



Design Objectives

- Maximize Infiltration
- Provide Retention
- Slow Runoff
- Minimize Impervious Land Coverage
- Prohibit Dumping of Improper Materials
- Contain Pollutants
- Collect and Convey

Description

Pervious paving is used for light vehicle loading in parking areas. The term describes a system comprising a load-bearing, durable surface together with an underlying layered structure that temporarily stores water prior to infiltration or drainage to a controlled outlet. The surface can itself be porous such that water infiltrates across the entire surface of the material (e.g., grass and gravel surfaces, porous concrete and porous asphalt), or can be built up of impermeable blocks separated by spaces and joints, through which the water can drain. This latter system is termed 'permeable' paving. Advantages of pervious pavements is that they reduce runoff volume while providing treatment, and are unobtrusive resulting in a high level of acceptability.

Approach

Attenuation of flow is provided by the storage within the underlying structure or sub base, together with appropriate flow controls. An underlying geotextile may permit groundwater recharge, thus contributing to the restoration of the natural water cycle. Alternatively, where infiltration is inappropriate (e.g., if the groundwater vulnerability is high, or the soil type is unsuitable), the surface can be constructed above an impermeable membrane. The system offers a valuable solution for drainage of spatially constrained urban areas.

Significant attenuation and improvement in water quality can be achieved by permeable pavements, whichever method is used. The surface and subsurface infrastructure can remove both the soluble and fine particulate pollutants that occur within urban runoff. Roof water can be piped into the storage area directly, adding areas from which the flow can be attenuated. Also, within lined systems, there is the opportunity for stored runoff to be piped out for reuse.

Suitable Applications

Residential, commercial and industrial applications are possible. The use of permeable pavement may be restricted in cold regions, arid regions or regions with high wind erosion. There are some specific disadvantages associated with permeable pavement, which are as follows:



- Permeable pavement can become clogged if improperly installed or maintained. However, this is countered by the ease with which small areas of paving can be cleaned or replaced when blocked or damaged.
- Their application should be limited to highways with low traffic volumes, axle loads and speeds (less than 30 mph limit), car parking areas and other lightly trafficked or non-trafficked areas. Permeable surfaces are currently not considered suitable for adoptable roads due to the risks associated with failure on high speed roads, the safety implications of ponding, and disruption arising from reconstruction.
- When using un-lined, infiltration systems, there is some risk of contaminating groundwater, depending on soil conditions and aquifer susceptibility. However, this risk is likely to be small because the areas drained tend to have inherently low pollutant loadings.
- The use of permeable pavement is restricted to gentle slopes.
- Porous block paving has a higher risk of abrasion and damage than solid blocks.

Design Considerations

Designing New Installations

If the grades, subsoils, drainage characteristics, and groundwater conditions are suitable, permeable paving may be substituted for conventional pavement on parking areas, cul de sacs and other areas with light traffic. Slopes should be flat or very gentle. Scottish experience has shown that permeable paving systems can be installed in a wide range of ground conditions, and the flow attenuation performance is excellent even when the systems are lined.

The suitability of a pervious system at a particular pavement site will, however, depend on the loading criteria required of the pavement.

Where the system is to be used for infiltrating drainage waters into the ground, the vulnerability of local groundwater sources to pollution from the site should be low, and the seasonal high water table should be at least 4 feet below the surface.

Ideally, the pervious surface should be horizontal in order to intercept local rainfall at source. On sloping sites, pervious surfaces may be terraced to accommodate differences in levels.

Design Guidelines

The design of each layer of the pavement must be determined by the likely traffic loadings and their required operational life. To provide satisfactory performance, the following criteria should be considered:

- The subgrade should be able to sustain traffic loading without excessive deformation.
- The granular capping and sub-base layers should give sufficient load-bearing to provide an adequate construction platform and base for the overlying pavement layers.
- The pavement materials should not crack or suffer excessive rutting under the influence of traffic. This is controlled by the horizontal tensile stress at the base of these layers.

