Permeable Concrete Pavements: a-state-of-the-art report

Author: John Tuxworth, Managing Director, Built Environment Collective

ABSTRACT

This report provides information on the common types of permeable concrete pavements, their application & functional advantages, design, indicative costs, and specification as based on an international literature review. The significant bibliography details source materials and relevant documents cited.

The term 'permeable (or pervious) concrete pavement' broadly covers pavements utilising open texture porous insitu concrete mixes, concrete block pavers or flagstones and grassed infill systems that allow air and liquids to pass through.

These pavements are typically adopted for their environmental, cost, and/or functional advantages in relation to stormwater management. Water Sensitive Urban Design (WSUD) has been adopted in several countries around the world in order to decrease stormwater flow rates and also the volume of catchment runoff. Permeable pavements are considered a 'source control' option in providing a means of collecting and treating stormwater, and thus minimising the extent and cost of traditional stormwater infrastructure.

Permeable concrete pavements are predominantly employed in two stormwater management system types, viz infiltration or retention/attenuation:

- **Infiltration systems** utilise base materials, subgrade soils and the natural groundwater system to filter, treat and discharge stormwater. Sub-grade soils of low infiltration rates (incorporating significant clay content) may require modification in order to accommodate design discharge capacities.

- **Retention/attenuation (or tanked) systems** incorporate base and subbase storage in conjunction with standard drainage infrastructure to provide a delayed stormwater discharge. Retention systems can also enable reuse of stormwater for some domestic purposes such as irrigation.

Parking lots, sporting facilities, and residential streets can be constructed in permeable concrete insitu pavement as well as flagstones and pavers. Benefits of the various different types of permeable concrete pavements also include high slip/skid resistance, noise attenuation, groundwater recharge and pollution/siltation control. Usage is restricted by site/terrain flatness; typically, pavement and subgrade slopes of 5% are the steepest at which they are effective. Performance of permeable pavement systems is considered in terms of percolation rate, the units of measurement commonly used are millimetres per hour (mm/hr), litres per minute per square meter ($l/min/m^2$) and litres per second per hectare (l/s/ha).

Assessment of whole-of-life costs, and the other benefits of incorporating permeable concrete pavements, should be compared with the costs of traditional pavements and stormwater infrastructure, inclusive.

Active pollution mechanisms inherent with these pavement types include absorption, straining, and microbiological decomposition. Studies indicate permeable pavements are effective in the removal of sediments, total phosphorous, nitrogen, zinc, lead, and chemical oxygen demand. Filtration occurs due to percolation through the base and subbase mediums while anaerobic microorganisms assist in breaking down hydrocarbon pollutants. Incorporation of a geotextile layer can further assist with pollution control.

Key words:

attenuation, cement, concrete, infiltration, no-fines, pavement, paver, permeable, percolating Percrete, pervious, pollution, porous, Portland, storage, storm, sustainability, tanked, water

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INTRODUCTION

The term ‘permeable (or pervious) concrete pavement’ broadly describes the utilisation of open textured porous insitu concrete mixes, concrete block pavers & flagstones and grassed infill systems, that allow air and liquids to pass through the pavement surface.

Insitu concrete applications are also known internationally as Percrete, Percolating Concrete, No-fines Concrete, and Portland Cement Porous Paving.

Permeable pavements can be categorised into 3 groups with respect to storm water management:

1. Infiltration Systems: where storm water disipates into the natural ground water table through the formation sub-grade,
2. Retention/Attenuation (or tanked) Systems: Incorporating impervious formation liners and a traditional piped network to transport attenuated storm water into either a soak-away, or storm water system,
3. Porous Surfacing Systems: Overlaying conventional impervious pavements to improve spray control and noise attenuation.

RESEARCH & UTILISATION

Europe

Research has been documented within Europe on deep (400mm-600mm thick) porous surfacing systems with consideration to noise attenuation characteristics, heavy vehicle loadings and lateral turning loads. The majority of research has been undertaken in France, with further testing and development required to qualify suitability for these applications.

Permeable block paver systems have also been installed in wharf areas, with testing being undertaken to assess suitability for heavy vehicle loading.

