www.cmaa.com.au) for updates to these specifications.



Figure 18: Typical cross-section for pavements with no infiltration

8 THICKNESS DESIGN

For a permeable pavement two thicknesses need to be designed:

- 1. The thickness of base needed for water management ie Hydraulic Design (Figure 12b)
- The thickness needed to resist traffic (only where vehicles are to be carried) ie Structural Design (Figure 12c).

The hydraulic and structural designs often give different basecourse thicknesses. The greater of these should be adopted as the final design thickness.

8.1 HYDRAULIC DESIGN

The hydraulic design is best implemented by using the PERMPAVE software provided by CMAA (Ref 10, 11). The main tasks implemented by this program are:

- **1.** To calculate the capacity of the pavement to manage design rainfall events by infiltration to the subgrade or to the storm sewers ie Flood Control.
- **2.** To determine the quality of the effluent leaving the pavement after removing pollutants ie Water Quality.
- **3.** To determine the extent to which is it possible to store and reuse the water ie Water Harvesting.
- 4. To design the size of any drainage pipes connecting to the storm sewers.

Permeable pavements are capable of meeting multiple water management objectives. The PERMPAVE flood control, water quality and harvesting/reuse modules each operates independently of the others. This means that, if a design requires a solution to achieve more than one objective each of the relevant modules can be used separately and sequentially.

For flood control the design storm approach as incorporated in standard design procedures (Ref 10,11, and 15) is used. However it is not feasible to design for water quality and harvesting using some particular nominated storm. Rather the pattern of rainfall needs to be modelled (simulated) over a substantial period of time. This is achieved by using the concepts of hydrological effectiveness

curves which represent the performance of a pavement to manage runoff from a specified catchment.

Permeable paving can handle runoff from adjacent impermeable surfaces including roofs. It is therefore common practice to place permeable paving adjacent to conventional impervious surfacing such as asphalt and then to drain this through the PICP (eg see **Figure 4**). As a rule of thumb, the ratio of the impermeable contributing surface should not be more than about two to five times that of the paving. Greater ratios may require uneconomical PICP base thicknesses (this can be checked using the PERMPAVE software). Also, the risk of silt being washed onto the paving causing it to clog increases as the contributing impermeable area increases.

8.1.1 Flood Control

A design storm, or design storm event, is a storm event which is applied in the hydrological design of stormwater infrastructure. The 'design storm' for a given area is based upon a statistical analysis of rainfall patterns over a given catchment area. In the PERMPAVE software design storms are derived automatically according to the specified region. For a thorough understanding of the background to, and derivation of, a design storm, users should refer to Australian Rainfall and Runoff (Ref 15).

Briefly, the design storm approach involves the use of local average design storm intensity bursts for a particular Average Recurrence Interval (ARI). A storm temporal pattern is applied to the average storm intensity to provide a rainfall distribution pattern over a period of time. Such data are stored within the PERMPAVE software for specified Australian geographical locations. Design inputs include the area of the permeable paving, the hydraulic conductivity of the surfacing (Ref 10, 11, 15 and 16), any impervious area draining to the permeable paving, the permeable paving storage and the saturated hydraulic conductivity of the subgrade.

The flood control module determines the storage required to achieve the maximum peak discharge flow rate permitted from the permeable paving system. The maximum peak discharge is set by either specifying the allowable



peak flow rate or an equivalent runoff coefficient. When selecting a crosssection that includes a pipe discharge with or without infiltration to subgrade, the analysis determines the smallest pipe size and storage volume required to achieve a maximum discharge from the pavement that is just less than that set by the user. Importantly, the discharge pipe diameter as calculated by the program should not be increased or reduced. This may require fitting an orifice to the outlet pipe.

8.1.2 Water Quality

There are several water quality processes relevant to the infiltration of stormwater. The processes include filtration, sorption and biodegradation of nutrients. The water quality design option is used where the primary purpose for the porous or permeable pavement is for the control of water quality prior to infiltration or detention. In the current version of the Permpave software, the water quality assessment of porous and permeable paving is undertaken using linear algorithms. These will be updated with the availability of further research into the water quality performance of porous and permeable pavements.

