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Review

Clogging in permeable concrete: A review

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A R T I C L E I N F O

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A B S T R A C T

Permeable concrete (or "pervious concrete" in North America) is used to reduce local flooding in urban areas and is an important sustainable urban drainage system. However, permeable concrete exhibits reduction in permeability due to clogging by particulates, which severely limits service life. This paper reviews the clogging mechanism and current mitigating strategies in order to inform future research needs. The pore structure of permeable concrete and characteristics of flowing particulates influence clogging, which occurs when particles build-up and block connected porosity. Permeable concrete requires regular maintenance by vacuum sweeping and pressure washing, but the effectiveness and viability of these methods is questionable. The potential for clogging is related to the tortuosity of the connected porosity, with greater tortuosity resulting in increased potential for clogging. Research is required to develop permeable concrete that can be poured on-site, which produces a pore structure with significantly reduced tortuosity.

Contents

1. Introduction

Urban areas are associated with hard impervious infrastructure that increases surface water run-off during heavy rain and the

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potential for localised flash flooding. Permeable concrete shown in Fig. 1, is widely-regarded as an important cost effective sustainable urban drainage system that can reduce storm-water run-off to alleviate the problem of localised urban flooding (EPA, 2004). It is made by omitting most or all of the fine aggregate from normal concrete and by careful control of the cement paste fraction. This produces a highly porous material with typically 15–35% volume of interconnected voids that allow very rapid water percolation.

A typical permeable pavement system consists of a top permeable concrete layer placed above a sub-base coarse aggregate layer and subgrade soil (Fig. 2). In practice, there are many variations in the number, thickness and composition of each layer, but all with the purpose of storing stormwater runoff until it infiltrates into the existing soil or is drained. Permeable pavement systems can be designed for full, partial or zero exfiltration depending on site soil conditions. Partial and zero exfiltration systems contain sub-drains or an impermeable liner to prevent water reaching the underlying soil. These systems are best suited for sites with poorly draining soils, contaminated soils or in groundwater sensitive areas (Drake et al., 2013; Crookes, 2015).

Permeable concrete is primarily used in car parks, pedestrian footpaths, cycle paths and other low-traffic areas. The hydrologic benefits of permeable pavements for reducing run-off volume and peak flow rates are well-documented (Abbott and Comino-Mateos, 2003). For example, annual run-off volume reductions of 50–100% have been observed (Stenmark, 1995; Legret and Colandini, 1999; Dempsey and Swisher, 2003). Even if the underlying soil is poor draining, permeable pavement systems can reduce peak flows by over 90% and surface run-off volumes by 43% (Drake et al., 2014). As such, permeable concrete pavements are well suited to existing urban areas that lack conventional storm-water management facilities. In new urban areas, they can decrease development costs by limiting the need for other storm-water management infrastructure (ACI, 2010; Ferguson, 2005; Tennis et al., 2004).

It has also been reported that permeable concrete captures suspended solids, P, N, Zn, Cu and motor oil, improving stormwater and groundwater quality (Schueler, 1987; Brattebo and Booth, 2003; Scholz and Grabowiecki, 2007; Calkins et al., 2010; Welker et al., 2013; Sansalone et al., 2008). It is also reported to improve skid resistance and minimise heat island effects in cities (Tennis et al., 2004; Amde and Rogge, 2013; Schaefer et al., 2006). However, the latter is probably due to a change in pavement colour (black asphalt to grey concrete), rather than the high permeability of permeable concrete.

While permeable concrete clearly has many benefits, it is inevitably susceptible to clogging that leads to serviceability problems and premature degradation (Deo et al., 2010; Yong et al., 2013; Mata and Leming, 2012; Coughlin et al., 2012; Tong, 2011). Physical clogging is caused by debris build-up on the surface and in the pore structure; this is likely to be the most common mechanism. Biological clogging caused by algae and bacteria, and penetration of plant roots can also occur (Ye et al., 2010; Mishra et al., 2013). Addressing this problem will substantially improve the durability of permeable concrete and optimize its application as a sustainable urban drainage system. Yet, this is not well-understood and limited information is available on factors influencing clogging (Tong, 2011; Mishra et al., 2013; Radlinska et al., 2012).

The objective of this paper is to critically review available studies on clogging, summarise current understanding of the problem and mitigating strategies. We aim to identify knowledge gaps and highlight research needs. A major challenge is that such research requires a range of expertise including cement and concrete materials science, pavement design, mass transport phenomena, structural, environmental and water resources engineering. Also, the amount of related studies has increased significantly in recent years. Therefore, a review that summarizes work from across these expertise is much needed. The structure of this paper is as follows. Properties of permeable concrete and factors influencing performance are first reviewed. Then, research related to understanding clogging and methods to unclog permeable concrete are addressed. Finally, future research needs are discussed.

2. Properties of permeable concrete

2.1. Composition and mix design

Materials used in permeable concrete are the same as in normal concrete, but the mix proportioning is different. The aim in permeable concrete mix design is to achieve a balance between voids, strength, paste content and workability. Fine aggregate content is significantly reduced (Tennis et al., 2004; Obla, 2007). Various mix proportioning methods have been recommended, and

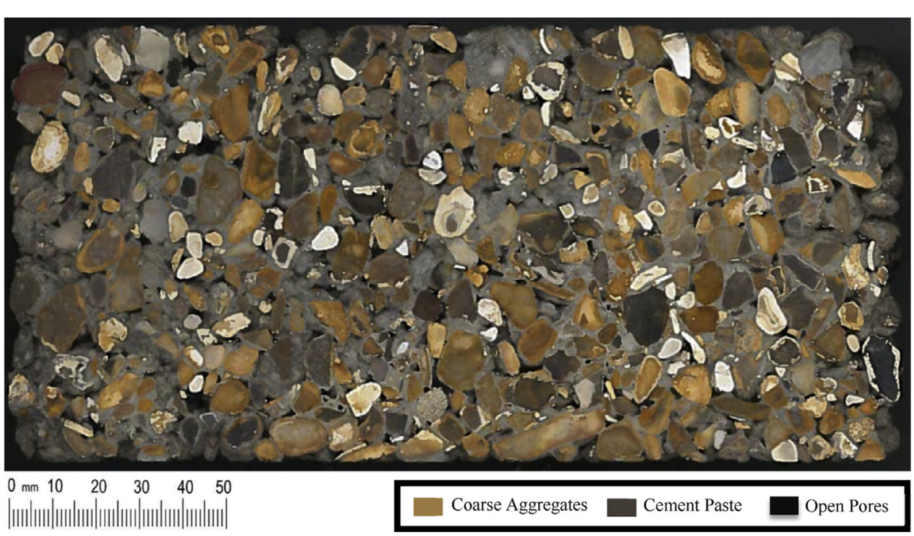

Fig. 1. Cross-section of a typical permeable concrete with porosity of 22%.