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USE OF POROUS CONCRETE IN PARKING AREAS FOR IMPROVING URBAN DRAINAGE

P.C.D. Alencar[1], O.M. Cordeiro Netto[2] & C.A.B. Vasconcellos[1&3]
1. Brazilian Army Force - Department of Construction Engineering
2. University of Brasília – Department of Civil and Environmental Engineering
3. Military Engineering Institute - Program in Transportation Engineering

ABSTRACT: As urban development causes changes on the quality and the quantity of the runoff due to rain events, cities used to adopt technical measures in order to compensate for the human action in urbanized areas, trying to restore or improve the original conditions of drainage or, at least, mitigate the negative impacts. Adoption of porous concrete in parking areas is an example of such measures. This paper aims to present an assessment of performance of porous concrete pavement in reducing runoff generation when applied in parking places. The experiments were carried out at the Brazilian Army's Headquarters, in Brasilia, Brazil. The relationship between the performance of the drainage and the state of the pavement was evaluated in three different situations (new, clogged and recovered concrete). For this, a paved area of 37.5 m² allocated to three parking spaces for light vehicles. Each of the place was built with 15 cm thick of concrete over a drainage bed of 30 cm thick, adopting differences in the paving construction technique. The evaluation of the hydraulic performance of the pavement occurred through results obtained from runoff generated by artificially simulated rain. The rainfall simulations were performed first with the new pavement. In such experiment, the porous concrete absorption ability was higher than 2.35 mm/min, since the volume of the rain, generated adopting this intensity, was fully conducted into the draining bed. Subsequently, new measurements found a decrease of the permeability when the pavement was clogged. After a surface cleaning, adopting the same simulated rain of 2.35 mm/min, the maximum infiltration rate observed reached 1.75 mm/min. One can conclude that the recovery of the permeability was not completely successful. Therefore, the solution studied by using the porous concrete can play an important role in attenuation of peak flow of rainwater in urban areas, although its efficiency is conditional to maintain the drainage capacity of the floor.

Key Words: Flood Management, Urban Drainage, Permeable Pavement, Porous Concrete

1. INTRODUCTION

The United Nations Population Fund UNFPA (1999) pointed out of the strong exodus of populations from rural to urban areas in various regions of the world over the second half of XXth century. The urbanization process was much more intense in poorer countries. In 2010, the Brazilian urban population already represented 84.4% of total residents (IBGE, 2010). Due to this process of rapid change, many Brazilian cities suffered disastrous consequences in the urban management and in citizens' quality of life.

All those changes directly affect the environment, particularly in the quantity of water drained from the surface. Tucci (2006) mentions that this process may cause changes in the hydrological cycle:

- reduction of infiltration of rainwater into the soil;
- increasing runoff;
- increasing flow velocity in storm water pipes;
- increasing peak flows and anticipation of those peaks in time;
- decreasing in groundwater level;
- reduction of groundwater flow;
- and reduction of evapotranspiration due to decreasing vegetation cover.

Among urban flooding consequences, one can identify: losses of life; material damages, disruption of economic activity in flooded areas; contamination by water-borne diseases such as leptospirosis, cholera and others; water contamination by flood deposits of toxic material, and contamination in water treatment plants (Tucci, 2005).

Reis *et al.* (2008) emphasize that the runoff under conditions close to the natural permeability of the soil could be an important strategy for the restoration of the hydrological cycle in urban areas. The mitigation of the urbanization impacts cannot ignore the study of the basin, which should be the unit for prioritizing interventions or measures of integrated planning and land uses and be linked to effective urban drainage systems. In this sense, Mendes (2006) reports that one of the major environmental challenges lies in the ability to understand the interrelationships between natural resource and pressure undertaken by human activities.

