9th. International Conference on Concrete Block Paving. Buenos Aires, Argentina, 2009/10/18-21
Argentinean Concrete Block Association (AABH) - Argentinean Portland Cement Institute (ICPA)
Small Element Paving Technologists (SEPT)

WATER PERMEABLE PAVEMENTS IN BELGIUM. FROM RESEARCH PROJECT TO REAL APPLICATION

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Note: The following is the notation used in this paper: (.) for decimals and ( ) for thousands.

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.

1. INTRODUCTION

Water-permeable paving is used more and more in Belgium. One of the reasons is the adapted legislation which is encouraging the constructors to use permeable surfaces. Usually, in the previous legislation, to construct or renovate a building or parking, a water storage system and preferable an infiltration system had to be put in place. With the adapted legislation no storage capacity has to be foreseen for the surface constructed with water permeable paving. 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.

Important for a durable and well functioning pavement is the combination of bearing capacity and permeability. For this, in combination with a frost protection of the soil, standard structures are developed in Belgium to optimize the dimensioning and the application of water pervious systems.

These standard structures are the result of a research project funded by the Flemish Government (through IWT), which was undertaken to model the permeability and storage capacity of water permeable structures and to optimize the preservation of permeability.

Different test sections have been applied, on which a first report was made during the previous conference [Beeldens, 2006]. This project was running from 2003 to 2007 and included laboratory tests on the paving materials as well as on the base and sub base materials, and field tests on soils and water-permeable pavements. In addition, a parking area with twelve different sections (each 120 m^2 in area) was constructed on the premises of the Belgian Road Research Centre 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 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) 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 [BRRC, 2009] and through brochures dealing with the theory and application of water permeable pavements [Beeldens, 2009]. Additionally, courses are given to the different stake-holders, namely to the producers of the pavement blocks as well as to the design engineers as to the managers of the pavements.

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 the structure in the case of permeable blocks. It is retained for a certain time, after which 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 results from the higher porosity of the base layer and the paving and, consequently, for the lower resistance to traffic.

To ensure 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 pavement blocks 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 since the pumping effect which could occur at the surface of the structure in the presence of water and traffic is avoided as much as possible. 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 an intensity of 270 liters per second per hectare. An initial permeability of 5.4*10-5 m/s is demanded (safety factor 2),

to compensate for the fact that the permeability of the structure may be reduced by air enclosures or by clogging at 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. DECISION TREE, STANDARD STRUCTURES AND MATERIAL CRITERIA

To come to an optimum design, different stages have to be looked at, starting from the soil and the necessary drainage system to the choice of pavement blocks over the material and dimensions of the sub base and base layer.

3.1 Decision tree

In the following decision tree, Figure 1, different steps have to be taken: first the drainage system is determined in function of the soil permeability. According to Shackel, no drainage, an overflow or drainage at the bottom has to be foreseen in relation to the permeability of the soil [Shackel, 1997]. In the next step, the thickness of the base layer and type of material is fixed in relation to the traffic on the structure. Subsequently 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. Finally, a choice of pavement blocks is made and with this, the choice of joint filling material and base layer material. A geotextile is added at the bottom of the structure to prevent the infiltration of fines into the structure and above the base layer, in the case pervious lean concrete is used.

3.2 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 which is present 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 2.

3.3 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 the quality of the criteria 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 cm^2 has to be reached 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) has to be lower than 15 and the LA (Los Angeles value) lower than 20. This means that only some limestone aggregates as well as porphyry aggregates can be used.

