THE PAVEMENT STRUCTURE AS BUFFER AND INFILTRATION SYSTEM: OVERVIEW OF THE BELGIAN APPLICATIONS

A. BEELDENS, S. PEREZ, O. DE MYTTENAERE
Belgian Road Research Centre, Woluwedal 42 - 1200 Brussels, Belgium
a.beeldens@brrc.be
s.perez@brrc.be
o.demyttenaere@brrc.be

SUMMARY

Water permeable pavement blocks are a durable and ecological solution to prevent water run off, to minimize the risk of flooding and to increase the efficiency of water purification. This type of structure is more and more applied in Belgium, especially in car parking lots. New guidelines for hydraulic design are developed, resulting in standard structures related to the traffic intensity and soil characteristics. This has been done incorporating the results of a research project executed at the Belgian Road Research Center between 2003 and 2007.

In the project, the efficiency of water buffering and infiltration in the soil has been tested on a parking lot where 12 different test sections were applied. Validation of the results was done by studying different parking lots on site. Special applications, such as water permeable pavement blocks in allotments, were studied.

This paper focuses on the results of the research project, underlining the influence of the choice of material, the new approach towards buffering capacity and the overall conclusions of the project. Subsequently, the paper summarizes the applications in Belgium, where measurements have shown a good behaviour of the structure and a good durability of the permeability. Data from newly constructed projects, as well as data from old projects, concerning pavement structures in use for more than eight years, are presented.

Key words: water pervious structures, pervious concrete pavement blocks, permeability test methods.

1. INTRODUCTION

The use of water-permeable paving is increasing fast in Belgium, due to a change in legislation. The road and building owners are encouraged to use permeable surfaces as parking lots and roads by this legislation. This avoids the construction of a water storage system, which saves place and money. By storing the water in the pavement and infiltrating it into the soil or discharging it over a long period, the risk of flooding due to the pavement is minimized.

For a durable and perfectly operational permeable pavement the most important is providing to the structure a combination of bearing capacity and permeability [1]. In Belgium, an additional thickness has to be foreseen in order to prevent damage due to the freezing of the soil. This thickness present in the sub base layer will be used for storage of the rain water, prior to infiltration or retarded outflow. Standard structures are developed. The efficiency of these structures has been tested during a research project funded by the Flemish Government (through IWT). In this project, the influence of different parameters on permeability and storage capacity of water permeable structures was determined and optimized in order to preserve the permeability over longer period.

The research project included laboratory tests in order to characterize the materials, as well as field tests, where the permeability and structural behaviour over time were looked at. 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 in order to test different types of water-permeable concrete paving blocks and two different types of base layer. Furthermore, the water permeability of existing and new permeable pavements in Belgium was measured and monitored over time. The BRRC, 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) were joint in this project.

Following the project, a technical assistance is put in place in order to disseminate as much as possible the gained technology and results obtained in the research project. This is done by distributing information through the website of the BRRC [2] and through brochures dealing with the practical applications of water permeable pavements [3]. Additionally, courses are given to the different stake-holders, namely to the producers of the pavement blocks as well as to the design engineers and pavement managers.

2. THE PERMEABLE PAVING CONCEPT

The concept of water-permeable block paving differs in at least one important aspect 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 into the structure in the case of permeable blocks. It is retained for a certain time, and then it has to leave the structure by infiltration into the ground or by drainage – preferably into a ditch or rain water 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 could occur if the structure is saturated with water and, consequently, for the lower resistance to traffic.

To ensure as much as possible the combination of the bearing capacity and the water storage of the pavement, a special design is applied where both parameters are assigned respectively to the base and the sub base layer.

The working principle of water pervious structures is as follows: the pavement blocks themselves make the water pass through the surface and prevent water run off. The storage of the water is done at the bottom of the structure, preferably in the sub base layer. This is done to maintain the bearing capacity of the structure by protecting the base layer material from the pumping phenomenon which could occur at the top of the structure in the presence of water and traffic loads. Also the reduction of bearing capacity of the aggregates in the base layer due to saturation by water is minimized. The evacuation of the water is done by infiltration or by drainage or by a combination of both.

From the environmental point of view, infiltration into the soil is desirable, unless the paving structure is situated in a water collecting area. In the latter case, a water impermeable membrane has to be placed beneath the structure and the permeable paving will only serve as buffering system.

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. Hydraulically speaking, water-permeable pavements are designed for a 30 years frequency rainfall event of ten minutes. Belgium statistics indicate this is a rainfall with intensity of 270 liters per second per hectare ($2.7*10^{-5}$ m/s). An initial permeability of $5.4*10^{-5}$ m/s is demanded (safety factor 2), to compensate the risk of permeability reduction caused by air enclosures or clogging of the surface.

In Belgium, most applications can be found in parking lots for cars at shopping malls, park & rides and on parking lots near apartments or factories (limited amount of heavy vehicles).

3. DESIGN OF WATER PERMEABLE PAVEMENT STRUCTURES

The design of water permeable pavement structures implies the determination of the thickness of all layers, the choice in type of drainage system and the choice of type of materials.