The water quality module uses the hydrological effectiveness relationships built into the PERMPAVE software to assess the water quality improvement provided by the pavement. The program adopts a simplified, linear approach to the improvement of stormwater quality by permeable pavements and determines the minimum volume required to achieve some target reduction in pollution load (eg expressed in kg/yr).

8.1.3 Water Harvesting

The water harvesting design option should be used where the porous or permeable pavement will be used for water harvesting and reuse using the base course volume as a storage volume. Here, contrast to flood control, the objective is to keep the pavement full for as much of the time as possible. Water may be stored within the base course material or by the use of proprietary storage units. In this analysis, hydrological design procedures outlines in the document Australian Runoff Quality (Ref 17) are applied. The water harvesting module utilises hydraulic effectiveness curves incorporated into the PERMPAVE software to determine the storage volume required to meet a nominated water demand. Three key inputs are required for the analysis. They include a constant daily demand rate (L/day), the average annual rainfall, and the storage voids ratio.

Determining the size of storage can be subjective and although supply for a given demand can be achieved it may not be necessarily the most appropriate or economical solution. With most storage systems there is a point where the return (supply) for a unit increase in storage will diminish. The software analysis determines two storages, one based on a diminishing rate of return and the other based on achieving the total demand.

8.2 DESIGN FOR TRAFFIC

Where the pavement carries any trucks or commercial vehicles, it is necessary to check that the thickness chosen for water management is also adequate to carry traffic. This is done by running the LOCKPAVE structural design module which forms part of the overall design process shown in **Figure 12c** (Ref 18).

In conducting the LOCKPAVE analysis it is important that the designer recognise that the pavement sub-structure will often be fully or partially filled with water. The resilient moduli of saturated granular materials are typically only about half the values measured at normal test saturations (Ref 19). This needs to be considered during design.

MATERIALS AND CONSTRUCTION SPECIFICATIONS

9.1 PAVERS

Concrete segmental pavers shall comply with the requirements of AS/NZS 4456 as amended.

The paver selected for use should be consistent with the type, thickness and size of paver given in Section 7 above (also given in the PERMPAVE software selection screen). Pavers which, by virtue of their thickness or type do not comply fully with the descriptions given here or in the program or where their size exceeds that specified in the PERMPAVE selection screen are not covered by the PERMPAVE analysis and may not perform satisfactorily in service.

Not all types of paver are equally suited to carrying vehicle loads and, depending on the traffic application selected, some types of permeable paver may not be available for selection in PERMPAVE.

Except for the choice and specification of the laying course and jointing materials, the construction of the paver surface is little different from the construction of conventional segmental pavements. Detailed recommendations for installing the pavers are given in CMAA Technical Note T46.

9.2 BEDDING, JOINT AND DRAINAGE VOIDS FILLING MATERIALS

Permeable pavement should be laid on clean uniform aggregate bedding layers. Conventional sand bedding and jointing materials are not suitable because of their relatively low permeability and must not be used.

Australian laboratory infiltration and structural tests and experience show that good performance is obtained using a clean 2-5 mm uniformly graded aggregate as a bedding course. This is specified in **Table 2** and conforms to ASTM gradation #9. Whilst overseas practice is to use a slightly coarser material complying with ASTM gradation #8 this appears not to be supported by any test data. Importantly, the gradation given in **Table 2** can be used to fill the joints and any drainage openings or slots ie a single material can be used for both bedding and jointing. However, where systems with widened joints are used or where porous concrete pavers are selected a finer joint filling material may sometimes be needed. In Europe, a clean uniformly graded 1-3 mm aggregate has been successfully used for joint filling.

