**Cite this ariticle as:**

*Palla, A., Gnecco, I., Carbone, M., Garofalo, G., Lanza L.G. e Piro, P. (2015). Influence of stratigraphy and slope on the drainage capacity of permeable pavements: laboratory results. Urban Water Journal, 12(5), 394-403. DOI: 10.1080/1573062X.2014.900091*

# Influence of stratigraphy and slope on the drainage capacity of permeable pavements: laboratory results

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# Influence of stratigraphy and slope on the drainage capacity of permeable pavements: laboratory results

A small size laboratory test-bed has been realized at the University of Genoa in order to evaluate the drainage capacity of permeable pavements by monitoring inflow, runoff and subsurface outflow. The laboratory test programme has been designed in order to investigate the influence of the rainfall intensity and pavement slope on the hydrologic response of permeable pavements. Four permeable pavement systems realized combining two paver typologies (concrete cell and pervious brick) with two filter layers made of recycled glass aggregate and a mix of gravel and coarse sand are tested. The hydrologic response of permeable pavements is analysed by using a dimensionless volume index (discharge coefficient) and a timing index. Laboratory results reveal that the hydrologic performance is fairly consistent for all the investigated permeable pavements. The recycled glass aggregate turns out to be a valid solution. No surface runoff occurs even at 98 mm/h rainfall intensity.

Keywords: permeable pavements, hydrologic performance; urban drainage; laboratory test; low impact development

## 1. Introduction

The development of urban areas causes the increase of impervious surfaces that rapidly contribute to generate runoff and the reduction of the pervious areas that store and deliver subsurface flow over long periods. The direct consequence of the reduction of soil permeability is the increased runoff and decreased concentration times.

In this framework, Low Impact Development (LID) principles and applications are a relatively new approach to storm water management. LIDs are basically a source reduction approach aiming at restoring the critical components of natural flow regimes. LID solutions include storm water infiltration systems, rain gardens, storm water wetlands, green roofs and permeable pavements to be properly distributed throughout the urban area (Ahiablame et al., 2012; Palla et al., 2010).

Permeable pavements offer one solution to convert parking areas as well as low-density traffic lanes and pedestrian pathways into pervious surfaces towards a more sustainable approach in road construction practices (Schlüter and Jefferies, 2002). Permeable pavements include both monolithic (i.e. pervious concrete, porous asphalt) and modular forms (i.e. permeable pavers, plastic grid). Modular systems are commonly made up of a matrix of blocks with voids filled with sand or specific engineered soil and laid on granular material such as e.g. coarse sand underlain by a geotextile with a drainage layer below. Regardless the permeable pavement system design (employed materials and components), the use of recycled materials (such as glass) has been recently introduced in an attempt to provide sustainable management and to minimize the consumption of natural resources (Su and Chen, 2002; Huang et al., 2007). While a mixture of gravel and sand is traditionally utilized underneath as a filter layer, recent studies indicate the use of recycled glass (a by-product of the glass recycling industry) as an alternative solution (Disfani et al., 2011; Imteaz et al., 2012; Seelsaen et al., 2006). However, the hydraulic characterization of the recycled material as well as the experimental evidence of its performance is still limited thus hindering its application in permeable pavements.

Research studies demonstrate that permeable pavements are effective in reducing runoff volumes, peak flood discharges and pollutant loads by infiltration and adsorption through the pavement stratigraphy (Pratt et al., 1995; Brattebo and Booth, 2003; Pagotto et al. 2000; Gilbert and Clausen, 2006; Ball and Rankin, 2010). Drake et al. (2013) report a comprehensive review of the hydrologic performance and impacts on water quality of permeable pavements including a rigorous analysis on the longevity, functionality and maintenance need of these systems.

In comparison to conventional asphalts, runoff volume reduction ranges between 36% and 93% on average (i.e. Andersen and Foster, 1999; Dreelin et al. 2006; Collins et al., 2008; Fassman and Blackbourn, 2010). Permeable pavements contribute in reducing the peak flow up to 40% and increasing the concentration time (Scholz and Grabowiecki, 2007; Bean et al., 2007; Piro et al., 2012). Dreelin et al. (2006) monitored the hydraulic performance of a porous parking lot and an asphalt parking lot on clay soils for nine small events: the porous lot generates 93% less runoff than the asphalt one despite being sited on clay-rich soils. Fassman and Blackbourn (2010) demonstrate that the discharge volume is comparable to predevelopment conditions even for large events.

Some authors pose particular attention on the long term behaviour of permeable pavement solutions thus the impact of clogging on the quantitative and qualitative performance has been investigated (i.e. Gilbert and Clausen, 2006; Sansalone et al., 2012; Siriwardene et al., 2007; González-Angullo et al., 2008). Case study results show that the performance decrease is likely due to fine particles clogging the paver surface and the underlying layers.

The proposed approach in the present research study consists in a laboratory test programme aimed at assessing the drainage capacity of four permeable pavement systems including both traditional and alternative (recycled) materials. The first specific objective is to characterize the hydrologic response of a permeable pavement in terms of drainage capacity, sub-surface outflow and discharge coefficient. A second objective is to evaluate the influence of the rainfall intensity on the system behaviour; at this aim laboratory tests were performed by simulating the high-frequency and 5-years return period rainfall events. Finally, the third objective is to assess the impact of slope and stratigraphy configuration on the hydrologic performance. To support this investigation, experimental results were statistically compared.