There is no current structural design method specifically for pervious pavements. Allowances should be considered the following factors in the design and specification of materials:

- Pervious pavements use materials with high permeability and void space. All the current UK pavement design methods are based on the use of conventional materials that are dense and relatively impermeable. The stiffness of the materials must therefore be assessed.
- Water is present within the construction and can soften and weaken materials, and this must be allowed for.
- Existing design methods assume full friction between layers. Any geotextiles or geomembranes must be carefully specified to minimize loss of friction between layers.
- Porous asphalt loses adhesion and becomes brittle as air passes through the voids. Its durability is therefore lower than conventional materials.

The single sized grading of materials used means that care should be taken to ensure that loss of finer particles between unbound layers does not occur.

Positioning a geotextile near the surface of the pervious construction should enable pollutants to be trapped and retained close to the surface of the construction. This has both advantages and disadvantages. The main disadvantage is that the filtering of sediments and their associated pollutants at this level may hamper percolation of waters and can eventually lead to surface ponding. One advantage is that even if eventual maintenance is required to reinstate infiltration, only a limited amount of the construction needs to be disturbed, since the sub-base below the geotextile is protected. In addition, the pollutant concentration at a high level in the structure allows for its release over time. It is slowly transported in the stormwater to lower levels where chemical and biological processes may be operating to retain or degrade pollutants.

The design should ensure that sufficient void space exists for the storage of sediments to limit the period between remedial works.

- Pervious pavements require a single size grading to give open voids. The choice of materials is therefore a compromise between stiffness, permeability and storage capacity.
- Because the sub-base and capping will be in contact with water for a large part of the time, the strength and durability of the aggregate particles when saturated and subjected to wetting and drying should be assessed.
- A uniformly graded single size material cannot be compacted and is liable to move when construction traffic passes over it. This effect can be reduced by the use of angular crushed rock material with a high surface friction.

In pollution control terms, these layers represent the site of long term chemical and biological pollutant retention and degradation processes. The construction materials should be selected, in addition to their structural strength properties, for their ability to sustain such processes. In general, this means that materials should create neutral or slightly alkaline conditions and they should provide favorable sites for colonization by microbial populations.

Construction/Inspection Considerations

- Permeable surfaces can be laid without cross-falls or longitudinal gradients.
- The blocks should be laid level
- They should not be used for storage of site materials, unless the surface is well protected from deposition of silt and other spillages.
- The pavement should be constructed in a single operation, as one of the last items to be built, on a development site. Landscape development should be completed before pavement construction to avoid contamination by silt or soil from this source.
- Surfaces draining to the pavement should be stabilized before construction of the pavement.
- Inappropriate construction equipment should be kept away from the pavement to prevent damage to the surface, sub-base or sub-grade.

Maintenance Requirements

The maintenance requirements of a pervious surface should be reviewed at the time of design and should be clearly specified. Maintenance is required to prevent clogging of the pervious surface. The factors to be considered when defining maintenance requirements must include:

- Type of use
- Ownership
- Level of trafficking
- The local environment and any contributing catchments

Studies in the UK have shown satisfactory operation of porous pavement systems without maintenance for over 10 years and recent work by Imbe et al. at 9th ICUD, Portland, 2002 describes systems operating for over 20 years without maintenance. However, performance under such regimes could not be guaranteed, Table 1 shows typical recommended maintenance regimes:

Activity	Schedule
<ul style="list-style-type: none"> ■ Minimize use of salt or grit for de-icing ■ Keep landscaped areas well maintained ■ Prevent soil being washed onto pavement 	Ongoing
<ul style="list-style-type: none"> ■ Vacuum clean surface using commercially available sweeping machines at the following times: <ul style="list-style-type: none"> - End of winter (April) - Mid-summer (July / August) - After Autumn leaf-fall (November) 	2/3 x per year
<ul style="list-style-type: none"> ■ Inspect outlets 	Annual
<ul style="list-style-type: none"> ■ If routine cleaning does not restore infiltration rates, then reconstruction of part of the whole of a pervious surface may be required. ■ The surface area affected by hydraulic failure should be lifted for inspection of the internal materials to identify the location and extent of the blockage. ■ Surface materials should be lifted and replaced after brush cleaning. Geotextiles may need complete replacement. ■ Sub-surface layers may need cleaning and replacing. ■ Removed silts may need to be disposed of as controlled waste. 	As needed (infrequent) Maximum 15-20 years