Table 2: Recommended grading for bedding and jointing material

Sieve size mm	%	
9.5	100	
4.75	85-100	
2.36	10-40	
1.18	0-10	
0.3	0-5	

NOTE: It is very important that the joints be completely filled during construction and that they be kept full in service. Failure to fill the joints allows sediments to penetrate to the bedding course where they cause clogging and are impossible to remove without lifting and relaying the pavers. However, provided the joints are filled with aggregate, sediments are trapped within the upper 20-40 mm of the jointing aggregate which, if necessary, can be removed using road sweepers and then replaced without any need to reconstruct the pavement.

9.3 BASECOURSE AND SUB-BASE MATERIALS

The CMAA in conjunction with both the University of New South Wales and overseas partners began a comprehensive program of testing basecourse materials for PICP in 2010. Pending the results of this testing the recommendations given in **Tables 3**, **4** and **5** below should be considered as interim and may be revised in the future. In the meantime, the recommendations are believed to be conservative. It is should be noted that, based on Australian testing to date, the recommendations given here may differ from specifications that are recommended in the USA and Europe which have been largely untested.

For pavements carrying vehicular traffic, the base and sub-base must be fully compacted. Suitable compaction standards are given in Section 9.6.

During construction, care should be taken to avoid construction vehicles trafficking mud onto the basecourse as this may cause clogging. Where this is unavoidable the base should be made 50 mm thicker than required. This topping should then be scalped off and discarded immediately prior to installing the bedding course.

9.3.1 Granular Permeable Base and Sub-base

Worldwide, the most common base and sub-base materials used in permeable interlocking concrete pavements (PICP) comprise unbound granular materials. The grading curves for unbound granular materials currently recommended for PICP in Australia are given in **Table 3**. In **Table 3** the materials having the greatest permeability and water storage capacity comprise single sized (uniform) granular base or sub-base (Gradings 3 and 4). Such materials are suitable for applications such as hard landscaping, residential applications including driveways and for car parks. They are not, however, recommended for use where the pavement must carry trucks or other heavy vehicles.

Where trucks, commercial vehicles or heavy industrial vehicles are to be carried the use of conventional dense graded road base materials (Grading 1) may be feasible. However, it is important to note that such materials have very low permeability and relatively low void ratios. This means that the amount of water that can be stored in a given thickness of dense graded base is less than for the open-graded materials. The best compromise between load carrying capability, permeability and water storage is given by the use of graded permeable roadbase. The material shown in **Table 3** as Grading 2 is based on Australian experience and tests of permeable basecourse materials (Ref 18). In general Grading 2 is to be preferred to Grading 1 but may prove difficult to source in some areas.

In the case of the uniformly graded granular materials (Gradings 3 and 4 in **Table 3**) it is inadvisable to use the 80mm material shown as a base rather than as a sub-base. Such material should always have at least 100 mm of the 40 mm uniform base (Grading 3 in **Table 3**) above it.

The single size uniform materials given as Gradings 3 and 4 in **Table 3** may be prone to segregation during transport and installation. Segregation can be minimised by selecting crushed angular materials with high internal friction.

Sieve size (mm)	Dense Graded Granular Base	Open Graded Granular Base	Single Size (uniform) Granular Base	Single Size (uniform) Granular Sub- Base
	1	2	3	4
80				100
63				98-100
40			100	85-99
31.5			98-100	
26.5	100	100	-	
19	-	95-100	85-99	20-70
13.2	71-84	70-93	-	
10			20-70	
9.5	-	55-85		
4.75	42-60	20-75	0-15	0-15
2.36	27-45	10-50	0-5	0-5
1.18	-	0-25	-	
0.6	-	0-12	-	
0.425	13-27	-	-	
0.3	-	0-8	-	
0.15	-	0-6	-	
0.075	5-12	0-5	-	

Table 3: Grading recommendations for unbound basecourse for use in PICP

9.3.2 Filter Criterion

To avoid bedding material migrating into the base or to prevent base and subbase materials flowing into one another it is necessary to apply an appropriate filter criterion to the gradings of the materials based on the 15th and 50th percentile particle sizes, D15 and D50, determined by a sieve analysis. This information is normally taken from the grading curves available from the suppliers of the laying course, base and sub-base materials.

