Study of the drainage properties of pervious concrete

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Abstract: The current trend in the management of urban drainage systems is to return to pre-development conditions that mimic the flow characteristics of natural ecosystems. To do so, cities must implement technologies designed to increase water infiltration and reduce the runoff speed. Pervious concrete is among the new technologies seeking to return paved urban areas to conditions that mirror original soil drainage properties. The prototype described in this study is based on specifications provided by Caderno de Encargos do Departamento de Esgotos Pluviais (DEP) from Porto Alegre, where prototypes of grids similar to those produced by DEP are described, however our prototype was made using pervious concrete. Tests were conducted to compare the mechanical strength of our pervious model and those of DEP, made with conventional concrete. Pervious concrete performed better than conventional concrete in all assessments, suggesting that the application of this technology could be a viable alternative.

Keywords: elements of drainage; pervious concrete; urban drainage.

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1 Introduction

Episodes of floods in urban areas have increased exponentially, reducing quality of life and bringing harm to property worth. This is a result from the accelerated urban development and soil sealing that result in the channelling of storm-water. The effects of urbanisation on storm-water runoff have been observed in different localities, the main aspects are the increased magnitude of the critical flow rates, volumes disposed, and the reduced time for the maximum peak flows to occur. The consequences of these impacts are shown in the form of urban flooding and mudslide. Urbanisation may have negative environmental impacts as storm-water runoff from paved surfaces and roofs increases, possibly causing erosion and carrying additional storm-water and related pollutants to water bodies (Haselbach et al., 2014).

Pervious concrete pavement is a low impact development pavement alternative (Henderson and Tighe, 2013). It is a unique construction material that serves simultaneously as a structural surface and a storm-water best management practice. Due to its void structure, pervious concrete allows for water and air to flow through the pavement (Haselbach, 2010). In this direction, pervious concrete is one of the important emerging technologies for sustainable facilities and infrastructure (Montes and Haselbach, 2006).

Storm-water management has become a concern for cities and municipalities due to increased urbanisation of residential and commercial neighbourhoods (Gupta, 2014). The storm sewer systems direct and assist the flow of non-absorbed water after the occurrence of atmospheric precipitation, preventing the formation of floods. These traditional drainage systems usually consist in a transportation network of galleries and underground conductors, responsible for quickly carrying the excess water downstream. There has been a great number of observed cases of inefficiency of the existing storm-water networks, since the vast majority of the existing systems are exceeded and do not meet the actual needs of urban centres, which grew and stretched beyond its limits compromising the entire flow of water in the basin (Aciolli, 2005).

The classic conception of drainage systems mainly aims rapid storm-water runoff, transporting it from upstream to downstream in the shortest time. As a result, the increase in peak flows and runoff volume, the reduction of flow time and especially the occurrence of floods and mudslides can observed. Even though this principle has not been applied in the developed countries since the early 1970s (Tucci, 2003) some Brazilian cities still adopt this concept.

Modern concepts of urban rainwater drainage systems consider that new projects should not contribute to the peak discharge increase in natural conditions. For this reason, the basin plan should include measures to control the output volume avoiding the transference of impacts downstream. The control of draining power can be managed through infiltration areas and infiltration trenches, permeable pavements and restraint systems. The principle is to maintain the existing flow, not allowing the problem to dissipate towards upstream locations of the basin.

Pervious concrete is a novel pavement which is being developed to aid in preventing storm-water related environmental problems. Pervious concrete has a network of interconnected voids which allow water exfiltration to the sub-base below (Kevern et al., 2012).

The use of pervious concrete in urban drainage is an alternative to reverse the impact that urban waterproofing caused to the environment, allowing greater infiltration of rainwater and helping to reduce the need for costly infrastructure projects. When used outdoors, the permeable concrete allows the rainwater to infiltrate directly into the soil, decreasing the flow that goes to the city drainage system. Furthermore, its adoption also contributes to the maintenance of underground aquifers and to reduce speed and volume of groundwater runoff, contributing to a more sustainable development.

