Maintaining Permeable Pavements: Unveiling the challenge through long-term monitoring and forensic engineering

Entretien des chaussées perméables: dévoiler le défi grâce à une surveillance à long terme et ingénierie inversée

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RÉSUMÉ

Il a été largement rapporté que les chaussées perméables (PP) posaient des problèmes d'encrassement qui réduisaient leur capacité à long terme. Malgré de nombreuses recherches menées à la fois en laboratoire et sur le terrain, il n'existe toujours pas d'études complètes couvrant toute la durée de vie opérationnelle du PP dans des conditions réelles. Le présent article décrit les résultats de 11 années de surveillance sur un parking expérimental sans activités de maintenance dans la ville de Santander, dans le nord de l'Espagne. Les mélanges poreux (MP) tels que l'asphalte poreux (PA) et le béton poreux (PC), ainsi que 2 types de revêtements en béton autobloquant (ICP), ont été testés conformément à la norme espagnole NLT-327/00 et à la norme ASTM C1781/C1781M-15 et C1701/C1701M-17a. Les performances hydrologiques à long terme et les courbes de tendance obtenues pour toutes les surfaces au fil du temps ont révélé que les particules étaient complètement obstruées après 10 ans, tandis que les ICP à joints ouverts continuaient à atteindre des taux de perméabilité élevés après 11 ans à compter de leur construction. L'ingénierie inversée est nécessaire pour mieux comprendre les modèles de performance à long terme du PP.

ABSTRACT

Permeable Pavements (PP) have been widely reported to present clogging issues which diminish their capacity in the long-term. Despite numerous researches conducted both at a laboratory and field scales, there is still a lack of comprehensive studies covering the entire operational life of PP under real conditions. The present article reports the results for 11 years of monitoring at an experimental car park with no maintenance activities in the city of Santander, Northern Spain. Porous Mixtures (PM) such as Porous Asphalt (PA) and Porous Concrete (PC), as well as 2 kinds of Interlocking Concrete Pavement (ICP), were tested under the Spanish Standard NLT-327/00 and the ASTM's C1781/C1781M-15 and C1701/C1701M-17a. The long-term hydrological performance and trend lines obtained for all surfaces over time revealed that PM were completely clogged after 10 years, whilst ICP with open joints proved to keep reaching high rates of permeability after 11 years from their construction. Forensic engineering is needed to further understand long-term patterns of performance of PP.

KEYWORDS

Clogging, flood resilience, interlocking concrete pavement, porous mixtures, SUDS.

1 INTRODUCTION

Porous Mixtures (PM) such as Porous Asphalt (PA) and Porous Concrete (PC), and Interlocking Concrete Pavement (ICP) have been the most widely used surfaces for Permeable Pavements (PP) worldwide (Sañudo-Fontaneda et al. 2018).

Recently published reviews on PP have highlighted the need to conduct more long-term studies to solve the knowledge gaps about the relationship between their performance and maintenance (Erickson et al. 2018), whilst Razzaghmanesh and Beecham (2018) pinpointed the need to follow standardised experiments in order to get comparable results internationally. Furthermore, field studies such as Winston et al. (2016) informed how PP could recover their infiltration capacity depending upon the maintenance activity. However, few investigations have been conducted about how PP loss their infiltration capacity over time with no maintenance activities, as pointed out by Sañudo-Fontaneda et al. 2018. This research seeks to fill these gaps and provide key data from a forensic perspective, analysing how different PP in an experimental car park reach their hydrological "*end-of-life*", a concept defined by McLaughlin et al. (2016).

2 METHODS

2.1 Location, climate context and car park materials

The car park monitored in this research is located in Santander, a coastal city next to the Cantabrian Sea, Northern Spain (Figure 1). Its Köppen-Geiger's climate classification is Cfb (Essenwanger, 2001), with 15ºC of yearly average temperature and 1,136 mm/year of average rainfall (García Couto 2011).

Figure 1. Location and car park scheme (Source: Google Maps).

37 out of the 45 car park bays in this experimental parking area (Figure 1) have been monitored for this study over 11 years. The breakdown of these bays is as follows: 9 of PA, 9 of PC and 2 types of ICP (10 of ICP-1 and 9 of ICP-2).

All car park bays presented the same base (50 mm of clean limestone aggregate) and sub-base layers (350 mm of clean limestone aggregate) in their cross-section. PC, PA and ICP-2 presented the same combination of filtration and separation layers: 4 bays of Polyfelt TS30, 4 bays of Danofelt PY150 and 1 bay with no geotextile. The remaining car park bays built by using the ICP-1 surface contained 4 bays of Inbitex, 4 bays of One-Way and 2 bays with no geotextile. These 2 kinds of geotextiles were those used by the PP industry in the UK in combination with the ICP-1 at the time of construction of this car park in 2008. Polyfelt and Danofelt were used by construction companies in Spain. Further details about the materials utilised could be found in Sañudo-Fontaneda et al. (2018).