The criterion is:

(D15 for base)/(D15 for bedding) < 5 or

(D15 for sub-base)/(D15 for base) < 5

9.3.3 Cement-Bound Permeable Base

Two types of cement-bound base are suitable for permeable pavements. These are:

- **a.** Cement-treated permeable base
- b. No-fines concrete

N.B. The suitability of any cement-bound material selected as a permeable base needs to be confirmed by laboratory tests. It should have a voids ratio of at least 20% and a permeability > 0.3 m/s in order to comply with the assumptions of PERMPAVE.

9.3.4 Cement-treated Permeable Base

Cement-treated base should comply with the gradings given in **Table 4** below and will typically require 150 kg/cu m of cement or more (This needs to be verified by laboratory tests).

9.3.5 No-Fines Concrete

No fines concrete should have gradings similar to those in **Table 5** below and will typically have water/cement ratios between 0.35 and 0.45 and cement contents typically greater than 5%. The unconfined compressive strength should be greater than 2.5 MPa. Laboratory tests need to be conducted to ensure that the material has adequate permeability and strength to meet in-service conditions (see note above).

Table 4: Suggested gradings for cement-treated permeable base

Sieve size (mm)	Grading A	Grading B
25	-	95-100
19	95-100	77-87
13	67-77	53-63
9.5	50-60	41-51
4.75	19-29	15-25
2.36	0-6	0-6

Table 5: Suggested gradings for no-finesconcrete base

Sieve size (mm)	20 mm maximum size	10 mm maximum size
25.5	100	-
19	85-100	-
13	0-10	100
9.5	0-5	85-100
4.75	0	0-10
2.36	0	0-2
Typical Cement Content (kg/cu m)	210	250



9.4 SUBGRADE

The subgrade is the natural soil underlying the pavement. Its properties will determine the rate at which the pavement will drain naturally and, therefore the type of pavement cross-section that is appropriate (Section 7). Moreover, the subgrade strength will determine how thick the pavement will need to be in order to withstand vehicular traffic.

9.4.1 Subgrade Permeability

The subgrade permeability is the rate at which the subgrade soil will transmit water through its pore spaces. Subgrade permeability is best measured by laboratory test. One relevant test method is available in AS 1289.6.7.1-2001: Methods of testing soils for engineering purposes – Soil strength and consolidation tests – Determination of permeability of a soil. Alternatively, to a lower accuracy, subgrade permeability can be deduced from the soil classification. Selecting values based on the soil type (classification) is appropriate where the user has no or limited test data for the subgrade materials. In this case, the PERMPAVE software will suggest conservative values based on the Unified Soil Classification System (USCS) soil type of the subgrade.

9.4.2 Subgrade Stiffness and Strength

The subgrade needs to be characterised in term of either its stiffness or strength in order to calculate the pavement thicknesses need to resist traffic loads. The most common measure of stiffness is the Resilient Modulus determined in accordance with AS 1289.6.8.1 – 1995 Methods of testing soils for engineering purposes – Determination of the resilient modulus and permanent deformation of granular unbound pavement materials.

The strength provides a less reliable indicator of subgrade support. Here the most commonly used measure is the California Bearing Ratio, CBR, determined in accordance with AS 1289.6.1.2-1998: Methods of testing soils for engineering purposes – Soil strength and consolidation tests – Determination of the California Bearing Ratio of a soil.

Both the Resilient Modulus and CBR should be measured for the subgrade soil in a soaked (saturated) condition as this is both representative of in-service conditions in PICP and represents the weakest value.

Where laboratory test data are not available the PERMPAVE and LOCKPAVE SOFTWARE will suggest values of modulus and CBR based on the Unified Soil Classification System (USCS) soil type of the subgrade.

