International study on the long-term efficiency of stormwater infiltration by permeable pavements

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Abstract: Although permeable pavements have been used all over the world in recent years to infiltrate and treat stormwater, only limited research has been undertaken to investigate and compare the long-term performance of these sustainable urban drainage system devices. This paper presents the results of an extensive international review of research on the reduction of infiltration capacity of permeable pavements over time. The results of these studies, coupled with specific knowledge of the key environmental factors on the individual research locations and infiltration testing methods used, enables the maintenance of these SUDS to be strategically planned in order to meet specific European and international infiltration capacity guidelines.

Keywords: permeable pavement; stormwater infiltration; sustainable urban drainage systems (SUDS);

Introduction

Permeable pavements are a type of sustainable urban drainage system (SUDS) treatment device that are used globally to infiltrate and treat stormwater runoff. Permeable pavements are specifically designed to promote the infiltration of stormwater through the paving and base-courses where it is filtered through the various layers (Lucke and Beecham, 2011).

There are several types of permeable pavements typically used in Europe including concrete pavers with wide joints or apertures (Figure 1a), and porous concrete pavers, either with or without wide joints (Figure 1b). These are usually manufactured as blocks and are generally referred to as permeable concrete interlocking pavers (PCIP). Concrete and plastic grid pavers (CGP and PGP) have more open void spaces to promote infiltration. Stormwater is able to infiltrate through the large gaps in these pavers which are usually filled with gravel, or topsoil planted with grass (Figure 1c).

Infiltration rates of newly installed PICP systems have been shown to be very high. However, this has been shown to decrease significantly over time due to clogging (Borgwardt, 2006; Pezzaniti et al., 2009; Lucke and Beecham, 2011; Boogaard et al, 2014). It is the long-term infiltration performance of a PICP that determines their ultimate success (Yong and Deletic, 2012). Whether the surface infiltration rate obtained from PICP testing is considered acceptable or not depends on a number of factors, including the location of the pavement, the intended purpose of the pavement and the stakeholder expectations. Research data suggests that the most important factor that influences PICP clogging is time. To enable better prediction on the long-term performance of PICPs and plan appropriate maintenance, more research data is needed on the infiltration capacity of PICPs installed in a variety of international locations after 5, 10 and 15 years, without maintenance. This paper presents the results of an extensive international review of research on the reduction of infiltration capacity of permeable pavements over time.

Figure 1 (a) Impermeable Concrete PICP; (b) Porous Concrete PICPs; (c) Grass-filled PICPs.

Material and Methods

A number of previous permeable pavement infiltration studies have been based on results using a modified version of either the single or double-ring infiltrometer test (ASTM D3385-09). In these tests, rings are sealed to the pavement surface and filled with water. The time taken for the water to infiltrate through the permeable surface area is used to estimate an average infiltration rate (usually in mm/h) for the test location. Both the constant head and the falling head methods can be utilized in these testing procedures. Double-ring infiltrometer tests (DRIT) have generally been the preferred method in the past (Figure 2c).

The permeable pavement infiltration testing methods described above are based on the infiltration rate through a very small area of the pavement that is used to represent the total pavement area infiltration. For example, the area of the inner ring of the ASTM D3385-09 DRIT test is 0.0707 m^2. The minimum area recommended by the Dutch guidelines [Kiwa, 2014] is even smaller, at only 0.01 m2. Using such small areas for testing could potentially lead to erroneous results as a number of studies have demonstrated a high degree of spatial variability between different infiltration measurements undertaken on the same pavement installation. In the Netherlands, several infiltrometer tests have been performed on one location within 2 m^2 from each other leading to a high variation of results. Dutch results from four infiltrometer tests taken within 10 m^2 on one location in 'Meijel' showed a variation of between 34 and 596 mm/h and in Heerhugowaard only two tests were taken showing an infiltration rate of 825 and 3511 mm/h [Boogaard 2015].

Figure 2. Full scale testing in the Netherlands (a) Impermeable barriers; (b) Plastic wrapped soil core; (c) DRIT testing

For this reason a full-scale test was developed in the Netherlands in order to get higher accuracy results (Figure 2). PICP infiltration rates from a variety of international research studies were collated and analysed in order to evaluate and predict infiltration reduction and clogging performance over time. The analysis results were then compared to international guideline requirements.