2.2 Monitoring

The cark park bays were monitored according to two different standards. On the one hand, the Spanish NLT-327/00 (CEDEX 2000) allows to measure the infiltration capacity of PA surfaces by providing their permeability. This test can also be conducted to determine the permeability of PC surfaces, as proved by Fernández-Barrera (2008) and Sañudo-Fontaneda et al. (2014), having its correspondence with the European Standard EN 12697-40 (European Committee for Standardization 2012). On the other hand, the ASTM C1781/C1781M-15 (Figure 2) and C1701/C1701M-17a Standard Test Methods (ASTM 2015 and 2017) were developed to measure the infiltration rate in ICP surfaces and PC surfaces, respectively, being also used the latest one for PA surfaces. Table 1 shows the different tests carried out throughout the years on each car park bay, presenting the monitoring scheme followed by using standardised permeability tests.

Table 1. Tests performed on each permeable surface.

Year	PA	PC	ICP-1	ICP-2
0	NLT-327/00	NLT-327/00	Industrial specifications	Industrial specifications
5	NLT-327/00	NLT-327/00	-------	-------
8	NLT-327/00	NLT-327/00	-------	-------
10	NLT-327/00 and ASTM C1701/C1701M-17a	NLT-327/00 and ASTM C1701/C1701M-17a	ASTM C1781/C1781M-15	ASTM C1781/C1781M-15
11	-------	-------	ASTM C1781/C1781M-15	ASTM C1781/C1781M-15

Figure 2. Permeability test ASTM C1781/1781M-15 and view of the ICP-1 and ICP-2 lines.

3 RESULTS AND DISCUSSION

Trend lines for the long-term performance were obtained over 11 years of monitoring (Figure 3). The equations for each surface inform about the potential time when maintenance should be carried out for the specific conditions of Santander, Northern Spain. Based upon these trends, both PC and PA surfaces should have been maintained after 6-7 years of performance whilst ICP-1 and ICP-2, would require maintenance activities after 15 and 21 years, respectively, based on the predictive nature of these models. Time to clog has increased for ICP-2 in comparison to what it was found after 10 years in Sañudo-Fontaneda et al. (2018). This supports the idea of keeping a long-term monitoring in order to feed and update the predictive models.

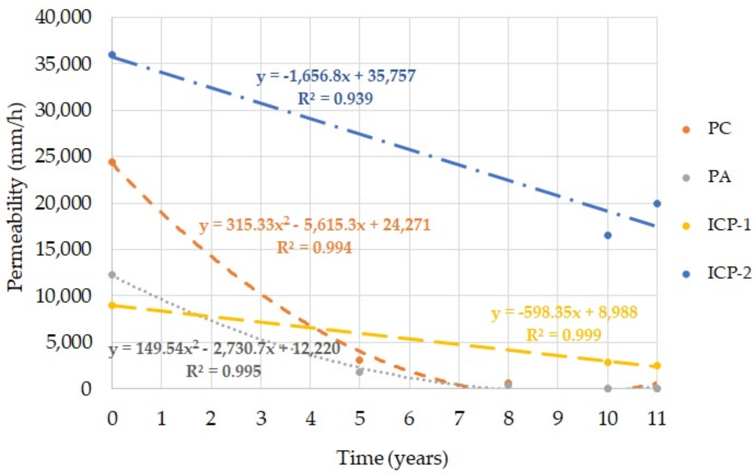

Figure 3. Trend lines for each permeable surface.

Furthermore, the average permeability values obtained for the ICP-1 surface after 11 years of performance (2,527 mm/h) fit into those reported by Razzaghmanesh and Beecham (2018) in their review on ICP surfaces, and those from Bean et al. (2007). However, the average permeability reached by the ICP-2 surface (19,966 mm/h) was comparable to the values measured after 2-4 years of performance at other locations considered in the previous review. This difference can be explained due to the lack of aggregate materials between the joints in the ICP-2 design, which confers extra volume for permeability.

According to Sañudo-Fontaneda et al. (2018) and what is has been found in this new research, PC and PA were reported completely clogged after 10 years of performance. These results respond to one of the gaps identified by Razzaghmanesh and Beecham (2018), since no field study was reported to monitor both PC and PA beyond 4 years and only one reached this figure for PA (Winston et al. 2016). Thus, this paper contributes to inform how different PP approach their "*end-of-life*".

4 CONCLUSION

PM surfaces (PC and PA) were reported completely clogged after 10 years of performance under the specific characteristics of the city of Santander, Northern Spain. Instead, ICP continued providing high infiltration rates after 11 years. Consequently, this research demonstrates that PP can keep providing a notable hydrological response over the years even with no maintenance. Thereby helping to break down one of the greatest barriers that hinder the implementation of SUDS with respect to traditional drainage networks. The results from this research can also be transferred to other parts of the world which share the same or similar climatic conditions.

To get more insight into the clogging susceptibility of PP, future research using standardised tests is of great importance in order to obtain comparable results across the world. Moreover, forensic engineering is needed to further understand long-term patterns of performance of PP. Therefore, dismantling those car park bays which have reached their end-of-life and analysing their sediments and final state of their cross-section is highly recommended.

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