Some sporting fields and minor roads have also been constructed in England.

Japan

Significant application of infiltration systems utilising permeable concrete pavement has been undertaken in Japan since the 1980’s, due predominantly to the countries hydrological features and mountainous terrain. Lightly trafficked streets, pedestrian areas, and footpaths appear to be the main focus of application. It is envisaged that a significant further amount of data would be available for review following translation of Japanese language texts.

USA

Research and use of insitu pavements (nominally 125mm thick) in America has mostly occurred in Florida, due to the sandy subsoils of the region and the suitability of Infiltration Systems. Car parks and sporting surfaces (ie. tennis courts) are the most commonly documented applications, with some urban subdivision streets constructed. A technical committee – 522 Pervious Concrete, has also been formed by the ACI (American Concrete institute) .

Australia/NZ

There is apparently little to no documented usage of permeable concrete insitu pavement within Australia, accepting some tennis courts in both Australia and New Zealand. Several large projects have been undertaken however utilising block pavers, such as the surrounds to Homebush Olympic Stadium in Sydney. Proprietary Block and grass-infill pavers are readily available in Australia, and are marketed and distributed by several companies.

FUNCTIONALITY

Advantages

The benefits of permeable pavements relate to storm water run-off (& first flush) retention, ground water recharge, pollution/siltation control, traffic safety/skid resistance, and in some instances noise attenuation.

Numerous scientific studies indicate a link between high amounts of impervious surfaces, and water resource degradation[1]. In at least two areas of America the utilisation of insitu concrete pavement is considered as Best Management Practice (BMP) for water management. Where pavements are utilised to replace (or minimise) the size of storm retention facilities, cost savings in the order of 30% have been realised[2]. Pavement life span does appear to vary significantly between system/product types, and hydraulic capacity is significantly dependent on percentage void ratio and the amount of clogging. Design life of insitu concrete systems and some types of permeable paver systems are quoted as being from 15, to over 20 years. Replacing the subbase layer and the relaying of pavers can renew the hydraulic capacity of a clogged block paver system.

Permeable pavements are considered to be practical for pedestrian, sporting areas, low vehicular traffic areas, and tree surrounds. Permeable insitu pavements have been used for sub-divisional streets in America, and block paver systems have been utilised similarly in Australia. In Europe, deep insitu concrete systems (400-600mm thick) have also been utilised for test projects subjected to heavy truck and bus loading (including turning areas).

Permeable concrete is considered more suitable than porous asphalt in warmer climates, where heat may reduce asphalt strength resulting in rutting. Asphalt is also considered more susceptible to serviceability decline due to aging. Being of lesser density and generally of lighter colour than asphalt, permeable concrete pavements are less able to absorb and store heat energy. Pervious/permeable insitu concrete is the USA's Cool Communities choice of pavement.

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[1] 'Frequently Asked Questions: Pervious Alternative Materials'-web page, University of Connecticut.
[2] Kim Sorvig, 'Porous Paving', Landscape Architecture: February 1993 Issue.

Disadvantages/Limitations

The main restriction to the hydraulic functionality of permeable pavement is the requirement for shallow pavement slopes, in order to minimise flow concentration. For insitu systems, slopes less than 3-5% are advisable to restrict transverse/lateral percolation. Clogging and related preventative maintenance are commonly viewed as the main disadvantages of employing permeable pavements. Tests undertaken in America however, indicate clogging of well-designed insitu systems does not significantly affect infiltration performance, even after 20 years of service[1]. The possibility of ground water contamination is another consideration for parking areas adjacent to wells, and pollutant 'hot spots' such as service stations should be avoided. For insitu infiltration systems, the bottom of the 'recharge' subsoil layer is advised to be 0.6-1.5m above the ground water table, or bedrock level.

Insitu permeable pavement is not suitable for reinforced or prestressed construction due to it's inherent high void ratio, and care should be taken in areas associated with soft or aggressive ground waters. Also for insitu systems, contractor inexperience and the requirement for strict installation quality practices are other perceived limitations. As with any concrete element, permeable insitu concrete requires curing (3-7days). Freeze thaw cycles aren't typically a problem due to free draining nature and high void ratio of the material.