A number of issues need to be considered when using the new test method. These include:

1. Selection and isolation of pavement section for testing;
2. Various methods of containing the water within the pavement test section;
3. Water supply alternatives; and
4. Accurate determination of surface infiltration rate.

Test Area Selection

To enable an accurate estimation of the average surface infiltration rate using the new test method, a permeable pavement area of approximately $50m^2$ was recommended for all tests. However, achieving this was dependent on site practicalities such as pavement width, length, slope and cross-fall, location of drainage gullies, parked cars and resident access requirements.

Water Containment

A number of variations can be constructed to contain water:

1. Soil core wrapped in plastic sheeting
2. Sand core wrapped in geotextile (figure 3b)
3. Soil- or sand-filled plastic bags (figure 3c)
4. Impermeable barriers inserted into paving gaps; and
5. Use of existing traffic calming devices (speed-humps)

Figure 3 Various Dam Variations Used at the Different Test Locations (a) Impermeable barriers; (b) Plastic wrapped soil core; (c) Soil-filled plastic bags.

Water Supply

The new infiltration test requires large volumes of water to be discharged onto the test paving section in order to inundate the pavement surface. Depending on the site location, there are a number of different water supply options, including transporting water directly to site with water trucks (Figure 4-a) or water tanks (Figure 4-b), and pumping water directly from nearby canals (Figure 4-c).

Figure 4 (a) Water truck supply; (b) Water tank supply; (c) Pumping from canal.

Determining Pavement Infiltration Rates

Pressure transducers were used in the study as the primary method of measuring and recording the reduction in water levels over time at various locations on the pavement surface. Two wireless, self-logging, pressure transducers were installed at the lowest points of each test pavement area. The transducers continuously monitored the static water pressures at those locations and transmitted this information to a laptop computer. The static water pressure was then converted to an appropriate depth of water above the pavement. This process produced accurate and reliable data over the duration of the tests. It also enabled visual representation of the pavement infiltration process.

Three different measurement methods can be used in conjunction with the pressure transducers in order to calibrate and verify the transducer readings. The three methods were:

- Hand Measurements
- Calibrated Underwater Camera
- Time-Lapse Photography

Guidelines for the construction and performance of permeable pavements are limited. However, a number of European countries have construction and infiltration guidelines for concrete permeable pavements. For example, new PICP installations in the Netherlands, Belgium and Germany need to demonstrate a minimum infiltration capacity of 194 mm/h. Other permeable pavement guidelines in the Netherlands [RIONED, 2006] recommend that maintenance is undertaken on permeable pavements when the infiltration falls below 0.5 m/d (20.8 mm/h).

Results and Discussion

Figure 5 shows the research results of international infiltration testing studies from the Netherlands [Boogaard, 2015], Belgium [Beeldens et al.,2006], Germany [Nolting et al., 2005], Sweden [Al-Rubaei et al., 2013] and Australia [Lucke & Beecham, 2011]. It is clear from Figure 5 that there is a large variation in infiltration rates depending on the location and age of the pavement.

