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Do sediment type and test durations affect results of laboratory-based, accelerated testing studies of permeable pavement clogging?

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HIGHLIGHTS

- We investigated whether PICP clogging tests were affected by test methodology.
- Laboratory-based, accelerated testing was found to affect PICP clogging rates.
- PICP clogging was dependent on the type and size of sediment.
- Larger sized, genuine sediment particles (up to 1.18 mm) caused more PICP clogging.

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ABSTRACT

Previous studies have attempted to quantify the clogging processes of Permeable Interlocking Concrete Pavers (PICPs) using accelerated testing methods. However, the results have been variable. This study investigated the effects that three different sediment types (natural and silica), and different simulated rainfall intensities, and testing durations had on the observed clogging processes (and measured surface infiltration rates) of laboratory-based, accelerated PICP testing studies. Results showed that accelerated simulated laboratory testing results are highly dependent on the type, and size of sediment used in the experiments. For example, when using real stormwater sediment up to 1.18 mm in size, the results showed that neither testing duration, nor stormwater application rate had any significant effect on PICP clogging. However, the study clearly showed that shorter testing durations generally increased clogging and reduced the surface infiltration rates of the models when artificial silica sediment was used. Longer testing durations also generally increased clogging of the models when using fine sediment (<300 μm). Results from this study will help researchers and designers better anticipate when and why PICPs are susceptible to clogging, reduce maintenance and extend the useful life of these increasingly common stormwater best management practices.

1. Introduction

Increasing impervious surface area due to urban development can cause significant reductions in the quality of stormwater runoff, produce greater catchment runoff volumes and increase the potential for downstream flooding (Dietz, 2007; Lucke and Beecham, 2011). The use of permeable pavements in place of traditional impervious pavement surfaces can help reduce the negative effects of urbanisation and achieve best management practice (BMP) stormwater objectives including pollution removal and downstream flood mitigation (Bernot et al., 2011; Scholz and Grabowiecki, 2007).

There are a number of different types of permeable pavements including porous, concrete, porous asphalt and modular block paving systems (Mullaney and Lucke, 2014). The majority of modular permeable pavement systems consist of concrete blocks or pavers with open joints which allow infiltration of stormwater runoff between the pavers. These are generally called Permeable Interlocking Concrete Pavers (PICPs). The stormwater infiltrates through the PICP surface and bedding layers, and then permeates into the surrounding soil or is drained away via underground pipes (Fig. 1).

PICPs can improve water quality via the filtration processes that occur within the pavement structure (Nichols et al., 2014; Pezzaniti et al, 2009; Dierkes et al., 2002). Stormwater treatment takes place through the removal of suspended solids during infiltration of the stormwater through the pavement surface. Sediment is captured in the voids within and between individual paving joints, and in some cases, within the pavement material itself (Lucke and Beecham, 2011; Dierkes et al., 2002; Legret et al., 1999).

Previous research has demonstrated that clogging takes place in the spaces within and between the pavement and bedding layers and this causes a reduction in the pavement infiltration capacity after a few

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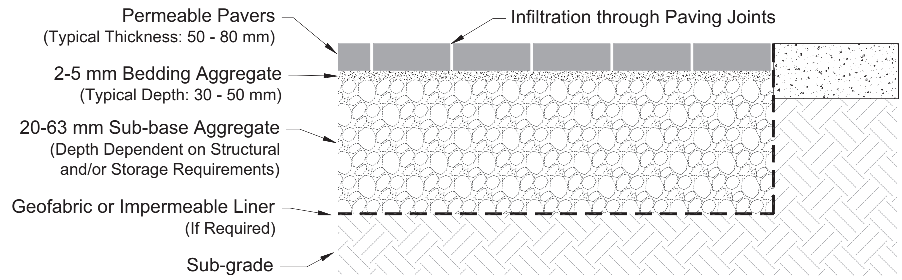

Fig. 1. Typical PICP structure.

years in service (Dierkes et al., 2002; Pratt, 1990; Borgwardt, 2006; Pezzaniti et al., 2009; Boogaard et al., 2014). Other reasons for lower PICP infiltration rates over time include poor construction practices, lack of maintenance, and unfavourable site conditions such as loose soils or excessive tree litter at the pavement location (Bean et al., 2007; Fassman and Blackbourn, 2010; Lucke and Beecham, 2011; Boogaard et al., 2013; Nichols et al., 2014).

Due to the relatively recent emergence of PICPs as a stormwater BMP, the opportunities to collect authentic, long-term field performance data have been limited. Many research studies have therefore used laboratory-based, accelerated testing methods using simulated stormwater to predict the long-term clogging behaviour of PICP field installations. Accelerated testing can be defined as using annual rainfall volumes over shorter durations during testing in order to provide timely results. The results and subsequent conclusions drawn from each of these studies appear to have been strongly influenced by the different techniques used in the study to measure and predict clogging and its effects on PICP surface infiltration.

