

LONG-TERM IN-SITU INFILTRATION PERFORMANCE OF PERMEABLE CONCRETE BLOCK PAVEMENT

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SUMMARY

Since it is a design criteria for road drainage and sewer systems, the infiltration performance of permeable concrete block pavement (CBP) is of important significance during the service life of a road construction. Due to the entrainment of mineral and organic fines into the pores of porous concrete blocks or into the aggregates used in joints or openings, the irreversible reduction of water permeability can be assumed. Research results show that the infiltration performance decreases in the order of the power to ten after a few years.

These results are confirmed by in-situ field tests with a special infiltration-meter. This instrument measures the infiltration capacity in the laid condition with no disturbance and gives immediate results, taking into consideration local conditions such as age and traffic-load. The infiltration curves are shown as regression curves of the averaged infiltration values. These tests can be continuously repeated to observe the long-term performance.

These tests show especially a significant relation between infiltration and age. The study states moreover that the long-term in-situ infiltration performance and its observed decrease depend from the grain size of the aggregates used for joint filling. It is furthermore partly induced by the ratio of openings of permeable pavements respectively the pore size of porous concrete blocks.

The overall conclusion is that although permeable concrete block pavements cannot drain a traffic area entirely, they can still have a considerable impact on the run-off process of the entire catchment area. Due to the fact that part of the rainfall is retained, this part is not added to the run-off total and it can dampen the run-off peaks because of its delaying effect. In view of an overloaded sewer system this is of considerable ecological importance since the overload can be reduced by permeable concrete block pavements thus also avoiding discharge into the receiving water with the accompanying pollution. The respective relation between surface run-off and actual infiltration means for the hydraulic sizing of a drainage system that a more precise design method can be applied.

The fact of a decreasing infiltration performance leads to accurate design, application and maintenance proposals to achieve a long lasting infiltration performance on a high level for a sustainable and environmental useful management of affordable drainage and sewer systems.

1. DESIGN PRINCIPLES FOR ROAD DRAINAGE WITH PERMEABLE CBP

1.1 Permeable CBP as a part of road drainage systems

One significant effort of infiltration management is to relieve overstressed urban sewer systems from surface runoff of roads and other impermeable paved areas. Because managed infiltration systems have high demands on land use, the application of permeable pavements is an important contribution to proper and integrated road drainage.

The design of drainage systems needs constant factors for dimensioning, i.e. the possible output or infiltration rate because of a present permeability. With permeable pavements the infiltration performance is decreasing over its service life due to the entrainment of mineral and organic fines into the hydraulic system which normally provides the constant data for the permeability. In other words: the clogging of the pores of porous concrete blocks or aggregates used in joints is leading to an irreversible reduction of water permeability and infiltration performance. Consequently the application of permeable CBP is more a method of reducing surface runoff rather than a controlled drainage system (Borgwardt, S., 1997).

Nevertheless – although not managed drainage system – permeable CBP still have a considerable impact on the run-off process of the entire catchment area. Due to the fact that part of the rainfall is retained, this part is not added to the run-off total. These means reducing the total amount of rainwater in the drainage facility and in addition dampen the run-off peaks because of its delaying effect (SZTRUHAR, D. and H.S. WHEATER, 1993; Borgwardt, S., 1996). But for an appropriate application of permeable CBP and for the use as a supporting part of drainage the exact development of the infiltration process, the lasting infiltration performance and its dependence to the interacting factors have to be known.

1.2 Design storm, infiltration rate, permeability and surface water runoff

For the hydraulic design of drainage systems the design storm as the input quantity for the dimensions of sewers as well as for the infiltration capacity of the permeable pavement itself has to be considered. The precipitation events are characterized by their four components of amount, intensity, duration and frequency. For the design procedure the value r describes the specified amount of water the pavement or a drainage facility has to be able to capture. In the following consideration the value r is measured as a rainfall with 10 minutes duration occurring once a 5 years ($r_{10(0,2)}$) in the dimension of millimeters per minute [mm/min] or liter per second and hectare [l/(s×ha)]. A heavy storm for example with $r_{10(0,2)}$ has around 400 to 600 l/(s×ha) or 2.4 to 3.6 mm/min. In direct relationship stands the infiltration rate i as the amount of water – to result from a particular design storm – which can be retained or absorbed by a reservoir or a permeable surface.