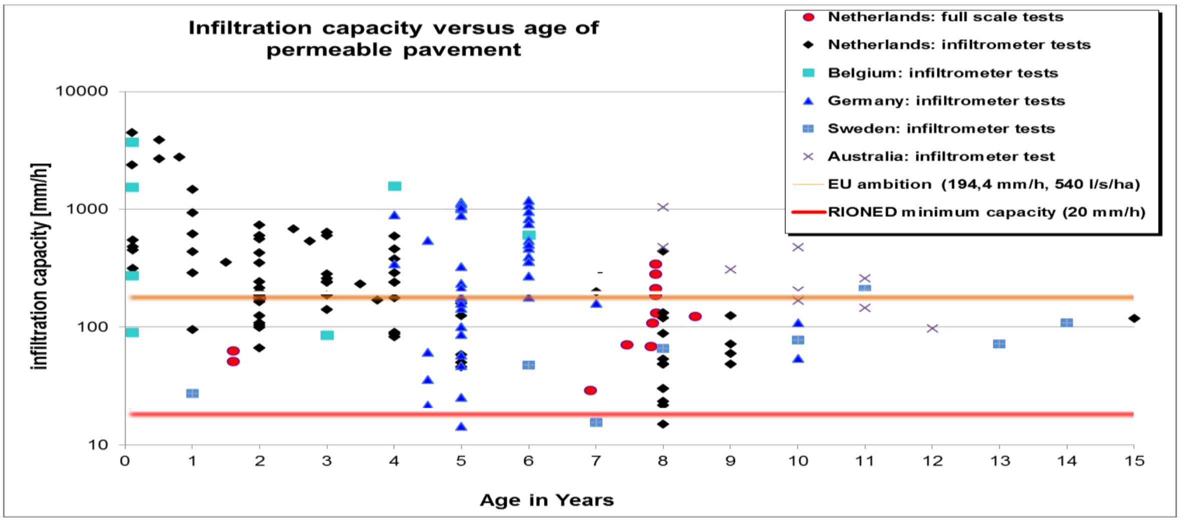

Figure 5 International permeable pavement infiltration capacity research results [Boogaard, 2015]

Figure 5 shows that infiltration rates of newly installed permeable pavement systems are generally very high (in the order of over 1000 mm/h), although this tends to decrease over time. Newly installed permeable pavements in many European countries must demonstrate a minimum infiltration capacity of 194 mm/h and are expected to have this capacity for years without maintenance. The results in Figure 5 demonstrate that the infiltration rates of many of the pavements tested would be sufficient for around five years.

Figure 5 shows a large variation in the calculated infiltration rates between the study pavements. There are a number of potential reasons for the observed variations in surface infiltration rates between the test pavements including:

• Age. Although most of the pavements were generally of a similar age range, small variations can be expected in surface infiltration capacity in the older pavements

• Construction. While the construction of the test pavements were generally similar to that shown in Figure 1, there were slight differences between the sites. These included the size of the paving joints, different types of bedding aggregates and different pavement laying processes.

• Maintenance. There were distinct variations in the pavement maintenance procedures between the different municipalities. All municipalities conducted regular street sweeping of their permeable pavements as other pavements but no attempts were made reduce clogging of the pavements.

• Variations in Hydraulic Ground Conditions. The water table was higher at some pavement test locations (particularly in the western areas of the Netherlands), while the permeability of soils in the eastern test locations were generally higher.

• Environmental Site Conditions. The type and amount of trees surrounding the pavements are not the same. Trees are known to affect the infiltration rate of permeable pavements. Pavement Usage. There are variations observed between the type and number of vehicles using the different pavements on a daily basis.

Conclusions and Recommendations

Traditional permeable pavement infiltration testing methods generally base results on the infiltration rates obtained through a very small area of the pavement, which is then used to represent the total pavement area infiltration. This approach of using small areas for testing could potentially lead to erroneous results being obtained. This study presented a newly developed, full-scale infiltration test to evaluate the infiltration performance of permeable pavements.

Infiltration rates of newly installed permeable pavement systems are generally very high, although they have been shown to decrease significantly over time. Newly installed permeable pavements must demonstrate a minimum infiltration capacity of 194 mm/h in several European countries as The Netherlands, Germany and Belgium. This study found that the infiltration rates of most of the new installed pavements tested were above this requirement. Other permeable pavement guidelines in the Netherlands recommend that maintenance should be undertaken on permeable pavements when the surface infiltration falls below 20.8 mm/h. According to these guidelines, most of the tested pavements will have sufficient capacity for at least five years and will not require immediate maintenance before that time. However, this study shows a large variation in the calculated infiltration rates between the study pavements and some pavements show significant clogging just after implementation due to factors as: poor design or traffic during construction.

Visualisation of the hydraulic behaviour of SUDS infiltration is recommended for understanding the conducted research and it contributed for a better understanding of SUDS by many actors (e.g. urban planners from water authorities and municipalities). This visualisation (Figure 6), which allowed real-time monitoring of the entire infiltration process, was useful as a logbook for the conducted experiments and also facilitated precise verification of the pressure transducer measurements.

Figure 6 visualisation by time-lapse camera showed the infiltration capacity before and after maintenance of permeable pavement at the same time on video (http://www.climatescan.nl/page?details=60). (Tipping, 2015)

It is intended to extend this study to include pavement testing in a number of other European countries in future.

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