Clogging of Permeable Pavements: Case Study

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Abstract. The use of permeable pavements has been an important tool for flood reduction and minimization of the greenhouse effect in urban centers. This type of pavement allows the passage of water and air through its layers and, when designed and applied correctly, may contribute to the reduction of surface runoff during the occurrence of peak flows. The problem with this type of pavement is the decrease in permeability that will inevitably occur due to the use over time. This is called clogging and is caused by the gradual deposition of particulate material between the voids, which originally allowed the rapid passage of water. Studies show that sealing of permeable pavements can occur between 5 and 10 years after their construction, depending on sources of pollution, punctual or diffuse, that can reach the coating layer. In this way, part of the clogging to which the pavement will be exposed can be avoided, even in the design phase, increasing its useful life. This study presents an evaluation of the sealing mechanism in some types of permeable pavements. The evaluation was carried out in the field, through the monitoring of measurements of the permeability coefficient in an area used as light vehicle parking. The measurements were carried out shortly after the work was finished and fourteen months after the release to traffic, which allowed to evaluate the level of natural reduction of the permeability coefficient and the impact on the functioning of the pavement and, in parallel with this evaluation, similar in a simulator, with the empirically accelerated clogging. The objective was to demonstrate that the deposition of residues that cause septum, in most cases, is limited to the coating layer, which would facilitate the cleaning of the pavement, recovering its main functionality, the permeability.

1. Introduction
Developing urbanization and covering more areas with imperfect whether roads, streets, sidewalks or buildings, the natural process of rainwater seepage has been diverted and slowed. The decrease in the infiltration rate causes a reduction in groundwater recharge, which, in general, is responsible for the formation of supply areas to the population.

Besides that, the waterproofing of urban centres makes these regions more susceptible to flooding, given the inability of surface drainage to withstand the increasing volume of rainfall in these areas due to changes in the microclimate in the region.

Therefore, drainage has become another problem in the urban development model almost worldwide. In this context, permeable paving presents itself as a design option for effectively draining urban drainage. Permeable pavements are an alternative to traditional asphalt or concrete surfaces, which can help alleviate some of these issues.
In areas with suitable permeability soils, permeable pavements allow rainwater to seep into the soil, reproducing the natural hydrological cycle and recharging groundwater. Even if this direct infiltration does not occur in the soil, the permeable pavement contributes to the withdrawal of surface water, creating a delay in its arrival to watercourses through drainage channels, minimizing the occurrence of floods, and allowing increased surface evaporation, which provides increased relative humidity at the site and minimized surface temperature, reducing the heat island effect.

A relevant point in the adoption of permeable pavement is its durability as a drainage device, even considering the clogging process. Studies show that clogging of permeable floors can occur between 5 and 10 years after their construction, depending on occasional or diffuse sources of pollution that may reach the floor covering. In this way, part of the clogging to which the pavement will be exposed can be avoided, even in the design phase, increasing its useful life.

2. Permeable Pavements

The construction of permeable pavements arose due to the great need from urban drainage. As an infiltration device, it acts as an alternative technique for water infiltration into the soil, thus becoming an important drainage tool (Virgiiliis, 2009).

The permeable pavement is a structure that allows water and air to pass through its layers. The water, when captured by the pavement, can be conducted to a reservoir, allowing its reuse, or be infiltrated through the subsoil, depending on its permeable capacity. In waterproof coatings, rainwater flows only through the surface. The water depth is thicker the higher the intensity of the rain (Figure 1, GNCSC, 1996).

![Figure 1. Surface runoff of water in waterproof coating (GNCSC, 1996).](image1)

In the permeable pavements, due to the high voidness of the structure, a network of channels is formed, from the covering layer to the subgrade, which must be able to percolate a large portion of the precipitated rainwater. Under these conditions, surface flow is greatly reduced, as shown in Figure 2.

![Figure 2. Infiltration and percolation in permeable coating (GNCSC, 1996).](image2)

The Environmental Protection Agency has classified permeable pavements as Best Management Practice (BMP), one of the sustainable solutions for urban drainage.

The pioneer country in the application of permeable flooring was France from the 1950s. Without much success at the time, it was again studied in the late 1970s in other countries, such as the United States, Japan and Sweden.
According to various sources, currently the country that uses this system the most is Germany, where approximately 20 million square meters of this floor are installed in residential and commercial buildings per year.

In Brazil, permeable pavement has been used by construction companies to meet standards regarding the percentage of permeability required on land and also by municipalities in several states, but we are still far from reaching the scale of use in Europe or the USA.