3.1. Standard structures

The application of water pervious paving systems can be brought back to standard systems, related on one hand to the permeability of the soil and on the other hand to the traffic on the pavement. The choice of these parameters will determine the drainage system as well as the thickness of the base layer. For the latter, choice between unbound granular material and bound pervious lean concrete can be made. The choice of material influences the final thickness of the base layer. An overview of the standard structures is given in figure 1.

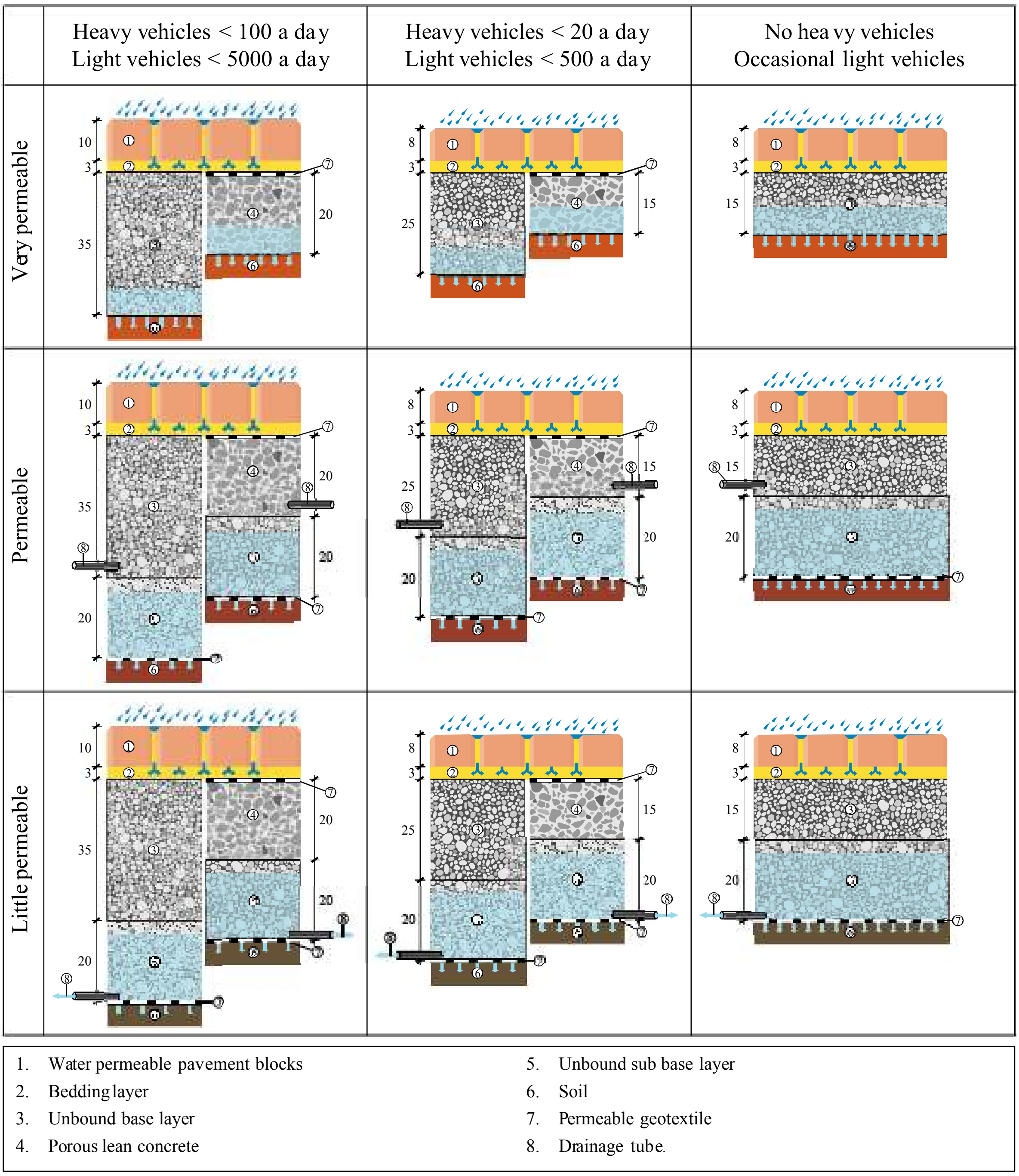


Figure 1 – Standard structures (in cm) in relation to soil permeability and traffic.

The drainage system is determined by the type of soil. If the soil has a limited permeability (< 10^{-6} m/s) a drainage system has to be foreseen at the bottom of the structure, in the case the permeability is high (> 10^{-4} m/s) no sub base layer is necessary, infiltration will be done directly in the soil. In between, an overflow is put in place to prevent the water raising in the base layer and jeopardizing in that way the bearing capacity of the structure.

The thickness of the base layer, in relation to the type of material, is determined by the amount of daily traffic over the structure. All vehicles heavier than 3,5 ton have to be considered as heavy vehicle.

The thickness of the sub base layer is determined either by the necessary thickness to protect the soil against frost or by the necessary thickness to provide the buffering capacity. The largest thickness between them is adopted for the design.

