Using Field Tests to Evaluate the Hydraulic Performance of Existing Concrete Block Permeable Pavements

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by ***Tom Emerton BSc (Hons) GMICE***[1] *and* ***Chris Griffiths***[2]

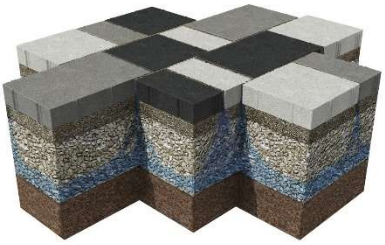
[1]*Pavement Engineer Manager, Marshalls Plc,* [2]*Engineering Marketing Manager, Marshalls Plc.*

Background.

Concrete Block Permeable Paving (CBPP) is an effective SuDS component which provides either source control infiltration or a controlled flow of clean water. However, there are a number of misconceptions about CBPP technology which impede its uptake and adoption.

CBPP is a block paved surface which allows rainwater to permeate through the surface via widened joints between the blocks. Once in the sub-base, water is stored until it either infiltrates into the ground or, if ground conditions don't allow infiltration, is channelled away to a receiving watercourse or sewer at a controlled rate. It manages water quantity and also improves water quality, making it an effective (and passive) water management tool

However, one of the most persistent misconceptions about CBPP is that without maintenance the joints quickly become clogged with debris and within a short period of time the joints will become impermeable and water will be prevented from entering the sub-base.



A number of academic studies have disproved this myth. What happens in practise is that sand, dust and debris settle in the joint but form a thin "crust" (approx. 5-10mm deep) over the surface of the joints – and while this crust slows down the rate of infiltration, it still allows water to percolate into the sub-base. Soenke Borgwardt's 2006 study[1] concluded that with no maintenance whatsoever, after 10 years a CBPP system reduces to 10% of its initial infiltration rate and plateaus at this level. This reduced rate is still more than permeable enough to cope with the heaviest rainfall events, so Borgwardt's conclusion was that although annual sweeping is desirable to maximise infiltration rates, even with no maintenance whatsoever, a CBPP system will continue to perform at an acceptable level.

In addition, Luis Sanudo-Fonteneda (et al)'s 2017 report[2] compares the performance of various permeable surfaces in a car park in Santander, Northern Spain, attempting to ascertain an "end of life" timescale for each system. Again, the study concludes that although the infiltration rate degrades over time, the CBPP surface still performs its drainage function and has yet to reach a state of complete failure.

Despite this evidence, and despite the huge number of still-functioning systems that have been installed all over the UK, the belief that the surface will fail due to clogging remains the main reason why people avoid specifying CBPP.

Process.

In order to better understand the effect trafficking, weathering and time has on CBPP systems, a number of field tests were undertaken to measure the permeability of existing CBPP systems in the UK, following the American Standard method ASTMC1781/C1781M[3].

The process is detailed, but can be summarised as follows:

1. Take a cylinder of a known diameter
2. Using window putty, lay a circular bed on the surface the same diameter as the cylinder. (Ensure that extra putty is applied at the joints). ***(fig 1)***
3. Seat the cylinder firmly into the putty, ensuring a tight seal all the way round. ***(fig 2)***
4. Prewetting: Take a known volume of water and slowly pour it onto the surface within the cylinder. Maintain a consistent head of between 10-15mm at all times. ***(fig 3)***
5. Measure the amount of time it takes for all the water to disappear. ***(fig 4)***
6. Repeat this process for the actual test.
7. Use the following formula to convert this time into "mm per hour":

   $$I = KM/(D^2 * t)$$

   in which:
   I = Infiltration rate (mm/h)
   M = Mass of infiltrated water (kg)
   D = Inside diameter of infiltration ring (mm)
   t = time required for measured amount of water to infiltrate the surface (seconds)
   K = 4 583 666 000 in SI units

This process should be carried out at a number of locations across the chosen site and an average taken.

fig 1

fig 2

fig 3

fig 4

See a video of a test here: https://www.youtube.com/watch?v=sV-VccSr-P4

Download a copy of the method here: https://www.astm.org/Standards/C1781.htm.

