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Runoff infiltration to permeable paving in clogged conditions

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ABSTRACT

The effect of varying runoff on a clogged permeable surface was analysed using a specifically designed laboratory rig consisting of a variable gradient testing frame, a rain simulator and water collecting chambers. The results indicate that the apparatus can be used successfully to test the runoff resistance of concrete blocks in permeable surfaces. The results indicate that a surface at 2% gradient that is clogged with crushed construction debris still permits significant levels of infiltration.

KEYWORDS

SUDS; BMPs; clogging; pervious pavement; concrete blocks.

INTRODUCTION

Pervious pavements are an important subset of SUDS (Sustainable Urban Drainage Systems) and BMPs (Best Management Practices) (Pratt *et al.*, 2002). Pervious surfaces can be divided in porous and permeable pavements. Permeable pavements are surfaced with non-porous materials that filter through inlets or slots in the surface (Pratt, 1997). This is the case in permeable concrete block paving.

Some advantages of pervious surfaces in general are their high removal capacity of soluble and fine particulate pollutants in urban runoff, as well as the possibility of allowing groundwater recharge and controlling stream bank erosion (Novotny *et al.*, 1994). In addition, the use of pervious surfaces reduces land consumption, preserves the natural water balance at the site and improves the skid resistance of the surface, thus reducing hydroplaning (Schueler, 1987).

Conventional pavements may be substituted by pervious pavements in parking areas and in lightly trafficked areas, provided that the gradients, subsoil, drainage characteristics and groundwater conditions are suitable. Due to their filtration characteristics, pervious pavements cannot be used in areas where hazardous substances are likely to be washed into the subsoil and areas of aquifer recharge.

Furthermore, the use of pervious pavements may be restricted in cold or arid regions or regions with high wind erosion, due to the high risk of blockage of the surface. The most common factor causing the failure of pervious surfaces is clogging.

Clogging can be defined as the accumulation of silt within the pavement structure due to sedimentation, thus reducing its filtering capacity (Dierkes, 2002). This clogging of the pavement is most likely to occur in the surface layer and in the geotextile layers, if these are used (Rommel *et al.*, 2001). The type of silt can vary greatly depending on factors such as the type of soils in the area (clay silt, lime, silica, etc), the prevailing wind and the surrounding uses of land (building site, industrial areas, commercial areas, etc.). Blockage can be reduced by regular cleaning by suction sweeping or high-pressure water jet (Hollinrake, 1991).

This paper summarises part of the research on hydraulic performance of permeable pavements carried out in the University of Cantabria. Specifically, the performance of a clogged permeable surface with varying runoff entry is analysed.

AIMS AND OBJECTIVES

The aim of this research was to assess the infiltration rate of a clogged permeable pavement. The sample is subjected to varying runoff flows at a fixed gradient. Defining "runoff resistance" as the draining performance of a clogged permeable pavement, this can be analysed to characterise any concrete block used to build permeable surfaces.

The specific objectives of the work were to:

- propose a consistent laboratory procedure for permeable surface testing and assess its reliability

- analyse the effects of clogging on the hydraulic performance of permeable pavements with concrete blocks
- determine the runoff resistance for a permeable surface built with a specific block when clogged with a selected silt.

METHODOLOGY

The runoff resistance study was carried out at the University of Cantabria with a specifically designed test based on previous experience (Rodríguez *et al.* 2005, Davies *et al.* 2002 and Rommel *et al.* 2001). Firstly, trial tests were carried out to ensure optimum apparatus performance and feasibility. The trial tests also allowed the development of sample preparation criteria and testing procedures for the final tests.

Apparatus

The equipment was designed to test the drainage capacity of a sample of pavement 500 mm wide and 500 mm long. It not only allowed the measurement of runoff infiltration but also direct infiltration capacity for rain falling vertically. The rain intensity and runoff could be independently adjusted to the target intensity. The gradient could also be adjusted between 0% and 15%. The test rig, shown in Figure 1, consisted of the following components: testing frame, grid, water collecting chambers and rain simulator.

Testing frame and grid

The testing frame is made of steel and has four legs to support a grid on which the samples are placed. It is possible to adjust the frame to obtain varying gradients for testing the samples. The gradient for the runoff infiltration test was fixed at 2%.