Tucci (2008) subdivided the evolution of the paradigms of urban water management in four stages: pre-hygienist (until the early twentieth century); hygienist (prior to 1970); corrective (between 1970 and 1990) and sustainable development (after 1990). The author characterizes the first period by the presence of sewage in septic tanks or drains, without collection or treatment. Water used to be fetched from the nearest source, taken from groundwater (through wells) or from surface (across the rivers). At that time, diseases and epidemics, losses of life and major floods were observed. The second sentence stood out by the development of sewer pipes, reducing disease, but contaminating the rivers. The treatment of domestic and industrial sewage, besides the recovery of rivers, was the environmental progress that marked the third period. Finally, around the years 1990 to the present days, a new paradigm begins taking into account a greater concern for the environment (tertiary treatment of sewage and storm water runoff). Urban drainage systems that preserve or restore the natural hydrological conditions begin to be developed.

2. OBJECTIVES

Because traditional techniques, widely used in hygienist period, had no more satisfactory answers to urban drainage, studies were directed to look for solutions to minimize the impacts of urbanization. Thus, compensatory techniques, also known as sustainable techniques, were developed in order to explore mechanisms of runoff retardation, favoring infiltration or increasing evapotranspiration.

The main objective of this research was to analyze one of those compensatory techniques: the adoption of porous concrete. The attenuation of runoff could be achieved by a wide range of technical alternatives, through temporary storage of water in order to minimize or even negate the effects of rain peak. Alencar (2013) presented main compensatory techniques, relating them to their ways of action, as shown in Table 1.

Table 1 shows that the use of permeable pavements is in one of the viable solutions to minimize the problem of increasing runoff. Permeable pavements could be defined as a structure that allows the passage of water through its pores. It is not a good alternative if one wants a sealed floor, since it allows the infiltration of the runoff for the lower layers of the floor. Permeable pavement techniques include lawns, polyhedral tessellations and porous concrete.

Table 1: Forms of action for compensatory drainage techniques (Alencar, 2013)

COMPENSATORY TECHNIQUE	FORMS OF ACTION		
	Detention (delay)	Retention	
		infiltration	Evaporation
Green roof			X
Roof storage	X		
Micro reservoir	X	X	
Well infiltration		X	
Plan or infiltration trench		X	X
Plan, ditch or trench retention	X	X	X
Floor reservoir	X	X	
Permeable pavement	X	X	
Wetland	X	X	X
Detention basin	X	X	X
Retention basin		X	X

The National Ready Mix Concrete Association (NRMCA, 2008) points out that pervious concrete has other environmental benefits, such as:

- reducing the heating of urban areas (heat islands) by absorbing less solar radiation, because of its light color and a less dense structure;
- the survival of trees located on paved areas, by allowing the arrival of water and air to the plant roots; and
- reducing risk of aquaplaning of vehicles in the event of heavy rains.

The porous concrete, a particular type of porous pavement, consists of a binder, mixed with a coarse aggregate. After consolidation, it allows the formation of interconnected voids, which gives a void ratio of about 20 % (CRMCA, 2009). Under the concrete plate, a draining bed with a large gravel mattress was built, having the function of draining the excess of water coming from rain, as shown in Figure 1.

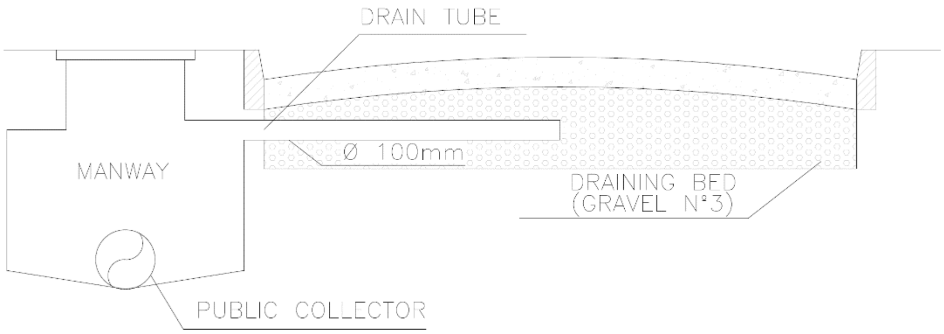

Figure 1 – permeable pavement typical

Nevertheless, given the large volume of voids, the mechanical properties of the pavements are reduced. Therefore, Grabowiecki and Scholz (2006) suggest the use of porous concrete for vehicle access roads (residential sidewalks, access ramps and service roads, utility lines), slope stabilization and erosion control, golf courses (roads and car parking), pedestrian sidewalks, bicycle paths and hiking trails.