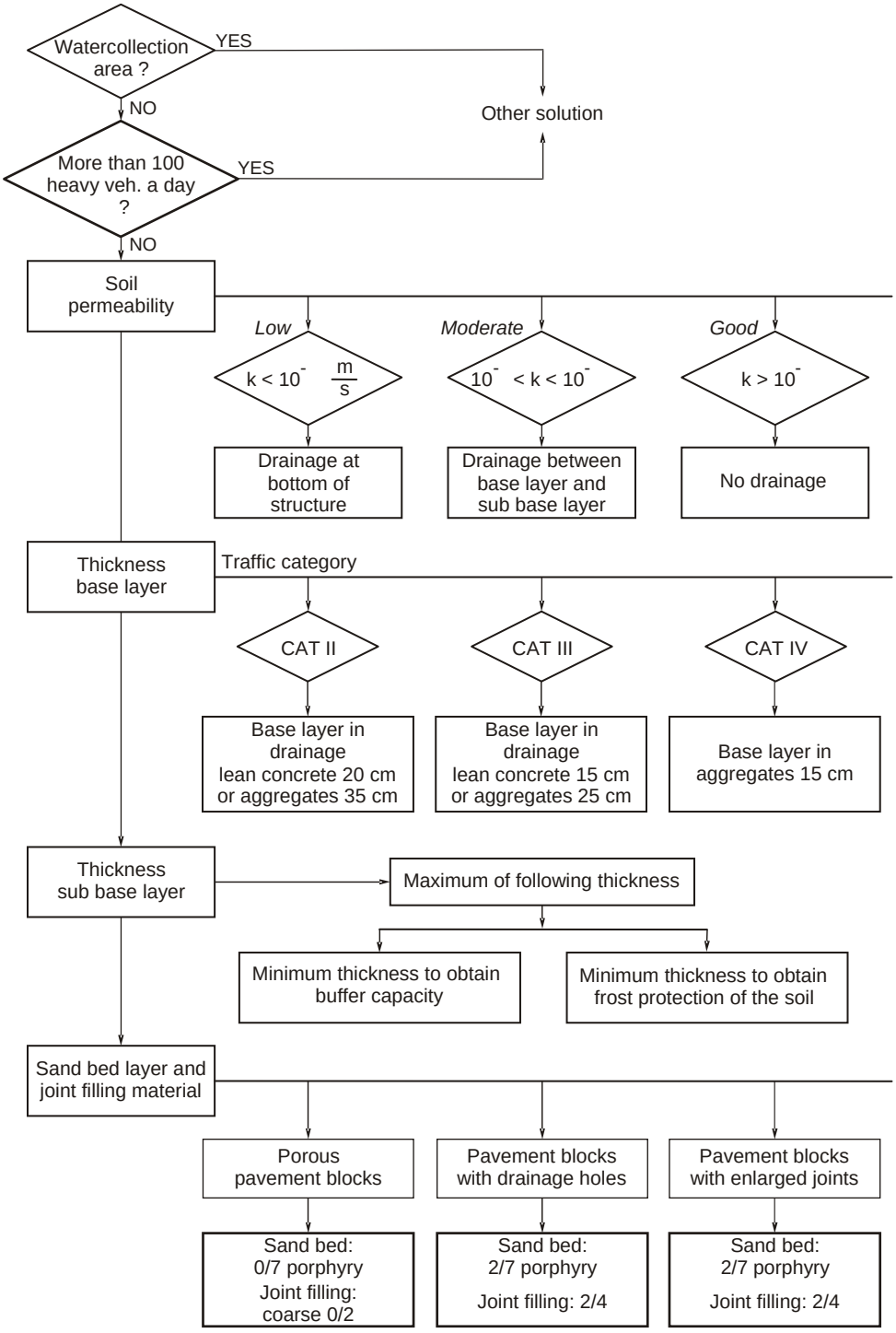