Water collecting chambers

Chambers are installed beneath the sample to collect the water that has infiltrated and also the residual water that has not infiltrated within the pavement length. Five chambers collect water that has infiltrated through the sample and conduct it to collecting chambers. The chambers are of equal size and placed parallel to the downward gradient, such that distribution *chamber 1* is the chamber located underneath the highest section of the sample and *chamber 5* is located underneath the lowest section of the sample. Residual runoff is conducted to a separate *chamber number 6*.

Rain Simulator

The rain simulator is the main component of the apparatus; it is designed to water the sample in two ways. A transverse pipe is located at the highest part of the apparatus which supplies a curtain of flow at adjustable flow to produce runoff. Five parallel pipes with sprinklers that produce raindrops are positioned directly on top of the sample. This source of rain has an adjustable flow, independent of the curtain runoff.

The rain simulator is attached to a separate upper frame positioned above the sample. The upper frame enables adjustments in its gradient to conform to the sample, thus a constant distance between surface and drop source can be maintained.

Two independent supplies of water allowed testing the sample with runoff only, direct rain or both combined. For this runoff resistance test, the rain simulator supplied runoff only and no direct rain was produced. The flow supplied at the top of the slope was varied to represent a range of rain intensities between 50 mm/h and 175 mm/h. These can be seen either as resulting from increasing rain intensity on a constant contributing area of 0.25 m^2, or as resulting from increasing this contributing area (for constant rainfall intensity). For example, runoff equivalent to 100 mm/h could represent either a rainfall intensity of 100 mm/h falling on the contributing area of 0.25 m^2, or a rainfall intensity of 50 mm/h falling on a total contributing area of 0.5 m^2. Where the increasing runoff is taken as the consequence of additional contributing area, and taking 50 mm/h as the notional constant rainfall intensity, the contributing areas considered ranged between 0.25 m^2 and 0.875 m^2. Defining permeable area ratio (PAR) as the permeable area divided by the total contributing area, the range of cases studied is given on Table 1.

No flow meters were used. The calibration of the flows was made varying the taps and checking directly the weight of water collected in a separate chamber during the time. When the flow was as required it was connected to the sample, checking again at the end of the test. All the weight measurements were made with scales (0.01 g). The temperature was around 20ºC and the humidity around 75%.

Sample

The pavement sample consisted of a bedding geotextile, granular base and concrete blocks enclosed in a square wooden frame of 500 mm length and 130 mm height. The sample was clogged with silt as described below.

Geotextile and granular base

The geotextile layer plays a fundamental role in the permeable pavement structure. It is used as separation, filter and even reinforcement (Pratt, 2003). The geotextile selected for the pavement was non-woven polyester of 150 g/m^2 and a water permeability flow rate of 110 l/m^2s. Its separation and filter properties provided a suitable permeability.

The granular base was pea gravel placed on top of the geotextile. The base was 50 mm deep, and was manually compacted and levelled. The selected aggregate was limestone with particle sizes between 4 mm and 6.35 mm diameter after sieving (Rodríguez *et al.* 2005).

Concrete Blocks

The blocks tested were developed in cooperation with Bloques Montserrat S.L., an established pre-cast concrete products manufacturer in Santander. The blocks were manufactured by pouring concrete by gravity into purpose-built moulds and curing in air.

The blocks had a rectangular base, 200 mm long by 100 mm wide, with elliptical vertical “slots” from top surface to base. These are left open, without any fill, to allow infiltration. Two slots were located along the longer sides of the blocks and one centred on the shorter side. This distribution provides complete horizontal symmetry and multiple surface layouts and distributions. Figure 2 shows the geometry of the block.

Sample preparation

The geotextile layer was laid on top of the grid, inside the sample frame. The geotextile was 600 mm square to allow 50 mm of upturn at each edge. The granular base was laid on top of the geotextile.

The blocks were placed in their frame on the base following the same pattern as that used by Davies *et al.* (2002). The blocks were pushed together and levelled to obtain an even surface, thus preventing the accumulation of water and the formation of pools. Having positioned the blocks, the screws in the frame were tightened and the gaps between frame and blocks sealed to prevent seepage.