## 2. Methods

### *2.1. Permeable pavements*

The permeable pavements investigated in the present research study are the most common and largely installed in urban areas especially for the realization of parking lots (Wardynski et al., 2012; Liu et al., 2012). In particular, the selected typologies are characterized by an open cell paver realized with concrete blocks and a pervious paver realized with pervious concrete bricks. Volcanic and fine sand are respectively employed as the joint filling material for the concrete cell and pervious brick pavers. These two surface layers are combined with two filter layers respectively made of a mix of gravel and coarse sand (as a traditional layer) and recycled glass aggregate (as an alternative solution) thus resulting in four different stratigraphies. Under the filter layer, a geotextile and a drainage layer made of plastic elements are posed for all the stratigraphies.

In Figure 1, the main characteristics of the four investigated stratigraphies are illustrated with the cross-section and the scheme of the laying (plan view). As described in Figure 1, the four stratigraphies are named as follows:

- CC-RG: Concrete Cell (surface layer) and Recycled Glass aggregate (filter layer);
- CC-GS: Concrete Cell (surface layer) and a mix of Gravel and Sand (filter layer);

- PB-RG: Pervious Brick (surface layer) and Recycled Glass aggregate (filter layer);
- PB- GS: Pervious Brick (surface layer) and a mix of Gravel and Sand (filter layer).

For the joint filling materials and the investigated filter layers, the particle size distribution (PSD) was measured at the University of Genoa. The PSD was determined by using the sieve analysis, where grains were separated on sieves of different sizes. The particle size distribution curves for the volcanic sand, the GS and RG media are compared in Figure 2.

The PSD curve for the GS medium (the black-dots line plotted in Figure 2) covers a narrow range of particle sizes corresponding to fine gravel. The GS values for $d_{60}$ and $d_{10}$ are respectively equal to 6 and 2.1 mm, therefore the coefficient of uniformity $C_u = d_{60} / d_{10}$ is equal to 2.9, thus confirming the GS medium as a uniform graded soil. The value of $d_{60}$, equal to 6 mm, allows classifying the GS medium as fine gravel according to the Unified Soil Classification System (USCS).

The PSD curve for the RG medium (the white-dots line plotted in Figure 2) is quite similar to the GS; it covers a narrow range of particle sizes corresponding to fine gravel too. In this case, the $d_{60}$ and $d_{10}$ are respectively equal to 3.3 and 1.3 mm, with resulting $C_u$ ~2.5. This confirms the RG medium as a uniform graded soil. Having $d_{60}$ = 3.3 mm, also the RG medium can be classified as a fine gravel according to the USCS.

As for the joint filling materials, the PSD curve for the volcanic sand (the grey-diamonds line plotted in Figure 2) is consistent with the one measured for the GS medium, while the river sand is uniformly graded at 4.75 mm.

### 2.2. *Laboratory device*

A small size laboratory test-bed was realized at the University of Genoa. The test-bed is composed of a plot (1 x 2.5 m), a rainfall simulator system, three cylindrical reservoirs and an automated monitoring system for measuring inflow and outflow (see Figure 3). The laboratory device does not include the outlet section (i.e. the catch basin) thus allowing to properly investigate the hydrologic response of an infiltration system per unit surface area. The plot may contain up to 1.25 $m^3$ of engineered soil, for a maximum layer depth of 0.5 m. In order to perform tests with different system slopes, the plot is supported by a manually controlled platform.

The inflow and outflow (sub-surface and runoff) measuring system is based on the real-time acquisition of the water level in properly proportioned reservoirs, with a verified cylindrical response, performed by ultrasonic sensors (Honeywell 946-380E) wired to a National Instruments data-logger. The scan rate is 10 Hz and both the inflow and outflow are recorded in terms of the average value over a sample of 600 readings (1 minute).

The rainfall generator system consists of a gear pump (ISMATEC MCP-Z) and a distribution system with three lines of nozzles. The installed gear pump allows generating flow rates until 7020 ml/min and is controlled by a single communication protocol (serial interface). The pump reduces the rotation speed shortly before the end of the dispensing cycle providing controllable and drop-precise dispensing cycles. In order to generate spatially uniform rainfall depth on the test bed, the distribution system is horizontally mounted 80 cm above the surface and 14 nozzles are properly distributed along the three lines.

### 2.3. *Laboratory test programme*

The test procedure consists of the following phases:

- preliminary wetting cycle of the pavement, and free drainage for a period of 12 hours before the test is started;
- generation of a constant precipitation rate for a duration of 15 minutes;
- measure of the inflow (rainfall) and discharge (sub-surface and runoff outflow) volumes during the rainfall duration and the following 6 hours.

The laboratory test programme was designed in order to investigate the influence of the rainfall intensity and the pavement slope on the hydrologic response of a specific permeable pavement stratigraphy installed in Southern Italy (Calabria Region). For each investigated stratigraphy, the tests were carried out for three system slopes and two rain intensities. In particular the characteristics of the performed tests can be summarized as follows:

- Slope: 0.5%, 2% and 3%;
- Rainfall intensity: 17 mm/h and 98 mm/h.