Permeable pavements are up to 25 % cheaper (or at least no more expensive than the traditional forms of pavement construction), when all construction and drainage costs are taken into account. (Accepting that the porous asphalt itself is a more expensive surfacing, the extra cost of which is offset by the savings in underground pipework etc.) (Niemczynowicz, et al., 1987)

Table 1 gives US cost estimates for capital and maintenance costs of porous pavements (Landphair et al., 2000)

Redeveloping Existing Installations

Various jurisdictional stormwater management and mitigation plans (SUSMP, WQMP, etc.) define “redevelopment” in terms of amounts of additional impervious area, increases in gross floor area and/or exterior construction, and land disturbing activities with structural or impervious surfaces. The definition of “redevelopment” must be consulted to determine whether or not the requirements for new development apply to areas intended for redevelopment. If the definition applies, the steps outlined under “designing new installations” above should be followed.

Additional Information

Cost Considerations

Permeable pavements are up to 25 % cheaper (or at least no more expensive than the traditional forms of pavement construction), when all construction and drainage costs are taken into account. (Accepting that the porous asphalt itself is a more expensive surfacing, the extra cost of which is offset by the savings in underground pipework etc.) (Niemczynowicz, et al., 1987)

Table 2 gives US cost estimates for capital and maintenance costs of porous pavements (Landphair et al., 2000)

Table 2 Engineer's Estimate for Porous Pavement

Porous Pavement													
Item	Units	Price	Cycles/Year	Quant. 1 Acre WS	Total	Quant. 2 Acre WS	Total	Quant. 3 Acre WS	Total	Quant. 4 Acre WS	Total	Quant. 5 Acre WS	Total
Grading	SY	\$2.00		604	\$1,208	1209	\$2,418	1812	\$3,624	2419	\$4,838	3020	\$6,040
Paving	SY	\$19.00		212	\$4,028	424	\$8,056	636	\$12,084	848	\$16,112	1060	\$20,140
Excavation	CY	\$3.60		201	\$724	403	\$1,451	604	\$2,174	806	\$2,902	1008	\$3,629
Filter Fabric	SY	\$1.15		700	\$805	1400	\$1,610	2000	\$2,300	2800	\$3,220	3600	\$4,140
Stone Fill	CY	\$16.00		201	\$3,216	403	\$6,448	604	\$9,664	806	\$12,896	1008	\$16,128
Sand	CY	\$7.00		100	\$700	200	\$1,400	300	\$2,100	400	\$2,800	500	\$3,500
Sight Well	EA	\$300.00		2	\$600	3	\$900	4	\$1,200	7	\$2,100	7	\$2,100
Seeding	LF	\$0.05		644	\$32	1288	\$64	1932	\$97	2576	\$129	3220	\$161
Check Dam	CY	\$35.00		0	\$0	0	\$0	0	\$0	0	\$0	0	\$0
Total Construction Costs							\$10,105		\$19,929		\$29,619		\$40,158
Construction Costs Amortized for 20 Years							\$505		\$996		\$1,481		\$2,008
Annual Maintenance Expense													
Item	Units	Price	Cycles/Year	Quant. 1 Acre WS	Total	Quant. 2 Acre WS	Total	Quant. 3 Acre WS	Total	Quant. 4 Acre WS	Total	Quant. 5 Acre WS	Total
Sweeping	AC	\$250.00	6	1	\$1,500	2	\$3,000	3	\$4,500	4	\$6,000	5	\$7,500
Washing	AC	\$250.00	6	1	\$1,500	2	\$3,000	3	\$4,500	4	\$6,000	5	\$7,500
Inspection	MH	\$20.00	5	5	\$100	5	\$100	5	\$100	5	\$100	5	\$100
Deep Clean	AC	\$450.00	0.5	1	\$225	2	\$450	3	\$675	3.9	\$878	5	\$1,125
Total Annual Maintenance Expense							\$3,960		\$7,792		\$11,651		\$15,483

Other Resources

Abbott C.L. and Comino-Mateos L. 2001. *In situ performance monitoring of an infiltration drainage system and field testing of current design procedures*. Journal CIWEM, 15(3), pp.198-202.

Construction Industry Research and Information Association (CIRIA). 2002. *Source Control using Constructed Pervious Surfaces C582*, London, SW1P 3AU.

Construction Industry Research and Information Association (CIRIA). 2000. *Sustainable urban drainage systems - design manual for Scotland and Northern Ireland Report C521*, London, SW1P 3AU.

