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Infiltration capacity assessment of urban pavements using the LCS Permeameter and the CP Infiltrometer.

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ABSTRACT

This paper presents the Cantabrian Portable Infiltrometer (CP Infiltrometer), a specially designed device based on rainfall simulation for the assessment of the infiltration capacity of all types of urban pavements. Several pervious and impervious surfaces were tested with the LCS Permeameter, an existing infiltration test based on the use of a column of water, and the CP Infiltrometer, simulating rain intensities with return periods of 10, 50 and 500 years and 5 minutes duration. The discussion of the results indicates that the CP Infiltrometer could be used successfully to identify different levels of infiltration capacity and to assess the correct performance of pervious surfaces on which design, construction and maintenance decisions are based.

KEYWORDS

BMPs; SUDS; infiltration; rain simulation; pervious surfaces.

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INTRODUCTION

Urban pavements are generally classified as impervious or pervious surfaces. Pervious pavements are an important subset of SUDS (Sustainable Urban Drainage Systems) and BMPs (Best Management Practices) (Pratt *et al.*, 2002). The main objective of pervious pavements is to collect and deal with any runoff, infiltrating it, and if possible, to replenish aquifers (Scholz *et al.* 2007). Pervious pavements are used mainly in parking areas and in lightly trafficked roads, provided that the gradients, subsoil, drainage characteristics and groundwater conditions are suitable (Castro *et al.*, 2005).

One of the problems of impervious pavements is that through use they degrade gaining permeability and losing bearing capacity due to the action of water (Dirección General de Carreteras, 1990). In consequence, one of the main inconveniences of pervious surfaces is the reduction of their infiltration capacity over time. Several authors agree that this reduction is due to blockage or clogging (Dierkes *et al.*, 2002; Pratt *et al.*, 2002; Scholz *et al.* 2007; Brattebo *et al.* 2003; Davies *et al.*, 2002). Some pervious pavements could become clogged in 3 years (Scholz *et al.* 2007) but others could maintain their infiltration capacity for over 6 years (Brattebo *et al.* 2003) or more.

The clogging of pervious pavements is most likely to occur in the surface layer and in the geotextile separation layers (Rommel *et al.*, 2001). Surface blockage must be controlled and it can be prevented and reduced by regular cleaning with suction sweeping or high-pressure water jet (Pratt *et al.*, 2002; Davies *et al.*, 2002; Dierkes *et al.*, 2002) For example, Dierkes *et al.* (2002) were able to recover the infiltration capacity of a 15 year old pervious pavement with porous slabs from 1 l/(s*ha) to values between 1545 l/(s*ha) and 5276 l/(s*ha).

In-situ infiltration measurement

The in-situ measurement of the infiltration capacity of any surface is made using infiltrometers, sometimes called permeameters. For soil determinations the most popular devices are tension disc and pressure ring infiltrometers (Angulo-Jaramillo *et al.*, 2000). However, these tests are too complex for determinations in pervious pavements. For pervious pavements the commonly used apparatus is classified in two main types: flooding or ring infiltrometers that use a column of water, constant or variable, over the surface, and the infiltrometers that use rain simulation, of any kind, over the test area.

Among the flooding type infiltrometers, the most usual employ a ring with a variable water column inside. Examples of these are the LCS Permeameter (CEDEX, 2000) and the ring permeameter described in the European Standard EN 12697-40 (2005). Infiltration measurement using these devices is easy, quick and cheap. They work by measuring the time taken for the water level to fall between two marks when water discharges through a small hole. Their main inconvenience is that results depend strongly on the conditions of the sample under test: cracks, fissures, moisture and temperature (Gerke, 1984).

The double-ring infiltrometer (ASTM, 2003) tries to correct these problems by testing a larger area and fixing the surrounding conditions. However, this test could give higher infiltration values due to the constant water head maintained on the soil surface during the observation period and the absence of raindrop impact effects (Bhardwaj and Singh, 1992). Nevertheless, it has been used

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successfully for soil hydrological studies and even for pervious pavement assessment (Bean *et al.*, 2004).

On the other hand, there are many infiltrometers which accurately simulate rain for testing urban pavements, but mainly in laboratory conditions (Johnston *et al.*, 1984; Davies *et al.,* 2002; Castro *et al.,* 2006). However, surface samples and laboratory testing may not simulate the true conditions that exist in real pavements and so in-situ infiltrometers with rain simulators are needed and several have been proposed (Gerke, 1982; Dierkes *et al.*., 2002; de Solminihac *et al.*, 2002)

One of the most straightforward in-situ infiltrometers with a rain simulator is called the Zarauz Permeameter. This infiltrometer simulates rain by allowing water to spill onto the pavement from a known height, filtering freely over it (de Solminihac *et al.* 2002). However, this kind of direct water pouring does not take advantage of the main characteristic of the rainfall simulator which is the raindrop impact effect. This effect has been proved to be an important factor affecting the infiltration process (Bhardwaj and Singh, 1992). Besides, the possibility to test different rain intensities to find the real limits of a pervious pavement is a very important advantage of this kind of infiltrometer (Shackel, 1997).

The University of Cantabria, in Spain, is carrying out several research projects related to pervious pavements. In this paper, a new infiltrometer with rain simulator for in-situ tests of all kinds of urban surfaces is proposed, especially for the assessment of pervious surfaces. The results are compared with those obtained with a selected ring infiltrometer based on the use of a water column to test the infiltration capacity.

