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Field Study of Infiltration Capacity Reduction of Porous Mixture Surfaces

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Abstract: Porous surfaces have been used all over the world in source control techniques to minimize flooding problems in car parks. Several studies highlighted the reduction in the infiltration capacity of porous mixture surfaces after several years of use. Therefore, it is necessary to design and develop a new methodology to quantify this reduction and to identify the hypothetical differences in permeability between zones within the same car park bay due to the influence of static loads in the parked vehicles. With this aim, nine different zones were selected in order to check this hypothesis (four points under the wheels of a standard vehicle and five points between wheels). This article presents the infiltration capacity reduction results, using the LCS permeameter, of Polymer-Modified Porous Concrete (9 bays) and Porous Asphalt (9 bays) surfaces in the University of Cantabria Campus parking area (Spain) 5 years after their construction. Statistical analysis methodology was proposed for assessing the results. Significant differences were observed in permeability and reduction in infiltration capacity in the case of porous concrete surfaces, while no differences were found for porous asphalt depending on the measurement zone.

1. Introduction

Intense urban growth during the last decades [1], together with large-scale waterproofing of the natural soil in cities [2] and changes in the rainfall intensity patterns in the world [3], have led to many problems regarding flooding. This is actually the most common and costly disaster in the world [4,5].

Porous surfaces are one of the main Sustainable Urban Drainage Systems (SUDS) for source control in car park areas [6–8]. Many different devices have been used to measure the infiltration capacity on-site. Some of the most widely applied field devices nowadays around the world are single-ring infiltrometers [9], double-ring infiltrometers [10], and the LCS ("Laboratorio de Caminos de Santander") permeameter [11,12].

Previous studies, [13], highlighted the importance of analyzing different zones within a car park bay in order to obtain a more comprehensive view of real infiltration behavior in a car park with porous surfaces. The static and dynamic loads produced by the vehicle wheels can produce permanent deformations in the pervious surface, which could affect both porosity and permeability. Moreover, the vehicle wheels are the main source of particulate matter that can clog the pervious surfaces, especially due to the compaction force produced by the vehicle loads, this effect being more important in the contact zone between wheel and surface [14,15].

A new methodology was created for this research. Firstly, a scheme of field tests was created by using the LCS permeameter to measure the permeability, and finally, a statistical scheme of several analyses was designed and developed specifically for this kind of on-site test.

The aim of the new methodology presented in this paper was twofold. Firstly, the analysis of the influence of the porous mixture surface type on the permeability and the reduction in the infiltration capacity after 5 years of use. Secondly, the analysis of the possible differences in the infiltration capacity in different zones within the pervious parking bays.

2. Experimental Methodology

The whole study was carried out in the "Las Llamas" parking area in the University of Cantabria campus in Santander (Spain) 5 years after this car park was opened for light traffic. No maintenance operations have been carried out during this period. This parking area registers intense traffic activity every day, being nearly 100% occupied. Eighteen car parking bays of 4.2 m long and 2.4 m wide were analyzed with nine bays of Polymer Modified Porous Concrete (PMPC) and nine of Porous Asphalt (PA) surfaces (Figure 1).

The specific characteristics of the two porous mixture surface materials used can be checked in [12] based on the dosage recommended by [16] for PMPC, and [17] for PA. The high percentage of voids is remarkable, 25%–30% in the case of PMPC and 23% in the case of PA [12], as was the thickness of both porous surfaces (80 mm).

Figure 1. (**A**) Scheme of the eighteen car parking bays analyzed; and (**B**) measurement zones selected within each car park bay and LCS on-site.

The infiltration capacity reduction was analyzed through the permeability results obtained now (after 5 years of operational life) in each test carried out using the LCS permeameter [18], comparing these values with those registered by [12] for the same porous surfaces when built (0.020 m/s for the case of the PMPC surfaces and 0.012 m/s for PA surfaces on average).

Nine different points were selected within each car parking bay in order to undertake the LCS tests. Each point represents a specific zone (Figure 1) which hypothetically could influence the infiltration capacity reduction. Points 1, 3, 7 and 9 (Figure 1) represent the zone of the car parking bays in static contact with wheels, the zones that directly support the weight of the vehicles when parked. In contrast, points 4 and 6 (Figure 1) represent the zones that were in dynamic contact with wheels while a vehicle is performing its parking maneuver, being part of the wheels path. Finally, points 2, 5 and 8 (Figure 1) represent the zones that almost never have been in contact with vehicles tires.

