# THE LONG-TERM PERFORMANCE OF PERVIOUS PAVING

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**ABSTRACT**

The most commonly asked questions about pervious paving is its clogging and long-term performance. To account for potential clogging an infiltration "safety factor" of 10 is generally applied. But what is the measured infiltration rate of different types of pervious paving over time in different environments? How effective is surface cleaning to restore its original infiltration rate?

This study measured surface infiltration rates and structural integrity of pervious paving installations constructed throughout the Auckland region since 2004. The paper also compares before and after changes in infiltration rates from cleaning. This new, innovative method for cleaning pervious pavement can be applied at scales from a single driveway to large parking areas. The 'Eco-pave Cleaner' works through the application of small water jets to initially dislodge the sediments, followed up by vacuum suction. The study shows a marked improvement of surface infiltration rates. Recommendations are given to the frequency and type of maintenance to ensure the long-term performance of pervious paving.

Keywords

**Pervious Paving, Permeable Paving, Porous Concrete, Gobi Blocks, Maintenance, Performance, Asset Management**

**PRESENTERS PROFILES**

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Steve Crossland is the Technical & Specifications Manager (Masonry) at Firth and has 17 years experience in masonry with a special interest in the manufacture, specification, research, design and construction, of pervious paving (since 2002) and pervious concrete (since 2009) systems.

# 1 INTRODUCTION

Pervious (or porous) paving consists of a permeable wearing surface that is bedded in sand/fine gravel, overlying a gravel basecourse to enable rainwater infiltration to an underdrain and/or ground infiltration (refer Figure 1).

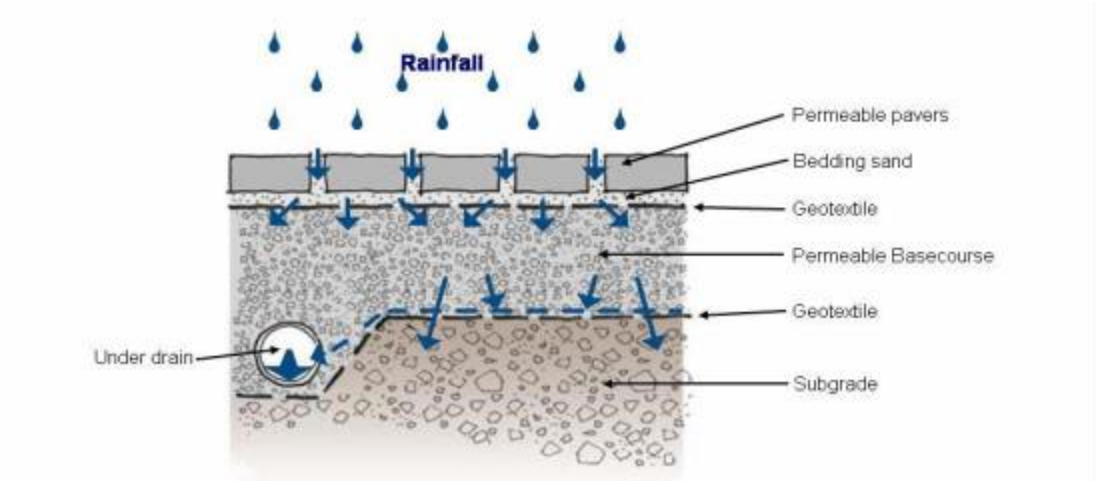



*Figure 1: Typical Layers in Pervious Paving*

Pervious paving allows runoff to infiltrate into the underlying basecourse where it is temporarily stored and slowly released either into the subgrade or underdrain. This provides stormwater attenuation of the peak flows, volume reduction through infiltration and wetting/drying of the filtration media and water quality treatment due to settling, filtration, adsorption and microbiological action in the bedding sand and basecourse. This provides both stormwater quantity and quality treatment, particularly important for maintaining stream health in the urban environment with increasing impervious areas.

Pervious paving is relatively new in New Zealand. The first was probably the parking area at Parrs Park, Waitakere in 2000. In USA it has been used from the 1990s and was first developed in Europe approximately three decades ago (1980s).

The focus of this paper is on the long term maintenance issues, often reported as one of the major concerns with the use of pervious paving. The two main ongoing maintenance issues are the surface infiltration rate (to maintain the stormwater management functions) and the structural support necessary to maintain the surface integrity and rider quality. Seven sites throughout Auckland with different types of pervious pavement surfaces, dating back to 2004, were visited and tested for infiltration and structural integrity. Recommendations are then given to the frequency and type of maintenance to ensure the long-term performance of pervious paving.

The design and construction of pervious paving, and their costs and benefits, are not the focus of this paper (although indicative maintenance costs are given for information purposes). Design and construction issues are covered elsewhere, such as Auckland Council's Permeable Pavement Construction Guide (no date) and the Draft Permeable Pavement Design Guidelines (Hartwell, S. et al 2004). Internationally, there are many pervious pavement technical documents such as the U.S. Department of Transportation TechBrief of Permeable Interlocking Concrete Pavement (Federal Highway Administration 2015). Detailed costs and benefits of pervious paving in Auckland have been presented at the 2015 Asia Pacific Stormwater Conference (Kumar et al., 2015) and in the Auckland

Council cost and benefit assessment report prepared as supporting information for the Auckland Unitary Plan planning process (Kettle and Kumar, 2013).