Permeable floors are known as reservoir structures. This denomination refers to the functions performed by the porous structure with which they are constituted, having to attend to two simultaneous functions (ACIOLI, 2005):

- Mechanical function, associated with the term structure, which allows to support the loads imposed by vehicle traffic.
- Hydraulic function, associated with the term reservoir, which ensures, by the porosity of the materials, to temporarily retain the water, followed by drainage and, if possible, infiltration into the subgrade soil.

ABNT NBR 16416 (ABNT, 2015) lists five types of permeable concrete coatings, as shown in figures 3 to 7.

**Figure 3.** Concrete pieces with flared joints. Percolation by the joints.

**Figure 4.** Concrete pieces with hollow areas. Percolation through the leaks.

**Figure 5.** Porous concrete pieces. Percolation by the pieces.
Therefore, the coating layer of a cement-based permeable floor may allow water to pass through the granular material of the joints, or the castings, or through the permeable concrete of the parts or plates themselves.

The minimum permeability coefficient established by standard by ABNT NBR 16416 (ABNT, 2015) is 10⁻³ m/s or 60 L/min, and the minimum void index is 32% for all granular layers of the floor. For permeable concrete, no void index is established; in any case, the permeability coefficient must be taken into account.

The building system for a floor to be permeable must contain the distributed layers, as shown in Figure 8.

![Building system of permeable pavements.](image)
3. Clogging
Permeable pavements are an important alternative as a hydraulic and mechanical support device, but these floors will certainly have their pores blocked by debris, gradually reducing the infiltration rate and, consequently, their hydraulic contribution as a drainage device.

In the work presented by AMIRJANI (2010), it is shown that the porous pavement clogging occurs between 5 and 10 years after construction, depending on the boundary conditions.

The cause of pore obstruction has been extensively studied and has a widely accepted definition where clogging materials or sedimentation solids, including soil, rock, leaves and other debris, can be carried by wind or, more commonly, rainwater. These infiltrate the water-borne voids and diminish the hydraulic function due to the gradual reduction in permeability and storage capacity of this system.

With this reduced hydraulic capacity, infiltration gradually decreases to form a relatively impermeable matrix. The development of clogging is therefore characterized by an increase in the amount of retained materials on the surface and an increase in surface runoff.

As described by Van BOCHOVE and Von GORKEN (1997), the factors on which the clogging of a permeable pavement depends are:

- Amount and sources of pollution;
- Size and structure of voids;
- Slope of the contribution area underlying the permeable area; and, speed and wiping effect of traffic.

Among these factors, the intensity of vehicle traffic seems to be a determining factor in clogging, because in roads with heavy traffic, pore clogging occurs more slowly, because there is the suction caused by the passage of vehicles, which tends to unclog the voids, whereas, where traffic is light, the pumping of particles out of the voids does not happen expressively, which results in faster clogging.

The studies by TONG (2011) present some cases where clogging effects can be caused (Figures 9 to 11).

![Figure 9. Clogging due to debris flow from an area with fine materials without vegetation cover (TONG, 2011).](image1)

![Figure 10. Clogging caused by traffic during construction (TONG, 2011).](image2)
It is important to note that different types of sediment cause different deposition patterns and different effects on the reduction of hydraulic performance and maintenance recovery.

As observed by HASELBACH (2010), larger particles tend to be trapped at or near the top, finer sand particles penetrate the pavement and get trapped inside concrete (in the case of porous concrete), even finer particles. They can seep into the pavement and can then be deposited between the surface of the concrete layer and the underlying soil.

Several studies have reported that thicker particles took longer to clog the pavement than finer particles. Clay materials tend to be trapped on or near the floor surface, gradually reducing the permeability coefficient.

Clogging cannot be completely prevented, but its formation can be delayed, and its effects minimized. According to PORTO (1999), a properly designed project minimizes surface clogging.

The maintenance of permeability properties over the useful life of the floor can be ensured by cleaning the permeable floor on a regular basis. RAZ (1997) made a comparison on Spanish highways on the evolution of clogging between clean and permeable treated permeable pavements, as shown in Figure 12.

Research points out that each floor will have its own cleaning needs at different time intervals, but as a general measure, one should think of the year following its construction as a time limit to consider the need for cleaning. Experimental values have shown that by cleaning, the loss of permeability that can occur in the first year is recoverable by around 50% and that if the annual frequency of the procedure is maintained, losses of the second year can be recovered by up to 70%.