The permeability k in meters per second [m/s] expresses the velocity of liquid in a porous medium in water-saturated conditions and accordingly is an attribute of soils or aggregates. A certain permeability k has to be made available e.g. by joint fillings or base courses to absorb a certain design storm. For design reasons the permeability k_u in unsaturated regions – like with aggregates for pavement structures – has a lower velocity and applies to the relationship $k_u = k/2$.

The specific peak runoff coefficient of a pavement as the quotient of the maximum surface runoff to maximum rainfall measure is important for the hydraulic design of the connected road drainage. A low runoff coefficient of a permeable pavement e.g. during intense storms indicates a good infiltration.

2. RESEARCH OF THE INFILTRATION PERFORMANCE OF PERMEABLE CBP

2.1 The reduction of permeability due to surface clogging

Research results show that during their service life the surface permeability of pavements is affected by the entrainment of mineral and organic fines into the pores of porous concrete blocks or into the aggregates used in joints (BWW, 1984; Binnewies, W. and M. Schuetz, 1985; Borgwardt, S., 1995). The findings also are confirmed by additional authors (Hade, J.D. and D.R. Smith 1988; Suda, S. et al. 1988; Field, R., H. Masters and M. Singer, 1992). These fines are based mainly on particulate emission, traffic-caused abraded particles and organic substances from surrounding areas.