# 2 TEST SITES

Seven sites were visited throughout Auckland (refer Figure 1) with five different pervious paving surfaces.

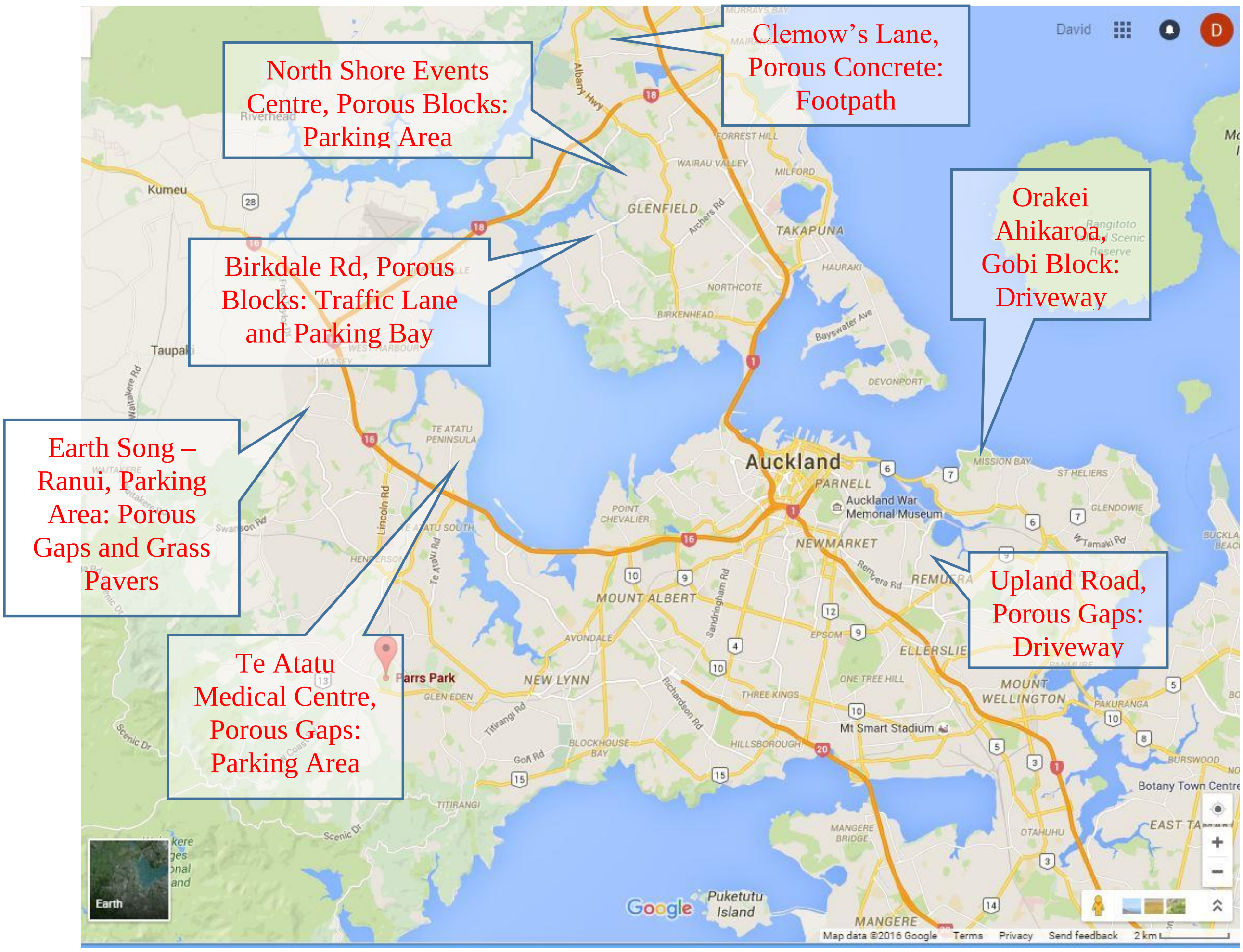


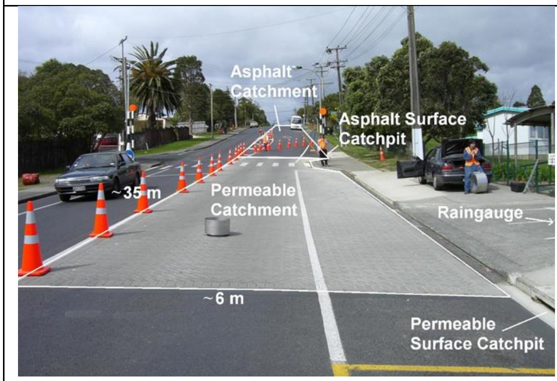

*Figure 1: Seven Pervious Paving Sites Visited Throughout Auckland*

Photos of the test sites are included in the following page.