OBJECTIVES AND HYPOTHESES

The main objectives of this research were:

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- To design an easily portable apparatus, based on rain simulation, able to produce a wide range of rain intensities in the field and to propose a new infiltration test.
- To obtain results over different types of urban surfaces, impervious and pervious.
- To use an existing infiltration test based on the use of a water column to assess the infiltration of the same types of surfaces.
- To discuss and compare the results analysing advantages and disadvantages of each kind of infiltration test.

The initial hypotheses considered for the proposal of the new infiltration test were:

- Different surfaces have different responses to different rain intensities.
- The responses of the surfaces to different rain intensities can be measured as the height of surface water.
- These measures permit the differentiation of several levels of infiltration capacity from impervious to pervious surfaces.

The LCS Permeameter was selected as the existing test and the comparison condition was that the area tested with the infiltrometer with rain simulator must contain the point tested with the LCS Permeameter. For the new infiltration test, the duration of each rain event simulated was fixed to 5 minutes, to limit the total test time. The selected rain intensities to be simulated correspond to return periods of 10, 50, and 500 years for each test location. The two first commonly used in urban runoff management and the third as the maximum requirement.

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METHODOLOGY

Apparatus

Two pieces of apparatus were used in this research: the LCS Permeameter and the Cantabrian Portable Infiltrometer (CP Infiltrometer). The LCS Permeameter (Figure 1) is detailed in the

Spanish standard NLT-327/00 (CEDEX, 2000), and it is similar to the ring permeameter described in the European standard EN 12697-40 (2005).

Figure 1. LCS Permeameter

The CP Infiltrometer was designed especially for this study and it is made up of four main parts: flooding chamber, rain simulator, charging chamber and recharging recipient. Secondary elements of the CP Infiltrometer are the sealing rubber, the fastenings between chambers and the support plastic plate for the recharge recipient (Figure 2).

Figure 2. Cantabrian Portable Infiltrometer (CP Infiltrometer)

The flooding chamber consists of a transparent box fitted with a ruler inside for measurement of water height with a precision of 1 mm. The object of this chamber is to accumulate the water that the surface is not able to infiltrate, enabling the direct measurement of the resultant flooding level after the simulated rain event. For this, the lower perimeter of the flooding chamber was covered with sealing rubber. To complete the sealing action of the rubber during the test, Vaseline was used along the area perimeter.

The rain simulators are plastic plates with droppers inserted in a rectangular arrangement. The rain simulator selected is fixed between the two chambers using the four fastenings which join them. The charging chamber is similar to the flooding chamber and it is graduated vertically with a precision of 1 mm. The function of this chamber is to ensure a constant height of water column over the rain simulator to produce the fixed rain intensity during the test duration.

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A supporting plate is placed over the charging chamber in order to support the recharging recipient. It is filled with 10 l of water, acting as load and allowing the recharge of the charging chamber with the water needed to keep rain intensity constant through the experiment.

Calibration

The LCS Permeameter did not need calibration because it is standard equipment. However, the CP Infiltrometer needed prior calibration to know the water height in the charging chamber that produces specific rain intensities over the test surface.

Two different rain simulators were used during the tests varying the number of droppers in them. One rain simulator had 16 droppers and the other 36, producing ranges of rain intensity between 37 - 190 mm/hr for the former and between 150 - 520 mm/hr for the latter varying the depth of water in the charging chamber.

The calibration of the CP Infiltrometer was carried out in the laboratory using the same methodology for the two rain simulators. After completely assembling the CP Infiltrometer with a specific rain simulator, the charging chamber was filled with water to a fixed height. The water level was maintained and the water volume precipitated during 1 minute was measured 4 times. This procedure was carried out 2 times producing 8 values of rain intensity for each height of water in the charging chamber.

The resulting data were processed obtaining relationships between ‘water height in the charging chamber’ and ‘rain intensity over the test area’ shown in Figure 3. For the linear regression equations, Y is the precipitation intensity (mm/hr) and X is the height of the water column in the charging chamber (cm). The coefficients of determination (R^2) are 0.96 for the rain simulator with 16 droppers (CP Infiltrometer 16) and 0.91 for the one with 36 droppers (CP Infiltrometer 36). It

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was observed that more droppers led to more dispersion in the simulated rain intensity, which made it necessary to check that all droppers were working properly each time.

Figure 3. Rain intensity according to the water level in the charging chamber.

Test procedures

The infiltration tests carried out with the LCS Permeameter were carried out according to the procedure indicated in the standard NLT-327/00 (CEDEX, 2000). This procedure comprised:

1. Placing the permeameter over the selected point, situating the load and the plug and filling the methacrylate pipe with water.
2. Allowing the permeameter to completely empty onto the pavement in order to saturate the surface.
3. Plugging and filling the methacrylate pipe with water again.
4. Allowing the permeameter to empty.
5. Noting the time in seconds from the moment the water level passes the higher mark till it reaches the lower mark.

This procedure was followed at 3 different points for each of the test surfaces (Figure 4). Apart from the rubber situated in the device contact with the surface, no agent was used to ensure the complete base sealing. Some leakage was observed working with irregular surfaces. With impervious surfaces, point 4 was limited to half an hour (1800 seconds), considering the surface impervious over this time. For the grass surfaces the test point did not include any part of the reinforcement, and for the concrete block surfaces the LCS Permeameter was placed over points where three joints of the concrete blocks coincide, just in the corner.