Clogging Conditions

The silt selected for the tests was crushed construction debris containing concrete, bricks, glass, metal and wood, with an organic matter content of 3%, by the potassium dichromate method, and 5% by ignition loss of material under 2 mm diameter. The particle size distribution used for the clogging tests was that used by Rodríguez *et al.* (2005) and is shown in Figure 3.

Method of Silt Application

Observations during the previous trial tests confirmed that, in order to obtain significant data for the blockage effect, the pavement had to be fully clogged.

In the trial tests, the silt was applied in a single filling and compacting operation. This produced some void spaces after initial wetting at high flow rates probably due to the lighter particles being washed out. It was therefore necessary to modify the method of application to ensure complete superficial clogging. In the final tests, after initial wetting, particle washing and void generation, additional silt was applied in the void spaces created.

Test Procedure

After clogging the sample, the gradient was adjusted to 2% and the sample was left under the inflow for 10 minutes of wetting to allow water to enter through the gaps in the blocks and wet the geotextile and base.

The measurement period for each test was 20 minutes. The first flow was equivalent to a rainfall intensity of 175 mm/h falling on a 0.250 m^2 contributing area (or a total area of 0.875 m^2 contributing runoff from a rainfall of 50 mm/h). After 20 minutes, the collecting chambers were removed and data recorded. The flow was adjusted to the next lower rate (in Table 1) for the following measurement interval. This sequence was repeated until the last value of runoff – equivalent to 50 mm/h falling on the constant contributing area (0.250 m^2).

RESULTS AND DISCUSSION

The runoff resistance performance of the tested permeable surface is given by the percentage water infiltration within the pavement length. This was calculated by adding the contributions of chambers 1 to 5, and comparing with the total volume of runoff applied. The lines on Figure 4 represent the results for particular numbered test conditions (with the mass of silt used to clog the permeable pavement in each case given in brackets).

Some variations in performance were due to the differences in clogging masses. For the lowest clogging masses the series showed the best infiltration performances, especially at greater inflows. For the higher clogging masses the series correspond to the worst infiltration performances.

Assuming that 800 g of construction debris silt, with the specified particle distribution, is the minimum amount necessary to ensure full clogging, the two tests with the lowest clogging masses were discarded. Figure 5 presents remaining results after discarding the series with clogging masses lower than 800 g. The trend line is linear and has a R^2 value of 0.897. By using the trend line it is possible to determine the percentage infiltration for a particular runoff rate supplied. It can be seen that for lower values of supplied runoff, percentage infiltration values would be slightly conservative. Values of percentage infiltration based on interpolation of this line are presented in Table 2. The pavement infiltration rate is the pace at which the pavement can absorb the body of water that is being supplied to it. This is given by the product of the percentage infiltration and the supplied runoff.

The data (on Figure 5 and Table 2) indicates that for runoff equivalent to a rain intensity of 50 mm/h falling on the contributing area, or a PAR of 1.0, 81% of runoff infiltrates the permeable surface at 2% gradient even when it is blocked. In practical terms this indicates that even when the openings provided to create the permeable nature of the surface have been completely filled with construction debris, all but one-fifth of the runoff arising from an intense rain event can still be drained by infiltration into the surface.

The results also indicate that for the blocked surface at this gradient, the maximum infiltration rate is 64 mm/h, achieved for a runoff rate equivalent to 125 mm/h, or PAR of 0.4; however this represents only 51% infiltration. For even higher values of runoff, the infiltration rate decreases. Interpolation of Figure 5 at the lower end of values of runoff suggests that for runoff equivalent to rain intensity of 25 mm/h, at least 90% infiltrates the permeable surface even when blocked.

Analysis of the Drained Water Distribution

The drainage path of a pervious pavement is the distance travelled by the surface flow from the beginning of the permeable surface to the point where it drains. This concept is illustrated in Figure 6.

The drainage path can be determined by identifying the point to which most of the input water is conveyed. In the runoff resistance test, the drainage path along the pavement increased with a reduction in the percentage of total volume in chamber 1.

If the length of the drainage path increases to more than the sample length, this will result in residual runoff. This residual runoff will be the volume of water drained to chamber 6 in the apparatus.

Figure 7 shows the distribution of water volumes in the collecting chambers for each input runoff. The results show that the percentage volume in chamber 6 was lower as the input runoff was lower. For input runoffs greater than 100 mm/h the measurements show that chamber 6 received more than 50% of the total volume of runoff.