**Photos of Test Sites**

North Shore Events Centre, Porous Blocks, Parking

Clemow's Lane, Porous Concrete, Footpath




Birkdale Road, Porous Blocks, Traffic Lane and Parking Bay

Te Atatu Medical Centre, Porous Gaps, Parking

Earthsong Ranui, Porous Gaps, Parking

Upland Road, Porous Gaps, Driveway

Earthsong Ranui, Grass Paver, Parking

Orakei Ahikaroa, Gobi Block, Driveway

The sites included driveways, parking areas and a roadway/parking bay, with the following different types of pervious surfaces:

- **Porous Gaps** – 200mm x 100mm x 80mm depth paving blocks manufactured as solid impermeable blocks. Infiltration is through the 6 to 8mm gaps between the blocks filled with a 2/7mm chip. Sites are Upland Road, Earth Song Ranui and Te Atatu Medical Centre.

- **Porous Blocks** – 200mm x 100mm x 80mm depth paving blocks manufactured with 'no-fines concrete' to produce a permeable block. Infiltration is through the porous block. Sites are the North Shore Events Centre and Birkdale Road.

- **Porous Concrete** – 1.5m wide x 21m long x 125mm depth no-fines concrete path laid on 100mm of 2/7 chip, on a geotextile over the subgrade. Infiltration is through the porous concrete. Site is Clemow's Lane.

- **Grass Pavers** – 400mm x 400mm x 80mm depth, concrete grid structure with large holes (86mm x 86mm). Infiltration is through the large holes (the holes make up 37% of the surface area) which can be filled with soil or gravel. Site is Earth Song, Ranui, with holes filled with 2/5 chip.

- **Gobi Block** – 200mm x 200mm x 100mm depth, concrete grid structure with 65mm and 45mm diameter holes. Infiltration is through the holes (the holes make up 29% of the surface area). Site is Orakei Ahikaroa with holes filled with soil for grass growth.

# 3 SURFACE INFILTRATION

The pervious paving stormwater objective is to achieve hydrological neutrality, with the post development flows equaling the predeveloped flows over the range of flows up to the 1 in 10-year event. Stormwater modelling for the Draft Auckland Permeable Pavement Design Guidelines (Hartwell, S. et al. 2004) showed this could be achieved with a pervious paving infiltration rate equal to the 2-year 24 hour peak flow rate (for Auckland this is about 120mm/hr). To account for clogging through the life of the pervious pavement, the as-built new infiltration rate is specified at ten times the design rate. That is, an as-built infiltration rate of 1,200mm/hr for Auckland.

This is similar to the Interlocking Concrete Pavement Institute (ICPI 2011) which gives a design infiltration rate of 250mm/hr, below which the pavement needs to be cleaned.

## 3.1 TEST PROCEDURE

The surface infiltration rate was first tested in its existing condition. Then an area of approximately 1m$^2$ was cleaned with the 'Eco-pave Cleaner', and then the infiltration rate retested.

The infiltration rate was tested using the ASTM Designation: C 1701/C 1701M-09; Standard Test Method for Infiltration Rate of In Place Pervious Concrete. The test procedure consists of an infiltration ring (300mm in diameter and 50mm high) being temporarily sealed to the surface of the pervious pavement. After prewetting the test location, a given mass of water is introduced into the ring and the time for the water to infiltrate the pavement is recorded (see Photo 1).

*Photo 1: Timing a set volume of water, at a constant depth of 10 to 15mm, to infiltrate the pervious surface within the steel ring. Concrete surround (with a soft closed cell foam on its base, see photos 2 and 3) provides a seal to minimise horizontal leakage from under the inside ring.*

*Photo 2: Soft closed cell foam on base of concrete ring.*

*Photo 3: Indentations in soft foam from being placed on the paver surface to form a seal.*

The surface was cleaned by Hydrovac Ltd using the 'Eco-pave Cleaner', a water jet/suction device (see Photos 4 to 8).

*Photos 4 (left) and 5 (right): Cleaning the pervious surface. The thirteen, 1,000 psi water jets dislodge the sediments/moss/weeds from the surface and in the joints, which are then picked up with the vacuum suction. Most weeds are dislodged and vacuumed up but some weeds with long roots remain and need to be hand plucked.*


Photo 6: Before cleaning.


Photo 7: During cleaning


Photo 8: After cleaning, before rechip.

After cleaning the Porous Gaps and Porous Blocks the joints are refilled with a 2/7mm chip (Porous Gaps) or a clean sand (Porous Blocks) and vibrated with a plate compactor.

## 3.2 TEST RESULTS

Table 2 summarises the infiltration test results carried out on the 22nd February 2016, plus previous infiltration tests where available. It is noted that unless specifically stated, the sites visited had received minimal cleaning since their installation, with only occasional weed pulling.