9.5 GEOTEXTILES AND MEMBRANES

Geotextiles and membranes are used as filters, to separate materials, to provide locations for the development of the microbes and bacteria that breakdown hydrocarbons and other pollutants and, where required, to prevent water movement between the pavement and the subgrade. Products such as geotextiles or geofabrics manufactured from polyethelyne or polypropolene filaments resistant to naturally occurring chemical or microbial attack are suitable. Guidance for the selection and testing of geotextiles and geofabrics is given elsewhere as AS 3706, 2001 as amended and Austroads Guide to Geotextiles, 1991(Ref 20, 21).

For PICPs designed to fully infiltrate rainfall to the subgrade (see Figure 15 and 16) the use of geotextiles is generally not required except where bio-remediation of hydrocarbons is a design objective. In such cases a permeable fabric may be placed below the bedding course to host microbial action. The use of geotextile at the sides or below the base/sub-base is optional as a construction expedient but is not essential and adds unnecessary costs.

Permeable geofabrics are particularly important where a system operates above a clay subgrade i.e where only partial infiltration of water is possible (**Figures 15** and **17**). Where water is permitted to drain to the subgrade the use of a permeable filter fabric prevents the migration of colloidal particles into the base or sub-base material which can have an adverse effect on the structural and hydraulic characteristics of the system. The use of such a filter fabric is mandatory in PICPs with partial infiltration and should be brought up the sides of the pavement as shown in **Figure 17**. Where the subgrade is expansive or where there is a problem with ground water salinity or contamination, water transfer must be prevented by using a impermeable membrane (liner) as illustrated in **Figure 15** and **18**. An impermeable membrane is also necessary where water harvesting is an objective of the PICP design. The liner typically comprises high density polyethylene or polypropylene materials having a thickness of 1 mm or more.

Geo-textiles should be overlapped by at least 300 mm. Liners should be welded or bonded at the laps to ensure that they are water tight.

9.6 COMPACTION

Traditionally, some landscaping applications of permeable paving have not required the pavement sub-structure to be compacted, presumably because compaction reduces the permeability of the materials comprising the pavement. Such an approach carries the very high risk that, wherever the pavement is subject to vehicles, traffic-induced rutting deformation will occur. Because of this, *all* permeable pavement materials that may have to carry *any* truck traffic should be compacted – including the subgrade and basecourse even though this will reduce their in-service permeabilities.

For trafficked permeable pavements, the following compaction standards to AS 1289 should be enforced:

Subgrade – 92 -96% Standard Maximum Dry Density (MDD) Unbound sub-base – 95% Modified MDD Unbound base – 98% Modified MDD Cement-Stabilised Materials – 96% Modified MDD



10 RETROFITTING

Permeable paving can be retrofitted to sites in order to reduce runoff and flooding or to improve water quality. This can be done during rehabilitation of an existing pavement. An example of retrofitting is shown in **Figure 8**.



MAINTENANCE

Tests in Australia have shown that, even without maintenance, PICPs can maintain adequate infiltration rates over periods of 10 years or more (Ref 22). Moreover, most of the particulate pollutants in PICP are trapped within the upper 20-40 mm of the materials filling the drainage opening and joints or, in the case of porous concrete pavers, within the concrete itself (Ref 23, 24). The infiltration capacity can largely be restored by removing and replacing the top 30 mm of the drainage material in the paving joints and drainage openings using conventional street vacuum sweeping equipment sometimes used in combination with water jet washing (Ref 23). In the case of porous concrete, hot water jetting and vacuum cleaning is usually required. While some overseas authorities recommend routine sweeping of PICP up to three or more times a year, experience in Europe and Australia suggests that such frequent maintenance is often unnecessary. In this respect many pavements have performed adequately for periods of 10 to 20 years without systematic cleaning. In addition, the area of paving constructed is typically dictated by such operational requirements as the length and width of a street or parking area and this is normally much greater than the minimum area needed to control runoff and infiltration. Accordingly, the effects of clogging are usually much less severe than might otherwise be expected.

In addition to occasional sweeping, the principal maintenance requirement for PICP is to maintain the joints to ensure that they are kept full of the jointing aggregate (Section 9.2) and to control weed growth.

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PAGE 26

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