3 . DESCRIPTION OF THE EXPERIMENT

The experiment consisted of the design and construction of an experimental pavement built in an area located in the parking of the Brazilian Army Headquarters (QGEx). The experiment consisted of three standard spaces for light vehicles (2.5 m wide by 5.0 m long), totaling 37.5 m² of porous concrete built *in situ*, with 15 cm thick. The plate was molded on a crushed stone bed of 30 cm thick with the same dimensions of the concrete plate. In addition, draining tubes at the bottom of this layer were installed, as well as control records.

Because of the experimental protocol, this particular location of the experiment was chosen taking into account the type of water diffuse pollution to be collected by the structure and the sediment charge carried by runoff, in order to "accelerate" the obsolescence of the structure, by the clogging of the voids. Thus, despite the flow of vehicles be considered small, this location was useful because of the:

- large volume of water carried from an area measuring about 1,200m²;
- proximity to workshops and garages area, which leads to the possibility of spillage of oils and lubricants;
- contribution of water from works, which enabled the transport of large volumes of sediment;
- proximity of trees, which favors the transportation of leaves and flowers by the runoff; and
- lack of cleaning services (on purpose).

The local soil was characterized as a sandy silt, with lateritic soil, infiltration average of 0.5 m³ / m² × day, without the presence of groundwater and Support California Index of 12.7%. As seemed in ACI (2010), the soil is able to receive flooring for the purpose of study.

Porous concrete has been machined into concrete mixer trucks, which used the same materials and quantities of materials (agglomerates and aggregates) adopted for the three slots. In order to evaluate the performance of porous concrete through construction criteria, amendments were incorporated in the form of implementation of each one of the three parking spaces, as shown below:

- Space 1: molded with the bottom of the drainage blanket waterproofed with asphalt and rolled concrete. This setting aimed to eliminate the possibility of contribution of infiltration from the ground.

- Space 2: made on compacted soil, the concrete was rolled and compacted using a vibrator. In this configuration, it was sought to simulate the loss of permeability due to compaction of the concrete, sometimes imposed by the need to gain strength to meet a higher traffic load.

- Space 3: molded on compacted soil and rolled concrete, performed following the guidelines of ACI (2010).

The experimental parking area is shown in plan in Figure 2 and in sections in Figures 3, 4 and 5.