CONCLUSIONS

The results indicate that a surface of permeable blocks at 2% gradient that is clogged with crushed construction debris still permits significant levels of infiltration. The data indicates that for runoff equivalent to 50 mm/h rain intensity falling on a 0.25 m^2 contributing area, 81% of runoff infiltrates the permeable surface. For the blocked surface at this gradient, the maximum infiltration rate is 64 mm/h, achieved for a runoff rate equivalent to 125 mm/h, or a total area 2.5 times that of the permeable surface contributing runoff from 50 mm/h of rainfall; however this represents only 51% infiltration. For even higher values of runoff, the infiltration rate decreases. At the lower end of values of runoff, the results suggest that for runoff equivalent to rain intensity of 25 mm/h, at least 90% infiltrates the permeable surface when blocked.

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FIGURE CAPTIONS

Figure 1. Apparatus

Figure 2. Trial concrete blocks tested

Figure 3. Particle size distribution of silt

Figure 4. Runoff Resistance Test Results

Figure 5. Interpretation of Infiltration Results

Figure 6. Drainage path illustration

Figure 7. Collected Water Distribution

TABLE CAPTIONS

Table 1. Runoff Conditions Studied

Table 2. Infiltration Results

FIGURES

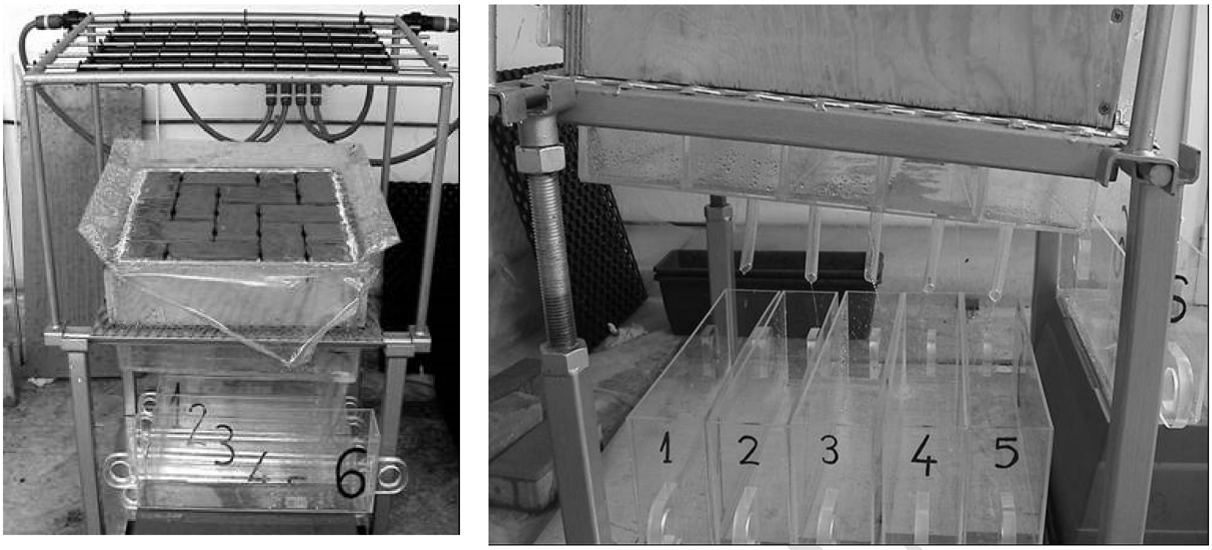


Figure 1.

