WATER PERVIOUS PAVEMENT BLOCKS: THE BELGIAN EXPERIENCE

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SUMMARY

Water permeable pavement blocks are used to minimize the far-reaching negative effects produced by sealing off the natural water balance. Due to the immediate uptake of water and due to the buffering by the permeable underlying structure, the risk on floods during thunderstorms by water running of the surface or due to overflow of the sewer pipes is minimized. In Belgium, a research program has started to investigate the buffer and infiltration capacity of different water permeable structures. The goal of this research program is to link soil characteristics and material properties, measured in laboratory to the final buffering and infiltration capacity in situ. Therefore, a test parking lot with 12 different test sections is constructed and monitored. Additional laboratory measurements and in situ measurements on permeable pavements with different types of pavement blocks and base layer materials are conducted. The project runs over a period of 4 years and will end in 2007. Preliminary results on durability (applications up to 10 years old) will be presented.

This paper describes the set-up of the project, with the Belgian demands towards permeability as well as stability. The concept and construction of the test parking sections at the laboratories of the BRRC will be illustrated. An overview of the results, obtained on the test section is given as well as a first comparison between different types of pavement blocks and of base and sub base layer materials. These results indicate a large buffer capacity which stretches the water outflow over several days, with a limited peak during the rain period. An overview of some Belgian applications will be given, where the permeability of different materials are measured, from soils, over base layers in aggregates and in lean concrete up to water permeable pavement blocks.

1. INTRODUCTION

Water-permeable paving is used to minimize the far-reaching adverse effects produced by sealing off the natural water balance. The risk of flooding during thunderstorms by water running off the surface or by overflow from sewer pipes is strongly reduced by the immediate absorption and subsequent storage of water in the permeable structure. Although drainage into the natural ground is possible, a water-permeable paving should be looked upon as a drainage-saving element rather than an actual drainage system. This is mainly because permeability may drop significantly as the pores become silted up [1]. Some research into the concept of water-permeable paving has been done to render their permeability as durable as possible, but so far it has been inconclusive in this respect [2-10].

A research project funded by the Flemish Government (through IWT[1]) was, therefore, undertaken to model the permeability and storage capacity of structures and to optimize the preservation of permeability. This project includes laboratory tests on the paving material as well as on the base and subbase materials, and field tests on soils and water-permeable paving. In addition, a parking area with twelve different sections (each 120 m² in area) was constructed on the premises of the Belgian Road Research Centre to test five different types of water-permeable concrete paving block and two different types of base layer. Furthermore, the water permeability of existing and new permeable paving in Belgium is measured and monitored over time. The Belgian Road Research Centre, the Laboratory for Soil and Water Management of the Katholieke Universiteit Leuven and the federation of Belgian manufacturers of linear and modular paving elements in concrete (FEBESTRAL) are working together on this project.

2. THE PERMEABLE PAVING CONCEPT

The concept of water-permeable block paving differs in at least one important respect from that of conventional paving. Whereas in the case of conventional paving water is banned from the structure as much as possible, it is supposed to enter the structure in the case of permeable blocks. It is retained for a certain time, after which it is to leave the structure by infiltration into the ground or by drainage – preferably into a ditch or sewer. As far as structural design is concerned, the rules for conventional block paving have to be followed, with due allowance for the lower bearing capacity that results from the higher porosity of the base layer and the paving and, consequently, for the lower resistance to traffic.

From the environmental point of view, infiltration into the soil is desirable, unless the paving structure is situated in a water collection area. The most suitable sites for water-permeable paving are shopping areas, company grounds, car parking areas, footways, squares, etc., where large surface areas are subjected to limited or light traffic. [9] Hydraulically speaking, water-permeable pavements are designed to be able to absorb the rainwater from a shower which occurs only once in thirty years for a duration of ten minutes, in Belgium statistics indicate this is a rain shower with an intensity of 270 litres per second per hectare. An initial permeability of $5.4*10^{-5}$ m/s is required, to compensate for the fact that the permeability of the structure will be reduced by air enclosures after a period of dry weather.

Carefully chosen materials are a prerequisite for a permeable paving structure to work well. The foundation can be made of unbound materials. Important is to find a good agreement between permeability and stability. Another important factor is the possibility to compact the material in situ. It is also possible to use cement-bounded materials in the base layer – for example porous lean concrete, which combines high porosity with relatively high strength. To ensure the stability of the structure, contamination between layers must be prevented, if necessary by separating them with a geotextile. However, this should be avoided as much as possible, to prevent one layer from sliding over another under the action of traffic.