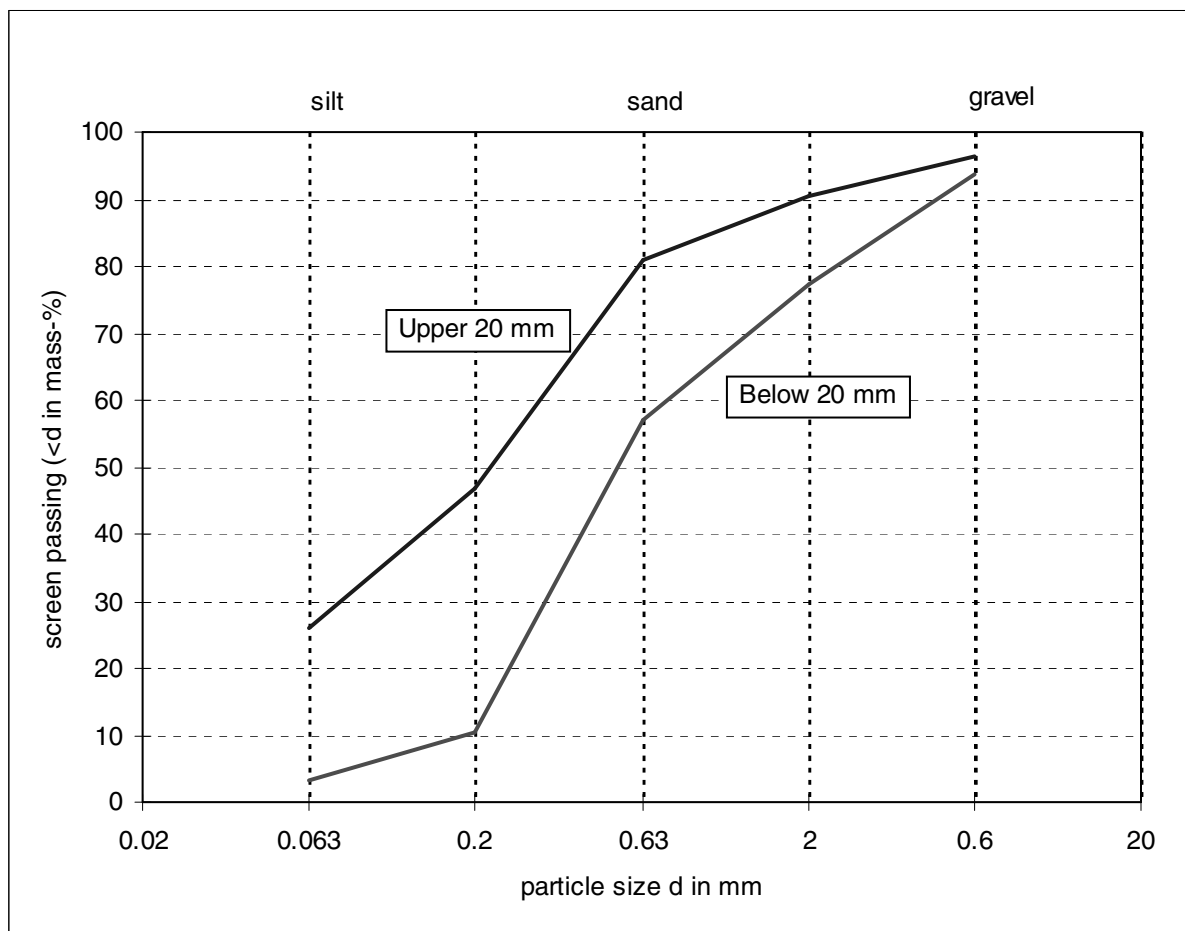


Figure 1. Particle-size distribution for joint material

The comparison of joint material from the upper 20 millimeters of a joint with unaffected material from below prove in the grain size analysis of Borgwardt (1995) that the fines (particles < 0.063 mm) increase from original 3.2 mass-% in the average up to 25.9 mass-% (Fig. 1). The difference is highly significant and relate to a drop of permeability from 23.9 to 2.0 millimeters per minute (Fig. 2). The enrichment of fines developments continuously over the years with its significant influx on the water

permeability measured out of the grading curve of the joint material. This means a rapid drop of permeability within the first few years and afterwards an asymptotical approximation to the accumulated value. These findings lead to further requirements on research of the actual in-situ infiltration performance of permeable CBP in the laid condition during its entire service-life.