For the calculation of the buffering capacity of the sub base layer, a safety factor of 1,5 on the porosity of the material is introduced in order to take into account the air inclusion, the clogging over time and the degradation of the aggregates over time (formation of fines) into account. The thickness is been calculated as:

$T_{\text{sub base layer, water storage}}$ = 1,5*buffering capacity / porosity

To determine the necessary buffering capacity one can take into account the statistic rain fall of 10 minutes, which has a return period of 30 years. In Belgium, this corresponds to a rain of 270 l/s/ha. The necessary buffering capacity is then 1,6 l/m². Another option is to take consecutive rain falls into account. For this, a statistic evaluation of the rain precipitations of the particular area has to be done. Table 1 gives the results of such calculation for Flanders. "Outflow" is then the flow by which the water infiltrates in the soil or is discharged through the drainage system. Since the structure is designed to store the water into the sub base layer, the overflow mentioned in Table 1 corresponds to the raise of the water in the base layer. This gives an extra security towards buffering capacity to the structure.

Table 1 – Buffering capacity for consecutive rain falls

Outflow	Return period overflow			
	2 years	5 years	10 years	20 years
30 l/s/ha			180 m³/ha	240 m³/ha
25 l/s/ha		160 m³/ha	200 m³/ha	240 m³/ha
20 l/s/ha	120 m³/ha	170 m³/ha	210 m³/ha	260 m³/ha
15 l/s/ha	140 m³/ha	190 m³/ha	240 m³/ha	290 m³/ha
10 l/s/ha	160 m³/ha	220 m³/ha	270 m³/ha	330 m³/ha
5 l/s/ha	210 m³/ha	280 m³/ha	340 m³/ha	410 m³/ha

3.2. Material criteria

The criteria for the material differ from layer to layer. The higher the material is situated in the structure, the more emphasis on strength and resistance to formation of fines is given.

The permeability of the material has to be minimal equal to $5.4 * 10^{-5}$ m/s in order to pass the water from the surface to the base layer. In general, special demands on the fine material (< 0.063 mm) are set as well as on the fraction 0 to 2 mm. In the case of an unbound material for the base or sub base layer with an aggregate distribution between 0 and 32 mm, this fraction is limited to 25 %. This leads to materials with a permeability of approximately 10^{-3} m/s.

In the case a pervious lean concrete is used as base layer, a minimum compressive strength of 13 N/mm² measured on cores with a surface of 100 cm² has to be reached after 90 days as well as a permeability coefficient of $4*10^{-4}$ m/s.

For the material of the bedding layer, an additional criterion towards resistance to friction is defined. The MDW (Micro-Deval coefficient in Water) has to be lower than 15 and the LA (Los Angeles value) lower than 20. This means that only some limestone aggregates but mainly porphyry aggregates can be used.

Testing has been done on recycled aggregates. Although some good results towards permeability were obtained, the analysis of the aggregate distribution indicates that during placement and compaction, fines are formed. A mixed recycled aggregate (concrete and masonry) 10/40 (10 to 40 mm) was tested. The fraction 0/2 raised to almost 10 %, only due to friction on the sieves. The risk to create fines due to the loading by traffic during service life is high, what can result in a decreased permeability.

In Belgium, special technical specifications are in place, where the characteristics of the material are determined. The concrete pavement blocks themselves have to fulfill the demands pointed out in the technical specification PTV 122. These demands are a permeability of at least $5.4 * 10^{-5}$ m/s or an open surface of at least 10 % in the case of pavement blocks with enlarged joints or drainage holes.

More information on the criteria for the materials can be found in the publication [4].

3.3. Gradient of the structure

Water permeable pavements can be put in place with a complete flat surface, no slope is needed in order to manage the water. The water will infiltrate in the surface of the pavement blocks. In order to prevent water run of at the surface, the maximum gradient of the pavement surface itself should be limited to 5% [5]. In order to prevent flooding at lower points, it is necessary not only to prevent water run-off at the surface, but also to prevent the water running down to the lowest point through the base and sub base layer. This can be done by working in terraces, but can also be done by putting a dam in the sub base and base layer. In addition, an extra buffering capacity can be foreseen just before the dam. An overflow is made by limiting the height of the dam to the base layer or by the installation of a overflow through the dam at the height of the base layer.

Figure 2 represents a cross section, where the water is stored in the additional height of the sub base layer and stopped by a dam made of lean concrete. The depth of the sub base layer is locally increased up to 300 mm over a distance of 4,5 m. This was done every 20 m. By this, 77% of the rain of 270 l/s/ha during 10 minutes can be stored in the structure and infiltrated over time. If no infiltration is possible, extra reduced drainage should be foreseen at the bottom of the dam.