*Table 2: Infiltration Test Results*

| **Pervious Surface Type and Test Location** | **Year Constructed and Age of Pavement when tested (years)** | **Surface Infiltration Rate (mm/hr)** | | |
|---|---|---|---|---|
| | | **Existing - Before cleaning** | **After cleaning with 'Eco-pave Cleaner' (22 February 2016)** | |
| | | | **After 6 passes** | **Another 6 passes** |
| **Porous Gaps** | | | | |
| - **Upland Road** Driveway | 2004 | | | |
| - Tested 2006(1) | 2 years | 2,700; 4,200 | | |
| - Tested 2007(1) | 3 years | 4,400 | | |
| - Tested 2014(2) | 10 years | 310 (weeds) | | |
| - Tested 2016(3) | 12 years | N/A | 12,600 | |
| - **Earthsong Ranui** Parking(4) | 2008 – 8yrs | 1,000(8) | 1,600 | |
| - **Te Atatu Medical Centre** Parking(4) | 2009 – 7yrs | 1,800 | 11,000 | |
| **Porous Blocks** | | | | |
| - **North Shore Events Centre**, Parking | 2004 | | | |
| - Tested 2006(1) | 2 years | 500 (sediment); 7,400; 2,900 | | |
| - Tested 2014(5) | 10 years | 640 (weeds); 4,200 (no weeds) | | |
| - Tested 2016(4) | 12 years | 290 (weeds) | 1,100 | |

| Pervious Surface Type and Test Location | Year Constructed and Age of Pavement when tested (years) | Surface Infiltration Rate (mm/hr) | | |
|---|---|---|---|---|
| | | Existing - Before cleaning | After cleaning with 'Eco-pave Cleaner' (22 February 2016) | |
| | | | After 6 passes | Another 6 passes |
| - **Birkdale Road,** Parking Bay(4) | 2010 – 6 years | 430 | 1,260 | |
| **Porous Concrete** | | | | |
| - **Clemow's Lane**, Footpath | 2010 | | | |
| - Under Tree, near driveway | | | | |
| - Tested 2010(9) (As-built) | 0 years | 6,700 | | |
| - Tested 2014(6) | 4 years | 330 | | |
| - Tested 2016(4) | 6 years | < 200 | 3,400 | 6,300 |
| - Midway between trees | | | | |
| - Tested 2014(6) | 4 years | 12,600 | | |
| - Tested 2016(4) | 6 years | 14,300 | | |
| - Under Tree, near outlet | | | | |
| - Tested 2010(9) (As-built) | 0 years | 7,670 | | |
| - Tested 2014(6) | 4 years | 860 | | |
| - Tested 2014(7) | 4 years | | 1,500; 4,700(7) | |
| - Tested 2016(4) | 6 years | 3,400 | 5,600 | |
| **Grass Pavers** | | | | |
| - **Earthsong Ranui** Parking(4) | 2008 – 8 years | 14,000 | N/A | |
| **Gobi Block** | | | | |
| - **Orakei Ahikaroa,** Driveway(4) | 2013 | | | |
| - Gobi Blocks(4) | 3 years | 5,500 | N/A | |
| - Adjacent grass area(4) | N/A | 3,800 | N/A | |

(1) Blackbourn 2007.
(2) Tested by Firth/Kettle 14 November 2014, covered with moss, silt and weeds
(3) Tested by Firth on 26 Feb 2016 after cleaning with 'Eco-pave Cleaner' back in August 2015.
(4) Tested by Firth/Kettle 22 February 2016.
(5) Tested by Firth/Kettle 14 November 2014, two sites, one with weeds, one with no weeds.
(6) Tested by Firth/Kettle 14 November 2014
(7) Cleaned 2 December 2014, trialing a water blaster. 1,500mm/hr was with 12 passes, 4,700mm/hr was with additional concentrated focus on test area.
(8) Since construction in 2008, the pervious pavers have been manually cleaned of weeds once by residents.
(9) Tested by Firth, Auckland University and Boffa Miskell) as-built, 2 September 2010.

General conclusions from Table 2 are:

- Within the first 1 to 2 years after construction, the infiltration rates of Porous Gaps and Porous Block paving surfaces which are relatively "clean" with few weeds are in the range of 2,700 to 7,400mm/hr. This is significantly greater than the recommended as-built infiltration rate of 1,200mm/hr (design rate of 120mm/hr times 10 to account for clogging, refer Section 2 introduction above).

- After construction the greatest reduction to infiltration rates are the presence of sediment, moss and weeds. Infiltration rates are reduced from the thousands of mm/hr, down to around 200 to 500mm/hr. As early as two years after construction overhanging trees and shrubs can drop leaf litter which clog the joints. It is worth noting that even these 'low' infiltration rates are still greater than the minimum design infiltration rate of 120mm/hr (refer Section 2 introduction above).

- The 'Eco-pave Cleaner' significantly increases infiltration rates, up to, or greater than the recommended minimum as-built of 1,200mm/hr. With cleaning the greatest increase in infiltration is for the Porous Gaps and Porous Concrete. For example, the Porous Gaps at the Earthsong Rauni Parking increased from 1,000mm/hr to 1,600mm/hr, the Te Atatu Medical Centre from 1,800mm/hr up to 11,000mm/hr and the Upland Road Driveway from 310mm/hr to 12,600mm/hr. The Clemows Porous Concrete Footpath increased from less than 200mm/hr up to 6,300mm/hr (with 12 passes). The Porous Blocks show a lower increase in infiltration with cleaning. For example, the Porous Blocks at the North Shore Events Centre increased from 290mm/hr to 1,100mm/hr and at Birkdale Road, from 430mm/hr to 1,260mm/hr with cleaning.