To avoid silting of the structure, it is advisable to start with a relatively fine material at the top and to use more porous materials at the bottom. The top layers will then operate as a sort of filter for the bottom layers in the way that if a small particles passes through the surface, it will not be blocked before it reaches the soil.

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[1] IWT[1], the Institute for the Promotion of Innovation by Science and Technology in Flanders

3. MEASUREMENT TECHNIQUES AND CONSTRUCTION OF THE TEST PARKING AREA

3.1. General design of the test parking area

A test parking area was constructed near the laboratories of BRRC at Sterrebeek (Belgium). The parking area comprises twelve test sections with five different types of paving block and two different base layers. Table 1 gives an overview of the various combinations of sub base layer, base layer, sand bed and joint filling material. Additional demands were made on the amount of fine material and on the quality of the aggregates, the latter to prevent rapid contamination of layers by the abrasion of stones.

Table 1. Overview of the different combinations on the test parking area

Paving blocks	Conventional		Drainage holes	Widened joints		Porous		Grass tiles	
Joint filling material	0/2 Sand of Lustin	White sand	2/4 porphyry	2/4 porphyry		0/2 sand of Lustin		sand + peat	sand + humus
Sand bed	2/7 limestone	0/7 porphyry	2/7 porphyry	2/7 porphyry		0/7 porphyry		Porph.2/7 +sand +peat	Porph.2/7 +sand +humus
Geotextile		Yes					Yes	Yes	
Base layer	0/32*	2/20	0/32*	2/20	0/32*	2/20	0/32*	2/20	2/20	
Subbase layer		7/32		7/32		7/32		7/32	7/32	
Test section number	9	10	8	1	7	2	3/6**	4/5**	11	12

* with a restricted amount of fine material

** sections 3 and 4 do not have an impermeable membrane at the bottom
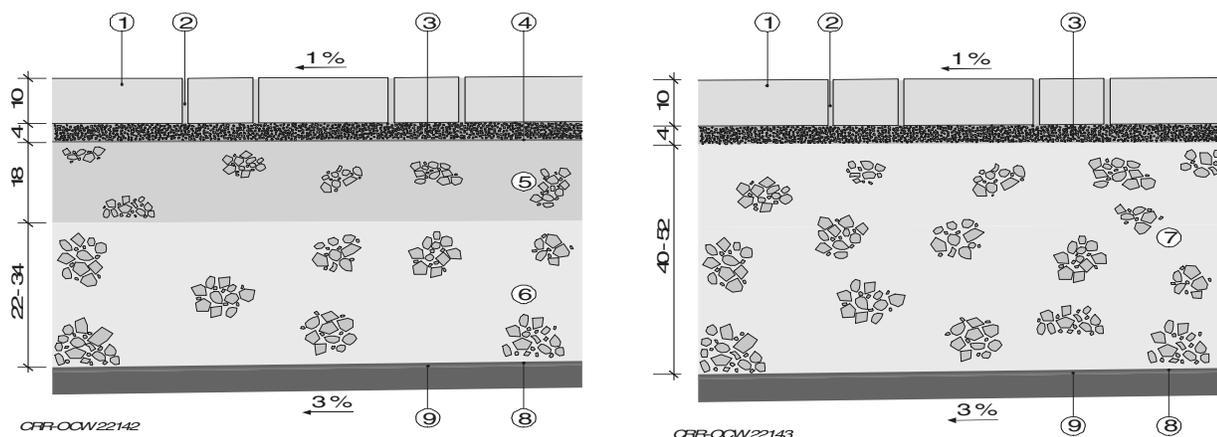
Figure 1. Cross sections of the structure with porous concrete paving blocks.