POLLUTION CONTROL

Pollution mechanisms inherent with infiltration and attenuation systems include absorption, straining, and microbiological decomposition.

Studies on insitu permeable pavements indicate readings of:

- Sediment removal efficiencies of 82-95%,
- 65% removal of total phosphorous,
- 80-85% removal of nitrogen,
- High removal rates for zinc, lead, and chemical oxygen demand[2].

A geotextile laid between subbase and subsoil can further assist with pollution control.

NOISE ATTENUATION

The documentation reviewed in relation to noise attenuation did not present quantitative results for typical pavements. However, general information indicates that the properties of insitu permeable concrete are advantageous. Testing undertaken in Europe indicates that the extent of benefit relies on several factors such as tyre size, type, as well as vehicle weight and speed.

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[1] 'Field performance Investigation: Portland Cement Pervious Pavement' Florida Concrete & Products Association, December 1989.
[2] 'Storm Water Technology Fact Sheet: Porous Pavement' EPA (USA), September 1999.

INSITU CONCRETE

Design & characteristics

Design procedures and criteria for the acceptance of permeable insitu concrete pavements have been documented in the Florida Concrete and Products Association's, 'Portland Cement Pervious Pavement Manual' by John E Paine - 1988, and also in Chapter 6 of the Florida Development Manual, 1988, Practice Number SW BMP 3.06[1].

Insitu pavements in pedestrian only traffic areas can be as little as 50-80mm thick. For light vehicular traffic conditions pavements typically consist of 100-150mm thick GP or GB cement, with 10mm aggregate, a water/cement ratio of 0.3-0.4, and an aggregate to cement binder ratio of 4-4.5. A void ratio of 20-25% is conceived as optimum for strength vs permeability characteristics. Aggregates to AS2858.1 should be clean and not too angular or flaky (flaky index <30%). Typical strengths obtained with this type of insitu pavement are between 5-13MPa.

Drying shrinkage of an insitu permeable pavement (in the order of 200-300 microstrain) is approximately ⅓ to ½ of conventional concrete. The modulus of elasticity of insitu permeable pavement is also lower than that of conventional concrete pavements, but the unit weight and compressive strength are nearly identical. Poisson's ratio is similar for that of conventional concrete, being in the range of 0.15-0.20. As vehicle loadings typically exhibit between 30-50psi, subgrade stresses are very low and can be accommodated by most soils. Subbase thickness up to 100-250mm are used as required for attenuation &/or strength.

Design procedures as derived by the American Association of State Highway and Transportation Officials (AASHTO) and also the Portland Cement Association (PCA), can also be used for evaluation of insitu pavement thickness. The PCA procedure is documented as being more applicable to pavements of 125mm or less.

Permeability

Permeability of the pavement is a function of void ratio, being generally between 15-30% (typically 20-25%). For a 125mm pavement, permeability in the order of 450 litres/min/m^2 has been recorded[2] – being well above natural surface percolation rates. Where required for strength and/or storage considerations, subgrades of 30-40% void ratio are recommended.

Subsoils for use in Infiltration Systems are indicated to require percolation rates greater than 12-13mm/hr, and should contain less than 30% clay. Typically if septic tanks are utilised within the vicinity, percolation rates are likely to be acceptable. Low percolation rates can also be bolstered by the use of under-drains. Only 15% void ratio is deemed as required to match typical subsoil percolation rates.

An equation for the calculation of porosity has been derived by Ghafoori, being:

$$P = 116.36-14(W)$$

Where P = porosity (as percentage of void volume), and W = unit weight (kg/m^3).

[1] Ghafoori 'Pavement Thickness Design for No-Fines Concrete Parking Lots', Journal of transportation Engineering November/December 1995.

[2] 'Field Performance Investigation: Portland Cement Pervious Pavement' Florida Concrete & Products Association, December 1995

Structural Capacity

Typical strengths obtained are between 5-13MPa. Additives such as silica fume and super plasticisers are noted to produce desirable characteristics with respect to strength, modulus of elasticity and resistance to freeze/thawing. Air entrainment can also significantly increase the freeze-thaw resistance of no-fines concrete.