Seeking an alternative to reduce the high costs of bulky drainage works, the present work proposes the use of pervious concrete in place of conventional concrete aiming the production of elements for urban drainage.

Pervious concretes are characterised by a large presence of interconnected voids that ensure permeability to rainwater. Therefore the fine aggregate (sand) is not used and its formulation is produced only with water, cement and coarse aggregate. It is guaranteed that the obtained material has a void volume between 15% and 25%, and percolation capacity around 200 L/m^2/min (ACI 522R-10, 2011). The degree of permeability related to pervious concretes is enough to allow the passage of all the precipitate flow from the climatic events, practically abolishing runoff. Due to the high porosity of this material, it permits a flow of water of around 5,080 mm/h, that means infiltration rates higher than 200 L/min/m^2 (Huffman, 2005).

The Institute of Hydraulic Research (IPH) from UFRGS demonstrates water flow rates of 120 L/m^2/min (2 mm/s) to 320 L/m^2/min (5.4 mm/s) on pervious concrete samples, corroborating to the high infiltration capacity of permeable pavements made with pervious concrete (Araújo et al., 1999). The authors emphasise that the results obtained are far beyond the capacity of most soils, which are limited to the soil properties located at the pavement-base.

Other pervious concrete advantages are associated with its thermal and acoustic properties, allowing its use as insulation for buildings walls, as well as soundproof barriers (Polastre and Santos, 2006). Collected evidences indicate that the use of this material can collaborate to reduce heat island effects, support vegetation, prevent accidents due to slipping on smooth surfaces with water accumulation, contribute to the capture of carbon dioxide (CO_2) and reduce the aggregate and cement consumption.

Due to its high porosity, the resistance of pervious concrete is normally inferior to its conventional concrete counterpart. For this reason its use is often limited to areas of low intensity traffic. According to the ACI 522R-10 (2011), mixtures of pervious concrete tend to develop compressive mechanic resistance in the range of 3.5 to 28 MPa, but according to Polastre and Santos (2006), the average resistance of pervious concretes is usually close to 25 MPa.

The time available for pouring operations of this type of concrete should be smaller than the time normally adopted for conventional concretes. It must be completed within one hour between the initial mixing time and the end of the work. This is necessary due to the characteristics of this material, which presents increased evaporation rate, with a faster loss of water.

The usage of pervious concrete is still in initial stages in Brazil and there are few published works and an even smaller number of practical examples of this type of material. The few references found in Brazilian literature involve applications in Park Belo Horizonte (Polastre and Santos, 2006), some exploratory projects of the IPH at UFRGS (Aciolli, 2005), and some studies carried out in USP (Silveira, 2010). Moreover, there are still no standards to guide the Brazilian manufacturing or quality control of pervious concrete.

2 Aims of study

This study aims to investigate the possibility of replacing conventional concrete for pervious concrete in the manufacture of louvers (grids), which are drainage elements normally used by the Departamento de Esgotos Pluviais (DEP) in the city of Porto Alegre. In order to compare the pervious concrete prototypes with the ones produced by DEP, mechanical strength and infiltration tests are performed. These activities are performed with assistance of the Laboratório de Ensaios e Modelos Estruturais in the Universidade Federal do Rio Grande do Sul (LEME/UFRGS), which has been working on the development of drainage elements using pervious concrete.

3 Methods, results, and discussion

In order to get closer to the real sample, pervious concrete prototypes are moulded according to DEP’s dimensional specifications for traditional grids (40 × 100 × 7 cm). To ensure accurate dimensions and reuse of the moulds, they are made with top quality cedar wood, attached with resistant screws and nuts.