Construction Industry Research and Information Association (CIRIA). 2000 C522 *Sustainable urban drainage systems - design manual for England and Wales*, London, SW1P 3AU.

Construction Industry Research and Information Association (CIRIA). *RP448 Manual of good practice for the design, construction and maintenance of infiltration drainage systems for stormwater runoff control and disposal*, London, SW1P 3AU.

Dierkes C., Kuhlmann L., Kandasamy J. & Angelis G. Pollution Retention Capability and Maintenance of Permeable Pavements. *Proc 9th International Conference on Urban Drainage, Portland Oregon, September 2002*.

Hart P (2002) Permeable Paving as a Stormwater Source Control System. *Paper presented at Scottish Hydraulics Study Group 14th Annual seminar, SUDS. 22 March 2002, Glasgow*.

Kobayashi M., 1999. Stormwater runoff control in Nagoya City. *Proc. 8 th Int. Conf. on Urban Storm Drainage, Sydney, Australia, pp.825-833*.

Landphair, H., McFalls, J., Thompson, D., 2000, Design Methods, Selection, and Cost Effectiveness of Stormwater Quality Structures, Texas Transportation Institute Research Report 1837-1, College Station, Texas.

Legret M, Colandini V, Effects of a porous pavement with reservoir structure on runoff water: water quality and the fate of heavy metals. *Laboratoire Central Des Ponts et Chaussées*

Macdonald K. & Jefferies C. Performance Comparison of Porous Paved and Traditional Car Parks. *Proc. First National Conference on Sustainable Drainage Systems, Coventry June 2001*.

Niemczynowicz J, Hogland W, 1987: Test of porous pavements performed in Lund, Sweden, in *Topics in Drainage Hydraulics and Hydrology*. BC. Yen (Ed.), pub. Int. Assoc. For Hydraulic Research, pp 19-80.

Pratt C.J. SUSTAINABLE URBAN DRAINAGE – A Review of published material on the performance of various SUDS devices prepared for the UK Environment Agency. *Coventry University, UK December 2001*.

Pratt C.J., 1995. Infiltration drainage – case studies of UK practice. *Project Report*

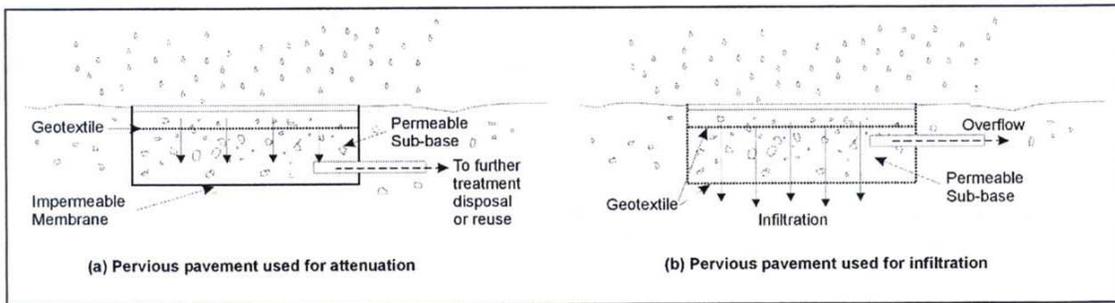
22, Construction Industry Research and Information Association, London, SW1P 3AU; also known as National Rivers Authority R & D Note 485

Pratt, C. J., 1990. Permeable Pavements for Stormwater Quality Enhancement. In: Urban Stormwater Quality Enhancement - Source Control, retrofitting and combined sewer technology, Ed. H.C. Torno, ASCE, ISBN 087262 7594, pp. 131-155

Raimbault G., 1997 French Developments in Reservoir Structures Sustainable water resources I the 21st century. Malmo Sweden

Schlüter W. & Jefferies C. Monitoring the outflow from a *Porous Car Park Proc. First National Conference on Sustainable Drainage Systems, Coventry June 2001.*

Wild, T.C., Jefferies, C., and D'Arcy, B.J. SUDS in Scotland – the Scottish SUDS database Report No SR(02)09 *Scotland and Northern Ireland Forum for Environmental Research, Edinburgh.* In preparation August 2002.



Schematics of a Pervious Pavement System