- The 'Eco-pave Cleaner' provides the greatest benefit for the "Porous Gaps" pervious paving because the water jets dislodge the majority of the joint grit (and accumulated sediment) between the pavers (to a depth of 50 to 80mm, up to the 80mm thickness of the paver). After cleaning, the joint grit is replaced with new clean grit (2/7mm grit) and vibrated into the joints with a plate compactor.

- Where the pervious surface is still relatively "clean" (with little weeds/moss/sediment), the infiltration rates are still close to or greater than the recommended as-built 1,200mm/hr, 7 to 10 years after construction. For example, Te Atatu Medical Centre Porous Gaps at 1,800mm/hr after 7 years and the North Shore Events Centre Porous Blocks at 4,200mm/hr after 10 years.

- The greatest infiltration rate was from the Grass Pavers filled with 2/5mm chip at 14,000mm/hr (Earthsong Ranui Grass Pavers Parking) and the Porous Concrete footpath of 12,600 to 14,300mm/hr (Clemow's Lane, where it had been clear of any overhanging trees).

- The Gobi block at Orakei Ahikaroa, filled with soil, had an infiltration rate of 5,500mm/hr, actually greater than the adjacent grass which had an infiltration rate of 3,800mm/hr.

# 4 STRUCTURAL SUPPORT

In order to maintain the integrity of the pervious pavement and provide the necessary support for the traffic loading, the pavement needs to be monitored for signs of structural distress that could impair the structural integrity. Typical observed distresses that may occur for pervious interlocking concrete block pavements and their severity rating are summarised in Table 3 (Source: Hein and Schaus (2015)). Areas of pavement that are showing signs of 'medium' and 'high' severity should be repaired. Depression and rutting depths are not as critical for pervious paving as standard asphalt surfaces where water ponds and can cause aquaplaning.

*Table 3: Structural Performance Criteria*

| Criteria - Description | Severity Level | | |
|---|---|---|---|
| | Low | Medium | High |
| **Depression (Depth in mm)** – Occurs by settlement of the underlying subgrade or granular base rather than a load related distress, such as over services cuts, catch basins and adjacent to other roadway types. | 5 to 13 | 13 - 25 | > 25 |
| **Rutting (Depth in mm)** – Surface depression that occurs in the wheel path under vehicle loading. | 5 to 15 | 15 to 30 | > 30 |
| **Faulting (Maximum Difference in Elevation, mm)** – When the elevation of small areas of the surface differs or has rotated to that of adjacent blocks. Typically caused by surficial settlement of the bedding sand, poor installation, pumping of the joint filler or bedding sand. | 4 to 6 | 6 to 10 | > 10 |
| **Excessive Joint Width (Width in mm) –** Joints between pavers are critical for both providing infiltration as well as structural interlock. Excessive joint width can occur from poor initial construction, lack of joint filler, poor edge restraint, adjacent settlement/heave etc. | 6 to 10 | 11 to 15 | >15 |
| **Joint Filler Loss (Depth in mm) –** Joint filler is essential to provide interlock and stiffness of the paver course and infiltration. Loss of filler can result from excessive vacuum force during sweeping, pressure washing, pumping under traffic loading etc. | < 10 | 10 to 25 | >25 |
| **Horizontal Creep (Horizontal movement in mm) –** Is the longitudinal displacement of the pavement caused by traffic loading. Any shifting of the joints or pattern indicates horizontal creep. | 6 to 10 | 11 to 20 | >20 |
| **Damaged Paver Units –** Typically caused by load related damage, includes cracks, chips or spalls. | One or two cracks, chips or spalls | Increased cracking, chips or spalls | Cracked into multiple pieces |
| **Edge Restraint Damage –** Loss of lateral support (typically kerbs) can result in movement/rotation of the pavers, loss of joint filler and bedding course material. | Joint width (6 – 10 mm), no evidence of paver/kerb rotation | Joint width (11 – 15 mm), evidence of paver/kerb rotation | Joint width (>15 mm), considerable paver/kerb rotation |
| **Additional Distresses** – include missing pavers, heaving (heave height in mm) and patching (some areas replaced with dissimilar material such as asphalt). | Single missing paver, heave 5 to 15mm | Two or more missing pavers, heave 15 to 30mm | Multiple missing pavers affecting ride quality, heave > 30mm |

## 4.1 TEST PROCEDURE

The test procedure for each criteria is summarised in Table 4.