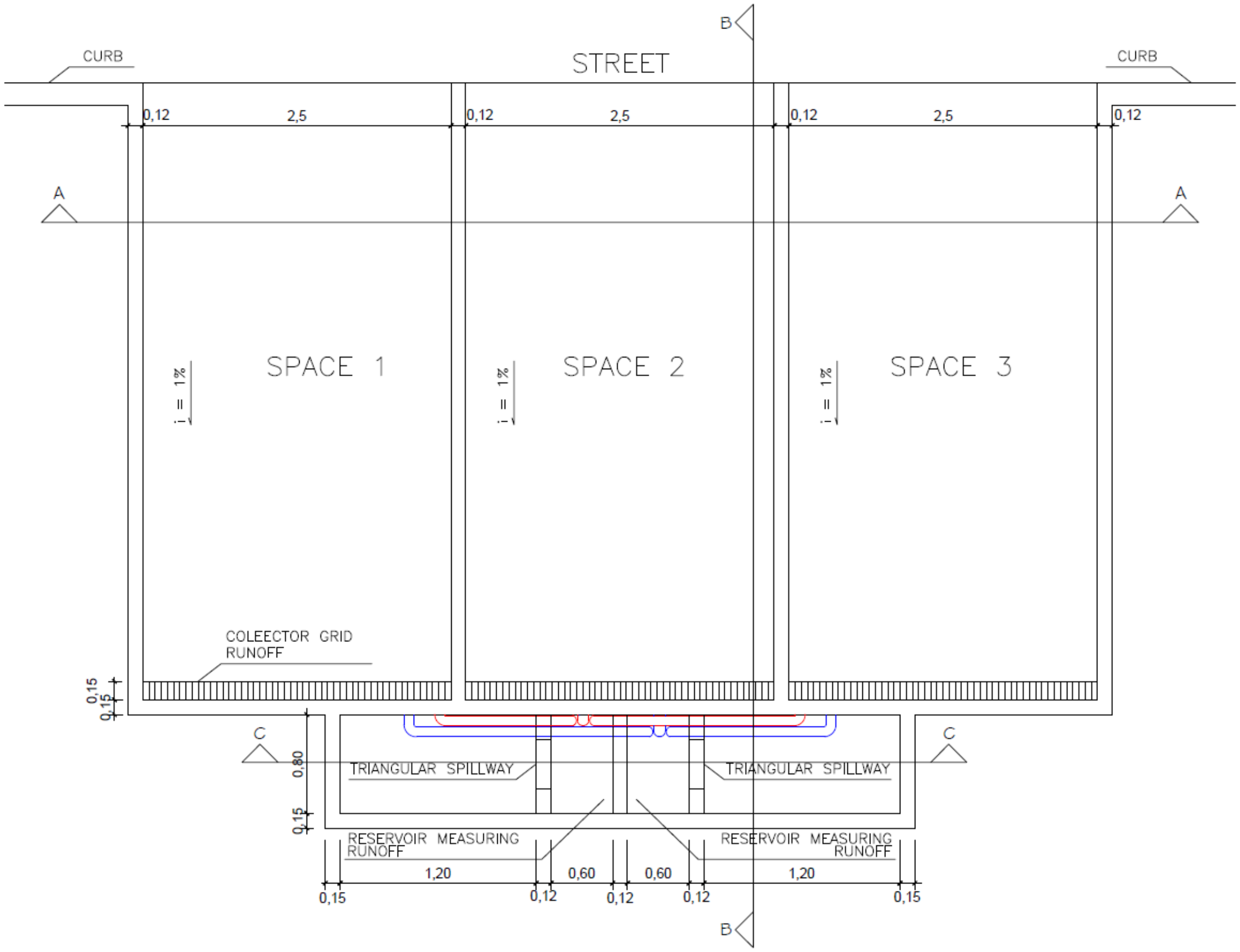

Figure 2: Plan view of the parking lot.

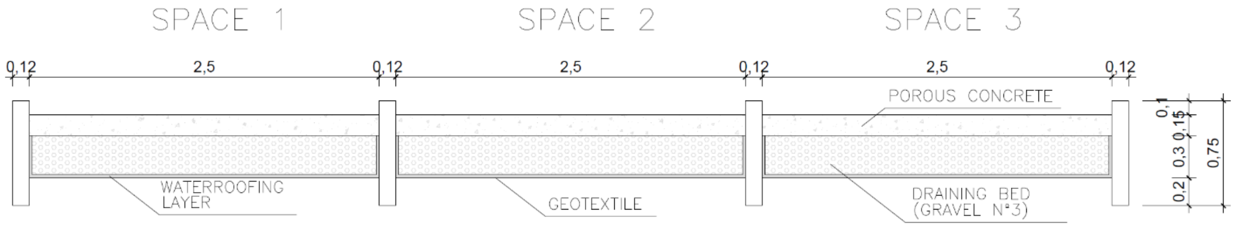

Figure 3: Cross section of the parking lot.