Considering the frequency of the maximum annual rainfall depths for a given duration (IDF curves), the selected rainfall rates equal for a duration of 15 minutes correspond to less than 1 year return period (high frequency event) and the 5-years return period design events. They have been derived from the IDF curves based on the rainfall data series observed in the Calabria region of Italy.

Each test was repeated at least three times in order to provide a consistent data base of validated results.

### 2.4. *Data analysis*

The hydrologic response of a permeable pavement was analysed by using two indexes: a dimensionless volume index (or discharge coefficient) and a timing index. The discharge coefficient, $D_{15}$ [-], is calculated as the ratio between the discharge volume (sub-surface flow) and the inflow volume measured at the end of the rainfall event corresponding to 15 minutes of constant rainfall intensity. Two values of the timing index are used, being defined as the elapsed time corresponding to the 50% and 80% of the normalized cumulative discharge volume of sub-surface flow, hereinafter indicated respectively as $T_{50}$ [min] and $T_{80}$ [min].

In order to statistically compare the hydrologic response measured for different permeable pavement configurations/settings, the one-way analysis of variance (ANOVA) tests were carried out with respect to the discharge coefficient values. Furthermore multiple comparisons including all significant pairwise combinations were performed to determine which settings are significantly different; for such purpose the Tukey test was used.

## 3. Results and discussion

The laboratory programme consists of 72 validated tests for which one-minute inflow and outflow measurements are available. In particular the following system and hydrologic characteristics have been tested:

- 4 stratigraphies (PB-GS, PB-RG, CC-GS and CC-RG);
- 3 slope conditions (0.5%, 2% and 3%);
- 2 rainfall intensities (17 mm/h and 98 mm/h).

Figure 4 provides an example of the inflow and outflow (sub-surface and runoff) measured during the laboratory test programme at high and low rainfall intensities for a specific pavement setting.

No surface runoff was observed for all the investigated systems, slope conditions and rainfall intensities, therefore the laboratory results confirm the effective drainage capacity of the permeable pavements.

In the first two sections, results of the laboratory test programme are examined with respect to the high and low rainfall intensities in order to point out the hydrologic performance of the permeable pavements. In the last section, the discharge coefficient values are statistically analysed to assess the impact of slope and stratigraphy on the drainage capacity of the permeable pavements.

### *3.1. Hydraulic performance of permeable pavements at high rainfall intensity*

Figure 5 illustrates the discharge coefficient, $D_{15}$, observed at high rainfall intensity with respect to the four permeable pavement stratigraphies, each one tested for three different slope conditions (twelve permeable pavement settings, in all). For each pavement setting, the mean and the standard deviation values of the $D_{15}$ coefficient are reported.

Looking at the different permeable pavements, results demonstrate that the concrete cell pavers show a predominant detention capacity. This is likely due to the larger percentage of voids filled with joint material (volcanic sand) with respect to the pervious brick paver. Indeed the $D_{15}$ coefficient ranges from 0.57 to 0.73 and from 0.55 to 0.63 for the PB and CC pavers respectively (see Figure 5).

In Figure 6 the normalized cumulative discharge volume of sub-surface flow is plotted vs. the elapsed time at high rainfall intensity, in particular the hydrologic response for the pervious brick pavers is reported on the left side while the ones for the concrete cell pavers is reported on the right side. In each graph the black lines refer to the gravel-sand filter layer and the grey lines refer to the recycled glass filter layer, tested for three different slope conditions. This figure reveals the pattern of the hydrologic response. At high rainfall intensity, the hydrologic response of concrete cell pavers (see the graph on the right side) is the same for all the pavement settings, at least across the first limb of the cumulative discharge volume curve. As for the pervious brick pavers the hydrologic response at 0.5% slope is delayed with respect to the one observed at 2-3% slope (see Figure 6).

Table 1 summarizes the hydrologic response at high rainfall intensity expressed in terms of the selected timing indexes $T_{50}$ and $T_{80}$, i.e. the elapsed time corresponding to the 50% and 80% of the normalized cumulative discharge volume. The mean and the standard deviation values of the timing indexes are reported for each of the twelve permeable pavement settings investigated in the present study. In addition, the mean and the standard deviation values are calculated for all settings and for the two permeable paver typologies.

From the results reported in Table 1 it appears that the mean and standard deviation values are fairly constant across the overall twelve settings showing comparable hydrologic performance. In particular the mean value of $T_{50}$ and $T_{80}$ are equal to 13 and 19 minutes respectively thus pointing out the high drainage capacity. Note that the 50% of the subsurface volume is drained before the end of the rainfall event. Only the pervious brick pavers reveal $T_{50}$ and mainly $T_{80}$ values decreasing with increasing slope. Furthermore it can be noticed that the pervious brick pavers respond faster than concrete cell pavers, indeed the standard deviation values decrease if the two paver typologies are examined separately (see Table 1).