Figure 1 Cedar wood mould used to for the pervious concrete grids (see online version for colours)

3.1 Materials

The pervious concrete used in this study is produced with construction materials typically found in Southern Brazil. The CP V – ARI cement is used as a hydraulic binder especially due to its greater fineness and purity. The water added to the mixture is obtained from the local supply network and the aggregate used is gravel with a maximum diameter of 9.5 mm and a fineness modulus of 4.80. As recommended by ACI 211.3R-02 (2009) this size fraction is the most appropriate for the production of pervious concrete (Figure 2).

Figure 2 Materials used: gravel and water (see online version for colours)

3.2 Methods of production of grids prototypes in permeable concrete

The castings are performed at LEME/UFRGS. For this study six prototypes of grids were produced with a 1:4 cement/aggregate ratio.

The trace definition used is based on an exploratory study of samples made with local materials and following the guidelines proposed by ACI 522R-06 recommendation: pervious concrete. The best results were obtained with a 1:4 ratios chosen for this study.

It is important to note that the pervious concrete trait is measured by volume and not by weight.

The mixing procedure order is as follows: gravel (42.07 kg), part of water, cement (10.52 kg) and the remaining water. The time interval between the loadings of materials is one minute, except after adding the cement, which remains in movement for two minutes before the addition of the remaining water (1.150 kg) and is mixed for two more minutes.

According the ACI recommendation pervious concrete should be compacted properly to ensure its strength and structural integrity after removal of formwork, but not excessively, which might close the pores and compromise its permeability. To compact the grids the ACI recommendation (ACI 522R-06) is followed and a steel roller weighing 90 kg/m is used. The mould and the roll used are shown in Figure 3.

Figure 3 (a) Adding the materials in the mixer (b) Filling the moulds (c) Thickening of the prototypes with the aid of steel roller (see online version for colours)

(a) (b) (c)

Figure 4 Prototypes covered with polyethylene film (see online version for colours)

The curing process, illustrated in Figure 4, is performed by covering the plates with a plastic film of polyethylene and transferring it to a compartment with controlled temperature (24°C). The samples remain in this environment for 14 days.

The healing time adopted follows the recommendations from ACI (522R-06), as well as the procedure adopted by DEP for its traditional grids.

3.3 Description of tests and results

To match the requirements of permeability and mechanical strength of pervious concrete, tests described by Brazilian and international standards are performed and are described below.

3.3.1 Bending test

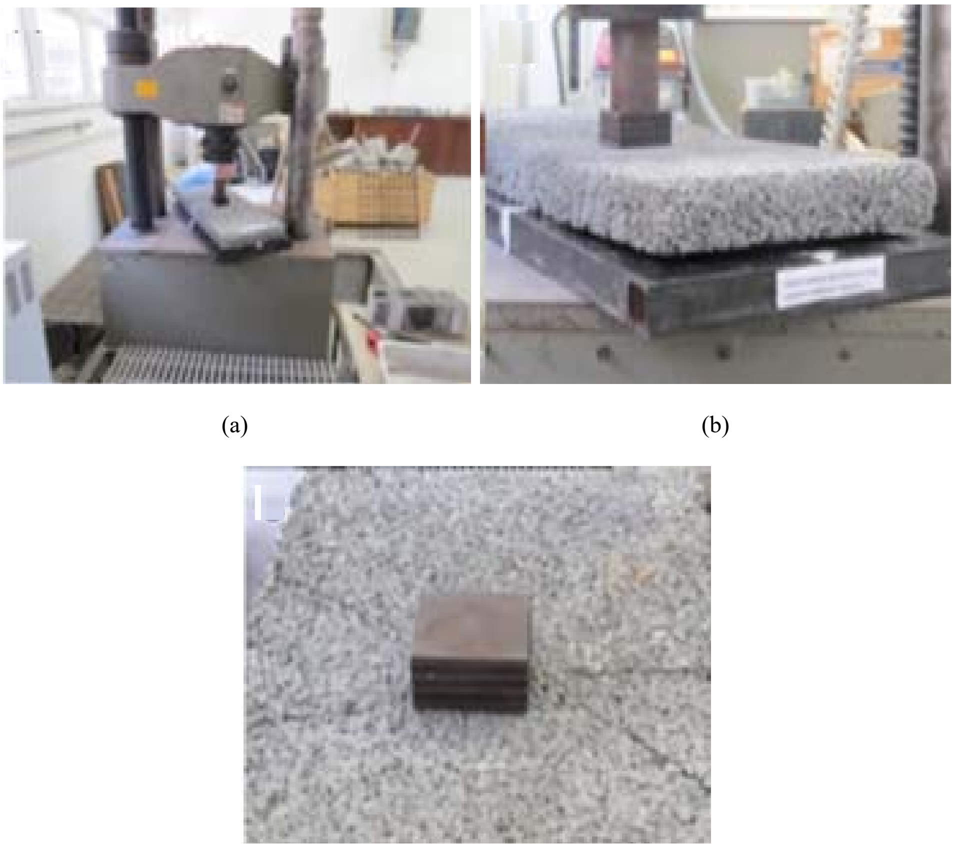
The grids used by the DEP are designed considering a 3 cm support-base at its borders. In order to simulate the real behaviour of the element when the efforts are applied the flexural strength test is performed using a metal mould to support the edges (Figure 5).