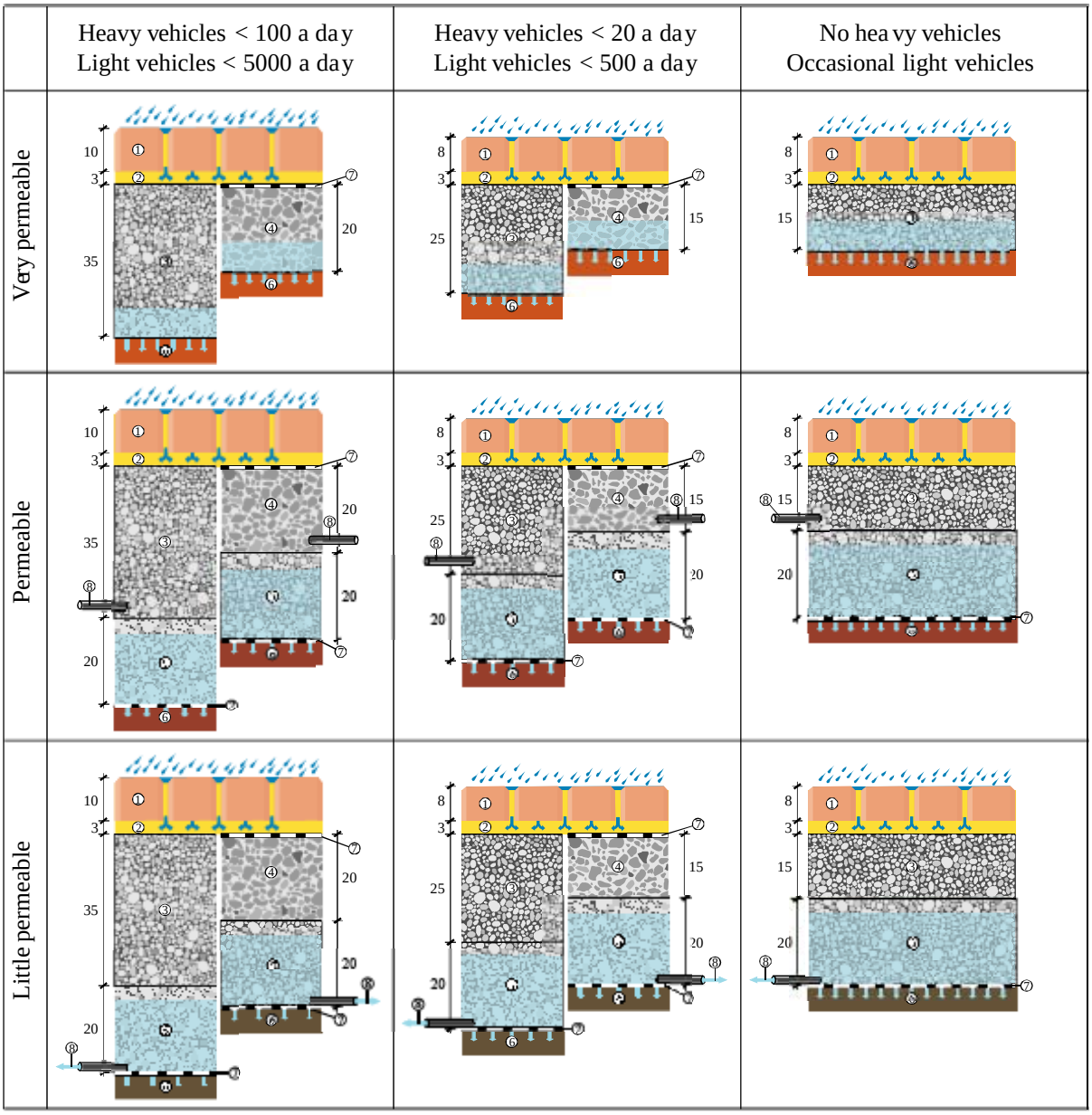