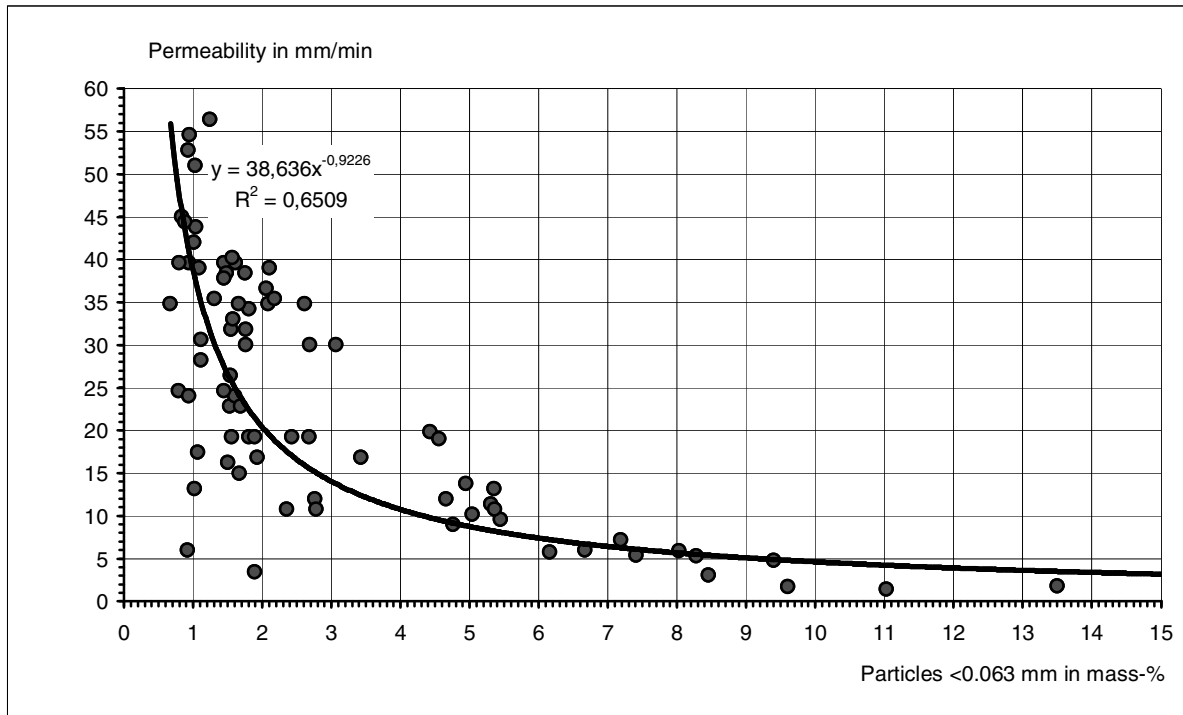


Figure 2. Relation between permeability and particle fraction < 0.063 mm

2.2 The infiltration-meter

For the realistic and reproducible non-destructive determination of the infiltration performance of permeable CBP in the laid condition the infiltration rate (*i*) is the more appropriate value than the permeability (*k*). This is because the infiltration rate as a mass parameter can be set in relation to a given storm and is therefore important in comparison with a determined rainfall measure as used e.g. for the dimensioning of drainage systems. In contrast to this the permeability is more important as an indicator for soils or aggregates.

For in-situ field tests a special infiltration-meter is designed for accurate and immediate results (Borgwardt 1998), taking into consideration local conditions such as age and traffic-load and allowing continuously repeated tests to observe the long-term performance.

The basic scheme of the infiltration-meter is that a sealed testing area of about 0.25 m² is symmetrical covered with constant intense model precipitation by sprinkler container connected to a tank or a water connection (Fig. 3). The precipitation intensity is chosen for a minimal water level within the sealed testing area to prevent a non-natural vertical water pressure. This goal is reached by a float switch or a sensoric distance meter in the testing area connected to a magnetic valve, which limits the water level within a few millimeters. A horizontal movement of the infiltrated precipitation is prevented because of an additional irrigation outside of the testing area. The infiltration is recorded by the change of flow

with a flow meter. The infiltration rate as infiltrated precipitation per time unit follows from the controlled flow dependent from the change of water level with the testing area.

The testing results as a infiltration rate are shown as regression curves of the averaged infiltration values in millimeters per minute [mm/min] or liter per second and hectare [l/(s×ha)]. They show a characteristic progress with a high value at the start, a decline with increasing water-saturation after 10 to 30 minutes and an asymptotic approximation to a constant value at the end. The value $i_{(10)}$ after 10 minutes testing is – analogous to a given design storm measure corresponding to the hydraulic dimensioning of e.g. road drainage – interpreted as a potentially infiltratable rainfall. The end value $i_{(60)}$ after 60 minutes testing corresponds to an infiltration in water-saturated conditions and can therefore construed as a permeability coefficient k in meters per second [m/s].