LEGEND:

1. Porous concrete paving blocks 122 x 100 x 100 mm	100 mm
2. Joint filling material: sand of Lustin 0/2	
3. Sand bed: porphyry 0/7	40 mm
4. Geotextile	
5. Crushed porphyry 2/20	180 mm

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6. Crushed limestone 7/32	220-340 mm
7. Crushed limestone 0/32	
8. Protective sheet	400-520 mm
9. Impermeable membrane	

Figure 1 shows the cross sections of the structure with porous concrete blocks, for both types of base layers. The designs with other paving blocks are similar, with adapted paving beds and joint filling materials. An impermeable membrane was applied at the bottom and to the sides, to catch all the water entering the test section and measure its flow rate at the outlet of the drain tube laid on the bottom of the section. The slope at the surface is taken equal to 1 %. This is easier for the contractor to apply than 0 %. At the bottom of the structure, a slope of 3 % is taken to facilitate the water to run off to the drainage pipe. In addition to the ten zones on the main parking, two test sections were constructed with grass grid tiles, to investigate the influence of the amount of humus in the upper layer on the growth of grass. Figure 3 presents an overview of the actual parking area. Each section is approximately 120 m² in size.
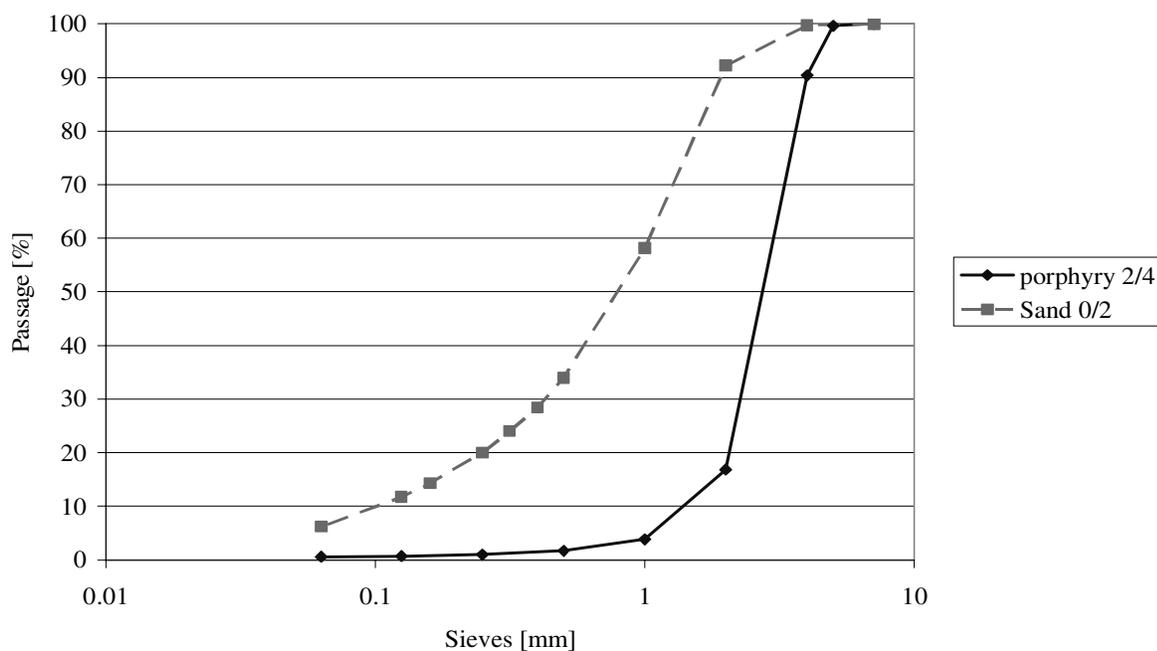
Figure 2. Gradation of the joint filling material in case of porous pavement blocks (sand 0/2) and of pavement blocks with widened joints and drainage holes (Porphyry 2/4)

As will show the results, the storage capacity of the base layer depends on the thickness of the layer and on the permeability of the material. It is important that fine particles and sand particles are avoided as much as possible to obtain a permeable base layer. On the other hand, the lack of fine material will hamper the compaction of the layer to a large extend. The use of different compaction equipment, such as a vibration plate can lead to good results where a drainable structure is obtained with a good mechanical resistance.

Figure 3. Overview of the test parking area – porous pavement blocks, pavement blocks with drainage holes, pavement blocks with enlarged joints, classic pavement blocks