ABNT NBR 16416 (ABNT, 2015) establishes that the pavement must undergo cleaning procedures when the permeability coefficient is equal to or less than m/s or 0.6 L/min, and cleaning actions should be performed with the objective of recovering its permeability. The recommended cleaning steps are:

- Removal of dirt and general debris from the floor surface by mechanical or manual sweeping;
- Application of water jets under pressure;
- Application of suction equipment for fines removal;
- Replenishment of grouting material if necessary.
The use of chemicals or contaminated water is prohibited in cleaning the floor. After performing the cleaning steps, the permeability coefficient of the floor should be measured again. Areas that have been cleaned must have at least 80% of the minimum permeability coefficient described above of $10^{-3}$ m/s or 60 L/min.

4. Experimental Evaluations
In this work, we study the evolution of clogging in the field, measuring the permeability coefficient of a permeable parking area, right after its execution and after 14 months of use. In addition, in the laboratory, we simulate accelerated clogging in order to evaluate its influence on pavement permeability.

The test method for measuring the permeability coefficient is described in NBR 16416 (ABNT, 2015). The method consists of using a (300 ± 10) mm diameter infiltration ring, which should be positioned at the test site and sealed at the contact with the floor, with caulk to prevent leakage, limiting the contact area with the water.

The water mass to be used for the permeability coefficient test is defined as a function of the prewetting time of the site to be tested. During pre-wetting, 3.6 kg of water should be poured into the infiltration cylinder, keeping a column of water between 10 mm and 15 mm from the floor surface, which helps to regulate the application rate of the water mass for the remainder of the test. Depending on the infiltration time during pre-wetting, the standard establishes the water masses to be used later in determining the permeability coefficient, as shown in Table 1.

| Pre-wetting time (s) | Mass of water (Kg) |
|----------------------|--------------------|
| ≤ 30                 | 18 ± 0,05          |
| > 30                 | 3,60 ± 0,05        |

The permeability coefficient determination test shall be run within 2 min after pre-wetting. The procedure follows the same pattern as for pre-wetting. The time interval from the moment the water reaches the surface of the permeable pavement should be marked until there is no more free water on the tested surface.

For calculation purposes, the standard states that equation 1 is used to obtain the permeability coefficient ($k$):

Equation 1:

$$k = \frac{c \cdot m}{(d^2 \cdot t)}$$

At where:

- $k$ - permeability coefficient (mm / h);
- $m$ - infiltrated water mass (kg);
- $d$ - inner diameter of infiltration cylinder (mm);
- $t$ - time required for all percolating water (s);
- $C$ - SI system unit conversion factor, with a value of 4 583 666 000.

5. Case Study
5.1. Onsite Testings
Field clogging was evaluated by monitoring a permeable area used as a light traffic parking lot. The place is at the headquarters of the Brazilian Association of Portland Cement - ABCP, in São Paulo. The work was completed in May 2016 and the site has seven parking spaces totaling 87.5 m$^2$, and in the rolling layer four types of coverings were used (Figure 13):

- Flared joints: samples A and B;
- Porous parts: sample C (10x20 cm) and sample D: (20x20 cm);
- Porous plates (40x40) cm: sample E.
- Pieces with leaks (Grass and Rock): Samples F and G.
The permeable stretch structure is made up of fine granular material totaling 2 m³, distributed in three different layers:

- Subgrade: consisting of a 20 cm layer of gravel, with a maximum diameter of 37.5 mm and void content of 43.8%.
- Bed: 4 cm intermediate layer of gravel, with a maximum diameter of 12.5 mm and voids index of 41.6%.
- Laying layer: 4 cm thick, with 6.3 mm maximum diameter and void content of 43.7%.

![Image](image13.png)

**Figure 13.** Overview of the permeable area right after the completion of the work (ABCP, 2016).

It is important to highlight that in the whole pavement structure there is no presence of fine materials in granular materials and the voids index is higher than 32% specified in ABNT NBR 16416 (ABNT, 2015).

Thus, not only the coating layer, but the entire floor structure allows water to pass through, thereby constituting a porous structure sufficient to allow temporary storage of the precipitated water.

The site has the characteristics of low traffic volume, as it is a private parking, with low turnover, and with diffuse and localized sources of organic material and others, enhancing the effect of clogging.

The permeability coefficient was measured shortly after completion of the work and 14 months after release for use. During the assessed period no maintenance or cleaning of the floor was performed. Figure 14 shows a view of the site.

![Image](image14.png)

**Figure 14.** Overview of the permeable area immediately after release for use (ABCP, 2017).

Table 2 and Figure 15 present the results of the average permeability coefficients for each type of permeable area coating, each being a parking space.
5.2. Laboratory Testings
Laboratory studies were performed on a floor segment of about 1 m², simulating the entire granular structure of a permeable floor, as shown in Figure 16.