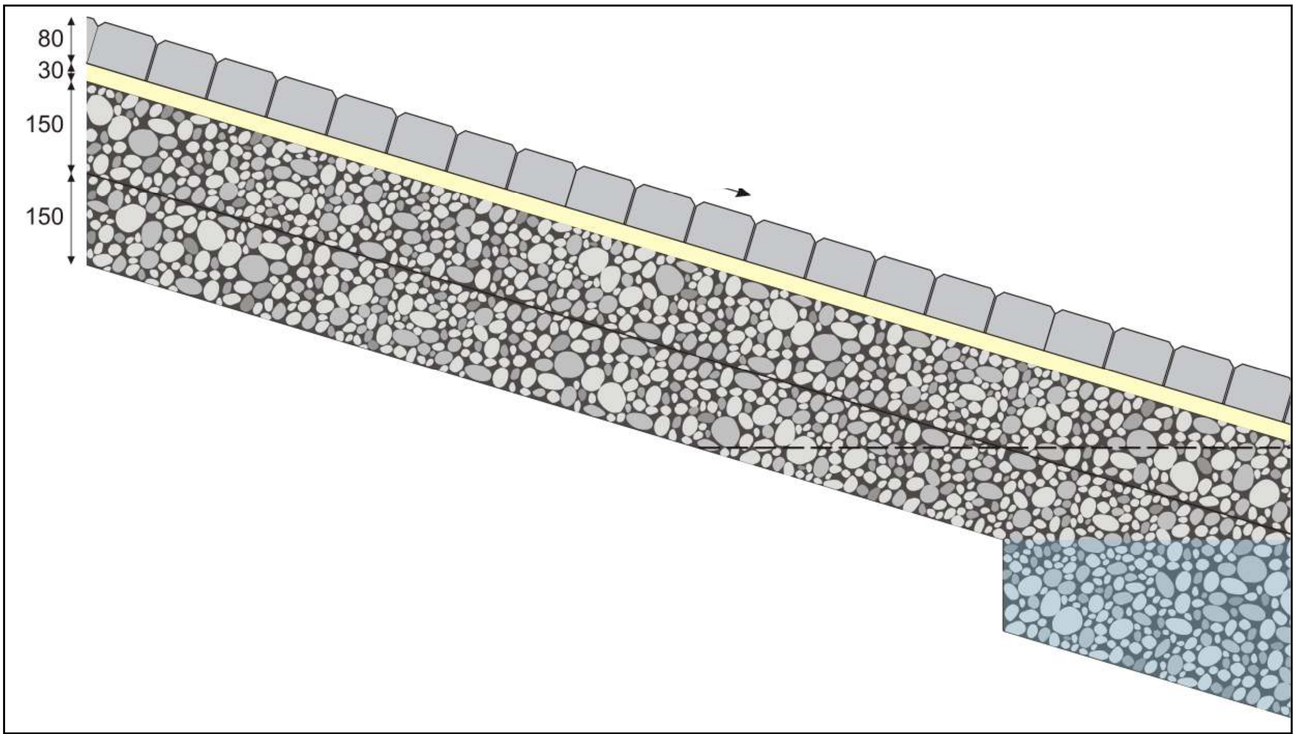


Figure 2 – Gradient of the structure (thickness in mm)

4. BELGIAN EXPERIENCE WITH PERMEABLE PAVEMENT STRUCTURES

Water permeable pavement structures are used for more than 10 years in Belgium. An effective design and a good execution lead to a durable pavement, structural as well as towards water permeability and infiltration over time.

The research project implied the installation of a test section at the premises of the BRRC in order to measure and observe the water behaviour in the structure. 12 different test sections were applied, with 5 different types of concrete pavement blocks. Measurements on the 12 different test sections on the parking lot of the BRRC have indicated that it is possible to design the pavement structure in order to store the water in the sub base layer.

To reach the necessary thickness for frost protection of the soil (which is 650 mm in Sterrebeek) the following structure is installed: pavement block (100 mm), bedding layer (30 mm), base layer (180 mm) and sub base layer (340 mm). Two types of base layer materials are used: unbound aggregates 0 to 32 mm and unbound aggregates 2 to 20 mm and 7 to 32 mm. An overview of the structures is given in figure 3. A slope of 1% was applied at the top surface. At the bottom of the structure, a slope of 3% was used in order to allow the water to run to the drainage tube and measuring installation. More information on the test sections can be found in the paper [5].

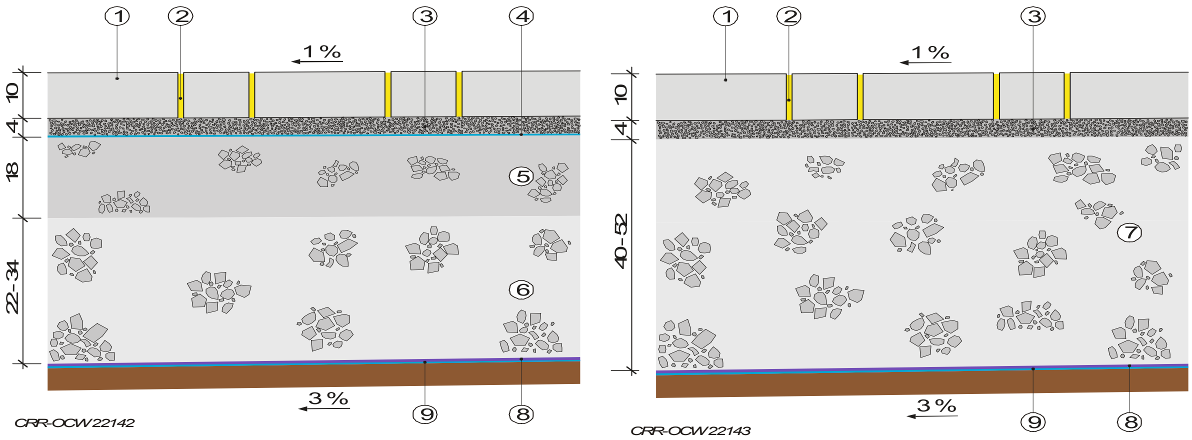


Figure 3 – Cross sections of the structure with porous concrete paving blocks.