2.1. Descriptive Analysis

The permeability results in the tests were partially described based on permeability ranges defined by [19] for porous asphalt surfaces when using the LCS permeameter. Each measurement zone in every car park bay and all car park bays received a score based on the time taken by the LCS test, using the criteria in Table 1. Moreover, plots of the average values of the outcome variables (permeability and reduction of the infiltration capacity) were used to analyze descriptively the infiltration behavior of the whole car parking area studied.

Table 1. Criteria for defining the permeability of a porous mixture surface when using the LCS permeameter.

Time (s)	Permeability (cm/s)	Score
<50	>0.50	Newly built
50–100	0.25–0.50	High
100–200	0.13–0.25	Medium
>200	<0.13	Poor

2.2. Statistical Analysis

To achieve the objectives explained in the introduction, a statistical methodology was designed, as can be seen in Figure 2.

Figure 2. Scheme of the statistical methodology designed.
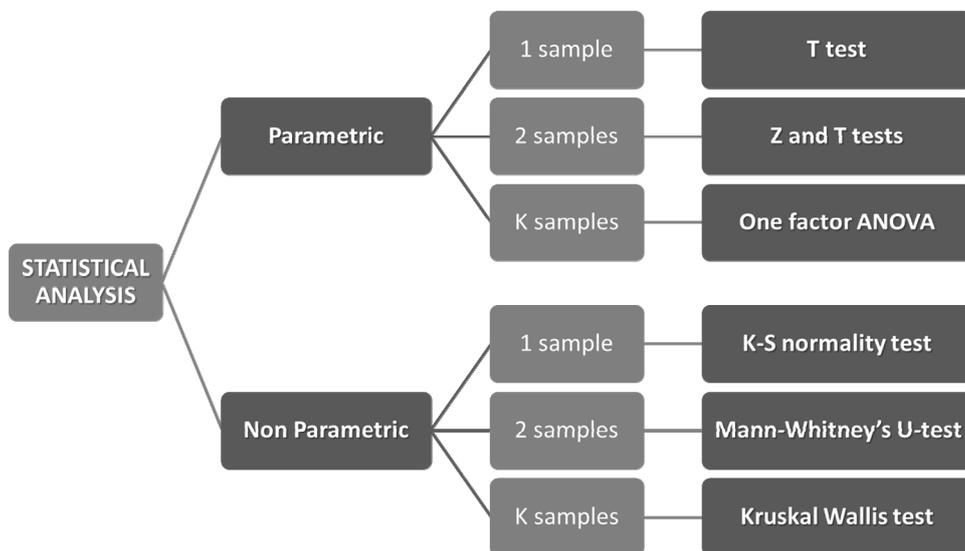
The statistical approach begins with the analysis of the normality distribution of the data in order to decide the path to follow in the statistical scheme in Figure 2: Parametric test for normally distributed data and non-parametric test for non-normally distributed parameters. Then, a more in-depth statistical analysis was done based on different significance tests (see Figure 2) with the aim of determining whether there are significant differences among the results obtained for the variables considered.

3. Results and Discussion

3.1. Descriptive Analysis

The distribution of the permeability values registered using the LCS permeameter at each measurement point of the analyzed parking bays of both types of pervious surfaces is in Figure 3.

It can be observed descriptively that there are differences in the infiltration capacity among the different measurement zones on both types of pervious surfaces, generally showing a reduction in infiltration capacity in some wheel-surface contact zones. Considering the average permeability values in

each measurement zone of each pervious surface type, the average reductions of the infiltration capacity were calculated and the results are shown in Tables 2 and 3 for the PMPC and PA surfaces, respectively.