Figure 1. **Decision tree to design the structure of water pervious pavements**.

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.



1. Water permeable pavement blocks.
2. Bedding layer.
3. Unbound base layer.
4. Porous lean concrete.
5. Unbound sub base layer.
6. Soil.
7. Permeable geotextile.
8. Drainig tube.

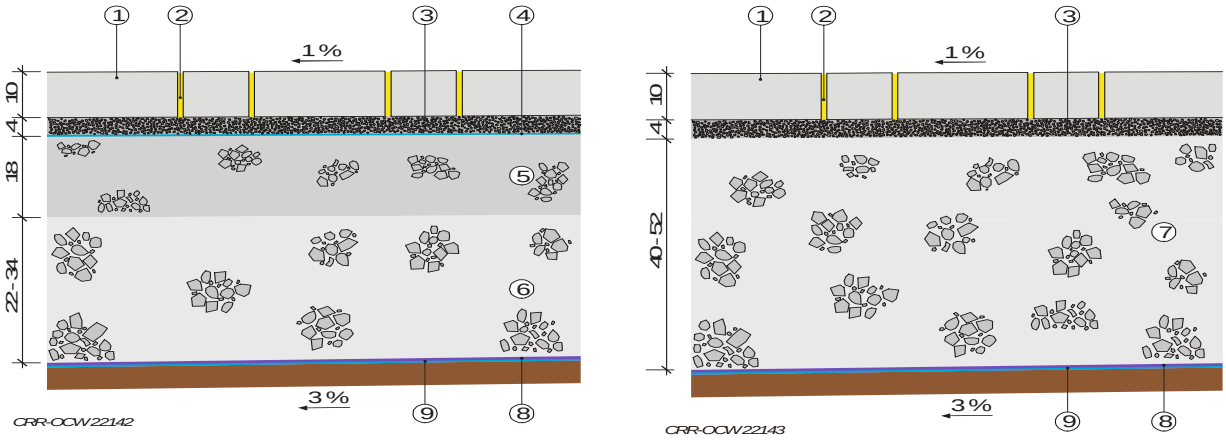
Figure 2. Standard structures in relation to soil permeability and traffic.

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 [Beeldens, 2009].

4. RESULTS OF THE RESEARCH PROJECT

The results of the research project pointed at the good buffering capacity of the water permeable paving 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. In Sterrebeek, the necessary thickness for frost protection of the soil is 650 mm. This is reached by following structure: 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. 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 outlet of the tube was arranged by two thin tubes 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. More information on the test sections can be found in the paper [Beeldens, 2006].



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)

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

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.

On the test parking area, measurements on the outflow were carried out. The water was collected at the bottom of the structure by an impermeable membrane. A restricted outflow was placed on the drainage tube in order to be able to measure small flows as well as important flows. This also simulates the conditions where no infiltration in the ground is possible and water has to be retarded

at the outflow before it is drained away to other infiltration units. 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 m^2. 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 [US Department, 1963]. 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 [Borgwardt, 2001]. 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.



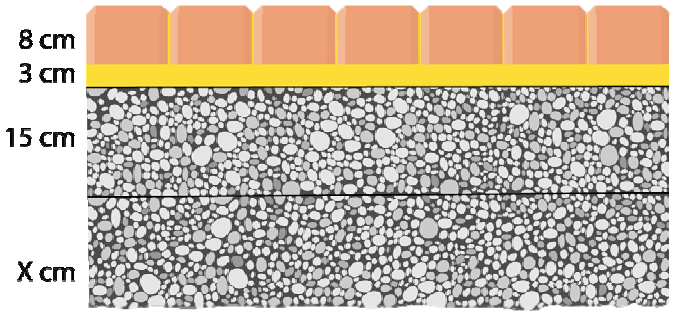
Figure 5. Double ring infiltrometer.

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. In Flanders, a storage capacity of 2000 l/100 m^2 is necessary in order to meet the legislation.

As can be seen in the calculations in Figure 6, 100 mm sub base would be sufficient to obtain this permeability. The extra thickness is due to the need for frost protection. To store the rain of 270 l/s/ha during 10 minutes, a thickness of 70 mm is needed. Frost protection will be the most restrictive criterion for the determination of the necessary thickness of 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 m^2 (=10 l/s/ha). As can be seen, the water almost never entered the base layer, even with rains up to 260 l/s/ha. Figure 7 also indicates the influence of the intensity of the rain. With heavy rains, the height will be much higher and the infiltration during the rain is less, if the rain falls down over a longer period or if only a small amount of water is falling, the height will be much less and infiltration will take part during the rain.



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

base layer: 0.15*0.23%*100*1000 = 3450 l

bedding layer: 0.04*28%*100*1000 = 1120 l

Figure 6. Storage capacity of the structure.