Figure 4. The three test areas of one of the pavements tested (porous asphalt surface course).

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The proposed infiltration test using the CP Infiltrometer followed these steps:

1. Determine the three rain intensities to be simulated according to the location and return periods.
2. Place the device, without rain simulator, over the selected area; seal the perimeter with Vaseline and situate a load over the supporting plate.
3. Pour 3 litres of water directly inside and check the perimeter sealing, letting the water infiltrate in order to saturate the surface.
4. Place the rain simulator needed to simulate the corresponding rain intensity and fill the charging chamber up to the specific water height.
5. Maintain the water height constant in the charging chamber for 5 minutes adding the water needed from the recharging recipient.
6. Note the water level inside the flooding chamber.
7. Repeat the procedure from point 4 until the three selected rain intensities have been tested.

This procedure was carried out at 3 areas for each of the tested surfaces (Figure 4) and these areas included the point tested with the LCS Permeameter. With impervious surfaces, point 3 of the procedure was completed extracting the water manually with sponges.

For both procedures the test surface must be flat, with gradients from 0% to 2%. The results obtained from the LCS Permeameter are directly comparable among themselves for all the locations as the requirement is always the same. However, the results extracted from the CP Infiltrometer are not directly comparable because the rain intensities are different for different locations. The results of the CP Infiltrometer could be directly compared only when the rain intensities simulated over the tested areas are similar for two locations.

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Locations and test pavements

Several impervious and pervious pavements were selected to be tested with the LCS Permeameter and the CP Infiltrometer. All of them were located in two urban areas: Santander and Gijón. These cities are situated in the north of Spain, in the wet regions of Cantabria and Asturias respectively.

The Intensity Duration Frequency curves of each location were needed to fix the 3 rain intensities corresponding to the selected return periods of 10, 50 and 500 years and 5 minutes duration. Table 1 shows the rain intensities to be simulated, obtained using the Spanish Surface Drainage Instructions (Dirección General de Carreteras, 1990) and the Maximum Daily Rain Intensities given by the Spanish Roads Service (Dirección General de Carreteras, 1999)

Table 1. Rain intensities with 5 minutes duration and return periods of 10, 50 and 500 years.

The rain intensities with return periods of 10 and 50 years were simulated with the CP Infiltrometer 16 and those of 500 years with the CP Infiltrometer 36, adjusting the corresponding heights in the charging chamber according to Figure 3.

Table 2 shows the reference of each pavement tested, its description and location. Two grass surfaces, four impervious surfaces and three pervious surfaces were selected. Grass surfaces were not considered as pervious because their infiltration capacity is very variable and they may even behave as impervious in certain conditions.

Table 2. Tested surfaces.

Each type is represented by two surfaces with some differences between them to check if each test was able to detect these differences. The metallic plate (MP) was tested in order to have a

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reference of a completely impervious surface. The pavements located in Gijón correspond to the experimental car park bays constructed with permeable pavements for their effluent quality monitoring (Rodríguez *et al.*, 2005).

RESULTS AND DISCUSSION

LCS Permeameter

Figure 5 shows the results obtained with the LCS Permeameter at all the points tested over the different surfaces. Higher values of time mean lower infiltration capacity. Three surfaces appear as clearly permeable with times around 25 seconds: the porous asphalt with light use (PA2) and the two surfaces with precast concrete blocks (B1 and B2). On the other site, two impervious surfaces may be seen with the three points over 1800 seconds: the new asphalt surface course (A1) and the metallic plate (MP).

Figure 5. LCS Permeameter results for the different tested pavements.

The grass surfaces (RG1 and RG2) had different behaviour mainly due to the type of soil, not to the kind of material used for reinforcement because concrete and plastic are both impervious. It was observed that the soil of the reinforced grass with plastic cells (RG2) displayed better infiltration because it had less clay content.

The old asphalt surface course (A2) had irregular results, similar those of the porous asphalt with high traffic intensity (PA1). These represent: one impervious point, one point with medium infiltration capacity and another nearly pervious one. These irregular results are due to visible cracks in the surface that cause both leakage and infiltration through them.

Figure 5 clearly indicates the differences between the pavements PA1 and PA2 because the LCS Permeameter was designed to assess porous asphalt surface courses (CEDEX, 2000). The

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values of the porous asphalt with high traffic intensity (PA1) indicated that it needs maintenance in some areas to recover the infiltration capacity. While, the porous asphalt with light use (PA2) presented a good general infiltration capacity.

However, the LCS Permeameter does not permit the differentiation of the two kinds of pavement with concrete blocks. Both surfaces (B1 and B2) seem permeable according to Figure 5. But the drain down times for the impervious pavement with concrete blocks (B1) are not representative because they are strongly influenced by the losses of water through the grooves between the device sealing rubber and the joints between blocks.

It was also observed that for the old asphalt surface course (A2), the apparently permeable points were due to lateral water losses caused by cracks and irregularities. In the case of the porous asphalt with high traffic intensity (PA1), the impervious and the slightly permeable points represent clogged points caused by surface degradation and silt moved by the road traffic.

CP Infiltrometer

Figure 6 presents the results obtained with the CP Infiltrometer. Higher heights mean lower infiltration capacity for each of the return periods. Two pervious surfaces were able to support the three rain intensities simulated with no flood in any of the three test areas: porous asphalt with light traffic (PA2) and concrete blocks without filler (B2). On the contrary, impervious surfaces (A1 and MP) had water heights over 2 cm for T=10 years, over 2.5 cm for T=50 years and around 3.5 cm for T=500 years.