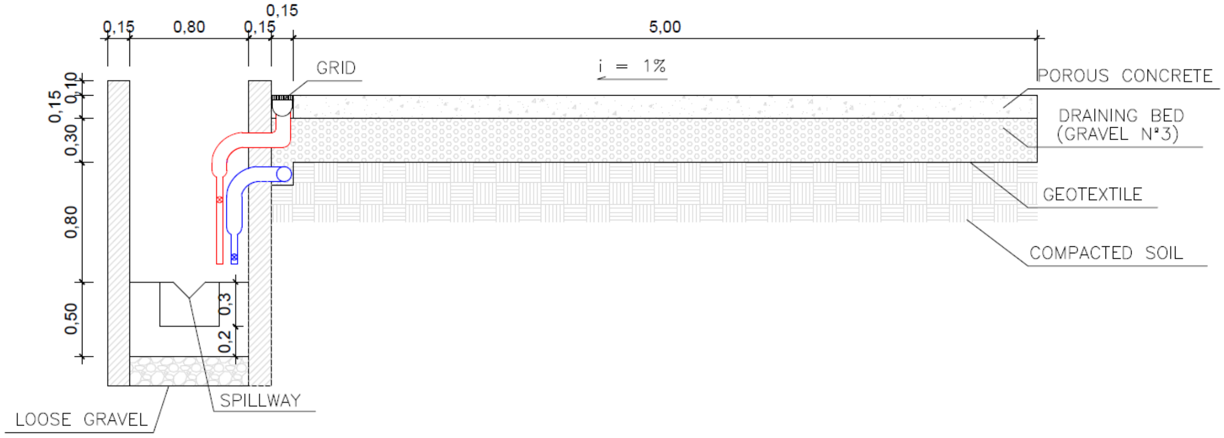

Figure 4: Longitudinal section of the parking lot.