### 3.2. *Hydraulic performance of permeable pavements at low rainfall intensity*

Figure 7 illustrates the discharge coefficient, $D_{15}$, observed at low rainfall intensity with respect to the four permeable pavement stratigraphies, each one tested for three different slope conditions (twelve permeable pavement settings, in all). For each pavement setting, the mean and the standard deviation values of the $D_{15}$ coefficient are reported. The $D_{15}$ value ranges between 0.01 and 0.12 thus pointing out that at low rainfall intensity, the detention process (temporary storage) is dominant across the whole setting (see Figure 7).

In Figure 8 the normalized cumulative discharge volume of sub-surface flow is plotted vs. the elapsed time at low rainfall intensity, in particular the hydrologic response for the pervious brick pavers is reported on the left side while the one for the concrete cell pavers is reported on the right side. In each graph the black lines refer to the gravel-sand filter layer and the grey lines refer to the recycled glass filter layer, tested for three different slope conditions.

The patterns of the hydrologic response illustrated in Figure 8 show the influence of the filter layers on the hydrologic response: the pavers laid out on recycled glass aggregate show a steeper rising limb of the cumulative discharge curve thus highlighting that the drainage capacity of RG is much higher than GS at low rainfall intensity. Such behaviour is more marked in the pervious brick pavers with respect to the concrete cell across the whole hydrologic response, since in the latter case the joint material partially reduces the filter layer effect.

Table 2 summarizes the hydrologic response behaviour at low rainfall intensity expressed in terms of the selected timing indexes $T_{50}$ and $T_{80}$, i.e. the elapsed time corresponding to the 50% and 80% of the normalized cumulative discharge volume. The mean and the standard deviation values of the timing indexes are reported for each of the twelve permeable pavement settings investigated in the present study. In addition, the mean and the standard deviation values are calculated for all settings and for the two permeable paver typologies.

The mean value of $T_{50}$ is equal to 67 minutes ($T_{80} > 6$ hours) thus confirming the predominant role of the detention process at low rainfall intensity for all pavement settings. Results reported in Table 2 confirm that the type of filter layer employed significantly affects the hydrologic performance at low rainfall intensity. Indeed the standard deviation value of $T_{50}$ calculated with respect to all pavement settings strongly decreases if the analysis is carried out with respect to the gravel-sand and recycled glass aggregate settings separately.

### 3.3. *The impact of slope and stratigraphy on the discharge coefficient*

The influence of slope emerges in the drainage capacity for all the pervious paver typologies. The higher the slope the higher is the $D_{15}$: the values observed for the 0.5% slope are significantly different when compared with the values observed for both the 2% and 3% slope settings ($p < 0.001$). On the contrary the $D_{15}$ values observed for the 2% and 3% slope settings do not significantly differ as confirmed by the statistical results: the p values range between 0.053 and 0.832. The exception occurs for the CC-GS configuration where the $D_{15}$ values are not statistically different.

Note that the statistical analysis has been performed by comparing the discharge coefficient observed under consistent hydrologic conditions (i.e. rainfall intensity).

The influence of surface layers on the discharge coefficient is observed mainly at high rainfall intensity: the PBs reveal a predominant drainage capacity when compared with the CCs. Statistical results confirm the impact of paver typology, indeed the $D_{15}$ values observed for the CCs are significantly different when compared with the values observed for the PBs ($p < 0.001$) at the corresponding slope condition. The only exception occurs at 0.5% slope.

The influence of the material used as filter layer (Recycled Glass and Gravel-Sand) is higher in the PBs than in the CCs. As for the pervious brick pavers it can be noticed that the filter layer affects the $D_{15}$ value, in particular at high rainfall intensity, the drainage capacity increases when the gravel and sand filter layer is used. Statistical results confirm the impact of the filter layers in the drainage capacity of the PB pavers: the $D_{15}$ values observed for the GS - filter layer configurations are significantly different when compared with the values observed for the RG – filter layer ($p < 0.001$) at the corresponding slope condition. On the contrary, by comparing the hydrologic behaviour of the cell pavers for the different filter layers, it emerges that the discharge coefficient is slightly variable as a function of filter layer typology thus confirming the predominant role played by the joint material (volcanic sand) in the detention process.

Results observed at low rainfall intensity show a limited impact of both the paver and the filter layers on the drainage capacity since the detention process mainly drives the hydrologic response.

## 4. Conclusions

The hydrologic response of the most common permeable pavement systems has been investigated under different hydrologic conditions and system settings at the laboratory test-bed of the University of Genoa.

Laboratory test results confirm the drainage capacity of the permeable pavements, indeed no surface runoff occurs for all the investigated systems. The hydrologic performance has been examined by using two index typologies: the discharge coefficient, $D_{15}$ and the timing indexes, $T_{50}$ and $T_{80}$. At two different rainfall intensity regimes, the laboratory tests show the following results:

- at high rainfall intensity, the discharge coefficient, $D_{15}$ is in the range 0.55 - 0.75 for all the tested permeable pavements settings and 80% of the inflow volume is discharged within the 5-10 minutes beyond the end of the rainfall event ($T_{80}$ = 16 - 22 min);
- at low rainfall intensity, the discharge coefficient, $D_{15}$ varies between 0.01 - 0.12 for all the tested permeable pavements settings. $T_{50}$ ranges from 42 to 58 min for permeable pavers laid on recycled glass aggregate, while it varies between 77 and 89 min when the gravel and sand aggregate is used as the filter layer.