Figure 6. CP Infiltrometer results for the different tested pavements.

Reinforced grass with concrete cells (RG1) show similar results in the three areas tested showing a generally deficient infiltration capacity, probably due to the clayey soil. On the other hand, the

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tests carried out on grass reinforced with plastic cells (RG2) offered contradictory information since the first and third areas displayed good and excellent infiltration capacities while the second was unable to infiltrate the 10-year precipitation. In this case, it was observed that the area with deficient infiltration capacity corresponds to poorly developed grass.

The differences between the two porous asphalt surfaces (PA1 and PA2) are clearly shown in Figure 6. Thereby, the results of the porous asphalt with high use (PA1) indicate the need for cleaning. The old impervious asphalt surface course (A2) shows a low infiltration capacity although slightly better than the new asphalt (A1). However, both asphalt surfaces (A1 and A2) could be considered as impervious.

The concrete block surface with sealed joints (A1) is almost impervious (see Figure 6) with measured heights even higher than those corresponding to the metallic plate (MP). These high values are probably due to an increase in the rain intensity simulated during the test. The initial calibration of the rain simulators was repeated at the end of the test programme finding that the coefficients of determination R^2 were 0.83 instead of 0.96 for the rain simulator with 16 droppers and 0.92 instead 0.91 for the rain simulator with 36 droppers offering slightly higher rain intensities for the same heights in the charging chamber.

Comparing the average heights generated in the flooding chamber for the impervious points, a strong correlation can be observed among the different return periods, with a R^2 of 0.95 for T=10/T=500 and 0.99 for T=50/T=500. These correlations mean that the degree of blockage could be measured with only one of the 3 return periods over an impervious or clogged pervious surface.

However, for pervious areas, the simulation of the three rain intensities was necessary to find the limit of the surface infiltration capacity. This limit could be expressed as the lowest return period

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which generates flooding. Thus, the best result would be T=500 years with a water height of 0 cm in the flooding chamber.

Comparison

Comparing the results shown in Figure 5 and Figure 6, several comparisons could be made:

- In both cases, continuous impervious surfaces (A1 and MP) are detected, as are the clearly pervious surfaces: PA2 and B2.
- Surfaces A2 and B1 were only identified as impervious by the CP infiltrometer while the LCS Permeameter was not able to properly show this characteristic.
- The CP Infiltrometer results offered more information about discontinuous surfaces (RG1, RG2, B1 and B2) thanks mainly to the complete perimeter sealing and the bigger area tested, including reinforced elements or with several joints.
- The CP Infiltrometer measurements allow better characterization of the infiltration capacity, even for impervious or nearly impervious surfaces.

Table 3 shows the average of the three results for each test and surface. In order to obtain a representative average that summarises the general surface infiltration capacity it is very important to select three suitable areas to be tested.

Table 3. Average results with the LCS Permeameter and the CP Infiltrometer.

In Table 3 it is observed that pervious surfaces all have low times with the LCS Permeameter (under 25 seconds) and heights of 0 centimetres for the three rain intensities simulated with the CP Infiltrometer. Impervious surfaces all had time values over 1000 seconds with the LCS Permeameter, and heights around 2 centimetres for the two low rain intensities and around 3 centimetres for the highest rain intensities. The main contradiction, previously explained, is the

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concrete blocks impervious surface (B1) in which the LCS Permeameter was unable to detect the impervious characteristic because of the lateral losses of water.

Without considering the results with the LCS Permeameter over 1800 seconds, or the results of the impervious concrete block pavement (B1), there is a strong correlation between LCS Permeameter times and the heights obtained with the CP Infiltrometer for the three return periods contemplated. These correlations have values of R2 around 0.90.

CONCLUSIONS

The discussion of results indicates that LCS Permeameter, a portable infiltrometer based on a column of water, permits the clear identification of the impervious points of a range continuous surfaces and the assessment of the blockage state of continuous pervious surfaces such as porous asphalt.

On the other hand, the CP Infiltrometer, a portable infiltrometer based on rain simulation over a representative area with the perimeter completely sealed, permits the clear identification of a range of pervious or impervious surfaces as well as its clogging level.

Moreover, the CP Infiltrometer gives information about the infiltration capacity of the test surface under different rain intensities, being able to indicate the return period of the precipitation that the pavement is no longer able to completely infiltrate generating consequent runoff. This allows the adjustment of any pervious surface to the hydrological conditions of any location.

Consequently, the CP Infiltrometer could be successfully used to assess the correct performance of pervious surfaces in order to aid in making design, construction and maintenance decisions.