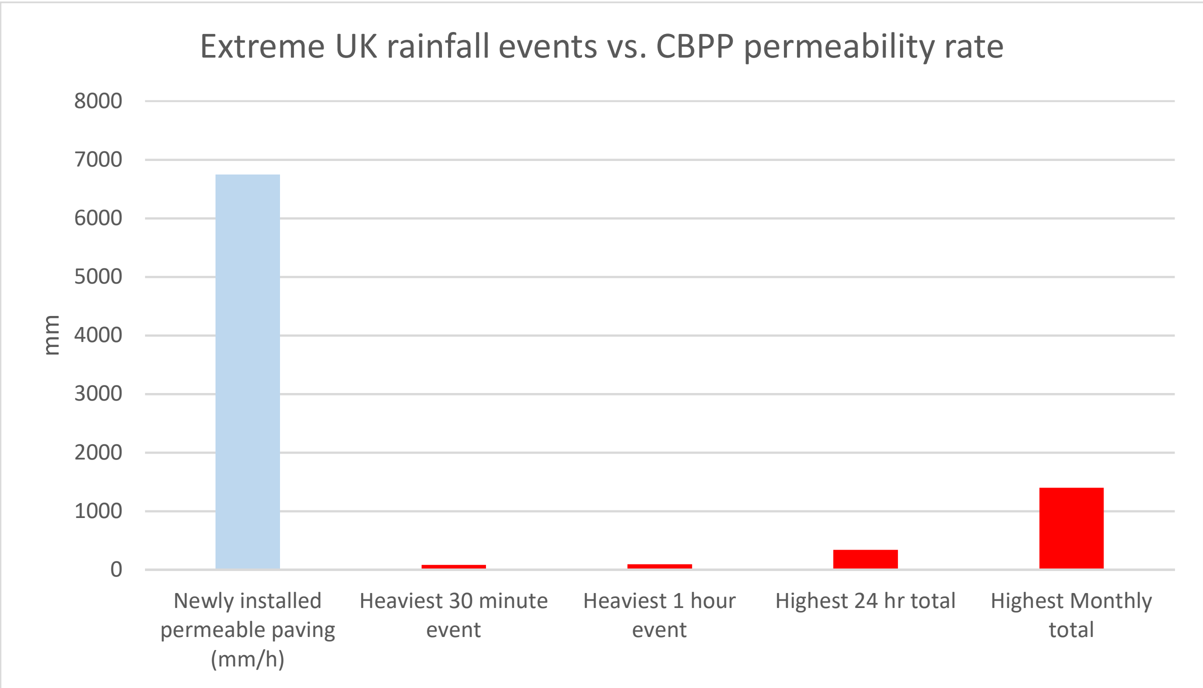
Context.

The infiltration rate of newly installed CBPP is virtually instantaneous; it's so fast that it's difficult to measure accurately. Lab tests demonstrate that the infiltration rate is *in excess* of 6,750 mm per hour.

Changing weather patterns mean that UK rainfall events are increasing in their frequency, duration and intensity. According to Met Office data[4], the UK's wettest day since records began in 1862 occurred on December 3rd 2019, when an average of 31.7mm fell in 24 hours. However, averages are not necessarily useful when designing drainage systems. It is important to recognise that intense "cloudburst" storms can generate significant volumes of rain on a small area in a short space of time. The Met Office records the following rainfall events as the heaviest in UK history[4]:

Event (duration)	**mm**	**Location**	**Date**
Highest 30-min total	80	Eskdalemuir, Dumfries and Galloway	26/06/1953
Highest 60-min total	92	Maidenhead, Berkshire	12/07/1901
Highest 24-hour total (1800hrs -1800hrs)	341	Honister Pass, Cumbria	05/12/2015
Highest monthly total	1396	Crib Goch, Snowdon	Dec-15

It is useful to recognise that from a hydraulic point of view CBPP is over engineered to be far more permeable than it needs to be – by a factor of 42, against the most intense half-hour storm on record.



Test Site Locations.

Field tests were undertaken at 3 UK sites between September and November 2020:

1. Brookfoot Works Car Park, Halifax.
2. Elland Road Park & Ride, Leeds.
3. Martlesham Park & Ride, Ipswich.

1. **Brookfoot Works Car Park, Halifax, HX3 9SY. Installed 2001.**

   A test panel (approx. 5mx10m) installed in the exit lane of a car park servicing a concrete works. The car park is heavily used by 3 daily shifts of factory staff 7 days a week (up to 100 cars daily) and is also subject to heavy plant moving pallets of concrete products and aggregates. No maintenance has been undertaken whatsoever.

   The surface is well worn. Most joints have sand and debris in them and some moss is visible. Some joints appear completely clogged with compacted sand.

2. **Elland Road Park and Ride, Leeds, LS11 0EY. Installed 2014.**

   A large out-of-town car park next to the football stadium. Two new phases have been added since this first one, both using CBPP. The car park receives regular daily trafficking from domestic cars. The car park is swept annually and during winter salt is applied (without added grit or sand) as a de-icer.