A small amount of sand (10-20% of total aggregate) is seen to improve strength characteristics. Strength increases with a rise in compaction energy and a decrease in aggregate-cement ratio. Ghafoori has also derived equations for strength[1] of no-fines (permeable) concrete pavements.

Construction & Placing

Quality controlled production and construction is not considered an easy task, and a high level of supervision is recommended.

The following points are considered essential for ‘best-practice’ installation:

- Subbase/grade compaction is required to 92-96% maximum density (AASHTO T-180), with the subbase to be moistened prior to laying pavement. Care must be taken to maintain the infiltration porosity by avoiding the over compaction of subsoils.
- Mixer trucks should have wide discharge openings (and elevated front wheels to rear discharge trucks).
- The correct water cement ratio is signified by a shiny metallic sheen on the aggregate surface.
- **Control of water content is critical.**
- Trial strips should be placed prior to pouring main pavements (to a maximum 4.5m wide.)
- Pavement thicknesses should be placed in layers of 150-200mm maximum.
- Removable 15-20mm tack strips on top of forms facilitate adequate compaction.
- Striking off is best achieved with a mechanical vibrating screed (set to low vibration).
- Over vibration can be a disadvantage in sealing the top 3-10mm of pavement.
- Full width compaction with a heavy drum roller is recommended,
- Additional compaction is required to longitudinal jointing/edges to prevent ravelling.
- Sealed contraction joints are recommended at 5-10m (to quarter of pavement depth), with expansion joints at 50m centres. Cold construction joints are not recommended, thus work planning is vital.
- **Initial set occurs at a reduced time of around 1 hour (1.5 hours with retarders).**
- Plastic sheet curing must be undertaken within 20 minutes, for 3-7 days. Curing compounds do not work well.

[1] Ghafoori ‘Pavement Thickness Design for No-Fines Concrete Parking Lots’, Journal of transportation Engineering November/December 1995.

Testing

At the time of writing, testing procedures were still in the process of being formally developed. Most commonly, testing assesses the unit weight of plastic and cured pavement. The Florida Concrete & Products Association have developed uniform procedures for assessing unit weight and permeability.

Maintenance

High-pressure machine washing and vacuuming is recommended around 4 times per year, subject to inspection. This form of maintenance is noted as restoring 80-90% of pavement void capacity.

Potholes and cracks can be filled for up to 10% of the pavement surface area, without significantly reducing percolation rates. Spot declogging can also be undertaken by the drilling of 13mm holes through the pavement layer. Salting and sanding in snow prone areas should be avoided, and care should be taken with plowing.

Specification

The Georgia Concrete & Products Association have developed specification guidelines covering installation and testing/acceptance criteria. It is advised that contractors must be able to provide details and testing results for 2 previous jobs (or employ an equivalently experienced overseer). Construction of 2 test panels (being a minimum of 21m^2) prior to starting proposed project works is also recommended.

Costs

Whole-of-life costing and cost benefits as a contribution to storm management systems must be considered with respect to viability. The installation cost of permeable concrete pavement is estimated as 20% more than normal concrete.

Installation costs (only) for permeable infiltration/attenuation systems have been estimated as[1]:

- Asphalt US$ 5.38-10.76 (/m^2)
- Porous Concrete US$ 21.53-69.86 (/m^2)
- Grass/Gravel pavers US$ 16.15-61.89 (/m^2)
- Interlocking Concrete Paving Blocks US$ 54-107.6 (/m^2)

As an average, comparative installation cost can be taken as US$ 40/m^2 for permeable concrete.

[1] ‘Permeable Paver Costs’ – web page, Low Impact Development Centre

BLOCK PAVERS & FLAGSTONES

Design & characteristics

Permeable block or flag profiles typically consist of paver units supported on a bedding material. Pavers can be of porous structure, but more generally consist of dense, impermeable units. These paving systems incorporate drainage gaps (or holes) of at least 10% of the surface area. Bedding material is placed over a geotextile membrane, on top of an open/gap-graded subbase. Several Australian companies are marketing permeable block paver product solutions and can also provide basic design assistance, or design referrals. Block paver and flag pavements can be honed/ground to produce an aesthetically pleasing terrazzo effect.