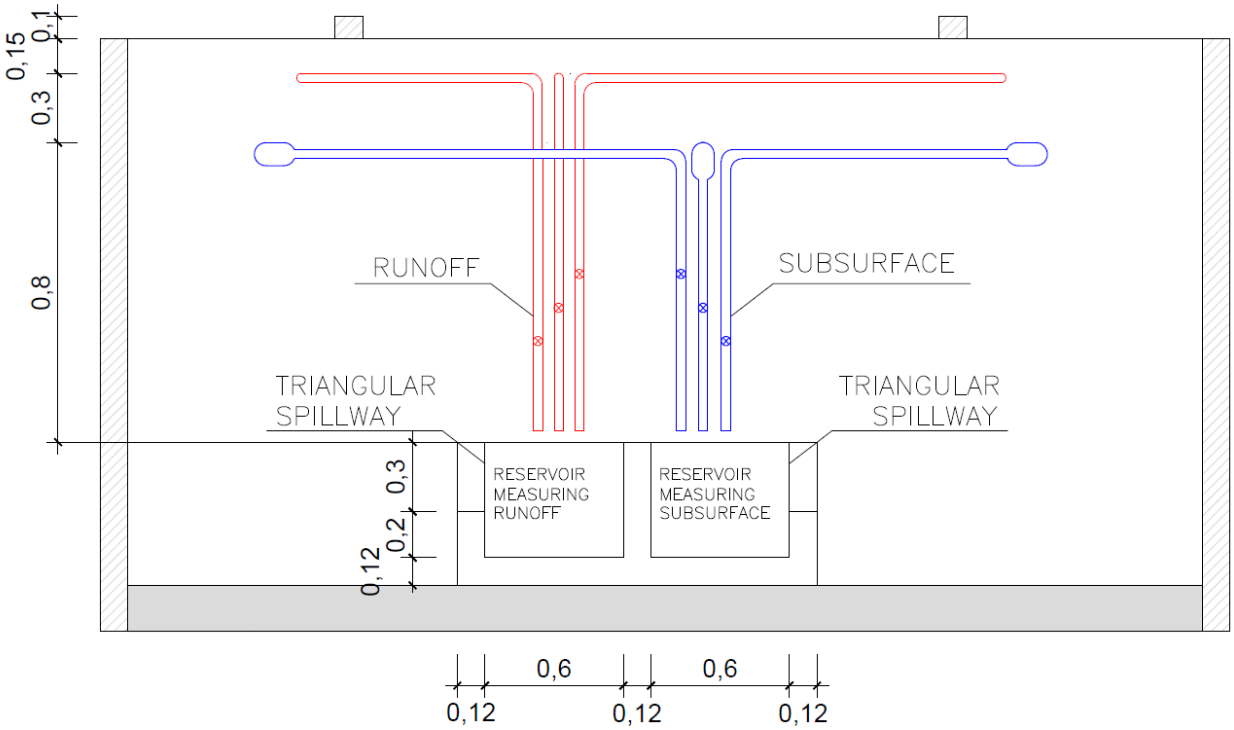

Figure 5: Cross Section pit measurement (measurements in meter).

As can be seen in Figures 2, 3 and 5, the pipes in red represent the runoff collection system, which includes devices for driving, storage, protection, control and maneuvering. The pipes in blue represent the subsurface flow collection system, which also includes devices for driving, storage, protection, control and maneuvering. Thus, the collection systems, shown in Figure 5, allow the quantification of the volumes of flows (runoff and subsurface flow) generated by the simulated artificial rains.

The flow rate was measured with a short-crested V-notch weir employing an automatic gauge recording system that measured water levels at 60s interval. A rainfall simulator was constructed in order to ensure uniform distribution and intensity of the artificial rain. The system consisted of a 500 L tank, a turbo pump ½ hp, micro sprinklers (Figure 7), pressure gauge and control records (Figure 8).

Figure 7: Micro sprinklers running.

Figure 8: Turbo pump, pressure gauge and control records.

Equation [1], proposed by NOVACAP (1996), corresponds to the Intensity-Duration-Frequency curve for the Brasilia region and was used for both tests and calibration of the rainfall simulator.

$$\mathrm{i} = \frac{21{,}7 \,.\, \mathrm{T_r}^{0{,}16}}{(\mathrm{t}+11)^{0{,}815}} \qquad [1]$$

where ***i*** is the intensity of rainfall (mm/h), T_r is the recurrence interval (in years) and ***t*** is the duration of the rain (min).

As proposed by the experiment protocol, the next step was to perform simulations of precipitation at three different times, initially in September, when the pavement was still new. Subsequently, the instrumental was removed and the parking was let free for use and collection of runoff pollution conducted by the gutters.

After the rainy season (October-April), the second stage of simulations began in June, in the subsequent year. At that time, the parking lot was closed for the use of vehicles and the test apparatus was assembled again to other simulations and measurements. It was found that the pavement was almost completely clogged.

In the third phase of tests, the surface of the pavement was washed using a high-pressure pump in order to recover the permeability of the porous concrete plate. Further, new rains were simulated and measured, showing a partial recovery of drainage capacity of porous concrete.

4 . RESULTS AND DISCUSSION

With all the experimental apparatus prepared, simulations of a reference rain (15 years recurrence period and 15 minutes duration, using Eq [1]) were performed, leading to a rainfall intensity of 2.35 mm / min . This intensity was applied to the experimental parking under the three situations (new pavement, clogged and recovered).

In early experiments with the new pavement, no runoff was detected, meaning that the entire volume of rain was reclaimed by draining mattress, as shown in Figure 9.

Also in Figure 9, it is observed that, for a volume of rain (Vp) of 441.0 L, collected subsurface volume (Ve subsup) corresponded to 417.4 L, having a difference of 24.3 L, that could be considered as system losses (wet floor, infiltration on the ground, waste disposal and others).