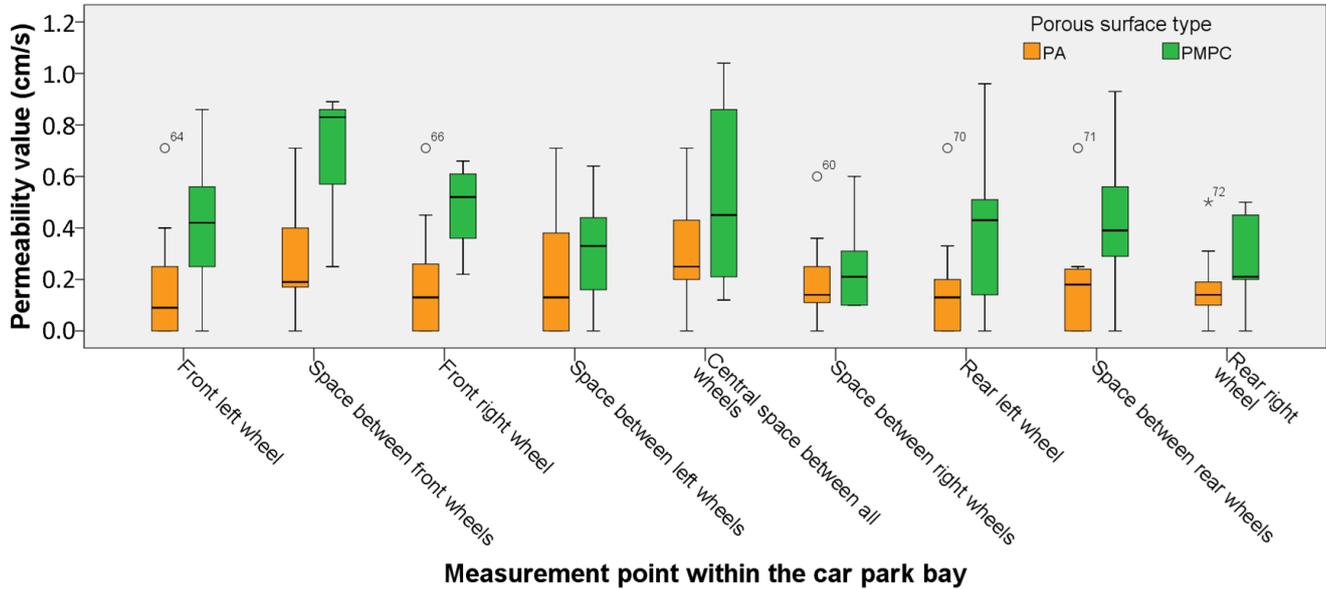**Figure 3.** Box-plots of the average values of permeability in each measurement zone of parking bays.

Table 2. Average permeability and reduction of the infiltration capacity values registered in each measurement zone within each Polymer Modified Porous Concrete (PMPC) surface car park and their corresponding score.

Measurement zone	Permeability (cm/s)	Score	Reduction of the infiltration capacity (%)
1	0.41	High	79..65
2	0.69	Newly built	65.62
3	0.47	High	76.45
4	0.31	High	84.47
5	0.54	Newly built	73.22
6	0.25	High	87.62
7	0.39	High	80.67
8	0.40	High	79.97
9	0.26	High	87.24
Mean value	0.41	High	79.43

Although the average value of the PMPC surface infiltration capacity demonstrated a high decrease of 79.43% (Table 2), the average permeability value is still high (0.41 cm/s). This value can be considered "high" in the score classification based on the criteria shown in Table 1. A highly similar decrease in the average reduction of the infiltration capacity was found in Table 3 for the PA surface (82.04%). However, the average score was "medium" for PA surfaces. This indicated possible problems in the future with the permeability behavior of this surface.

As can be seen in the box-plots in Figure 4, average PMPC permeability was almost double that of PA (0.41 cm/s for PMPC and 0.22 cm/s for PA), while the reduction in the infiltration capacity on both

porous mixture surfaces was quite similar (79.43% in the case of the PMPC surface and 82.04% in the case of the PA surface).

Table 3. Average permeability and reduction of the infiltration capacity values registered in each measurement zone within each Porous Asphalt (PA) surface car park and their corresponding score.

Measurement zone	Permeability (cm/s)	Score	Reduction of the infiltration capacity (%)
1	0.20	Medium	83.52
2	0.27	High	77.46
3	0.21	Medium	82.40
4	0.22	Medium	81.70
5	0.30	High	74.85
6	0.21	Medium	82.57
7	0.17	Medium	85.61
8	0.18	Medium	85.05
9	0.18	Medium	85.23
Mean value	0.22	Medium	82.04

Figure 4. Box-plots of the average values of permeability (**A**) and the reduction of the infiltration capacity (**B**).

(**A**)   (**B**)
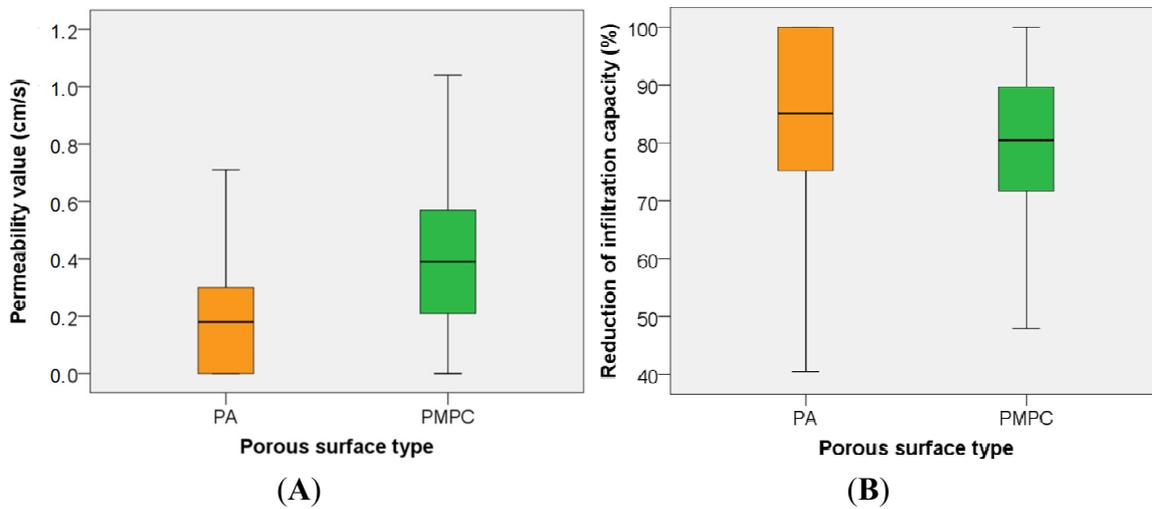
3.2. Statistical Analysis