*Table 4: Test Procedure*

| Criteria - Description | Test Procedure |
|---|---|
| **Depression (Depth in mm)** | Maximum depth measured using a 3m straight edge |
| **Rutting (Depth in mm)** | Maximum depth measured using a 3m straight edge |
| **Faulting (Maximum Difference in Elevation, mm)** | Maximum vertical difference between two blocks |
| **Excessive Joint Width (Width in mm)** | Maximum joint width between two pavers |
| **Joint Filler Loss (Depth in mm)** | Maximum depth loss of joint filler |
| **Horizontal Creep (Horizontal movement in mm)** | Maximum horizontal difference in pattern |
| **Damaged Paver Units** | Type of damage noted, e.g. cracks, chips or spalls |
| **Edge Restraint Damage** | Measured joint width between pavers and note any paver/kerb rotation. |
| **Additional Distresses** | Noted number of missing pavers and/or any patches (such as asphalt), height of any heave |

## 4.2 TEST RESULTS

Table 5 summarises the structural integrity test results carried out on the 22$^{nd}$ February 2016.

*Table 5: Structural Integrity Test Results*

| Severity | Depression | Rutting | Faulting | Joints | | Horiz Creep | Damaged Pavers | Edge Restraint (Joint width/ rotation) |
|---|---|---|---|---|---|---|---|---|
| | | | | Width | Filler loss | | | |
| Low | 5 to 13 | 5 to 15 | 4 to 6 | 6 to 10 | <10 | 6 to 10 | 1 or 2 | 6 to 10 |
| Med | 13 - 25 | 15 to 30 | 6 to 10 | 11 to 15 | 10 to 25 | 11 to 20 | > 2 | 11 to 15 |
| High | > 25 | > 30 | > 10 | > 15 | > 25 | > 20 | Pieces | > 15 |
| **Porous Gaps** | | | | | | | | |
| Parking Area - Earthsong, Ranui | None | 5 to 8 | None | 7 - 8 | 10 - 20 | None | None | None |
| Parking Area - Te Atatu Medical Centre | 3 areas at 25mm | <10 | None | 6 - 8 | 5 - 20 | None | None | None |
| Driveway - Upland Road | None | None | None | 6 - 8 | <10 | None | None | None |
| **Porous Blocks** | | | | | | | | |
| Parking Area - North Shore Events Centre | 18, 25, 68 | 4 to 7 | None | 3 to 6 | 30 - 40 | None | None | None |
| Traffic Lane – Birkdale Rd | 27 - 35 | 18 - 25 | < 5 | 10 - 15 | 20 - 30 | Minor < 10 | yes (approx 5 per sqm) | some movement along edges |
| Parking Bay – Birkdale Rd | < 5 | None | None | 3 - 4 | < 5 | None | None | paver rotation at driveway access |

General conclusions from Table 5 are:

- The Porous Gaps – Parking Areas (Earthsong, Ranui, Te Atatu Medical Centre) and residential driveway (Upland Road) performed the best, with the joint filler loss being the main concern with a medium severity ranking. The medium severity depression measurement for the Te Atatu Medical Centre (3 areas of approximately 1m$^2$ each in a total pavement area of 1,050m$^2$) reinforces the need for close construction monitoring when placing basecourse and pavers around physical structures such as catchpits, service trenches etc.

- To minimise joint filler loss Firth Ltd are trialing a water based acrylic joint stabiliser solution with initial good results.

- The worst performing was the Birkdale Road traffic lane trial on a local road with significant traffic loads (on a bus route) where the Porous Blocks have experienced 'high' depressions, joint filler loss and damaged pavers, along with 'medium' rutting and joint widths. In contrast, the adjacent parking bay has performed well with all 'low' severity performance. The Birkdale Road was a trial to test the performance of the pervious surface to significant traffic loads and reinforces the recommended design practice of restricting pervious paving for parking areas and driveways.

# 5 MAINTENANCE

As with any infrastructure, regular maintenance is the key to long-term performance. For pervious paving this is especially important because of the nature of the pavement surface and its potential to clog over time, resulting in a much reduced infiltration rate and structural performance.

Maintenance activities can be divided into three basic types:

1. **Monitoring** – Includes regular inspections of litter build up, sediment accumulation, plant/weed growth, erosion damage and surface ponding.

2. **Regular planned maintenance** – Includes vegetation/weed management, sediment removal and cleaning permeable surfaces.

3. **Corrective maintenance** - Intermittent, irregular maintenance, mid-life refurbishment and rebuild at the end of the design life of the device including replacing pavers and/or removal and replacement of contaminated bedding sand.

The testing of the sites presented in this paper have focused on the regular planned maintenance activities, including the measurement of the infiltration capacity (and the increased infiltration from cleaning the pervious paving surface with the 'Eco-pave Cleaner', a water jet/vacuum suction device) and signs of structural distress that could impair the structural integrity.

The type (and cost) of maintenance can also vary depending on whether it is a small household device (e.g. private driveway) or a public/commercial device (e.g. small or large parking areas). The recommended maintenance schedule is presented below for two types of installations, 'small' household driveways and 'large' public parking lots (of 1,000m$^2$).