3.2. Measurement set-up on the test parking area

The purpose of the test parking area is to provide good knowledge of the storage capacities of permeable paving structures and of the importance of the different properties of the materials. The parameters are determined by catching the water that runs off the surface separately from the water that penetrates the entire structure. To collect the latter, an impermeable membrane was laid on the bottom of the structure, with a drain tube conveying the water to measuring pits situated at the side of the paving sections. Figure 4 shows the membrane and the protective sheet as well as the drain tube on the bottom of the permeable paving structure.
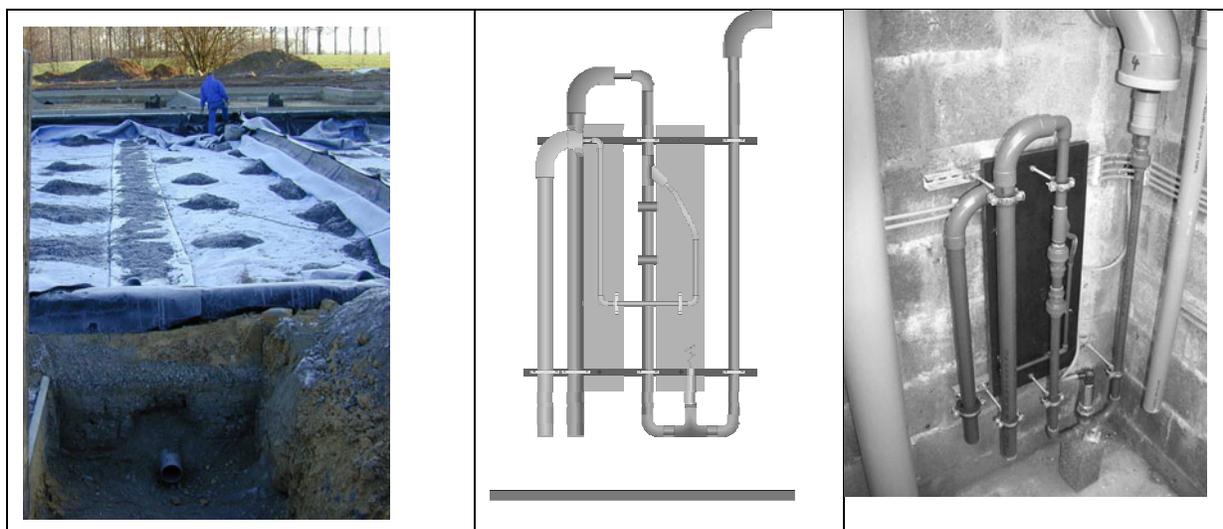
Figure 4. View of the membrane and its protective sheet, with the drain on the bottom of the structure, two outlets are used (3 mm and 5 mm) to be able to register the flow for small rains as well as for heavy thunder storms

The following measurements are performed on the various test sections:
- continuous measurement of the height of rise of the water in the drain and in the structure; this height is related to the flow at the outlet;

- continuous measurements of rainfall and temperature;
- measurements of the permeability of the structure by the "double ring" method applied at the surface of the structure;
- measurements of the bearing capacity by means of the falling weight method.

Run-off from the surface is not measured, since almost none is collected in gutters and gullies along the permeable paving.

3.3. Field measurement techniques

In addition to the measurements performed on the test sections, field measurements are carried out in various places in Belgium. The sites are mostly parking areas for cars, or pedestrian access roads. The surface areas vary between a few hundred to several thousands of m². To assist the engineer in designing the permeable paving, two different types of measurement are made.

First, the permeability of the soil is measured by means of an "open-end" test [2]. An overview of the measuring set is presented in Figure 5. Secondly, the permeability of the permeable structure is measured by means of a "double ring" infiltrometer [3]. Measurements with the double ring infiltrometer are made after the structure has been built. They provide information on the behaviour of the structure, from which more refined conclusions may be drawn for use in the design of new projects. Moreover, the measurements at the surface are repeated over time, to reveal changes in permeability. Figure 6 shows a double ring infiltrometer set up for measurement.

Figure 5. Open-end test   **Figure 6. Double ring infiltrometer**

3.4. Measurements on the subgrade soil

The permeability of the silty subgrade soil at Sterrebeek is measured in four different ways: by the open-end field test, on undisturbed ground samples (Kopecky rings), on large ($\varnothing$ 30 cm) undisturbed ground samples, and, finally, by a simple field test in which a hole is dug and filled with 5 l of water; in this test, the time needed for the water to penetrate the soil is measured and a penetration coefficient calculated. A permeability coefficient is calculated from each of the four measurements; the values determined in the laboratory are "saturated" permeability coefficients. The results are shown in table 2.