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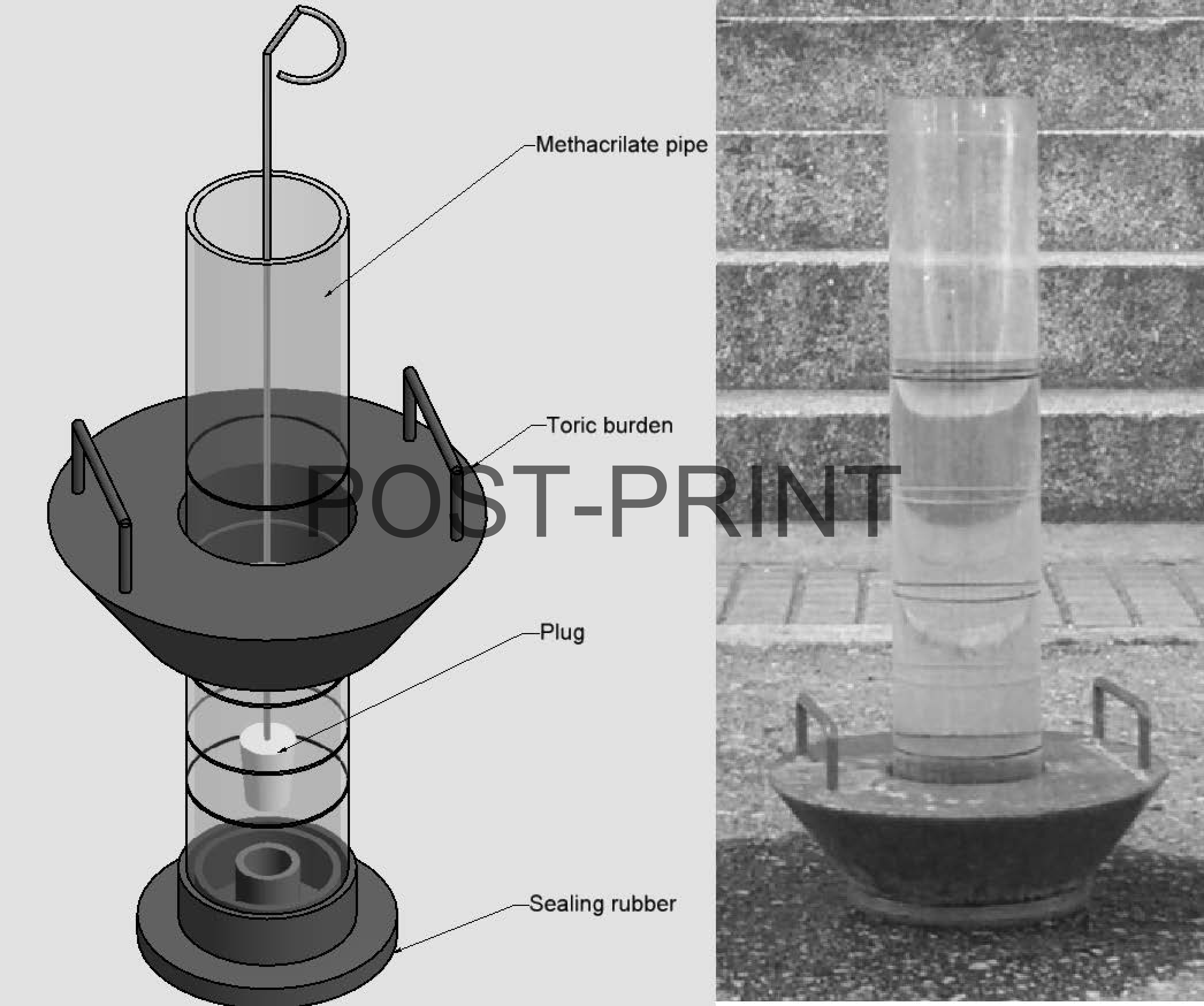

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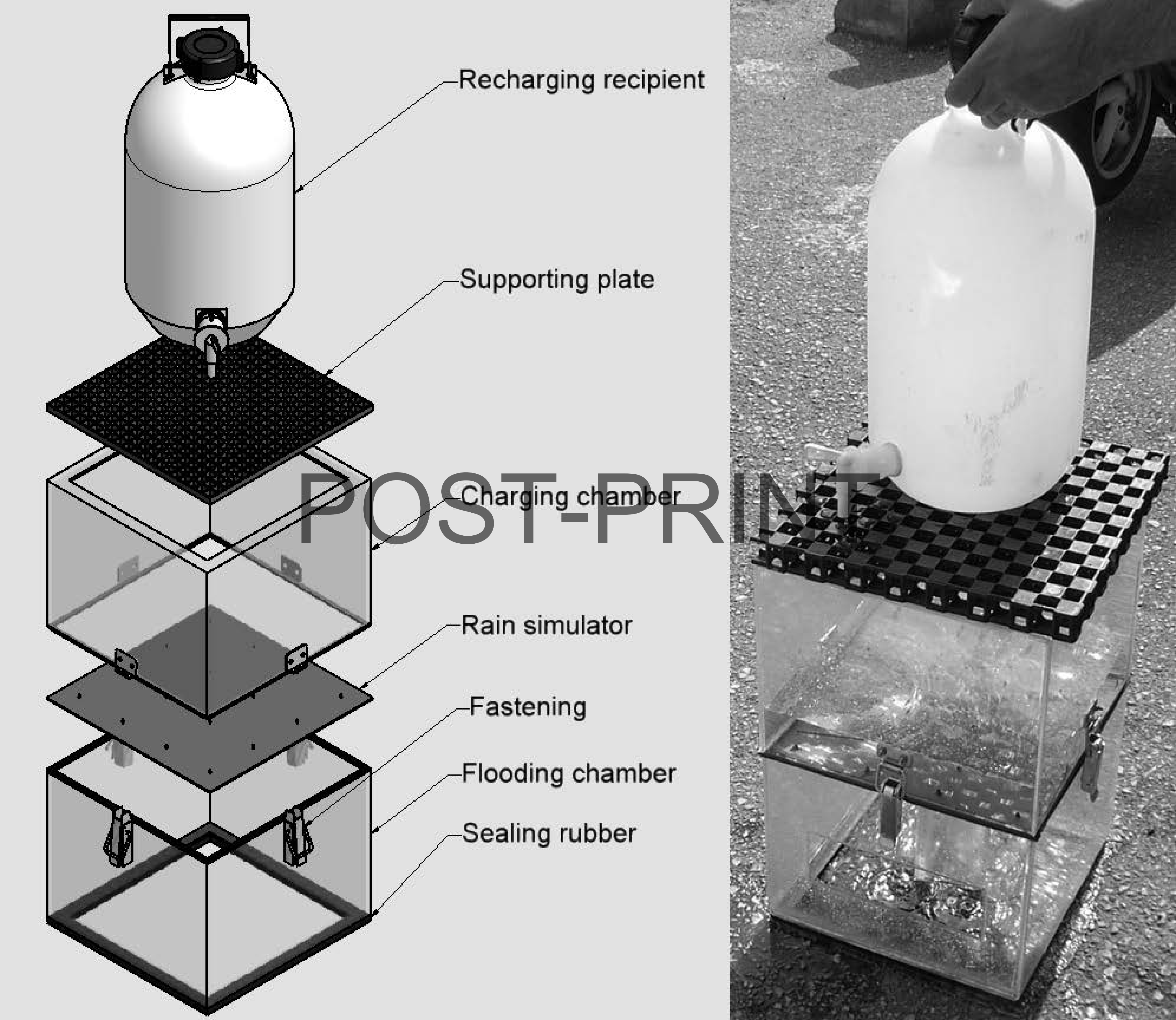
Recharging recipient
Supporting plate
Charging chamber
Rain simulator
Fastening
Flooding chamber
Sealing rubber