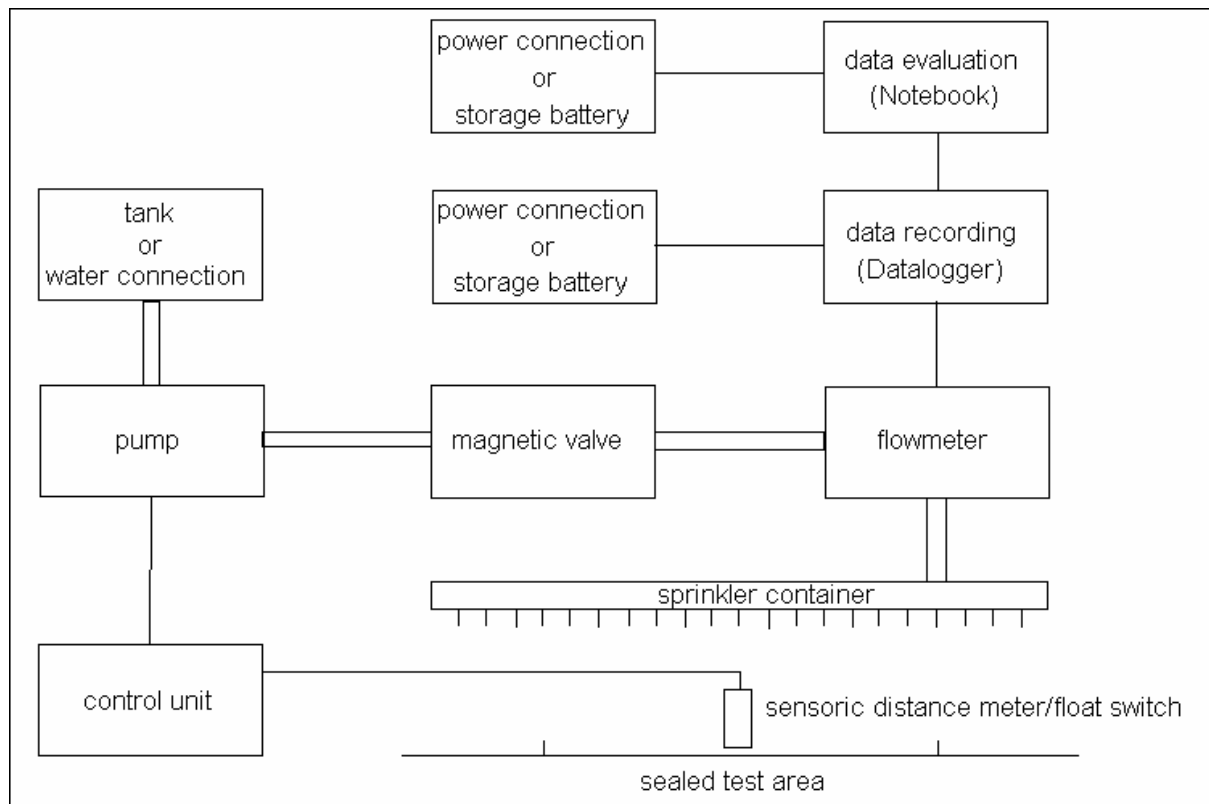


Figure 3. Basic scheme of infiltration-meter

The testing results as a infiltration rate are shown as regression curves of the averaged infiltration values in millimeters per minute [mm/min] or liter per second and hectare [l/(s×ha)]. They show a characteristic progress with a high value at the start, a decline with increasing water-saturation after 10 to 30 minutes and an asymptotic approximation to a constant value at the end. The value $i_{(10)}$ after 10 minutes testing is – analogous to a given design storm measure corresponding to the hydraulic dimensioning of e.g. road drainage – interpreted as a potentially infiltratable rainfall. The end value $i_{(60)}$ after 60 minutes testing corresponds to an infiltration in water-saturated conditions and can therefore construed as a permeability coefficient k in meters per second [m/s].

2.3 Results of infiltration-meter tests

As stated in chapter 2.1 the overall infiltration performance depends on the permeability of the pavement and therefore of the implementation of the open structured surface and of the pore structure of the perfused filter. This can be the aggregates of joints fillings or the pores of porous paving blocks and is mainly affected by the over the years increasing entrainment of mineral and organic fines in the upper 20 mm. The solid results of the change of the physics and chemistry of this filter in the course of time and the empirical connection to its water permeability are now measured with the actual in-situ infiltration performance.

The overall infiltration performance is characterized in numerous field tests with the infiltration-meter (Borgwardt, S. 1995, Borgwardt, S. 2000). Besides of the specific performance of different permeable CBP products in different object situations the influence of several indicators as joint filling, openings ratio and aging can be verified.

Testing areas were permeable paved areas with different age, traffic load, joint fillings and openings ratio. The tested permeable pavements can be differenced in paving blocks with widened joints, paving blocks with openings and porous paving blocks (Borgwardt, Gerlach and Koehler 2001). Compared to these, testing results of non-permeable CBP (Borgwardt 1995) can be viewed.