The testing of the pervious pavements presented in Sections 3 (surface infiltration) and 4 (structural support) highlight three key maintenance issues:

- Reduced infiltration rates from surface clogging - the importance of regular cleaning/blowing of leaves/grass to stop organics decomposing on the surface and the accumulation of sediment, moss and weeds

- Loss of joint filler – Firth Ltd are trialing a water based acrylic joint stabiliser solution to be sprayed on the gaps in the Porous Gaps pervious surface. This will minimise loss of joint filler from being washed out during rainfall events and general cleaning with hosing/rotary head cleaning methods.

- Depressions (settlement of the underlying subgrade or granular base such as over services trenches, catch pits and adjacent to other pavement types) – emphasising the importance of close construction monitoring when placing basecourse and pavers around physical structures such as catchpits, service trenches and adjacent to other pavement types.

Table 6 presents a summary of the recommended maintenance schedule. More detailed maintenance activities are given in Sections 5.1 and 5.2.

*Table 6: Recommended Maintenance Schedule*

| **Maintenance** | **'Small' Household Driveway** | **'Large' Parking Lot ($1,000m^2$)** |
|---|---|---|
| **1. Monitoring/Inspections** | | |
| General inspection | Carried out by owner as regular house/yard up keep. | Carried out as part of landscape maintenance contractor's responsibilities. |
| Council inspection | By Council, yearly for first three years, then once every three years after that. | By Council, 2 per year for first three years, then once every two years after that. |
| **2. Regular Maintenance** | | |
| Top up of joint chip between pavers | End of first year and again once every ten years. | End of first year and every five years alternating with 10-year corrective maintenance |
| General cleaning/weed control | Every year (including hosing surface and weed control). | Every year (including 'light' sweeping with a 'rotary head' cleaning system) to remove surface weeds/sediment) |
| **3. Remedial/Corrective Maintenance** | | |
| 'Deep' vacuum cleaning (water jet/suction device) surface to remove sediment jammed into joints and soiled aggregate (typically 15 to 25mm deep). Refill joints with clean aggregate, sweep surface clean and test infiltration rate again to minimum 50% increase or minimum 1,200mm/hr. Recommend infiltration tests every ten years. (Note: Firth Ltd provide free infiltration testing of their pervious paving products) | If water ponds on the surface and remains longer than one hour after a rainstorm and/or infiltration tests are below 240mm/hr (twice the minimum design infiltration rate of 120mm/hr). | Every ten years OR water ponds on the surface and remains longer than one hour after a rainstorm and/or infiltration tests are below 240mm/hr (twice the minimum design infiltration rate of 120mm/hr). |
| Repair and/or reinstatement of damaged edge restraints and resulting movement in the pavers; this may require removal and reinstatement of adjacent paving units. | As required through general inspections | As required through general inspections |
| Replace pavers, sand bedding and geotextile. Dispose of all contaminated material including pavers, sand and geotextile to landfill. | No general uplifting of pavers and sand bedding/geotextile is likely due to low traffic loading and contamination levels. | Every 20 years |

## 5.1 MONITORING/INSPECTIONS

For public/commercial parking lots the regular inspections should include the following (Federal Highway Administration 2015):

- Review maintenance and operations records and incidences to determine indicators of maintenance.
- Document general site features, take pavement photographs, etc.
- Note obvious sources of surface contamination such as sediment.
- Identify the extent and severity of any damage or deficiencies (settlement, ponding, cracked pavers etc. as per Tables 3 and 4 above).
- Identify any changes in adjacent land use that may impact contributing area runoff for potential sources of contaminants that may reduce system infiltration rates.
- Inspect vegetation around paving perimeter for cover and soil stability.
- Inspect edge restraints to ensure continued functioning.
- Check any observation well(s) and outlet drain(s) to ensure continued water drainage from the pavement structure.
- Check surface for buildup of sediment in joints.
- Check for loss of joint filler between pavers.
- If water ponds on the paving surface and remains longer than one hour after a rain storm, then clean surface with water/vacuum to increase infiltration rate.

Based on the results of the inspection, remedial/corrective maintenance may be required as given in Table 6.

For private driveways, homeowners should inspect the general performance of the pavement surface, focusing on any sediment build-up (especially from any pervious adjacent surfaces) and if ponding remains on the pavement surface for longer than one hour after a rainstorm event. Simplified brochures/pamphlets should be made available to all home owners that have pervious paving (and any other on-site stormwater management device) so they are aware that it is there, the purpose it performs and how to carry out any simple maintenance checks and remedial works that may be necessary (such as removal of weeds).

## 5.2 REGULAR MAINTENANCE

The regular maintenance activities are generally the same for private driveways and public/commercial parking areas, although they are more likely to occur in the heavily trafficked parking areas. Regular maintenance includes (Federal Highway Administration 2015):

- Inspect and if necessary clean the surface using regenerative air equipment (regenerative equipment does not evacuate jointing materials, such as light hosing for driveways and a rotary head cleaning system for parking areas) to remove debris and sediment in the spring and late autumn.
- Repair/replant vegetative cover for areas up slope from the paving surface.
- Repair all paver surface depressions exceeding 13mm and rutting exceeding 15mm (refer Table 1, 'Depression' and 'Rutting').