Based on the collected data, the hydrologic performance is fairly consistent for all the investigated permeable pavements. The recycled glass aggregate turns out to be a valid solution to replace sand and gravel mixture in permeable pavement, showing even a higher drainage capacity than the latter at high frequency rainfall events.

Concerning the impact of the slope condition, results indicate that the higher the slope the higher is the drainage capacity, irrespective of the stratigraphy and the rainfall intensity.

Laboratory results support the role of the permeable pavements in positively affecting the storm water management control as a suitable component of sustainable urban drainage system. Indeed such systems contribute to retain the small frequent rainfall events, detain the large events, and convey the extreme events.

Porous pavements are susceptible to clogging, which can severely reduce their drainage capacity. Thus, periodic maintenance is critical and surfaces should be cleaned at least two times per year, depending upon potential exposure to sediments. As maintenance represents a critical issue, it is essential to investigate how the materials functions and their capacity can be re-established after a certain period of time. Beyond the encouraging information presented here, a follow-up field survey is presently on-going at the University of Calabria where a full scale permeable pavement experimental site has been recently installed.

Acknowledgements

The study was funded within the project "Integrated and sustainable management service for the water - energy cycle in urban drainage systems" of the National Operational Program - Research and Competitiveness 2007-2013 (PON-REC), co-financed by the European Regional Development Fund and National Resources Grant.

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Table 1: Hydrologic response behaviour at high rainfall intensity with respect to the twelve permeable pavement settings. $T_{50}$ and $T_{80}$ indicate the elapsed time corresponding to the 50% and 80% of normalized cumulative discharge volume respectively.

| *Pavement typology* | *Slope [%]* | *$T_{50}$ [min]* | | *$T_{80}$ [min]* | |
|---|---|---|---|---|---|
| | | Mean | Std. Dev. | Mean | Std. Dev. |
| ***Pervious Brick - Gravel Sand*** | 0.5 | 13 | - | 20 | 0.5 |
| | 2 | 12 | 0.5 | 17 | 0.6 |
| | 3 | 11 | 0.6 | 16 | - |
| ***Pervious Brick - Recycled Glass*** | 0.5 | 13 | - | 20 | 0.6 |
| | 2 | 12 | - | 18 | 0.5 |
| | 3 | 12 | - | 18 | 0.6 |
| ***Concrete Cell - Gravel Sand*** | 0.5 | 13 | - | 21 | 0.6 |
| | 2 | 13 | - | 21 | 0.6 |
| | 3 | 13 | - | 22 | - |
| ***Concrete Cell - Recycled Glass*** | 0.5 | 14 | - | 22 | 0.6 |
| | 2 | 13 | - | 20 | 0.5 |
| | 3 | 13 | 0.6 | 20 | 0.6 |
| ***All pavers*** | Mean | *13* | | *19* | |
| | Std. Dev. | *0.7* | | *2.1* | |
| ***Pervious Brick pavers*** | Mean | *12* | | *18* | |
| | Std. Dev. | *0.7* | | *1.5* | |
| ***Concrete Cell pavers*** | Mean | *13* | | *21* | |
| | Std. Dev. | *0.5* | | *1.1* | |

Table 2: Hydrologic response behaviour at low rainfall intensity with respect to the twelve permeable pavement settings. $T_{50}$ and $T_{80}$ indicate the elapsed time corresponding to the 50% and 80% of normalized discharge volume respectively.

| *Pavement typology* | *Slope [%]* | *$T_{50}$ [min]* | | *$T_{80}$ [min]* | |
|---|---|---|---|---|---|
| | | Mean | Std. Dev. | Mean | Std. Dev. |
| ***Pervious Brick - Gravel Sand*** | 0.5 | 88 | 0.7 | >375 | - |
| | 2 | 80 | 2.6 | >375 | - |
| | 3 | 92 | 12.1 | >375 | - |
| ***Pervious Brick - Recycled Glass*** | 0.5 | 42 | 2.5 | >375 | - |
| | 2 | 44 | 4.2 | >375 | - |
| | 3 | 53 | 3.2 | 373 | 3.5 |
| ***Concrete Cell - Gravel Sand*** | 0.5 | 77 | 2.1 | >375 | - |
| | 2 | 82 | 1.4 | >375 | - |
| | 3 | 89 | 12.1 | 373 | 4.0 |
| ***Concrete Cell - Recycled Glass*** | 0.5 | 57 | 2.6 | 357 | 31.2 |
| | 2 | 46 | 4.0 | >375 | - |
| | 3 | 58 | 4.9 | 364 | 16.3 |
| ***All pavers*** | Mean | *67* | | *>375* | |
| | Std. Dev. | *19.1* | | - | |
| ***Pervius Brick pavers*** | Mean | *84* | | *>375* | |
| | Std. Dev. | *5.8* | | - | |
| ***Concrete Cell pavers*** | Mean | *50* | | *>375* | |
| | Std. Dev. | *6.9* | | - | |

Figure 1: Stratigraphy outline and plan view of the two typologies of permeable pavements tested in the present study. The dimensions are expressed in cm.