2.3.1 Influence of joint fillings

With the research of the correlation between infiltration performance and the kind of aggregates used for joint fillings the results for permeable paving blocks with widened joints and with openings are analyzed together with a sample size of 50 testing areas. Tested were aggregates shown in Table 1 with a theoretical permeability on the basis of an idealistic grading curve after BEYER (Borgwardt, Gerlach and Koehler 2000).

Table 1. Theoretical permeability of aggregates for joint fillings

Aggregate and particle size	k [m/s]
Crushed gravel 2/5 mm	$1 \times 10^{-2} - 1 \times 10^{-3}$
Crushed gravel 1/3 mm	$1 \times 10^{-3} - 1 \times 10^{-4}$
Mixed gravel and sand 0/5 mm	$1 \times 10^{-4} - 1 \times 10^{-5}$
Sand 0/2 mm	$1 \times 10^{-4} - 1 \times 10^{-5}$

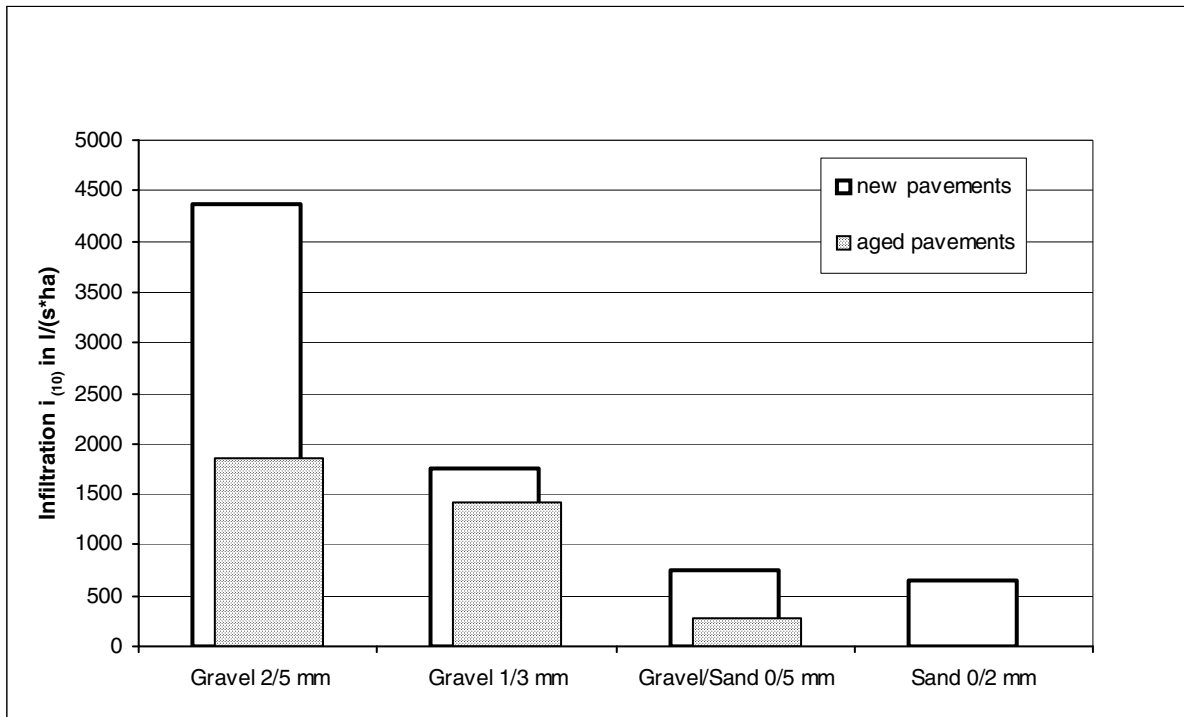


Figure 4. Infiltration performance in relation to different aggregates for joint fillings

Figure 4 shows that aggregates with a coarse particle size exhibit a higher infiltration rate $i_{(10)}$ than others with fine grained aggregates unconcerned that the testing area was new or aged. The tested gravel 2/5 mm for example has an infiltration rate of 4300 l/(s×ha) in new condition respectively 1900 l/(s×ha) which is far beyond normal storm intensities.