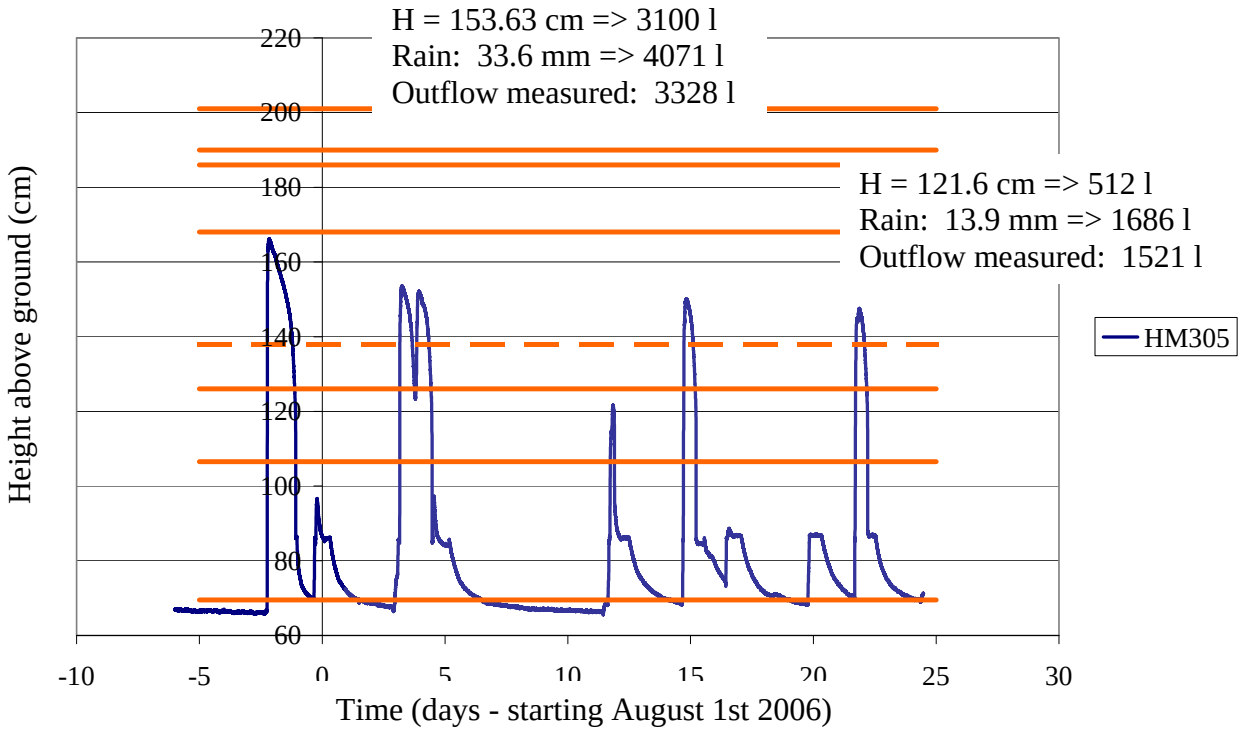


Figure 7. Actual height of the water in the structure during rainfall.

The results also indicated a good retarding capacity by 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.

On the other hand, there are neat differences in surface permeability as measured with the double ring test. 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.