   There is moss and debris visible in most joints in the parking bays, but joints the running lanes seem to be more open. Mossed joints are particularly evident in bays round the edge of the car park. Jointing aggregate is no longer present. Representatives from Leeds County Council were present at the test.

3. **Martlesham Park & Ride, Ipswich, IP5 3QN. Installed 2003.**

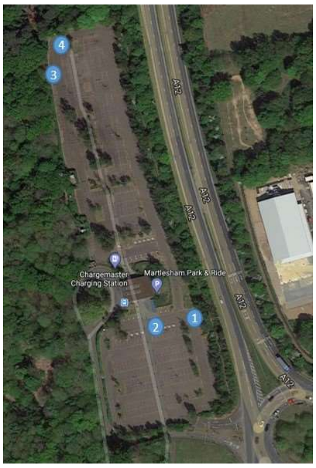
   A large out-of-town car park which receives regular daily trafficking from commuters and shoppers. Occasional sweeping is undertaken around the edge of the space to tidy up foliage from overhanging vegetation, but otherwise no specific maintenance has taken place.

   There is heavy moss in most joints. Towards the edge of the site there are large amounts of loose debris from trees and shrubs. The original designer of the scheme from Suffolk County Council was present at the test.

Approximate Test Locations.

Brookfoot – 19 yrs old

Martlesham – 17 yrs old



Elland Road – 6 yrs old

Results.

Brookfoot

Results	(mm/h)
Test 1 Prewetting	131
Test 1	146
Test 2 Prewetting	164
Test 2	164
Test 3 Prewetting	327
Test 3	361

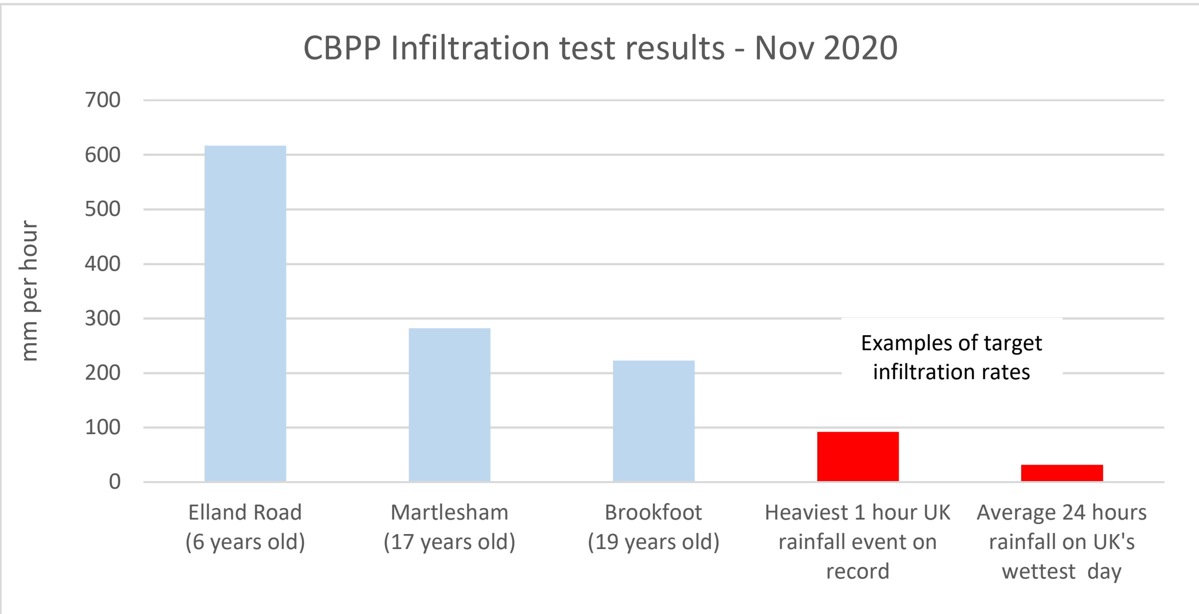
Martlesham

Results	(mm/h)
Test 1 Prewetting	837
Test 1	616
Test 2 Prewetting	359
Test 2	313
Test 3 Prewetting	701
Test 3	319
Test 4 Prewetting	682
Test 4	213