Figure 5 Metal template used in the flexural tests (see online version for colours)

The load application is performed on the centre of the concrete plate (grid) using a 10 × 10 cm neoprene plate and applying a deformation rate of 0.05 mm/min (Figure 6). The central axis of the element is marked and the pressure is applied gradually and without blows until the rupture. The equipment used in the tests is a Shimadzu press with load capacity up to 2,000 KN.

It is important to note that the tests are conducted with plates produced in pervious concrete as well as traditional concrete from DEP.

Figure 6 Bending tests on pervious concrete slabs (see online version for colours)



(a) (b)

(c)

The bending test conducted in conventional concrete grid produced by the DEP reaches an 8.4 KN resistance (Figure 7). The results obtained for six prototypes of permeable concrete grids produced are shown in Table 1.

Table 1 Tensile strength of flexion tests

Dash	*Plates*	*Tensile (KN)*
Grid 1	1:4	11.5 KN
Grid 2	1:4	17.5 KN
Grid 3	1:4	15.1 KN
Grid 4	1:4	13.0 KN
Grid 5	1:4	11.6 KN
Grid 6	1:4	10.1 KN

Figure 7 Bending test on conventional concrete grid from DEP (see online version for colours)

(a) (b)

(c)

The results show that all the prototypes made of pervious concrete presented rupture at higher tensile strengths than conventional concrete grids produced by DEP.

3.3.2 Water infiltration rate test

To obtain the water infiltration rate and to verify that the compaction using the roll is uniformly performed the ASTM C1701/C1701M (2009) recommendation is taken as reference. This method is adopted because there are just a few existing tests to evaluate the permeability of pervious concrete.

Although this is an interesting method to measure permeability it is complex and applicable for porosities of up to 22%, and the results of this method are equivalent to the permeameter for a surface condition that is directly in contact with the ground, which is not the case.

The process, as illustrated in Figure 8, works isolating the surface of the pervious concrete grid containing a ring of PVC with 300 mm in diameter and 70 mm in height. This ring has boundary marks between 10 and 15 mm from the bottom. Pre-wetting is performed with the pouring of water, keeping the water blade between the marks. As the time necessary for pre-wetting is obtained, the amount of water to be used in the test is indicated by the ASTM C1701/C1701M (2009). If the time is smaller than 30 seconds, 18.0 kg of water is used for the assay. If this time is longer than 30 seconds, 3.6 kg water is used. The infiltration rate of the pervious concrete is determined by measuring the time spent and the weight of water used in the test, according the equation recommended by the ASTM C1701/C1701M (2009):

$$I = \frac{K * M}{D^2 * t}$$

where

I infiltration in mm/h

M mass of water in kg

D pipe diameter

T time taken for water to infiltrate the surface

K constant: 4,583,666,000.