- Repair pavers offset by more than 6mm above/below adjacent units or kerbs (refer Table 1, 'Faulting').
- Replenish aggregate in joints if more than 10mm from paver chamfer bottoms (refer Table 1, 'Joint Filler Loss').
- Replace cracked paver units impairing surface structural integrity (refer Table 1, 'Damaged Paver Units').
- Clean and flush underdrain system if slow draining.
- Clean drainage outfall features to ensure free flow of water and outflow.

## 5.3 REMEDIAL/CORRECTIVE MAINTENANCE

Refer table 6 for details.

## 5.4 COMPARATIVE MAINTENANCE COSTS

For comparison, indicative maintenance costs are presented in Table 7 for pervious paving versus an asphalt surface large installation, such as a 1,000$m^2$ car park (Source: Based on Kettle and Kumar 2013, updated with the findings from the test sites).

*Table 7: Indicative Maintenance Costs for a 1,000$m^2$ Parking Area*

| Pervious Paving Item | Value | Asphalt Item | Value |
|---|---|---|---|
| **General inspection** (every year) – 2 @ $140 per year per 1,000$m^2$. | $280/yr | **General inspection** (yearly 1 to 5) – 2 @ $140 per year per 1,000$m^2$. | $280/yr ($0.28/yr/$m^2$) |
| **General cleaning/weed control** (every year) - $1.50/$m^2$ (including rotary head cleaning system at $0.10/$m^2$) | $1.50/yr/$m^2$ | **General cleaning/weed control** (yearly 1 to 5) – (surface sweeping, 6 @ $0.10/$m^2$ plus $100 weed control) | $0.70/yr/$m^2$ |
| **Above <u>plus</u> regular maintenance** (End of first year and every five years, alternating with corrective maintenance) – top up joint chip ($5.50/$m^2$), including joint chip stabilisation additive ($5/$m^2$) | $10.50/$m^2$, first year then year 5, 15, 25 etc. | **Above, <u>plus</u> regular maintenance** (yearly 6 to 10) - Lichen/moss control (1 per year @ $450/yr), surface crack sealing (50m per year @ $325/yr), pot holes (15$m^2$ per year @ $1,125/yr) | $0.98/$m^2$ plus $1.90/$m^2$ = $2.88/yr/$m^2$ |
| | | **Above <u>plus</u> larger failures** (yearly 11 to 19) – larger failures, 20$m^2$ per year at $250/$m^2$. | $2.88 plus $5.00/$m^2$ = $7.88/yr/$m^2$ |
| **Possible corrective maintenance** to deep clean with water jet/suction device ($3.50/$m^2$), extract and replace joint chip or sand ($5.50/$m^2$), including joint chip stabiliser ($5/$m^2$) (every 10-years between 20-yr major corrective maintenance) | Possible $14/$m^2$, year 10, 30 etc. | **Major corrective maintenance** of full rehabilitation (every 20 years) | $125/$m^2$ for year 20, 40 etc. |
| **Major corrective maintenance** to replace pavers, bedding sand and geotextile (every 20 years) | $112/$m^2$, year 20, 40 etc. | | |
| **Average Annualised[(1)] (per $m^2$)** | **$8.40/$m^2$** | **Average Annualised[(1)] (per $m^2$)** | **$9.00/$m^2$** |

(1) Average annualised maintenance costs, undiscounted – the total summed annual and intermittent maintenance costs divided by the appraisal period (25 years), with no discounting. This indicates the average yearly maintenance cost.

Table 7 shows that the maintenance costs for pervious paving are similar to a standard asphalt surface.

# 6 CONCLUSIONS

The performance testing of surface infiltration rates and structural support of a range of different pervious paving types on seven sites throughout the Auckland region constructed over the last 12 years indicate:

- 6 to 12 years after installation all sites had infiltration rates greater than the minimum design value of 120mm/hr (even though the sites had not received any regular cleaning).
- The greatest impact on reducing infiltration rates is the presence of sediment, moss and weeds – emphasizing the importance of regular cleaning/blowing of leaves/grass to stop organics decomposing on the surface and joints. This reduces infiltration rates down to between 200 and 500mm/hr.
- The 'Eco-pave Cleaner' (water jet/suction) can restore the infiltration rates, up to, or greater than the recommended as-built minimum infiltration rate of 1,200mm/hr (design rate of 120mm/hr times 10 to account for clogging over time). Increased infiltration rates varied from 1,600mm/hr to 12,600mm/hr.
- Where the pervious surface stay relatively "clean", the infiltration rates at 7 to 10 years after installation are still close to or greater than the recommended as-built minimum infiltration rate of 1,200mm/hr.
- The structural integrity of the pervious paving surfaces in driveways and parking areas has performed well over the 7 to 12 years since installation. Loss of joint filler and depression areas (settlement of the underlying subgrade or granular base such as over service trenches, catch pits and adjacent to other paving types) were the two areas of slight concern.
- The average annualised maintenance costs (average yearly maintenance cost) for an example 1,000$m^2$ parking area over 25 years for the pervious paving at approximately \$8.40/$m^2$ is similar to a standard asphalt surface of approximately \$9.00/$m^2$.

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