Table 2. Permeability coefficient (k) of the silty subgrade soil at Sterrebeek

	Average	Minimum
Laboratory measurements on large undisturbed samples (3 measurements on 2 samples)	$3.8*10^{-6}$ m/s	$3.1*10^{-7}$ m/s
Laboratory measurements on Kopecky rings	$1.4*10^{-7}$ m/s	$5.1*10^{-9}$ m/s

(50 measurements)		
Field measurements by open-end test (10 measurements)	$1.3*10^{-4}$ m/s	$5.2*10^{-5}$ m/s
Simplified hole method (10 measurements)	$4.8*10^{-5}$ m/s	$1.0*10^{-6}$ m/s

The results indicate wide variations between the different test methods and between individual results in each test. This is mainly due to the variation of the soil. Especially in the case of Kopecky rings, the results are much affected by local variations in the ground, due to the presence of different layers, where for example in one layer the loam is leached into a layer underneath. The results obtained in the laboratory on fully saturated undisturbed soil samples can be considered as the most correct, since these are large undisturbed fully saturated samples. Important is to notice that the permeability measured by the open-end test is much higher. This has to be taken into account when evaluating a soil. Although the infiltration capacity of the silty soil is limited, it is still sufficient to take heavy rain showers in the presence of a water-storing permeable structure, as will be shown by further results.

3.5. Measurements on the permeable structure
3.5.1. Static storage capacity
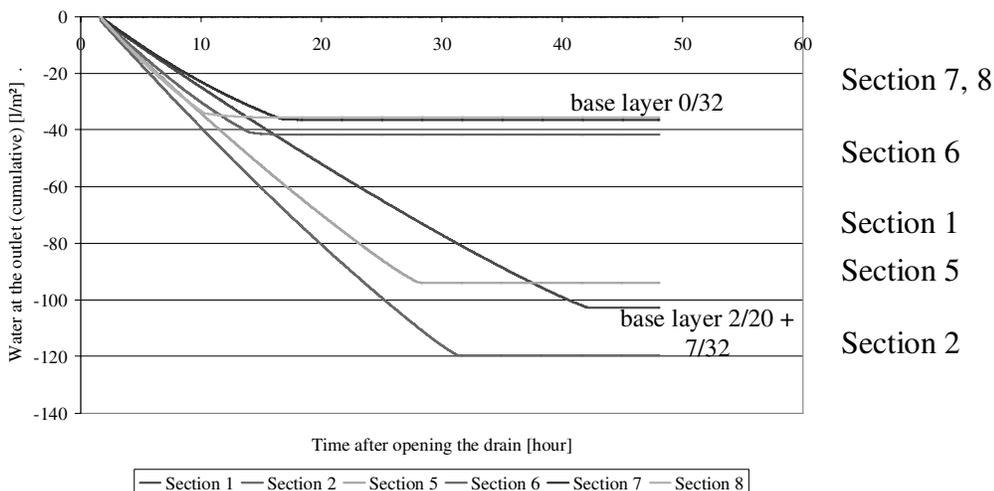
Figure 7. Static storage capacity for each section [l/m²]

To have an idea of the storage capacity of the parking structure, the static storage capacity is determined by closing down the outlet at the bottom of each zone and filling up the zone with water. Consequently, the amount of water is measured by opening the outlet. The results are presented in Figure 7. It is important to notice that this is not the maximum storage capacity during a thunder storm. Under normal circumstances, the water is infiltrated in the soil or drained by the drainage pipe. Therefore, the results in Figure 7 may be seen as a minimum storage capacity. Section 3 and 4 (without impermeable membrane) are not mentioned in the figure, since the water was infiltrated in the soil before the zone could be filled up. Section 9 and 10 are also not mentioned since the water does not penetrate easily through the classic pavement blocks.

The results indicate that the storage capacity is not related to the type of permeable pavement block, but rather to the type and thickness of base and sub base layer. The permeable pavement blocks

determine how fast the rain water will penetrate into the structure and consequently if any run off of the surface will take place during larger thunder storms.