Critical factors known to affect laboratory-based PICP surface infiltration rate testing include, simulated rainfall intensity and duration (Yong and Deletic, 2012; Yong et al., 2013), sediment mass, size and type (Borgwardt, 2006: Siriwardene et al., 2007; Lucke and Beecham, 2011), and intermittent drying times between tests (Yong et al., 2011; Fassman and Blackbourn, 2010; Yong and Deletic, 2012). Natural rainfall intensity and durations are difficult to replicate in the laboratory, and these are often compromised in laboratory-based studies in order to provide timely study results under controlled conditions. This is often demonstrated by the unrealistic intensities and rainfall durations used in many laboratory-based experiments.

It is also often difficult to collect and store sufficient quantities of natural stormwater runoff to use in laboratory studies. The quality of natural stormwater runoff is also highly variable, further complicating standardised testing procedures. Therefore, many laboratory-based PICP clogging studies use semi-synthetic stormwater runoff for their testing (Hatt et al., 2007; Siriwardene et al., 2007; Bratieres et al., 2008; Yong et al., 2013). The semi-synthetic stormwater is generally produced by mixing specific quantities of sediment and other pollutants into potable water to create semi-synthetic stormwater containing known pollutant concentrations. The sediment used is usually either natural sediment collected from existing stormwater pits or drains (Pezzaniti et al., 2009; Siriwardene et al., 2007; Yong et al., 2013), or commercially available, specialised silicon sands with particle size distributions similar to real sediment (González-Angullo et al., 2008; Ansaf et al., 2014).

The infiltration rates measured in previous laboratory-based PICP clogging studies have often been shown to be significantly higher than those observed in field-based studies. However, the causes of the large discrepancies between laboratory-based, and field-based tests are not yet fully understood. Variations in accelerated rainfall simulation techniques used during laboratory-based tests may significantly affect the clogging processes and results obtained, potentially leading to unrealistic long-term clogging and infiltration performance predictions of PICP systems.

1.1. Accelerated rainfall simulation

A study by Pratt (1990) appears to be the first published research to utilise accelerated rainfall and sediment application techniques on laboratory-based permeable pavement models. This study attempted to identify where, and in what proportions, sediment was retained within the models. Pratt (1990) collected real stormwater runoff and applied it to his laboratory models over a period of a few days to simulate 10 years of rainfall in the field. This laboratory setup included a stormwater storage tank with a continuous stirring mechanism and a pump to simulate rainfall, and runoff on the pavement models.

The study by Pratt (1990) pioneered the use of accelerated laboratory PICP testing techniques. Many studies have since used the methods similar to those developed by Pratt (1990) including: Dierkes et al. (2002), Borgwardt (2006), Siriwardene et al. (2007), González-Angullo et al. (2008), Pezzaniti et al. (2009), Yong et al. (2011, 2013). These studies used a variety of sediment types including natural and silica-based sediment.

This study investigated the effects that different sediment types (natural and silica) and different simulated rainfall intensities, and testing durations had on the observed clogging processes, and on the measured surface infiltration results of laboratory-based, accelerated PICP testing studies. The study results should be beneficial to practitioners and researchers to further understand PICP clogging processes, and their ability to anticipate when and why PICPs may clog.

2. Materials and methods

The objectives of this study were to attempt to quantify whether the clogging processes and the surface infiltration results observed using laboratory-based PICP models are affected by the type and size of sediment, and by the rainfall intensities and durations used in the testing procedures.

Semi-synthetic stormwater was used in the study (Hatt et al., 2007; Siriwardene et al., 2007; Bratieres et al., 2008; Yong et al., 2013). Three types of sediment were used to prepare the stormwater:

- Coarse sediment (prepared from real sediment < 1.18 mm in diameter);
- Adjusted Fine Sediment (prepared from real sediment < 300 μm in diameter); and
- Synthetic silica type 60G (sourced from Sibelco.com.au).

In January 2014, natural stormwater sediment was collected from three stormwater table drain catch-pits located on the University of the Sunshine Coast campus, Sippy Downs, Queensland. Litter and gross pollutants were first removed from the collected sediment, which was then placed in an oven to dry. The dried sample was then coarsely ground to remove agglomeration and passed through the respective sieve sizes (1.18 mm and 300 μm).

A review on urban runoff sediment by Walker and Wong (1999) reported that the particle size distribution (PSD) of sediment in runoff from Australian urban catchments was generally finer than sediment PSDs found in urban catchment runoff from other parts of the world.