LEGEND:

1. Porous concrete paving blocks 122 x 100 x 100 mm	100 mm
2. Joint filling material: sand of Lustin 0/2 mm	
3. Sand bed: porphyry 0/7 mm	40 mm
4. Geotextile	
5. Crushed porphyry 2/20 mm	180 mm
6. Crushed limestone 7/32 mm	220-340 mm
7. Crushed limestone 0/32 mm	400-520 mm
8. Protective sheet	
9. Impermeable membrane	(only for test sections)

4.1. Measurement techniques

In the project, different measurement techniques were used. In the laboratory, the permeability of different types of material (aggregates, porous lean concrete, pavement blocks,…) was tested. This was done in saturated conditions with the column test (300 mm in diameter).

On the test parking area, measurements on the outflow were carried out. 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. A restricted outflow, arranged by two thin tubes, was placed on the drainage tube in order to be able to measure also the influence of small rains. These outlets are comparable to an infiltration rate of $1*10^{-7}$ m/s. Through these measurements, a good knowledge of the storage capacities of permeable paving structures and of the importance of the different properties of the materials was obtained. A very limited runoff at the surface was detected, even during heavy thunderstorms.

In addition to the measurements performed in the laboratory and 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 square meters. 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 [6].

An overview of the measuring set is presented in figure 4. Secondly, the permeability of the permeable structure is measured by means of a "double ring" infiltrometer [7].

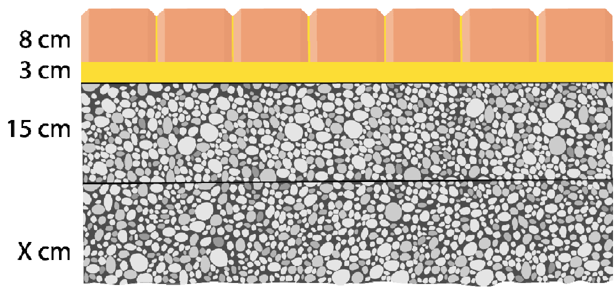
Measurements with the double ring infiltrometer are made after the structure has been built and can be used as control on the work of the contractor in combination with laboratory measurements on the material itself. During the project, the measurements at the surface are repeated over time, to reveal changes in permeability. Figure 5 shows a double ring infiltrometer set up for measurement.

Figure 4 – Open-end test.

Figure 5 – Double ring infiltrometer.

4.2. Storage and surface permeability

Tests made on the parking lot indicated that the storage capacity can be calculated from the water accessible porosity of the different layers. Figure 6 gives an example of the calculation for the structure of the test parking lot.



Structure:

- pavement blocks with enlarged joints
- bedding layer 0/7 – 30 mm (28 % porosity)
- base layer 0/32 – 15 cm
- sub base layer 0/32 – 30 cm

Storage capacity for 100 m²

- sub base layer: 0.30*23%*100*1000 = 6900 l/1,5 = 4600 l
- base layer: 0.15*0.23%*100*1000 = 3450 l/1,5 = 2300 l
- bedding layer: 0.04*28%*100*1000 = 1120 l/1,5 = 747 l

Figure 6 – Storage capacity of the structure.

To store the rain of 270 l/s/ha during 10 minutes (=1620 l/100m²), a thickness of 70 mm is needed, 105 mm if the safety factor of 1,5 on the porosity is taken into account. A storage capacity of 2000 l/100m², as is necessary in Flanders to meet the legislation, is obtained with a thickness of 130 mm. The extra thickness is due to the need for frost protection. Frost protection will be in most cases in Belgium the most restrictive criterion for the determination of the necessary thickness of the sub base layer.

The design of the structure is done in order to obtain the storage of the water (1620 l/100 m²) in the sub base layer. Figure 7 shows the height of the water in the structure under real conditions, with an outlet limited to 7 l/min for 120 m² (=10 l/s/ha). The influence of the rain intensity can also be deducted from figure 7. During a heavy rain, the water will be preferably stored in the structure and after some time released through the outflow. A long rain with reduced intensity will cause less buffering. The height of the water in the structure will be reduced and infiltration and outflow will be more spread in time.