Elland Road

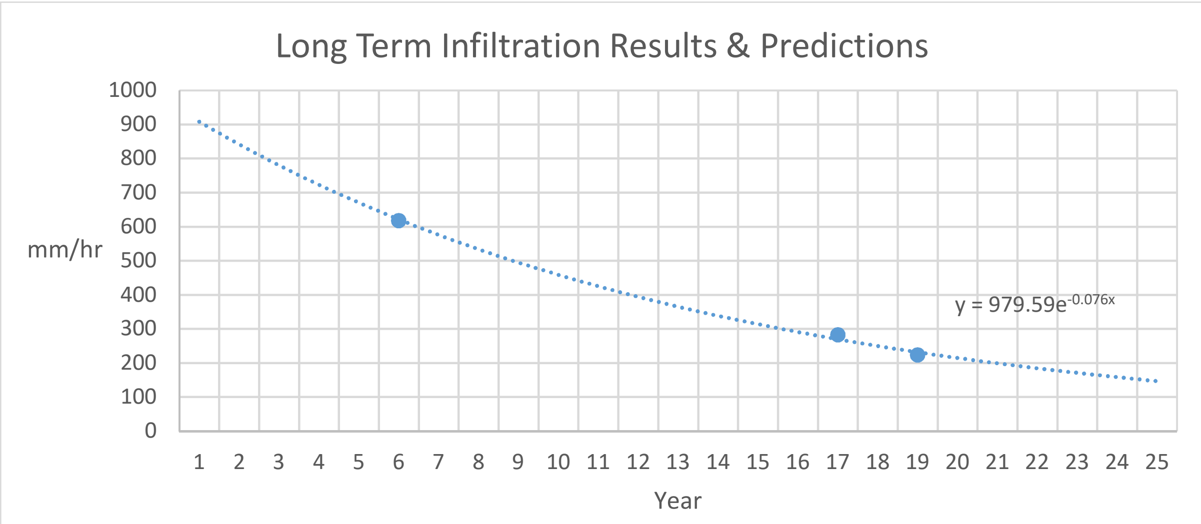
Results	(mm/h)
Test 1 Prewetting	150
Test 1	134
Test 2 Prewetting	189
Test 2	262
Test 3 Prewetting	1706
Test 3	1454

Avg. Test: **223 mm/h** **282 mm/h** **617 mm/h**



Predictions.

In line with previous research projects, these results demonstrate a decline in permeability over time. Plotting these points onto a graph produces a "degradation curve", and provides the opportunity to predict the rate at which CBPP permeability might continue to decline:



Formula for Predicted Long Term Infiltration:

$y = 979.59e^{-0.076x}$

y= Predicted Infiltration Rate (mm/hr)

e= Constant value of 2.71828

x= Age of surface in years

Based on this initial data, it would take 32 years before a CBPP surface would no longer be able to cope with the UK's heaviest 1 hour rain fall event on record.

Conclusions.

All of the CBPP sites tested, despite receiving no specific maintenance to improve permeability, still provide infiltration rates that would cope with any likely UK rainfall event. It was observed that at every site some patches have become less permeable than others; in these instances, it is likely that in a storm event excess water would flow to more permeable areas.

Although maintenance may be desired for aesthetic reasons (to remove weeds, for example), under normal use no maintenance is required to ensure that CBPP surfaces remain adequately permeable throughout their design life.

Further recommendations.

- Although acceptable, it is noted that the infiltration rates tested are far lower than when newly installed. As rainfall events become more intense the need to restore permeability may become necessary. **Research should be undertaken into the most suitable method for restoring permeability – eg: sweeping? vacuuming? re-laying? etc etc**

- The results show that infiltration rates have deteriorated beyond 10% of original value (in the case of Brookfoot, the rate is less than 4% of its original value – although it might have been anticipated that this would the worst performing site, as it is subject to regular industrial plant in addition to domestic cars). **Further annual testing should be undertaken at the existing 3 sites to understand if they continue to deteriorate, or if they eventually plateau at an acceptable level.**

- In order to generate more confidence in predicting the degradation curve, more data is required. **Continue to record results in different locations and populate the graph for a more defendable data trend.**

- It was noticed that on some sites there was marked difference in the permeability of the running courses and car parking bays. **Investigate "performance vs application" – eg: regular traffic vs parking bays, industrial plant vs domestic access roads etc.**

References:

[1] Long-Term In-Situ Infiltration Performance of Permeable Concrete Block Pavement. by Dr Soenke Borgwardt.

[2] The Long-Term Hydrological Performance of Permeable Pavement Systems in Northern Spain: An Approach to the "End-of-Life" Concept. by Luis A. Sañudo-Fontaneda, Valerio C. Andres-Valeri, Carlos Costales-Campa, Iñigo Cabezon-Jimenez and Fernando Cadenas-Fernandez.

[3] Standard Test Method for Surface Infiltration Rate of Permeable Unit Pavement Systems. - ASTM International

[4] UK Climate Extremes – The Met Office