Figure 2: Particle size distribution of the mixture of Gravel and Sand, Recycled Glass aggregate used as filter layers and the Volcanic Sand as joint filling material in the investigated permeable pavements. The dashed line refers to a percentage passing equal to 50%.

Figure 3: Laboratory test-bed outline.

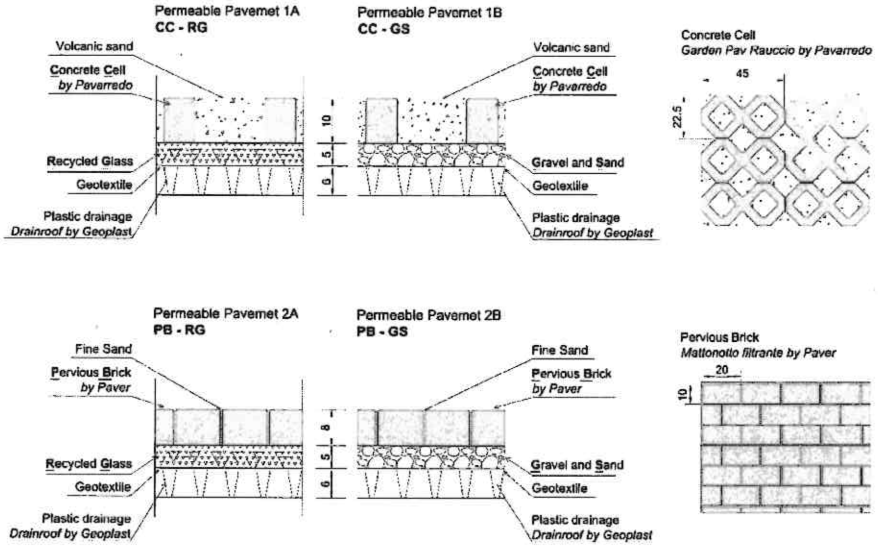
Figure 4: The inflow and sub-surface outflow measured at high (left side) and low (right side) rainfall intensities for the Pervious Brick - Recycled Glass stratigraphy and the 2% slope condition.

Figure 5: Discharge coefficient $D_{15}$ observed at high rainfall intensity with respect to the twelve permeable pavement settings.

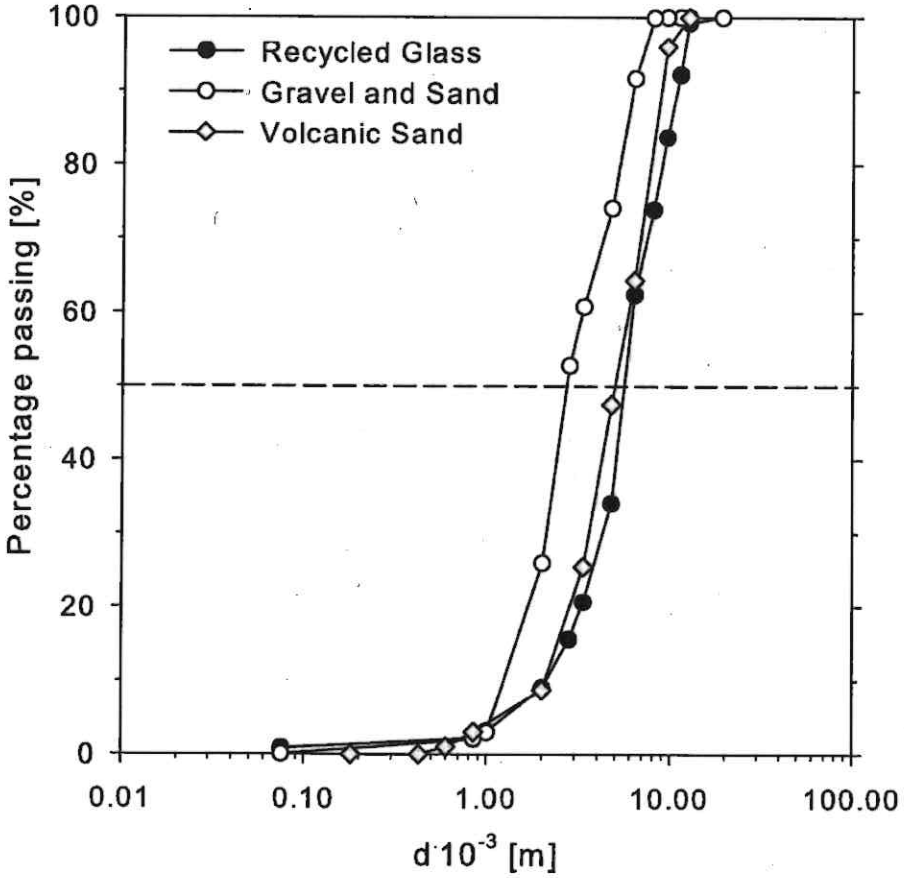
Figure 6: Normalized cumulative discharge volume plotted vs. the elapsed time at high rainfall intensity. The Pervious Brick (left side) and the Concrete Cell (right side) pavers are illustrated with respect to the Gravel-Sand (black lines) and the Recycled Glass (grey lines) filter layers for the investigated slope conditions.

Figure 7: Discharge coefficient $D_{15}$ observed at low rainfall intensity with respect to the twelve permeable pavement settings.