3.5.2. Dynamic storage capacity and infiltration

To see the working principle of water pervious pavements, the results obtained in May 2006 are presented. The histogram is presented in Figure 8 and indicates the daily rain fall. Although no exceptional rains have fallen during this month, it is very interesting to see how the structure is behaving under consecutive rain showers. Therefore, the results between the 18th of May and the 24th of May, 2006 are presented in Figure 9.
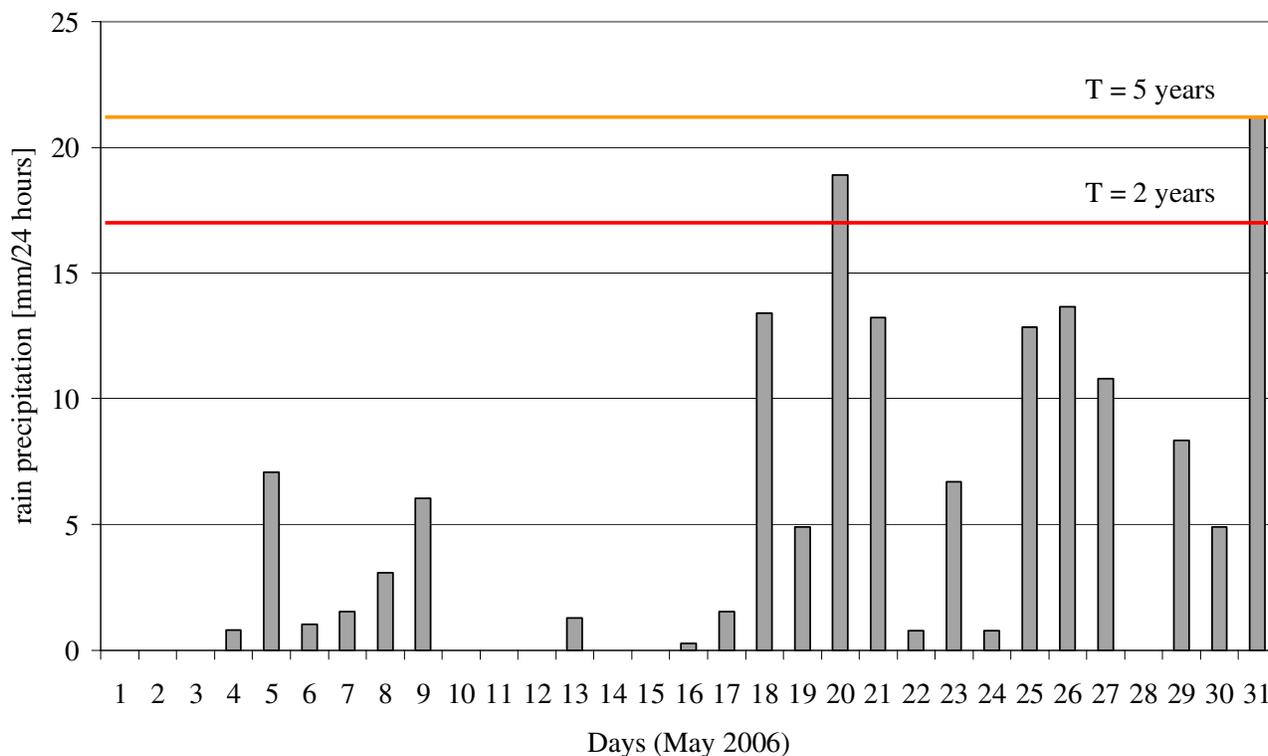
Figure 8. Histogram of rainfall in May 2006 – Return period of 24 hours shower of 2 years and 5 years is indicated

Figure 9 presents the flow at the outlet of the different test sections. This flow increases when the water rises in the structure. In the case of water-permeable paving blocks, no runoff was observed at the surface and all the water penetrated the structure. By contrast, on conventional paving blocks a substantial amount of water immediately ran off to the gutter.

The results indicate first of all retention of the water in the structure. The peak at the outlet is only obtained at least 1 hour after the start of the rain. This means that the water remains in the structure for a certain period. Due to the restricted outlet (1 tube of 2 mm and 1 tube of 3 mm), the flow is also very limited. The water is stored during 5 to 6 hours in the structure. During that time, the water level in the structure rises by 20 to 30 cm in the drainage pipe beneath the sub base layer. So it rarely attains the sub base itself, which explains why the flows at the outlet are similar for the different types of pavement blocks and base layers. Only the time of maximum flow differs from section to section.