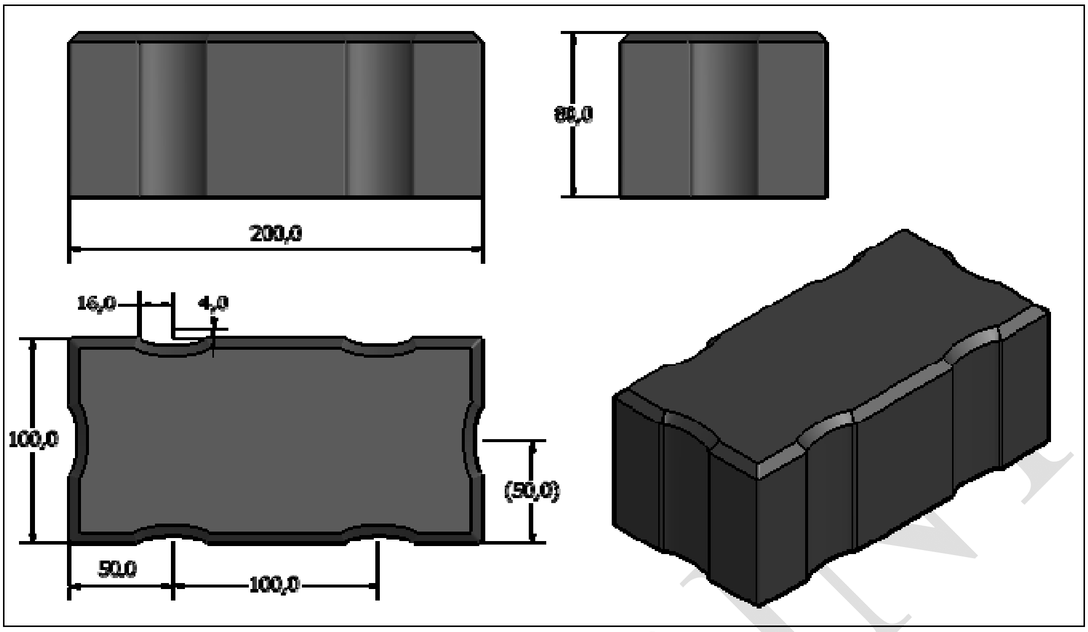


Figure 2.

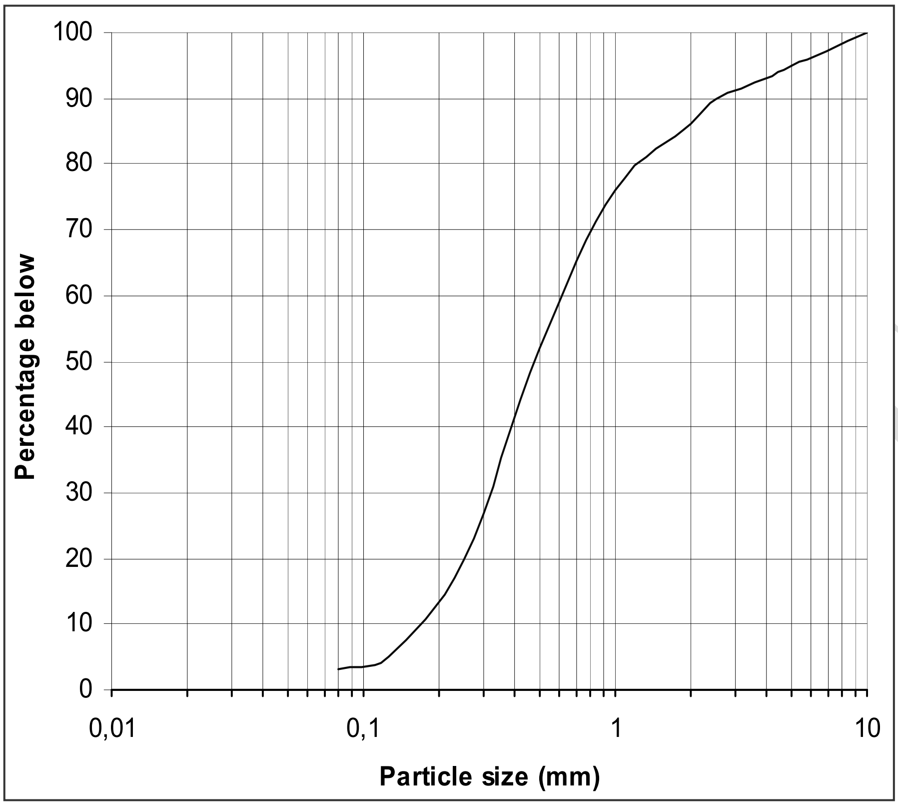

100
90
80
70
60
50
40
30
20
10
0
Percentage below
0,01
0,1
1
10
Particle size (mm)

Figure 3.