Literature indicates that design can be undetaken utilising the T45 'Concrete Segmental Pavements Design Guide for Residential Access Roads' distributed through the Concrete Masonry Association of Australia, or an equivalent design software package.

Permeability

Serviceable percolation rates (or durable permeability) are in the order of 300 l/(s.ha) for pavements with drainage holes or 'shaped on' paver spacers[1]. Literature recommends a drainage coefficient of 0.5 for safety as in-service infiltration or 'durable permeability' is reported as being significantly reduced from that of initial/installation rates due to clogging. The 'service life' of a pavement system is highly dependent on the extent of clogging, which with all other factors held equal, can be correlated the ratio of permeable to impermeable catchment area.

Structural Capacity

As with insitu pavements, system permeability is documented as being inversely proportional to strength. Simulated laboratory testing has shown however, that a reasonable permeability can be obtained from permeable block paver systems that can provide surface stiffness (and thus strength) comparable to traditional paving systems.

For the case of dense unit paver systems that incorporate drainage voids, strength and permeability are both affected by the size of open graded bedding infill.

Maintenance

Research has shown that adoption of a maintenance regime that includes sweeping and/or vacuuming will keep the pavement effective over its service life.

Specification

Companies marketing proprietary permeable block paver product systems have in most cases produced specification data and drawings for design purposes.

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[1] Sonke Borgwardt, 'Performance and Fields of Application for Permeable Paving Systems', Rocla Permeable Paving Manual, Rocla, May 1999

Costs

As with all building systems, cost varies dependant on order quantity and location. For permeable block pavers, prices are also dependent on the extent of excavation and required edge treatments. Indicative costs for block paver systems in Australia at the time of writing were quoted as being around $\$115/m^2$ and $\$125/m^2$ for infiltration and tanked systems respectively.

REFERENCES & BIBLIOGRAPHY:

‘*Managing Urban Storm Water Treatment Techniques*’ Draft Document, EPA (NSW, Aust), 1997

Prof Dr G. Leykauf & Dr D Birmann ‘*Concrete Block Pavement Structure with porous Concrete base*’, Munich Technical University.

Dr D Birmann ‘*Construction and Evaluation of Pavements with porous Concrete Bases*’, Munich Technical University.
.
Kim Sorvig ‘*Porous Paving*’, Landscape Architecture: February 1993 Issue

Jean-Pierre Christory, Gilles Pipien, Alain *Sainton ‘Porous Urban Pavements in Cement Concrete*’, France.

Saburo Matsuno ‘*Experience with Porous Concrete Pavement*’ Japan Road Association: PIARC Concrete Road Committee Meeting, 5 June 1990.

Jean-Pierre Christory, Gilles Pipien, Bernard Soudieu, Jean Chauchot *‘The Road and the Environment, a Marriage of convenience: Thick Porous Pavements*’ – extract from Concrete Pavement design and Rehabilitation Vol. 2

‘*Cutting Edge Stormwater Technology’* – BCME, August issue, Australia.

Okamoto, Wu, Tarr, Cole ‘*Early opening of PCC Pavements to Traffic*’ extract from Concrete Pavement design and Rehabilitation Vol. 2.

Kellersmann, Smits ‘ *An Experiment with Porous Concrete Top layer on J.C.P.’* – Session 5B: Recycling and Construction.

Griffiths, Bellanoff ‘*Design Notes on Porous Pavements*’ – English publication.

‘*Storm Water Technology Fact Sheet: Porous Pavement*’ EPA (USA), September 1999.

‘*Concrete Data: No-fines Concrete*’ C&CAA, July 1999.

‘*No-fines Concrete: A practical Guide*’, Cement & Concrete Institute (Sth Africa).

Diep, Wade, Roberts ‘*Pervious Concrete Offers Win-Win Solution for Developers*’ Florida Stormwater Volume 2, Issue 7, Winter 2001.

‘*Pervious Pavements Q&A*’– web page Georgia Concrete & Products Association, 10 August 2001.

Richard Woodard ‘*Pervious Pavements*’ Lowney Views Volume 9 Issue 1, Lowney Associates.