In these experiments, a delay of 11 minutes in time required for the flow to reach peak flow (tp) was observed. Other 15 minutes since the end of the simulated rain until the end of the subsurface flow was also observed.

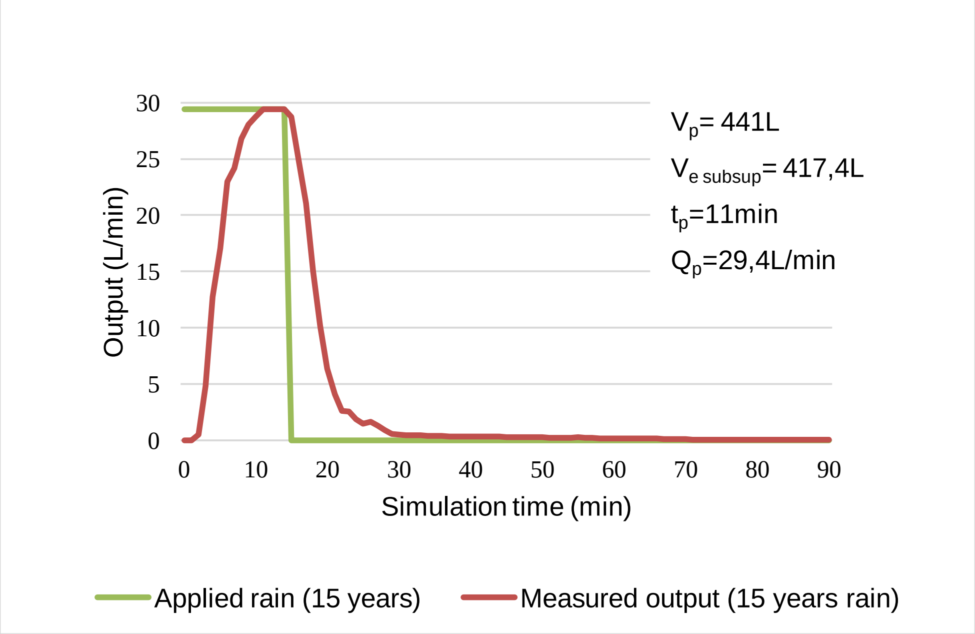

Figure 9: Throughput obtained for the new porous concrete pavement.

In the simulations of second phase, after the rainy season in Brasilia, it was noted that an intense use of the parking places led to a complete clogging of the porous concrete. In this situation, an infiltrated volume less than 0.5 L was measured. It could be considered negligible in relation to the volume of the simulated rain, of 440L. Thus, almost all the rainfall was transported by surface runoff and collected by the grid (blue pipes in Figures 2, 4 and 5).

After that, a cleaning process of the parking lot was performed, using a simple high-pressure pump. Other cleaning techniques were available, most of them more efficient. Since the cleaning issue was not the main objective of the experiment, the choice of a performant technique was not a priority. After the cleaning operation, a partial recovery of the permeability of the pavement was observed, as shown by the results of Figure 10.

In such experiment, for a precipitate volume (Vp) of 441 L, a subsurface volume (Ve subsup) of 239.2L and a runoff volume of 180.9L were measured. The difference of 21.6L could also be considered as system losses.

A delay of 11 minutes in time required for the flow to reach peak flow (tp) and the delay of 15 minutes since the end of the simulated rain until the end of the subsurface flow were also observed.