Figure 8 Procedure for testing the water infiltration rate (see online version for colours)

Table 2 shows permeability results obtained for the six pervious concrete grids. The elevated values are an indicative of the permeability of these elements moulded in pervious concrete.

Table 2 Infiltration test

Plates trace 1:4	*Identification grid*	*Grid side*	*Time (s)*	*K (mm /h)*	*K average*
Grid 1	Top	Side 1	24.63	36,009.555	32,194.7
		Side 2	31.25	28,379.7114	
	Background	Side 1	17.93	49,460.3357	47,286.6
		Side 2	19.66	45,113.0590	
Grid 2	Top	Side 1	29.61	29,953.4866	28,869.6
		Side 2	31.25	27,785.8001	
	Background	Side 1	20.51	28,869.6434	41,742.4
		Side 2	22.04	40,241.5036	
Grid 3	Top	Side 1	25.00	35,476.9096	35,721.4
		Side 2	24.66	35,966.0478	
	Background	Side 1	19.00	46,680.1442	45,513.1
		Side 2	20.00	44,346.1370	
Grid 4	Top	Side 1	21.62	41,023.2535	40,863.2
		Side 2	21.79	40,703.2006	
	Background	Side 1	19.92	44,524.2339	44,011.0
		Side 2	20.39	43,497.9274	
Grid 5	Top	Side 1	25.48	34,808.5848	32,622.5
		Side 2	29.14	30,436.6074	
	Background	Side 1	16.21	54,714.5429	53,816.7
		Side 2	16.76	52,919.0179	
Grid 6	Top	Side 1	20.36	43,562.0206	41,231.0
		Side 2	22.80	38,900.1202	
	Background	Side 1	18.16	48,839.3579	46,999.1
		Side 2	19.64	45,158.9990	
Grid 7	Top	Side 1	24.89	35,633.6979	30,411.6
		Side 2	35.21	25,189.5126	
	Background	Side 1	20.96	42,315.0162	39,759.0
		Side 2	23.84	37,203.1351	
Grid 8	Top	Side 1	34.30	25,857.8058	26,804.4
		Side 2	31.96	27,751.0244	
	Background	Side 1	22.10	40,132.2507	38,390.9
		Side 2	24.2	36,649.700	

3.3.3 Costs comparison between pervious concrete and conventional concrete grids

Table 3 shows the costs comparison between the conventional concrete used in DEP grids (dash 1:2:3) and pervious concrete plates produced in this research. The calculation of the cost per m^3 of pervious concrete considers the actual consumption of cement, while theoretical references are used for the conventional concrete.

Table 3 Cost of materials in conventional concrete 1:2:3 vs. permeable concrete trait 1:4

Materials/cost	*Concrete conventional*	*Pervious concrete 1:4*
Gravel	-	R$ 50.62
Brita1	R$ 43.59	-
Cement	R$ 210.87	R$ 214.29
Sand	R$ 33.74	-
Per m^3 total	R$ 288.20	R$ 264.91

The result indicates that the cost per m^3 of pervious concrete is about 8% lower than the cost of conventional concrete. This result reinforces the advantages related to the use of pervious concrete in substitutive plates over conventional concrete, currently used by DEP.

4 Conclusions

In virtue of the urbanisation process and large expansion of urban centres it is increasingly important to revise our storm-water management measures. Pervious concrete is inserted as an environmentally friendly and viable alternative, mitigating the effects caused by soil sealing and approaching the environment to pre-urbanised conditions.

The results from experimental trials and from the cost comparison between the two analysed elements (traditional concrete grids x pervious concrete grids) show that pervious concrete is a technically and financially interesting solution that may be implemented as a drainage element, replacing the grids currently being used.

Pervious concrete is an innovative alternative technology and if used in drainage elements it can contribute significantly for reducing problems related to urban flooding.

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