In the absence of an impermeable membrane (section 3 and 4), the water infiltrates in the soil, in spite of the low permeability. In the sections with classic pavement blocks, 50 % of the water goes through the structure. This is the consequence of the disappearance of the joint filling material, partly by washing out, partly by infiltration in the base layer. This emphasises the importance of a good drainage facility, especially in the case of classical pavement blocks.
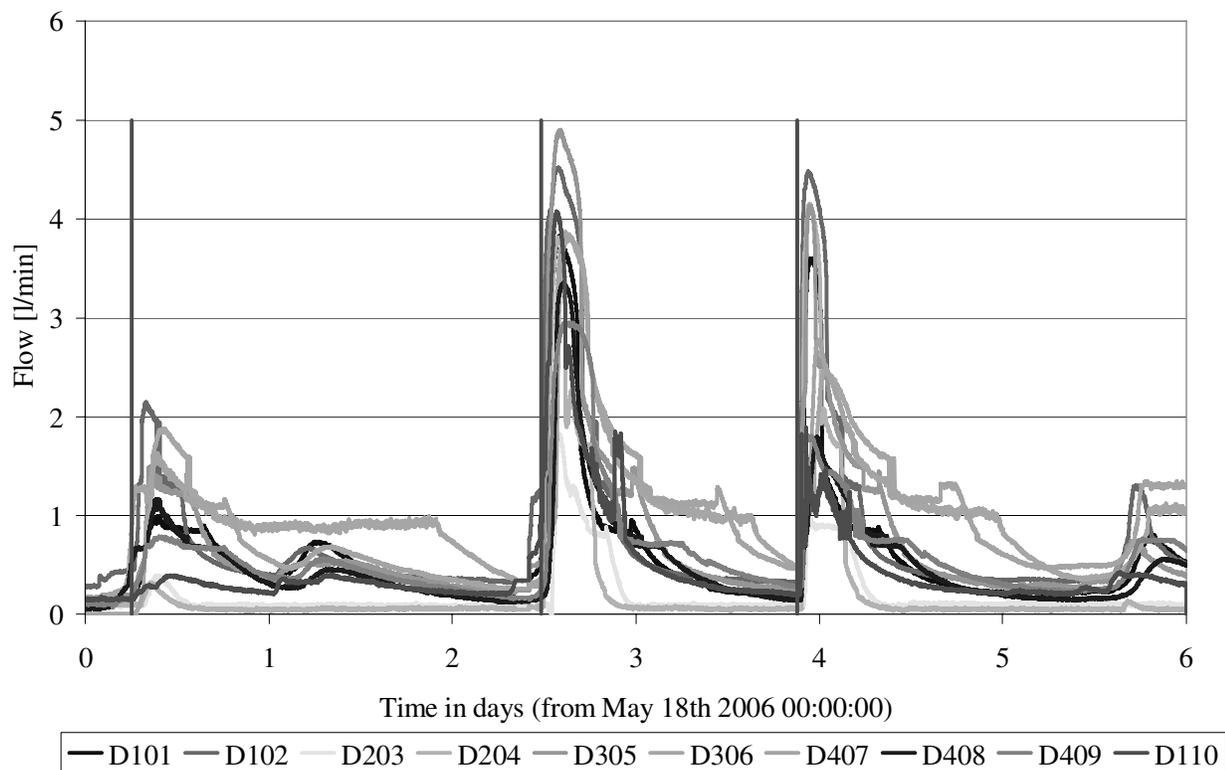
Figure 9. Flow at the outlet of the drainage pipe, at the bottom of each test section

It is also important to see that the structure is capable to contain consecutive rains. 10% of the rain comes out at the bottom during the rainfall, 50% during the hours following the rain and the other part is slowly dripping down in the structure. Clear differences between the various types of base layer and paving blocks are not visible at the outlet of the drain tube. On the other hand, there are neat differences in surface permeability as measured in the double ring test. The results are shown in table 3. In some cases the quantities to be measured were outside the range of the device.

Table 3. Results of the double-ring test

	[7/32-2/20]	[0/32]
Drainage holes [sections 1/8]	> 4*10-4 m/s	2.7*10-3 m/s
Widened joints [sections 2/7]	> 4*10-4 m/s	1.9*10-3 m/s
Porous paving blocks without membrane [sections 4/3]	1.0*10-4 m/s	1.5*10-4 m/s
Porous paving blocks with membrane [sections 5/6]	2.6*10-4 m/s	8.2*10-5 m/s
Conventional paving blocks [sections 9/10]	< 2.4*10-5 m/s	

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The obtained retention times and flows are to a large extend function of the geometrical parameters of the structure and the materials used. There is the influence of the size and height of the outlet, the height of the different layers in the structure and the porosity and permeability of the materials used in the drainage pipe, the sub base and base layer and in the sand bed. In the case of the test zones, the maximum flow at the outlet is equal to 3.5 l/h/m², which would be similar to a soil with a permeability of $9.7*10^{-7}$ m/s. The total height of the structure is 65 cm. This enlarges the storage capacity significantly but also protects the under laying soil against frost.