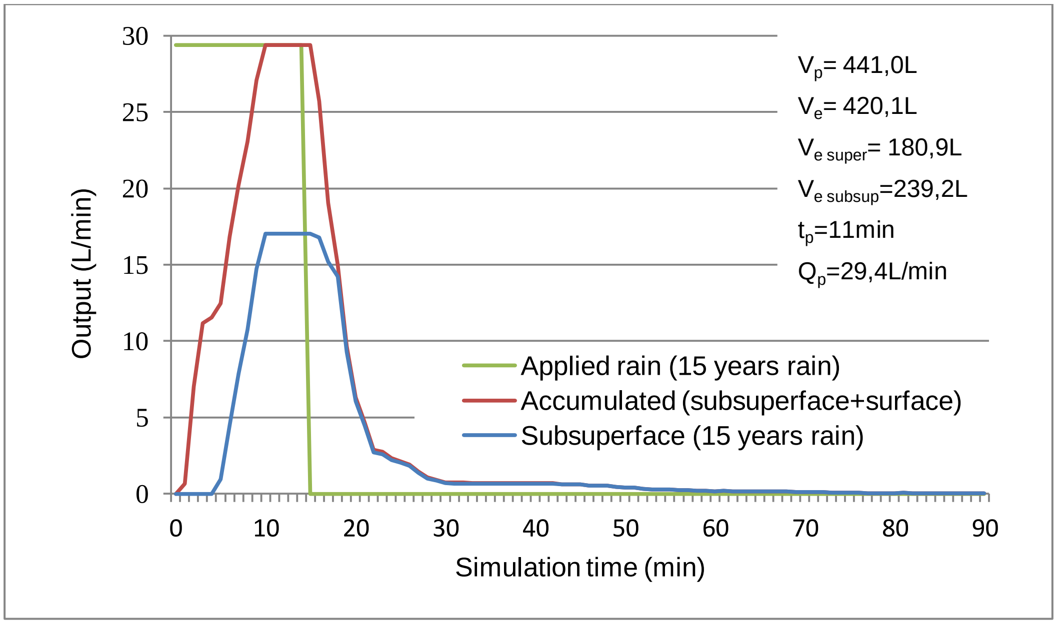

Figure 10 : Throughput obtained for porous concrete pavement recovered (washed).

The results of the simulations of rainfall led to the following observations:

- the new pavement showed high permeability ratios facing rainfall events;
- the desired clogging was perfectly achieved , leading to a negligible infiltrated flow for this experimental condition;
- if totally clogged, the porous pavement acts as an impervious floor;
- after the cleaning process, the reclaimed pavement still showed very good ability to absorb rain;
- after recovery, the presence of residues and impurities remaining in the pavement was noted and led to a reduction of the permeability of the concrete plate and to a small increase in the time delay of the flow.

5 . CONCLUSIONS

We can conclude that:

- The correct sizing of drainage mattress and its ability to reservation of water is an important element to be considered in further projects.
- Compression of the substrate of the floor can sometimes seal the natural soil, reducing its contribution of the leakage flow attenuation.
- The inability to run the concrete vibration more intensively on the draining mattress hindered the perfect leveling of this layer, which compromised the uniformity of the thickness of the porous concrete plate, which may have caused structural limitations and hydraulic performance. Thus, this reinforces the necessary care in implementing the correct leveling of drainage mattress.
- The position of the drain installed at the bottom of the drainage mattress facilitated the rapid drainage applied in the experiment, which may have been a determining factor for the low rain infiltration volume into the soil, determined in assays factors rain. In the implementation of real pavements, the alternatives of drain structures could contribute to raise the infiltration on the ground, storing water and reducing the volume of water drained.
- The experiment showed no significant results in regard of the attenuation of the peak intensity of the runoff. However, these are absolute time values associated to an attenuation at an experimental scale. In larger areas, the delay could be more significant.
- The porous concrete proved to be an effective alternative to mitigate the effects of runoff.

- The permeability recovery failed to be completely successful, since part of the sediment remained blocking the flow of water, reducing the permeability of the pavement.
- The technique adopted to clean the parking places could be at the origin of the lack of efficiency of the cleaning process.
- The choice of other cleaning techniques could probably provide a more efficient recovery of permeability.

In summary, the experiment carried out confirmed that the use of porous concrete for pavements may consist of an environmentally friendly solution for urban drainage management.

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