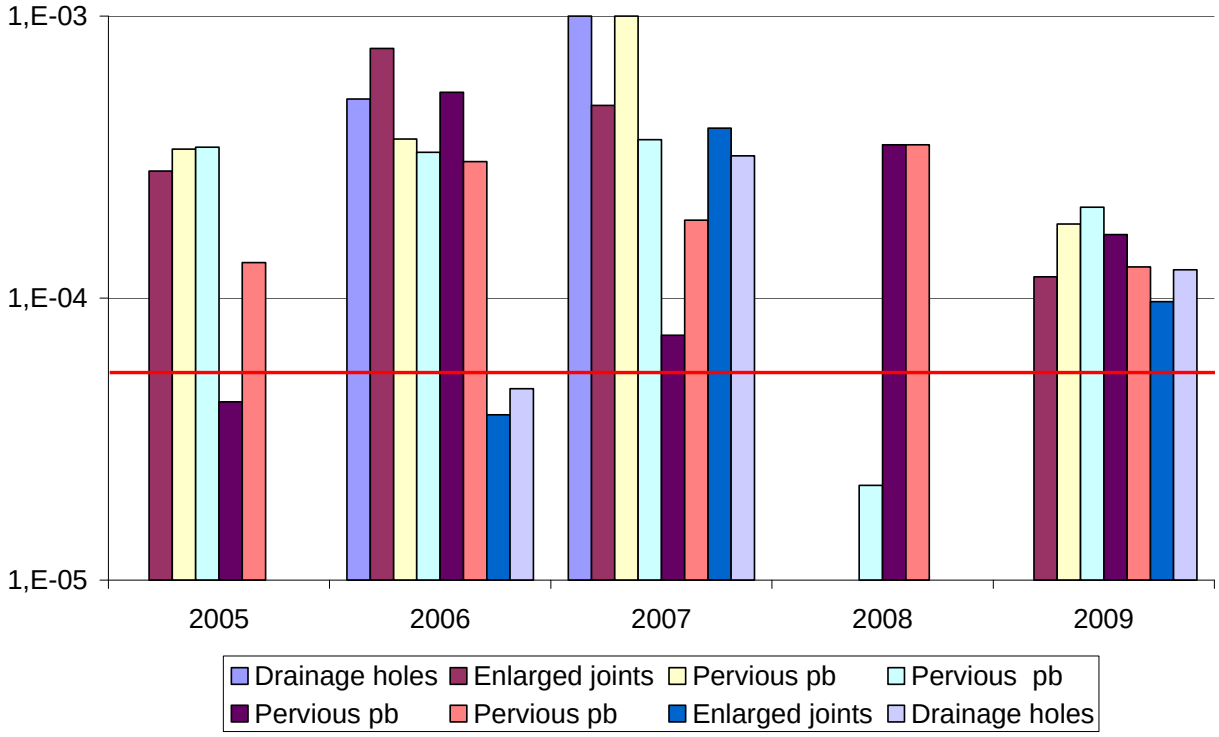


Figure 8. Surface permeability on the different test sections measured with the double ring test.

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, 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/m^2, which would be similar to a soil with a permeability of $9.7*10^{-7}$ m/s. The total height of the structure is 650 mm. This enlarges the storage capacity significantly but also protects the under laying soil against frost.

4.3 Field measurements

Approximately 50 projects are surveyed. 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 is, therefore, very suitable for infiltration.

An interesting case study is highlighted here. It is a parking lot situated in Kortenberg (near Brussels) from a car distributor D'Ieteren (Volkswagen, Audi, Seat and Skoda). Over 4000 places are foreseen on 70 000 m^2. In principle only cars will enter this parking lot. The parking lot was placed in an area sensitive to flooding.

To avoid any risk of flooding, drainage trenches were made into the sand layer beneath the loam soil. To minimize the risk of deformation on the heavy trafficked roads between the parking lots,

the roads were realized in colored concrete. Each section of the parking lot had a specific color to facilitate the use of the parking lot. An overview is given in Figure 9.