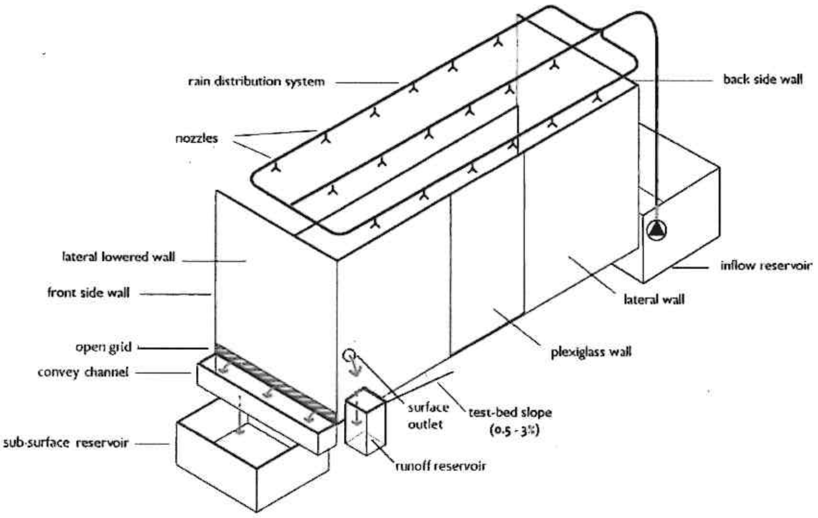
Figure 8: Normalized cumulative discharge volume plotted vs. the elapsed time at low rainfall intensity. The Pervious Brick (left side) and the Concrete Cell (right side) pavers are illustrated with respect to the Gravel-Sand (black lines) and the Recycled Glass (grey lines) filter layers for the investigated slope conditions.



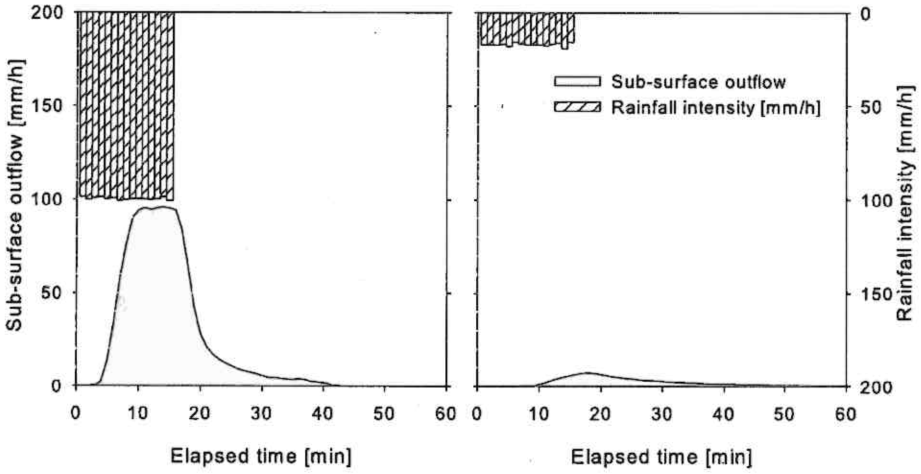
Stratigraphy outline and plan view of the two typologies of permeable pavements tested in the present study. The dimensions are expressed in cm.
841x594mm (600 x 600 DPI)



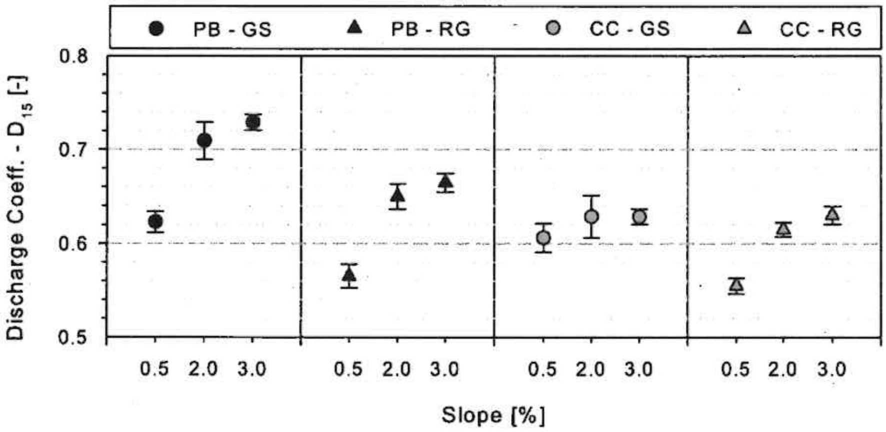
Particle size distribution of the mixture of Gravel and Sand, Recycled Glass aggregate used as filter layers and the Volcanic Sand as joint filling material in the investigated permeable pavements. The dashed line refers to a percentage passing equal to 50%.
101x101mm (300 x 300 DPI)