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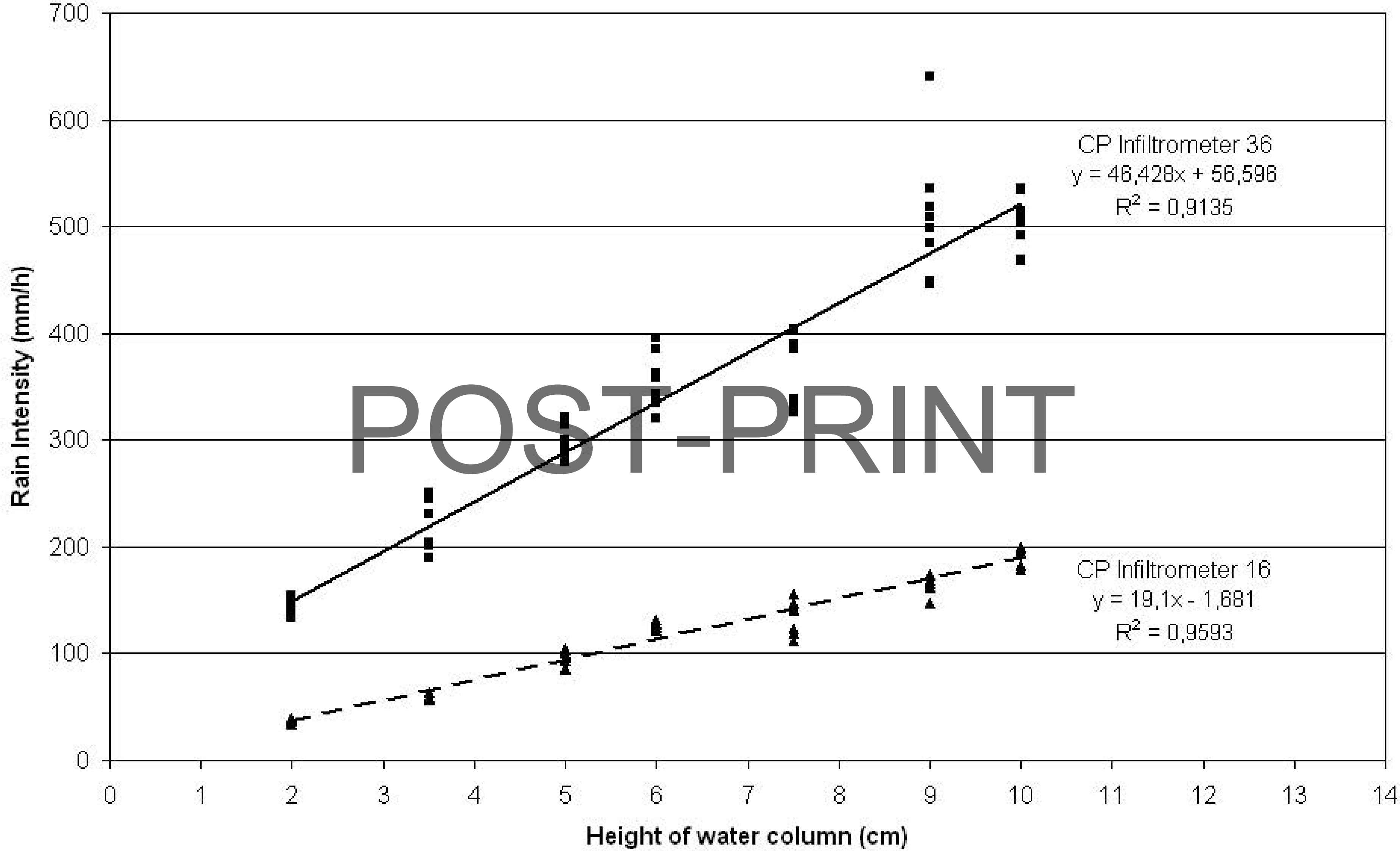