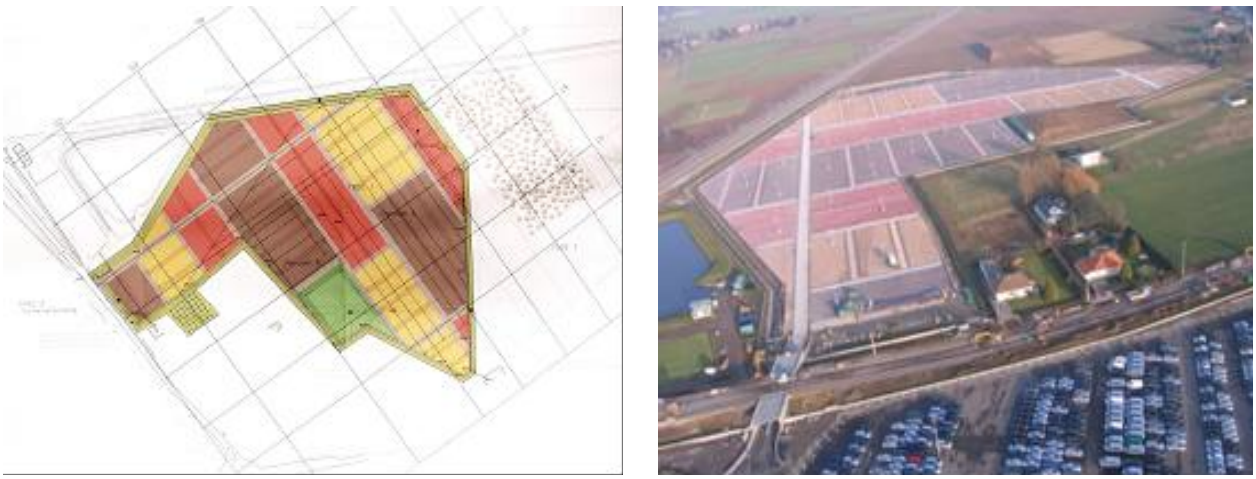


Figure 9. Map of the parking lot at car distributor D'Ieteren as well as view during construction.

For the permeable structure, a sub base layer of limestone 7/32 was used with a base layer porphyry 2/20 on top. Since the compaction of the limestone 7/32 was difficult with the normal compaction gears, an additional amount of limestone 0/7 was added. During the second phase of the work however, a new high energy compaction plate was used by which the compaction of the 7/32 was possible.

Besides help to choose the optimal aggregate distributions, the BRRC carried out permeability tests with the double ring infiltrometer on the finished surface. The surface permeability was equal to $2.7*10^{-4}$ m/s in 2005.

By measuring the projects over time, a decrease in permeability is seen. The results indicate, especially in the case of pavement blocks with enlarged joints and drainage holes, a very large permeability, just after construction. This permeability diminishes in time, but stabilizes around 2 to $5*10^{-5}$ m/s. Figure 10 gives a view of the surface permeability, measured on different sites in relation to the age of the pavement. The red line is the limit of $5.4*10^{-5}$ m/s. As can be seen, some decrease in permeability is noticed in time, but the permeability remains sufficient to pass the rain of 270 l/s/ha ($2.7*10^{-5}$ m/s). No distinction between the different types of water permeable pavement blocks is visible.

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 an 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.