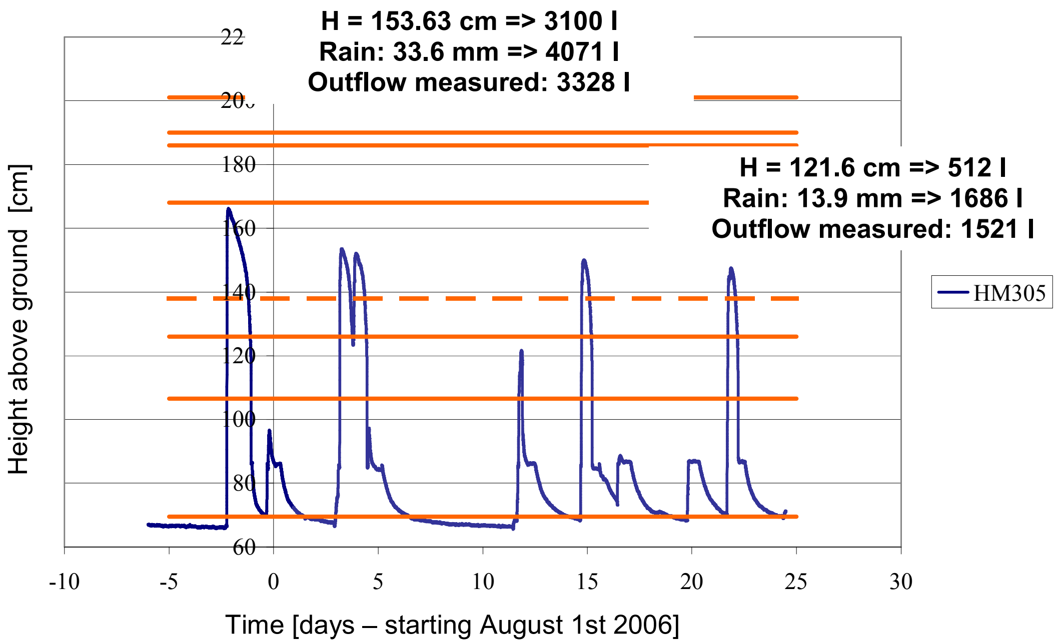


Figure 7 – Actual height of the water in the structure during rainfall.

The results also indicated a good retarding capacity of the structure. A small outflow during the thunderstorm itself (around 10 % of the water) was measured, 50 % of the water came out during the 5 to 6 hours following the rain and the other 40 % slowly dropped down in the structure and came out during the following days. The difference in material was visible by the time the water needed to reach the bottom of the structure. This was slightly longer in the case of 0/32 base material, but both materials in the applied thickness fulfilled the demands.

On the other hand, there were neat differences in surface permeability as measured with the double ring test after placement of the structure. These differences diminished after some time. The results are shown in figure 8. In some cases the permeability was beyond the range of the device (more than 10^{-3} m/s). These measurements have been done over a 5 year period. As can be seen, little changes in surface permeability of the porous pavement blocks have been noticed. For the pavement blocks with enlarged joints and with drainage holes, a reduction in surface permeability has been noticed, but it still remains more than sufficient to ensure the infiltration of the water for the design rainfall event.

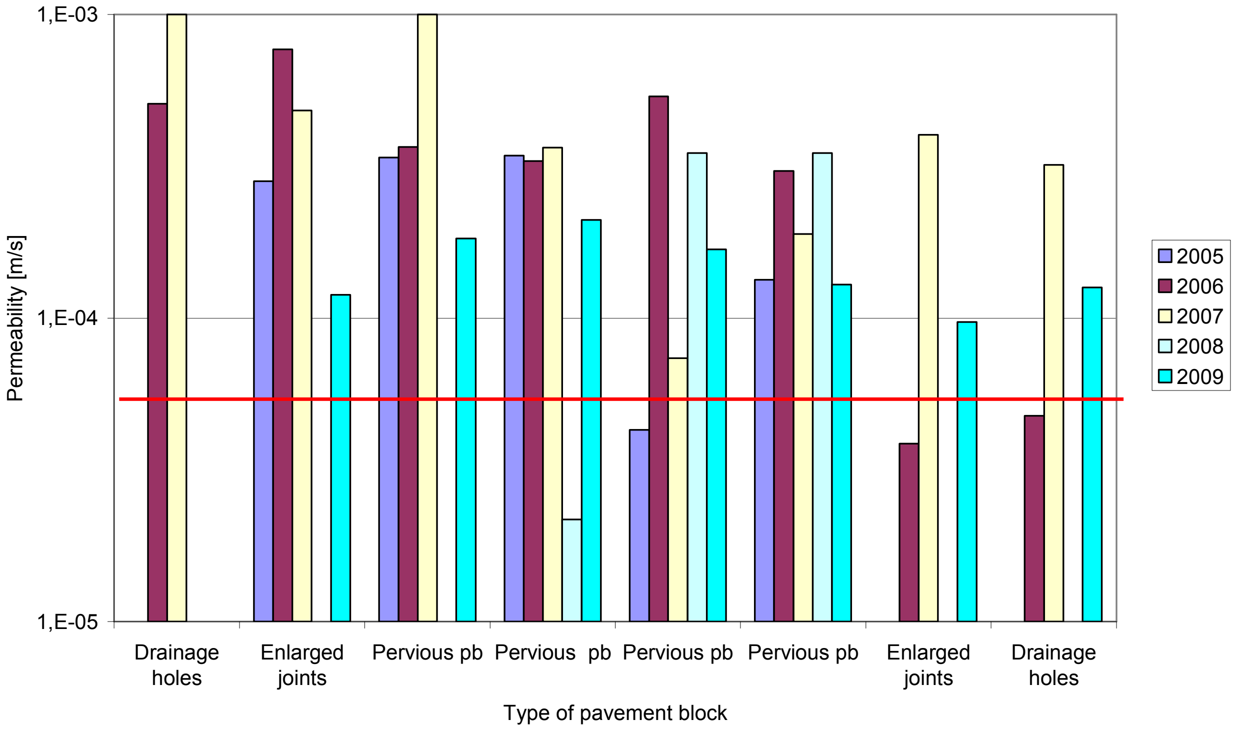


Figure 8 – Surface permeability on the different test sections measured with the double ring test.