The first step was to check the normality of both outcome variables by using the Kolmogorov-Smirnov test. Neither variable had a normal distribution. Therefore, non-parametric significance analyses were carried out (Figure 2), by using a Mann-Whitney test for the type of porous mixture surface (two samples: PMPC and PA) and a Kruskal Wallis test for the measurement zone (9 samples: zones 1 up to 9) (Table 4).

Significance tests shown in Table 4 demonstrate that only the type of porous mixture surface significantly influenced permeability results, while neither the type of porous surface nor the measurement zone influenced the reduction in infiltration capacity.

Table 4. Mann-Whitney and Kruskal Wallis significance tests for the outcome variables.

Significance test	Parameter	Permeability	Reduction of the infiltration capacity
Mann-Whitney *	U de Mann-Whitney	1888.5	2716.5
	Asymptotic significance	0.000	0.058
Kruskal Wallis **	Square Chi	12.493	13.329
	Asymptotic significance (bilateral)	0.131	0.101

Notes: * Grouping variable: type of porous mixture surface; ** Grouping variable: measurement zone.

Once the influence of the porous mixture surfaces has been demonstrated in Table 4, it is only necessary to verify the real influence of the measurement zone on the outcome variables for each type of porous mixture surface. With this aim, the normality and homoscedasticity of both outcome variables was analyzed as an initial step. PMPC surface permeability and reduction in infiltration capacity results were distributed according to a normal and homoscedastic distribution, while in the case of the PA surface, these results were not normal. Thus, in order to use the same test for both types of pervious surfaces, a Kruskal Wallis test was done to analyze the influence of the measurement zone on the outcome variables (Table 5) based on the statistical scheme shown in Figure 2.

Table 5. Significance analyses for k-independent samples (measurement zones) by using Kruskal Wallis test.

Type of surface	Statistical Significance Test	Permeability	Reduction of the infiltration capacity
PMPC	Square ChiChi	17.752	17.742
	Significance (bilateral)	0.023	0.023
PA	Square Chi	4.397	4.522
	Significance (bilateral)	0.820	0.807

Note: Grouping variable: measurement zone.

The results shown in Table 5 demonstrate the influence of the measurement zone on permeability values and on the reduction in infiltration capacity obtained after 5 years of use in car parking bays made of PMPC. However, in the case of PA, no influence was identified.

Therefore, both the statistical methodology and the measurement zones shown in this article can be used for present and future research when using the LCS permeameter to study the infiltration behavior of porous mixture surfaces on-site during their operational life.

4. Conclusions

The statistical methodology described in this article has proven its efficiency in this particular scenario. Therefore, this methodology could be used in similar investigation in order to prove the general suitability of materials used in infiltration surfaces

In this field study, permeability is significantly different for PMPC and PA surfaces after 5 years of use, as it was at the beginning of their operational life, the PMPC surfaces having higher permeability values.

No significant differences were found between PMPC and PA surfaces regarding their infiltration capacity reduction after 5 years of use.

The measurement zones proposed for this research for analyzing the infiltration capacity behavior of a porous surface car parking bay after 5 years have demonstrated a significance influence of the zone on permeability results for PMPC surfaces.

No significant differences were identified among all the measurement zones for PA surfaces, its infiltration behavior being quite uniform after 5 years of use.

Acknowledgments

Author Contributions

The four co-authors designed the research methodology, specifically Luis A. Sañudo-Fontaneda and Valerio C.A. Andrés-Valeri carried out the test in the car park and the statistical analysis of the results, while Jorge Rodriguez-Hernandez and Daniel Castro-Fresno validated the analysis, lead the discussion and stated the final conclusions.

Conflicts of Interest

The authors declare no conflict of interest.

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