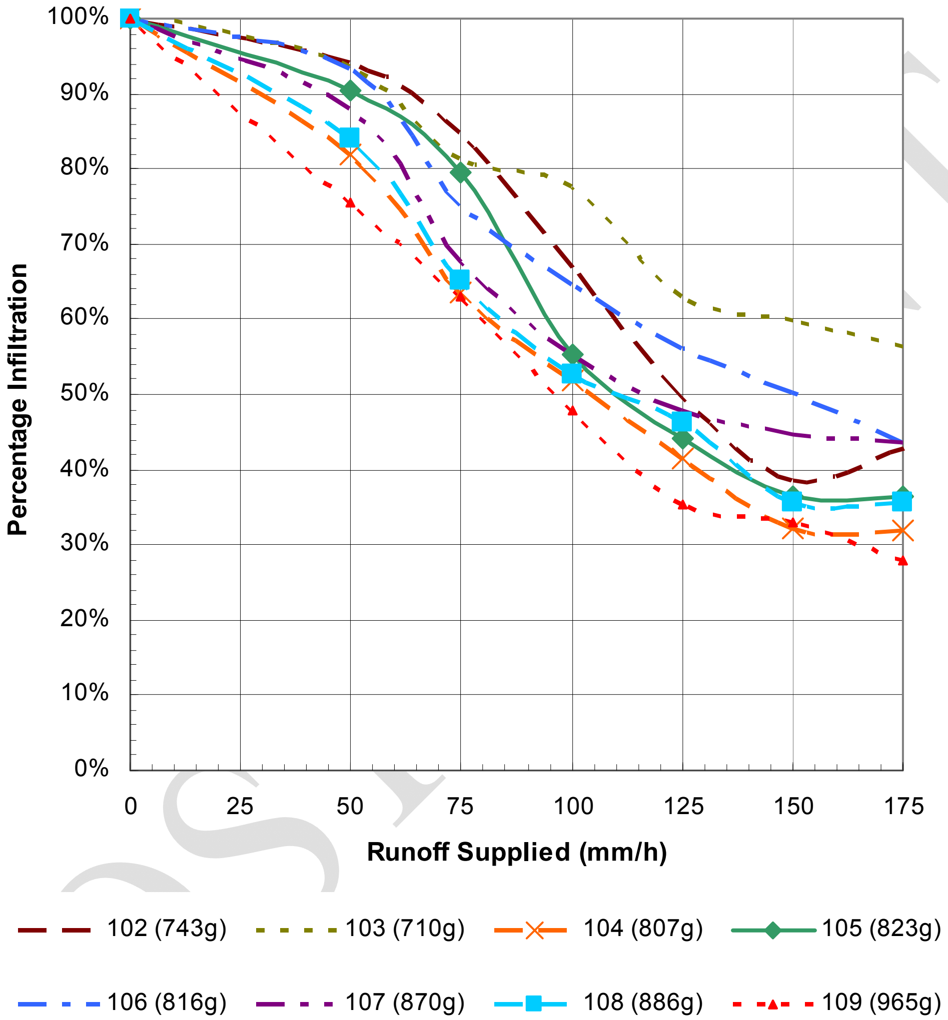
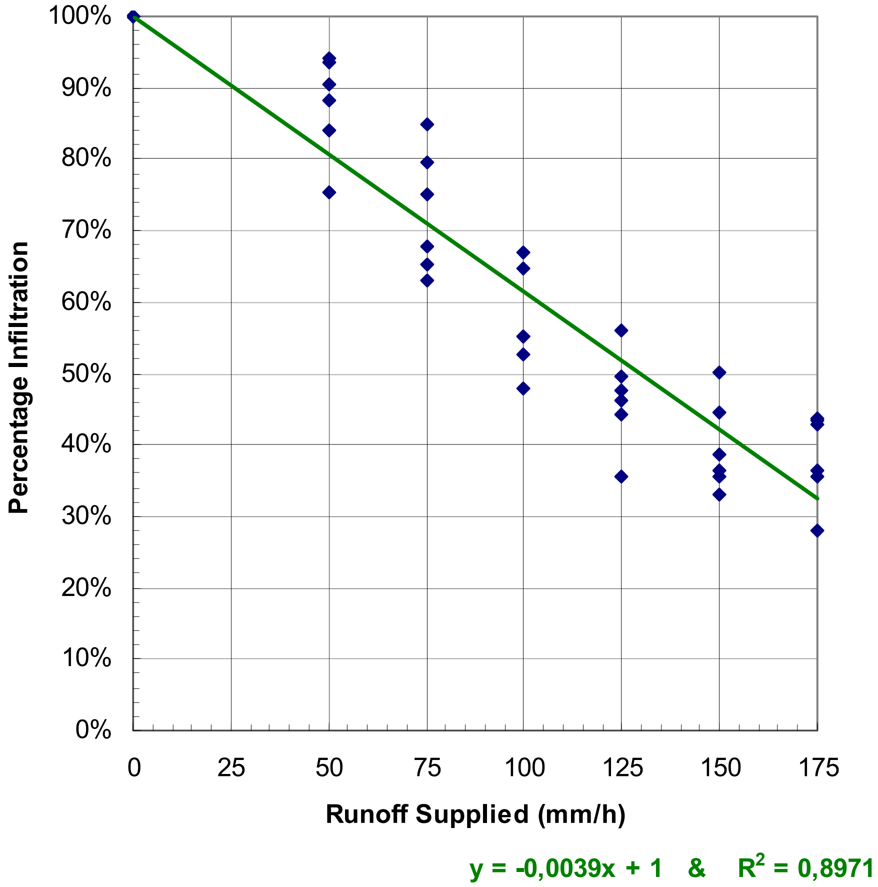