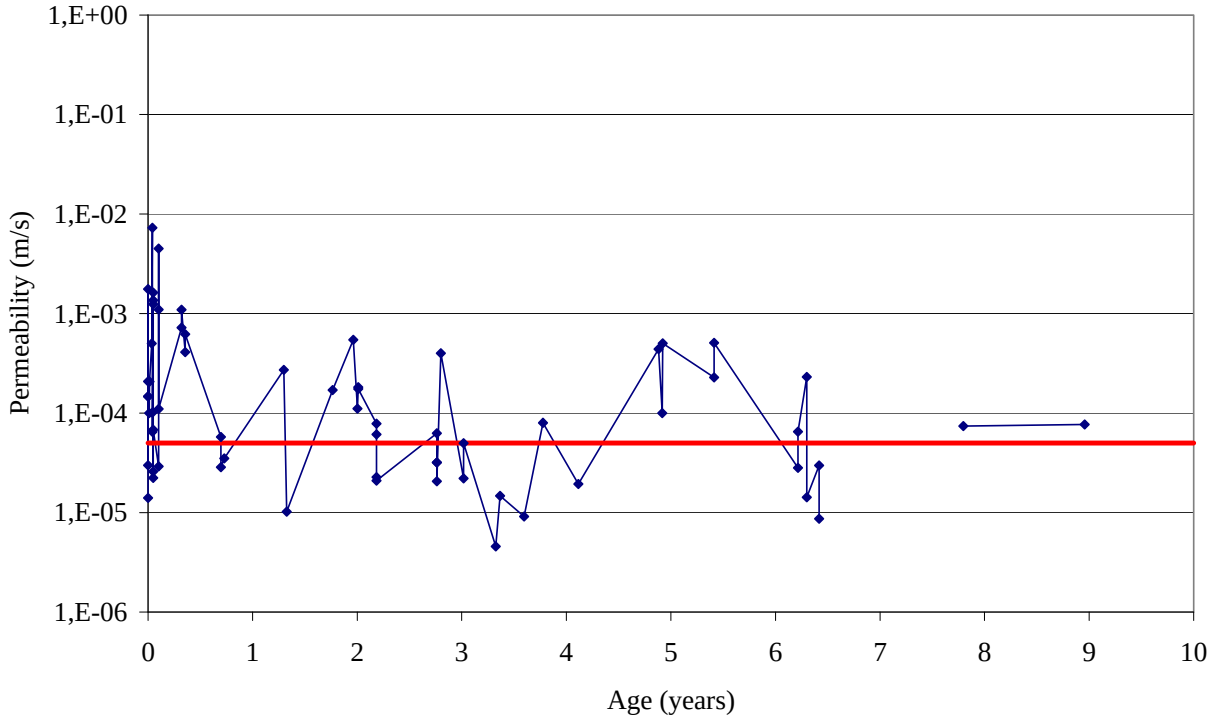


Figure 10. Surface permeability at different sites in relation to the age of the structure.

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 11. Once the asphalt and the lid are removed, the sub layer can be checked for clogging and locally replaced.

The application of water pervious pavement blocks in allotments has been done successfully on different places. Figure 12 shows the application in Sint-Niklaas, where a provisional asphalt layer is used.

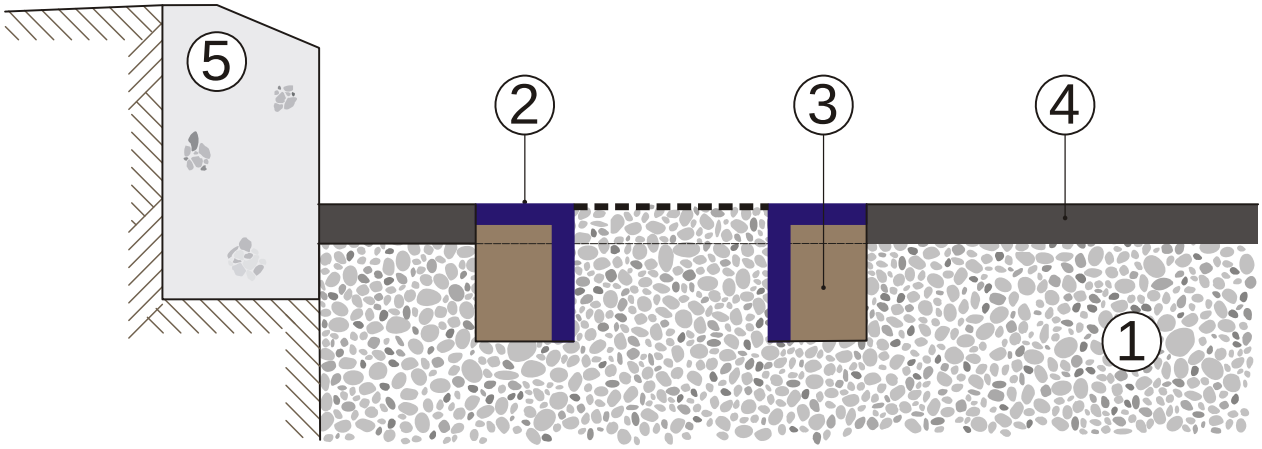


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Figure 11. Sstructure of the provisional road with the passing lid – 1: sub base; 2: passing lid; 3: sand-cement; 4: temporary asphalt layer; 5: kerbing.



Figure 12. 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, as well as result dissemination 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.

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8. 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.