Rain Intensity (mm/h)
Height of water column (cm)
CP Infiltrometer 36
y = 46,428x + 56,596
R^2 = 0,9135
CP Infiltrometer 16
y = 19,1x - 1,681
R^2 = 0,9593
0
100
200
300
400
500
600
700
0
1
2
3
4
5
6
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14

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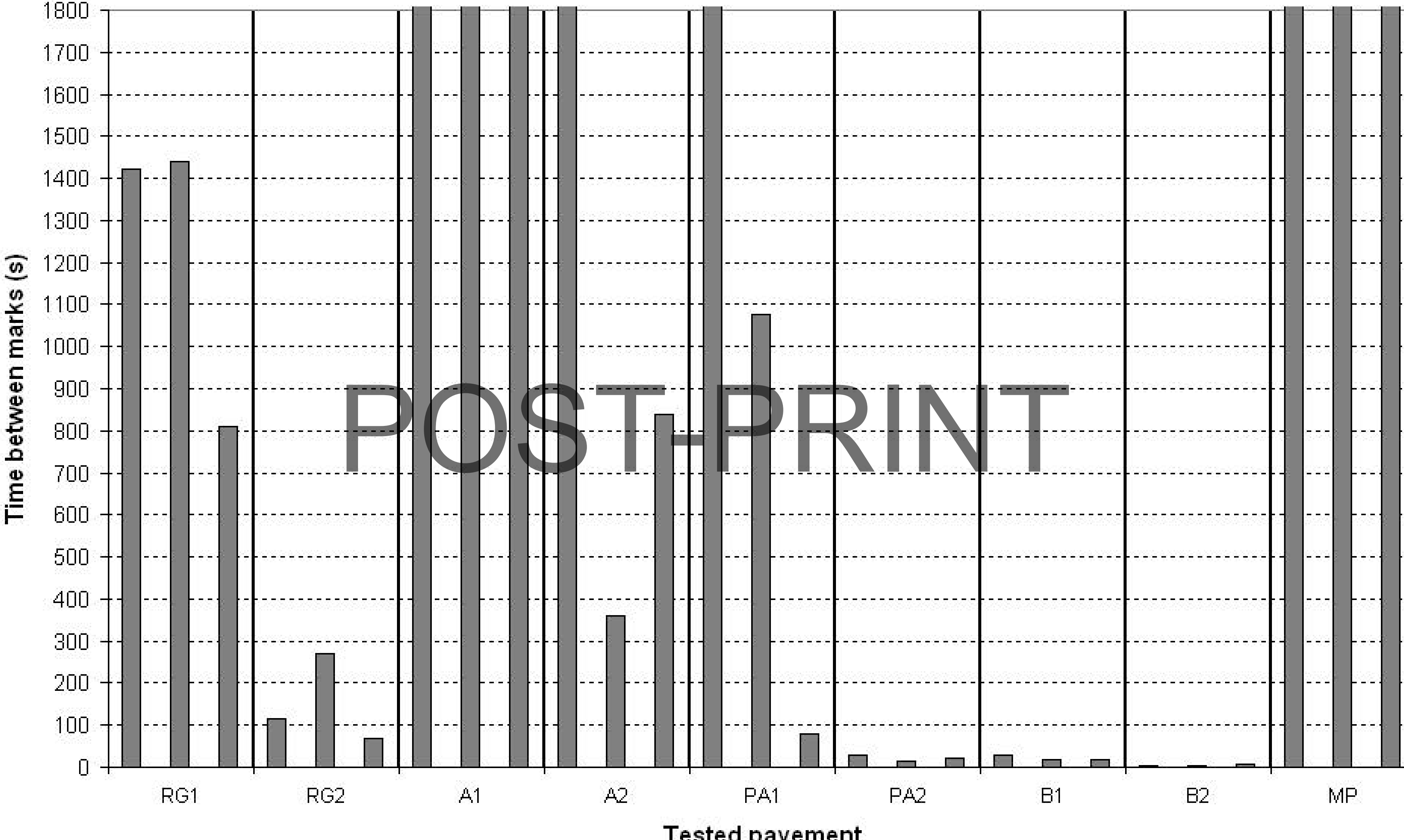

Time between marks (s)
1800
1700
1600
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
RG1
RG2
A1
A2
PA1
PA2
B1
B2
MP
Tested pavement