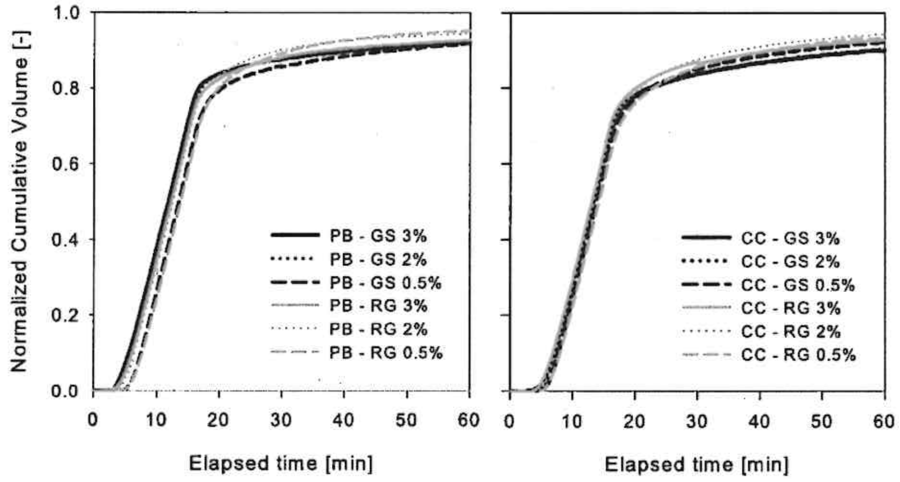
Laboratory test-bed outline.
762x423mm (150 x 150 DPI)



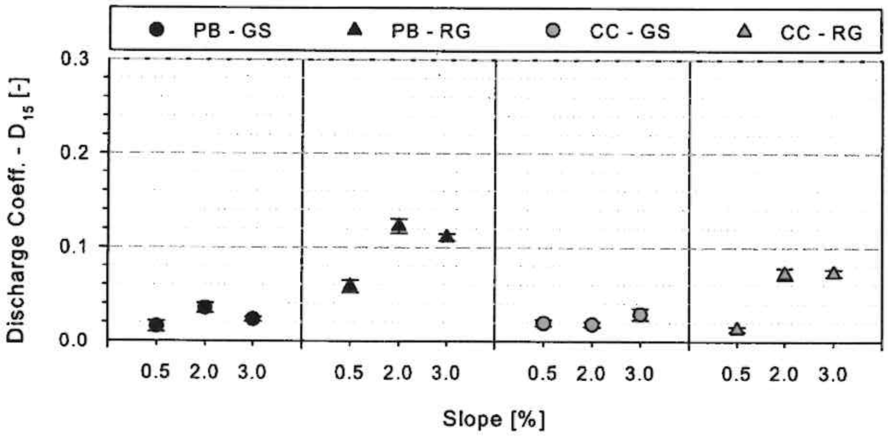
The inflow and sub-surface outflow measured at high (left side) and low (right side) rainfall intensities for the Pervious Brick - Recycled Glass stratigraphy and the 2% slope condition.
93x53mm (300 x 300 DPI)



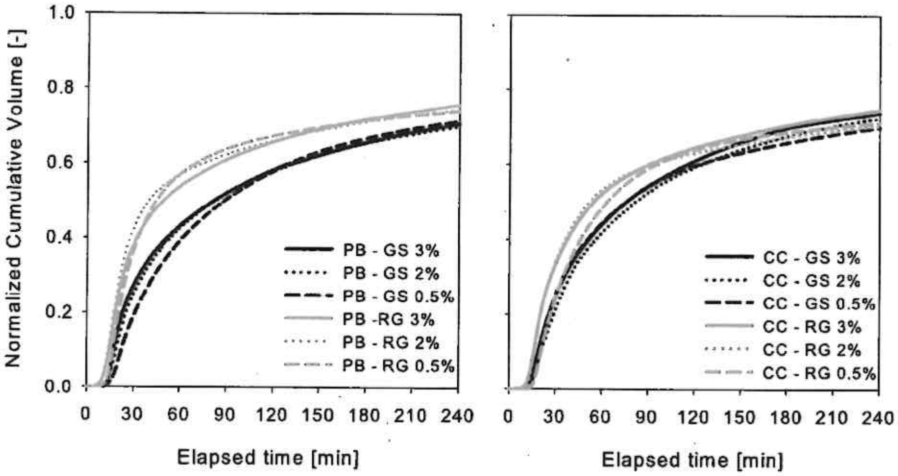
Discharge coefficient $D_{15}$ observed at high rainfall intensity with respect to the twelve permeable pavement settings.
68x31mm (300 x 300 DPI)



Normalized cumulative discharge volume plotted vs. the elapsed time at high rainfall intensity. The Pervious Brick (left side) and the Concrete Cell (right side) pavers are illustrated with respect to the Gravel-Sand (black lines) and the Recycled Glass (grey lines) filter layers for the investigated slope conditions.
94x55mm (300 x 300 DPI)



Discharge coefficient $D_{15}$ observed at low rainfall intensity with respect to the twelve permeable pavement settings.
71x34mm (300 x 300 DPI)



Normalized cumulative discharge volume plotted vs. the elapsed time at low rainfall intensity. The Pervious Brick (left side) and the Concrete Cell (right side) pavers are illustrated with respect to the Gravel-Sand (black lines) and the Recycled Glass (grey lines) filter layers for the investigated slope conditions.
93x53mm (300 x 300 DPI)