3.6. Field measurements

Approximately 50 projects are surveyed. The majority are under construction or newly constructed. The permeability of the soil as well as the surface permeability was measured, by the open-end-test and the 'double ring' method respectively. The soil mostly consisted of sand, which has a permeability ranging from $1.2*10-5$ m/s up to $4.5*10-4$ m/s and is, therefore, very suitable for infiltration.

Table 4. Field measurements in Belgium

Project	Surface permeability [m/s], measured according to the double ring-method
Shopping Centre Waasland, Sint-Niklaas porous pavement block(2003)	$4,3*10^{-4}$ m/s (2003) $7,6*10^{-5}$ m/s (2005 without filling of the joints) $2,5*10^{-5}$ m/s (2005 with filling of the joints)
De Panne – parking zone with porous pavement block (1998)	$1,69*10^{-4}$ m/s (2004)
Zuttendaal – parking zone with pavement blocks with enlarged zones (2004)	$1,03*10^{-3}$ m/s (2004)
Heist-op-den-Berg – parking zone (2000)	$4,4*10^{-4}$ m/s (2004)
Evergem – parking zone, metten[2] (2001), flooded by mud and consequently cleaned under high pressure	$2,38*10^{-5}$ m/s (2004)

Figure 10. Shopping Centre Waasland and Parking Zone Heist-op-den-Berg

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[2] Type of stone

Compared to the test sections, the permeability of this type of soil is 100 to 1000 times higher. Table 4 gives an overview of some projects. By measuring the projects over time, the decrease in permeability can be determined. The results indicate in most cases a very large permeability, just after construction. This permeability diminishes in time, but seems to stabilize around 2 to $5*10^{-5}$ m/s.

4. EVALUATING THE RESULTS ACCORDING TO THE FLEMISH IMPLEMENTATION DECREE OF 1ST OCTOBER 2004

The results indicate that by using water permeable pavement blocks in combination with a water permeable structure, a high storage capacity can be obtained. If permitted by the soil, infiltration is possible. Is this sufficient for disconnecting this type of permeable pavements from the sewer or drainage system? In other terms, is it necessary to demand extra drainage and storage capacity.

To answer this question, a comparison between the results of the test zone in Sterrebeek and the demands from the Flemish implementation decree is made. It is important to notice that only the water from the surface of the permeable pavement is looked at, the structure is not foreseen to collect water from other surfaces.

The results from the project indicate that the water permeable structure can easily provide storage for the water fallen on the surface. In the Flemish implementation decree, a storage capacity of minimum 300 l per 20 m² reference surface is demanded. In the case of the test zone, a static storage of 800 l/20 m² for a base layer in aggregate 0/32, and more than 2000 l/20 m² for a base layer in 2/20 and sub base layer in 7/32 may be reached.

If no infiltration is possible, a small outlet can be applied. In that case, a retarded drainage of the rainwater can be obtained. The maximum flow in the test zone was 3.5 l/h/m² or 350 l/h per 100 m² reference surface. This is significantly less than the flow of 1500 l/h per 100 m² reference surface as is indicated in the implementation decree.

5. CONCLUSIONS

The results from the project indicate good storage capacity for structures with water-permeable paving blocks. The difference between the various types of concrete paving block lies in the immediate infiltration rate at the surface during rainfall. On the other hand, storage capacity depends mainly on the type and thickness of the base layer and the rate of infiltration into the ground. A compromise between water-accessible porosity (to promote water permeability), compaction properties and bearing capacity (to resist traffic) has to be sought at all times.

The project comprises laboratory tests, elaborated measurements on the test sections, and field tests on water-permeable paving in various places. The results indicate good permeability, at least immediately after construction; no surface run-off, even during thunderstorms; and long retention times in the structures, depending on restrictions put on the rate of outflow by narrowing the drain tube or by slow infiltration into the ground. Continuous measurements on the test sections and repeated field measurements are made, and indicate a diminishing but sufficient surface permeability over time.

Comparison to the demands formulated in the Flemish implementation decree of 1st October 2004, indicate that in the case of good water permeable concept, the surface may be excluded from the total

calculations of water flow and run off, since it may provide its own storage and infiltration or delayed drainage.

6. REFERENCES

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7. ACKNOWLEDGEMENTS