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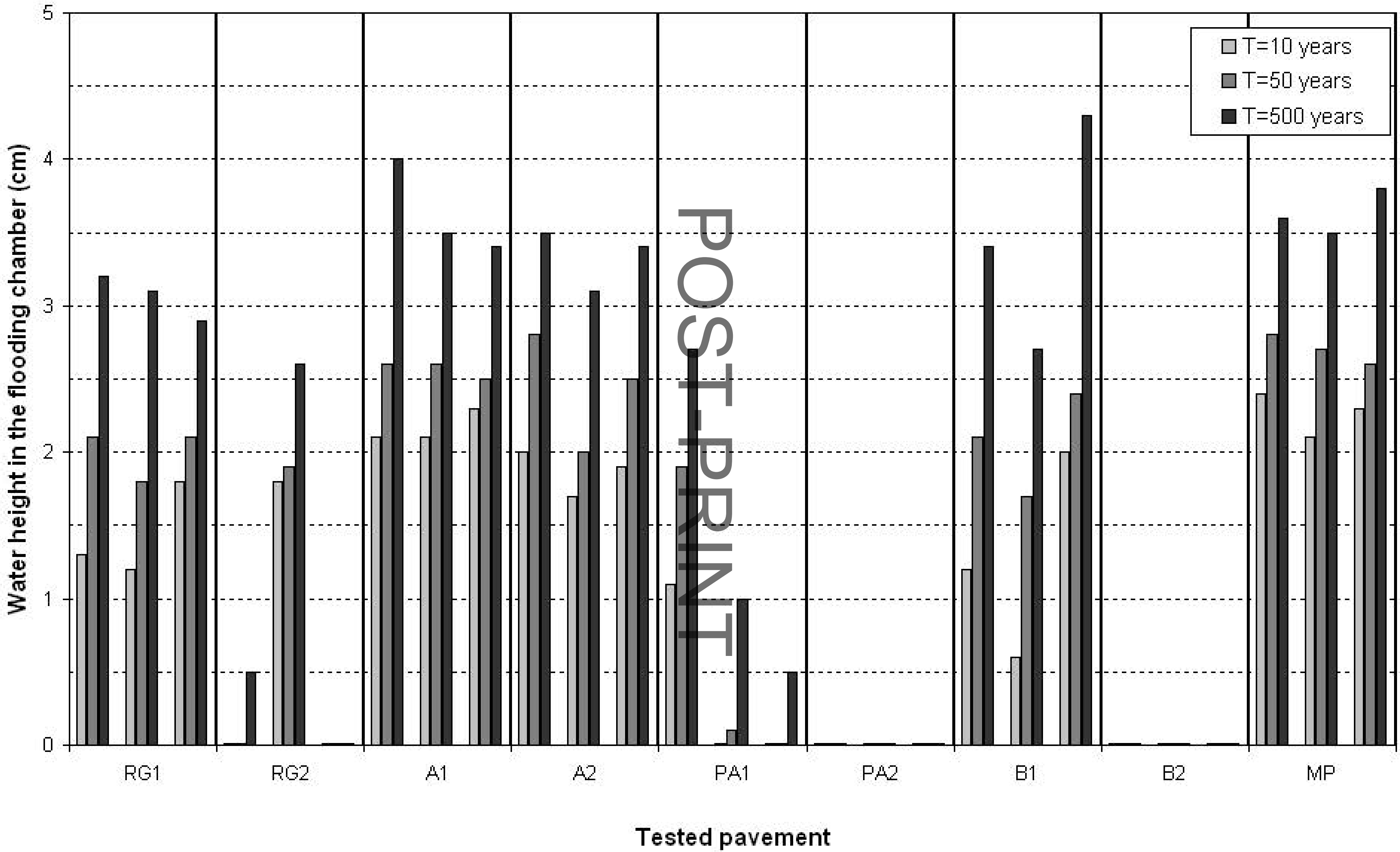

T=10 years
T=50 years
T=500 years
Water height in the flooding chamber (cm)
0
1
2
3
4
5
RG1
RG2
A1
A2
PA1
PA2
B1
B2
MP
Tested pavement

POST-PRINT

Location	Rain intensities with 5 minutes duration (mm/h)		
	T=10 years	T=50 years	T=500 years
Santander	109.50	152.61	224.84
Gijón	92.03	126.98	182.90

POST-PRINT

Reference	Type	Description	Location	Year of installation
RG1	Grass	Grass in clayey soil reinforced with concrete cells	Civil Engineering School, Santander	2005
RG2	Grass	Grass in sandy soil reinforced with plastic cells	La Guía Car Park, Gijón.	2005
A1	Impervious asphalt	New asphalt surface course.	Las Llamas Park, Santander	2007
A2	Impervious asphalt	Old asphalt surface course.	Civil Engineering School, Santander	1997
PA1	Porous asphalt	Porous asphalt surface course in a road with high traffic intensity.	Liencres Road, Santander	2006
PA2	Porous asphalt	Porous asphalt in a car park with light use.	La Guía Car Park, Gijón.	2005
B1	Concrete blocks impervious pavement	Concrete blocks with mortar in the joints.	Sardinero Car Park, Santander	2001
B2	Concrete blocks permeable pavement.	Concrete blocks without filler in the joints.	La Guía Car Park, Gijón.	2004
MP	Impervious surface	Metallic plate completely regular.	Civil Engineering School, Santander	2007

POST-PRINT

Reference	LCS Permeameter average results (s)	CP Infiltrometer average results (cm)		
		T=10 years	T=50 years	T=500 years
RG1	1223.86	1.4	2.0	3.1
RG2	150.94	0.6	0.6	1.0
A1	>1800.00	2.2	2.6	3.6
A2	1233.34	1.9	2.4	3.3
PA1	1052.01	0.4	0.7	1.4
PA2	21.21	0.0	0.0	0.0
B1	21.77	1.3	2.1	3.5
B2	4.55	0.0	0.0	0.0
MP	>1800.00	2.3	2.7	3.6

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