Jack Paine ‘*Portland Cement Pervious Pavement Construction*’ Concrete Construction September 1992.

‘*Construction of Portland Cement Pervious Pavement*’ Paving Information, Florida Concrete & Products Association.

‘*Recommended Specifications for Portland Cement pervious Pavement*’ – web page, Georgia Concrete & Products Association, August 1997.

Wilde ‘*Comments by Bob Wilde: A “Cool” Parking Lot*’ Concrete International January 2002.

'*Pervious Concrete Pavement….Pervious Pavements for a More Livable Environment*' – web page, Georgia Concrete & Products Association, Updated 22 March 2001.

'*Pervious Pavements: Frequently Asked Questions*'.

'*Field Performance Investigation: Portland Cement Pervious Pavement*' Florida Concrete & Products Association, December 1989.

Ghafoori '*Pavement Thickness Design for No-Fines Concrete Parking Lots*' Journal of Transportation Engineering November/December 1995.

'*Stormwater Design Guide: Portland Cement Pervious Pavement*' Florida Concrete & Products Association, February 1990.

'*Ready Mix Concrete: What the Experts are Saying About Pervious Concrete*' – web page Tarmac America.

'*Recommended Specifications for Portland Cement Pervious Pavement*' Georgia Concrete & Products Association, Inc., August 1997.

'*Gwinchs WPD*'.

'*Building with Concrete and WACA Awards*' – web page, Seattle Daily Journal of Commerce, 14 May 1999.

Michael Coren '*Natural Stormwater Management Systems: A review from Greenprints '99'*The Southface Journal of Sustainable Building.

'*Project: Kelvin Grove Urban Village Brisbane*' Building Australia October 2002.

'*Paving with Grass*' EBN Volume 3, No. 4 July/August 1994.

'*Permeable Paver Costs*' – web page, Low Impact Development Centre, Inc.

'Frequently Asked Questions: Pervious Alternative Materials' – web page, University of Connecticut.

'Stormwater Management Fact Sheet: Porous Pavement' – web page, The Storm Water Manager's Resource Center, 2002.

'*Innovations: Pervious Paving Helps Reduce Stormwater Runoff*' Cool Communities.

'Ready-Mix Concrete Articles: Pervious Concrete Pavements' – web page, Glacier Northwest, 2002.

'Permeable Paving' – web page, Paving Expert, 2002.

'Best Practice Approaches to Materials Use' – web page, Australian Landscape Management 2002.

'*Stormwater Best Management Practices for New Developments*' Santa Monica Bay Restoration Project.

S Crosswell *'Chapter 21:No Fines Concrete'* Fultons Concrete Technology,1994.

Richard C Meininger *'No-Fines Pervious Concrete for paving',* Concrete International, Aug 1988

'Concrete Pavements for Sporting Facilities', New Zealand Concrete Construction, June 1984

V. M. Malhotra *'No Fines Concrete – It's Properties and Applications',* ACI Journal/November 1976 Title No. 73-54.

K M Brook *'Current Practice Sheets - No-Fines Concrete'*, Concrete August 1982

M. Tamai *'Properties of No-Fines Concrete Containing Silica Fume',* Fly Ash, Silica Fume, Slag & Natural Pozzolans in Concrete, Third International Conference, Norway, 1989

'Concrete Data – No-fines Concrete', Cement & Concrete Association of Australia, July 1999 P1

Simon Davies "*Preserving the delights of Rainbow Beach*", Public Works Engineering, August/September 2003

Dr Brain Shackel & Alan Pearson "*Eco paving can help road run-off*", Public Works Engineering, August/September 2003

"*The world's driest continent needs permeable concrete paving"*, Public Works Engineering, August/September 2003

"*Hydra pave Stormwater source control system*", Technical Brochure, Boral

M Rommel et al "*Carpark with '1 to 1 (impervious/permeable) paving: performance of 'Formpave' blocks"*,

J W Davies et al "*Laboratory study of permeable pavement systems to support hydraulic modelling"*

"*Hydra pave*", brochure by Boral

Sonke Borgwardt, '*Performance and Fields of Application for Permeable Paving Systems'*, Rocla Permeable Paving Manual, Rocla, May 1999