For the simulation of clogging in the laboratory, the coating of porous concrete pieces with dimensions of (10X20) cm was chosen. The coating was tested in three different situations:
- Sample 1: Porous parts with clean surface;
- Sample 2: Porous parts with
- application of 0.4 kg of crushed powder (material passed through the sieve 1.4 mm and retained in the sieve 1.16 mm), previously diluted in 2 liters of water;

![Figure 16. Simulator of the section of a permeable pavement.](image)
Sample 3: Porous parts with application of 1 kg of quartz sand (through-screen material 4.8 mm), previously diluted in 2 liters of water. Reference samples (clean surface) and the two previously clogged samples were tested to determine the permeability coefficient according to ABNT NBR 16416. Figure 17 shows the tested surfaces.

Figure 17. Samples of porous concrete pieces (10x20 cm) tested to simulate accelerated clogging.

Table 3 presents the results obtained in the pre-wetting test to determine the amount of water to be used in the permeability coefficient test.

Table 3. Determination of water mass for permeability coefficient test.

| Pre-Wetting Time 3,6 Kg of water |
|-------------------------------|
| Samples | Time (s) | |
| Sample 1 | 6,19 | |
| Sample 2 | 16,43 | |
| Sample 3 | 21,31 | |

The pre-wetting time results were below 30s in the three preparation conditions, so in the test to determine the permeability coefficient, a mass of 18 kg of water was used. The infiltration times of each sample were measured in three determinations each and the results are presented in Table 4.

Table 4. Determination of infiltration time for each sample.

| Infiltration Time (s) |
|-----------------------|
| Determinations         |
|                        |
| Samples                |
| 1                      |
| 2                      |
| 3                      |

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The permeability coefficient was determined according to the equation specified in ABNT NBR 16416 and presented above. The results obtained are presented in Table 5.

### Table 5. Permeability coefficients.

| Determinations | Permeability Coefficient | Sample 1 | Sample 2 | Sample 3 |
|----------------|--------------------------|----------|----------|----------|
|                |                          | L/min    | M/s      | L/min    | M/s      | L/min    | M/s      |
| 1              |                          | 628.8    | 1.05 x 10^{-2} | 468.8    | 7.81 x 10^{-3} | 106.8    | 1.78 x 10^{-3} |
| 2              |                          | 619.5    | 1.03 x 10^{-2} | 467.8    | 7.80 x 10^{-3} | 69       | 1.15 x 10^{-3} |
| 3              |                          | 635.9    | 1.06 x 10^{-2} | 484      | 8.07 x 10^{-3} | 62       | 1.03 x 10^{-3} |
| Average        |                          | 628.1    | 1.05 x 10^{-2} | 473.5    | 7.89 x 10^{-3} | 79.3     | 1.32 x 10^{-3} |

### 6. Final Considerations

The results show that all types of onsite tested coatings presented permeability coefficients above the minimum specification of ABNT NBR 16416, above $10^{-3}$ m / s or 60 L / min, even after 14 months in use and with conditions favorable to the occurrence of clogging.

The most significant permeability reduction in this period occurred in the grass coating layer (72%), while in the 40x40 cm porous plate coating, there was virtually no reduction (only -2%) in relation to the initial use permeability. Larger clogging of the grass coating was expected, as with the growth of the grass, the largest rooting occurs, reducing the porosity of the coating.

This demonstrates the importance of treating permeable systems as a function of the permeability quantification by measuring the permeability coefficient rather than simply the type of coating, which is often mistakenly considered permeable, such as an area with vegetation cover.

In the case of simulated clogging, the thicker material (quartz sand) resulted in a greater decrease in clogging due to its more superficial deposition on the pavement, while the finer material (gravel dust) was able to penetrate to the bottom layer. settlement, dispersing more and thus less influencing permeability.

It can also be seen that permeability coefficient determinations at the same point as quartz sand clogging simulation (determinations 1 to 3) resulted in increased permeability. This is explained by the removal of clogging material as water was poured into the test, paving the way for water percolation.

The clogging process of the permeable pavement should be further studied, as its influence on the gradual decrease of permeability is evident.

The design of a permeable pavement should consider the likely sources of material that could cause clogging and evaluate ways to prevent its entrainment to permeable surfaces, thus avoiding premature decrease of permeability and / or shorter cleaning periodicity.

In any case, at least annual maintenance of the permeable pavement would be sufficient to prevent the pavement structure from being compromised in its ability to function as a temporary reservoir and thus contribute to decreasing runoff, and this maintenance should be part of good practice of implementing permeable floors.

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