100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Percentage Infiltration
0
25
50
75
100
125
150
175
Runoff Supplied (mm/h)
102 (743g)
103 (710g)
104 (807g)
105 (823g)
106 (816g)
107 (870g)
108 (886g)
109 (965g)

Figure 4



100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Percentage Infiltration
0
25
50
75
100
125
150
175
Runoff Supplied (mm/h)
y = -0,0039x + 1 & R2 = 0,8971

Figure 5

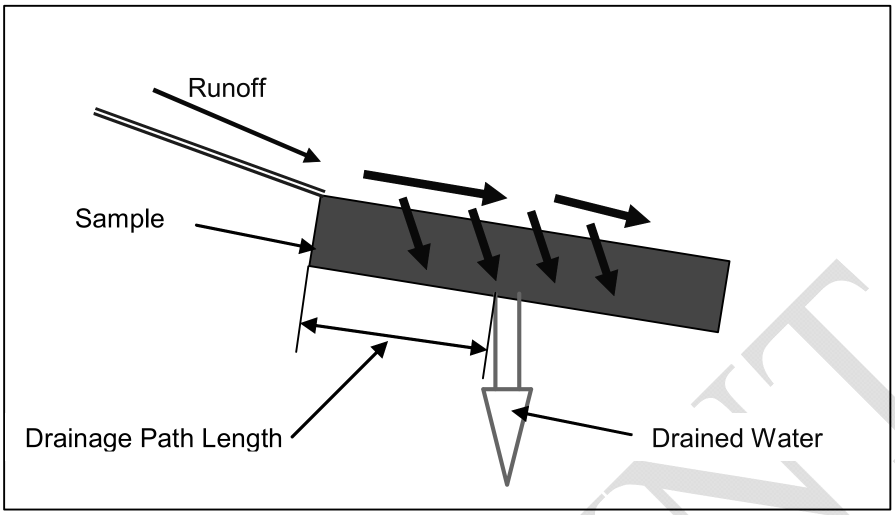


Figure 6

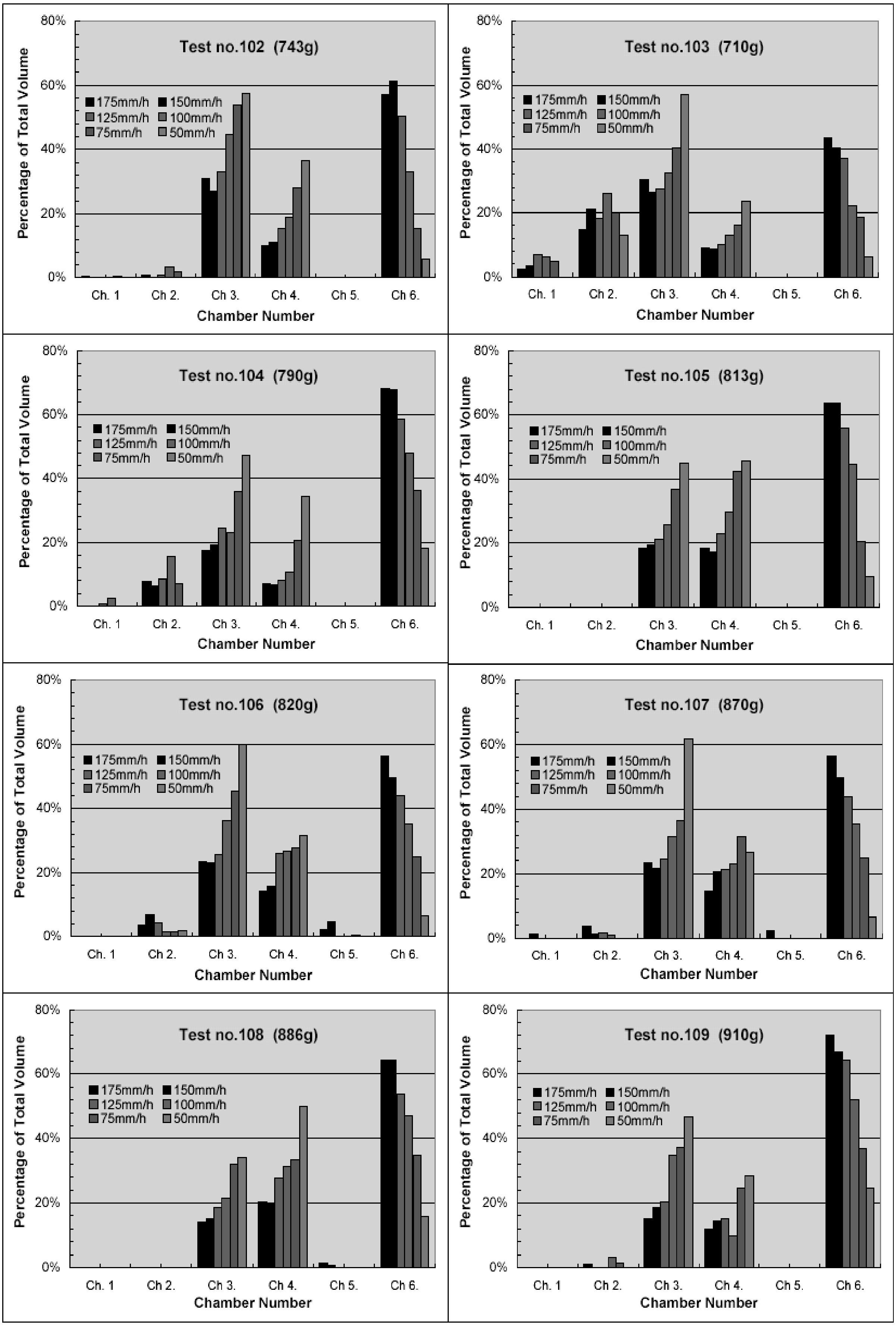

Test no.102 (743g)
Test no.103 (710g)
Test no.104 (790g)
Test no.105 (813g)
Test no.106 (820g)
Test no.107 (870g)
Test no.108 (886g)
Test no.109 (910g)
175mm/h 150mm/h
125mm/h 100mm/h
75mm/h 50mm/h
Percentage of Total Volume
0% 20% 40% 60% 80%
Ch. 1 Ch 2. Ch 3. Ch 4. Ch 5. Ch 6.
Chamber Number

Figure 7

TABLES

Table 1

Rainfall intensity falling on 0.25 m^2 surface (mm/h)	Total area contributing runoff to permeable surface from 50 mm/h rain (m^2)	Permeable Area Ratio (PAR) = permeable area (0.25 m^2) ÷ total area contributing
50	0,250	1.000
75	0,375	0.667
100	0,500	0.500
125	0,625	0.400
150	0,750	0.333
175	0,875	0.286

Table 2

PAR	Rainfall intensity (mm/h) on 0.25 m^2 area	Percentage infiltration	Infiltration rate (mm/h)
0,250	200	22%	44
0,286	175	32%	56
0,333	150	42%	62
0,400	125	51%	64
0,500	100	61%	61
0,667	75	71%	53
1,000	50	81%	40
2,000	25	90%	23