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 positioning 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, sub base, base layer and in the sand bed. In the case of the test zones, the maximum flow measured at the outlet is equal to 3.5 l/h/m², which is comparable to a soil with a permeability of $9.7*10^{-7}$ m/s.

4.3. Field measurements

Approximately 50 projects are surveyed during and after the project. The majority was under construction or newly constructed during the project. 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 therefore very suitable for infiltration.

Figure 9 gives the results of all measurements carried out over time on site on different projects. As can be seen, even after longer periods in use, the permeability fulfills the requirement of $5.4*10^{-5}$ m/s and 97% of the measured surfaces demonstrated a surface permeability higher than $1*10^{-5}$ m/s.

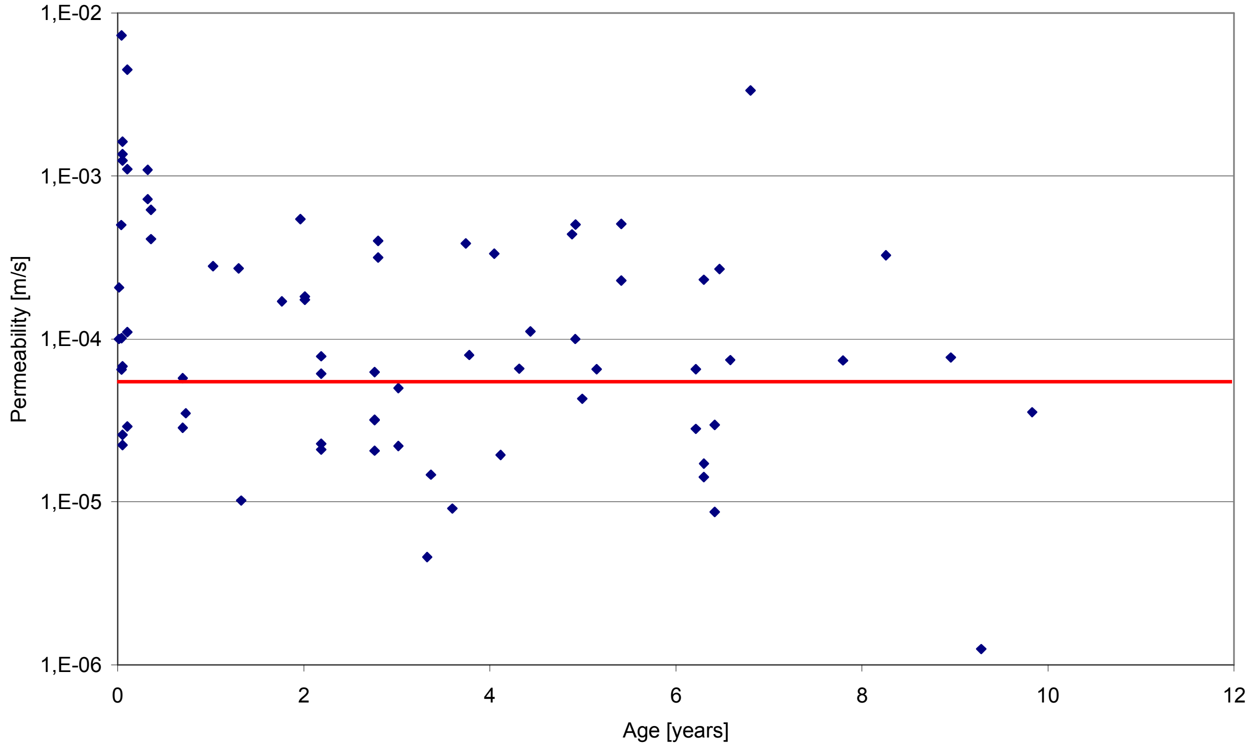


Figure 9 – Permeability in time for all surveyed projects

5. SPECIAL APPLICATION: WATER PERMEABLE PAVEMENT BLOCKS IN ALLOTMENTS

Water pervious pavements are very well adapted to be used in allotments: the traffic is in general very limited and low speed traffic, the amount of heavy vehicles is limited to the garbage truck and the space for extra storage systems is in most cases limited. The only difficulty is the fact that it is common to build the road before the houses, which means that during the construction of the houses, the silting up of the surface could be a great risk for the durability of the pavement towards permeability. To avoid this problem, two different solutions may be applied.

A first solution is to put the structure in place as foreseen by the designer. The whole structure is permeable and designed to store and infiltrate the water of the pavement. In this case sufficient cleaning of the surface has to be foreseen in order to avoid a loss of permeability. Another solution is to build a provisional road by putting a thin asphalt layer on top of the sub base layer. This layer will be removed after the construction of the houses and the road structure will be finished according to the design of the pervious pavement. Provisionally water removal has to be provided.

In both cases it is crucial for a good result that the time between the construction of the road and the building of the houses is limited and the condition of the road is followed up closely.

The advantages of the first method are that the construction is immediately at the correct height, no additional water discharge has to be provided and the street can be build in one phase. The disadvantage is the risk on clogging, the cleaning of the surface and refilling of the joints has to be done very securely.

It is of great importance in this case that the joints are filled completely. Otherwise, the fine material will penetrate deeply into the joint and the removal of this material will not be possible anymore. Measurements on site have indicated that the clogging of the surface generally takes place at the surface itself and therefore the cleaning by water jet and aspiration is possible.

In the case a provisional road is constructed, the risk on clogging is minimized. The disadvantages however are the fact that the road has to be constructed in two phases, additional water removal has to be foreseen and height differences between the entrance of the houses and the provisional road has to be dealt with.

To avoid in this case the application of additional water gullies one can use the final storage capacity, present in the sub base and drainage or infiltration at the bottom of the structure. The water is passed to this sub base layer by a sort of passing lid as shown in figure 10. Once the asphalt and the lid are removed, the sub layer can be checked for clogging and locally replaced.

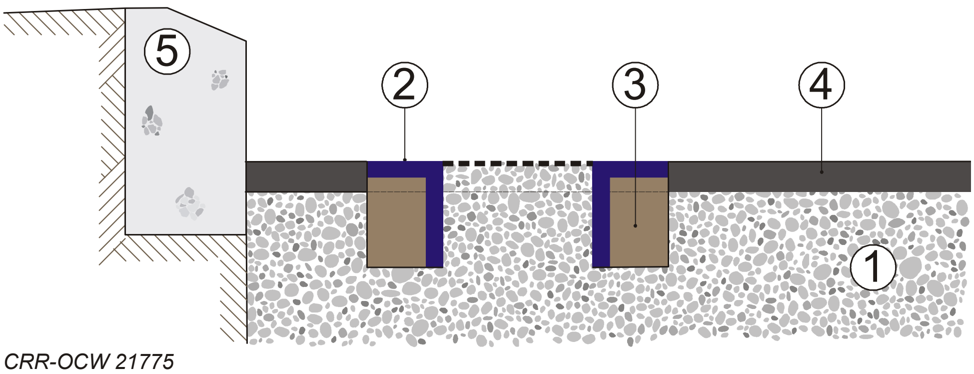


Figure 10 –Structure of the provisional road with the passing lid – 1: sub base; 2: passing lid; 3: sand-cement; 4: temporary asphalt layer; 5: kerbing.

The application of water pervious pavement blocks in allotments has been done successfully on different places. Figure 11 shows the application in Sint-Niklaas, where a provisional asphalt layer is used.

Figure 11 – Temporary structure to provide entrance to the houses and view of the final work site in Sint-Niklaas, Belgium.

6. CONCLUSIONS

The results from the research project have formed the basis of a new publication on the dimensioning and application of water permeable pavement blocks. A good storage capacity as well as infiltration or drainage has been shown. Standard structures are put in place depending on the permeability of the soil and the intensity of the traffic on the pavement.

The combination of bearing capacity and water storage is assured by splitting up these tasks over the different layers in the structure. The bearing capacity is provided by the base layer, the storage is provided by the sub base layer. In this way, the influence of saturation on the behavior of the structure is limited.

Measurements on the test parking lot at the BRRC and on applications in Flanders indicate a good durability of the permeability. Although a reduction in surface permeability is noticed over time, the original demand of $5.4*10^{-5}$ m/s is still reached after 10 years in surface. Moreover it has been stated that the clogging is mainly at the upper surface of the structure, which means that it can be cleaned by jet blasting and aspiration. A condition to obtain this is the application of an adequate joint filling material from the start of the project.

Following the research project, the BRRC has started a technical support project, in which technical support during design, execution or after construction is offered. The BRRC is also disseminating all the result of its research project by leaflets, state-of-the-art publications and follow up of the projects. This stimulates the application of water permeable pavements in combination with the legislation, by which it is permitted to apply water permeable pavements without extra water storage capacity.

9. REFERENCES

1. Shackel, B, 1997. Water Penetration and Structural Evaluations of Permeable Eco-Paving. Concrete Precasting Plant and Technology 3/1997; pp110-118.
2. BRRC, 2009, Information on water permeable pavements and information on projects (in Dutch or French). http://www.brrc.be/ocw/n15/n15_03a_b1.php.
3. Beeldens A, e.o., 2008. Dossier 5: Waterdoorlatende verhardingen met betonstraatstenen (in Dutch or French). dec. 2008, http://www.brrc.be/pdf/mededelingen/med77t.pdf.
4. Beeldens A. , Herrier G., 2006. Water pervious pavement blocks: the belgian experience. 8th International conference on Block Paving materials.
5. Guidance for designers, developers, planners and local authorities, edition 3, BRITPAVE, Uniclass L534:L217
6. United States Department of the Interior-Bureau of Reclamation, 1963. Earth manual-A guide to the use of soils as construction materials for hydraulic structures. Denver, Colorado.
7. Borgwardt S, Gerlach, A, Köhler, M, 2001. Kommentierung des Merkblattes für wasserdurchlässige Befestigungen von Verkehrsflächen. FGSCV, pp 249.

10. ACKNOWLEDGEMENTS

The author wishes to thank IWT (the Institute for the Promotion of Innovation by Science and Technology in Flanders) for the support of this project. They would also like to express their gratitude to FEBESTRAL (the federation of Belgian manufacturers of linear and modular paving elements in concrete) for their support in this project.