2.3.2 Influence of openings ratio

The research of Borgwardt (1995) and Breuste et al. (1996) states that a correlation between openings ratio and infiltration rate is not valid in the aged condition. A high percentage of openings is thus only an indicator for a good infiltration, if the fines content is at the same time low. Is the clogging over the years in progress, the permeability of the pores is affected unattached from the openings ratio.

New permeable pavements with openings fillings of crushed gravel 2/5 mm view at least a significant increase of the infiltration rate with advancing openings ratio and a relative high performance with 10 % or more openings ratio (Fig. 5).

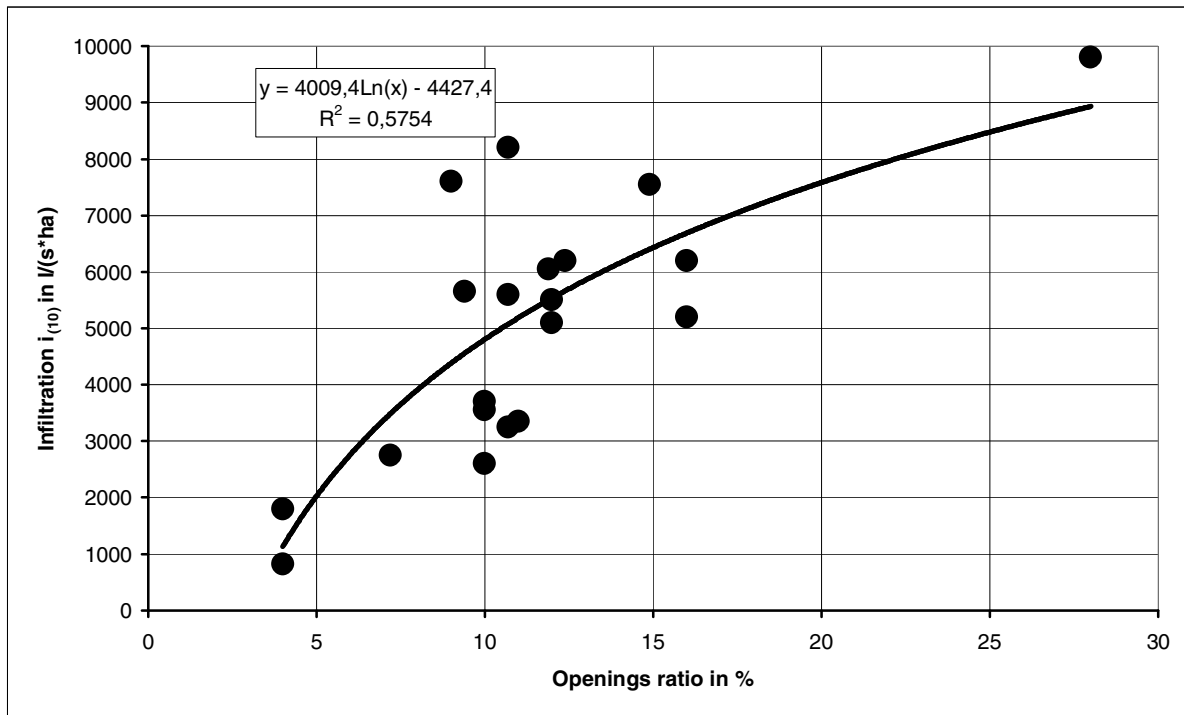


Figure 5. Infiltration performance in relation to openings ratio with new permeable CBP

2.3.3 Influence of aging

The influence of aging – which means increasing clogging of the joints and openings – on the infiltration performance is verified by the infiltration-meter tests with a sample size of 80 testing areas. Figure 6 shows the results with the different kinds of permeable CBP in various age groups. A characteristic aging process is shown by a typical example of a paving block with openings, average openings ratio of 11.9 % and a joint filling with crushed gravel 2/5 mm. The infiltration rate in new condition is about 5000 l/(s×ha) and decreases in the period under review of 10 years to app. 1300 l/(s×ha) (Fig. 7).

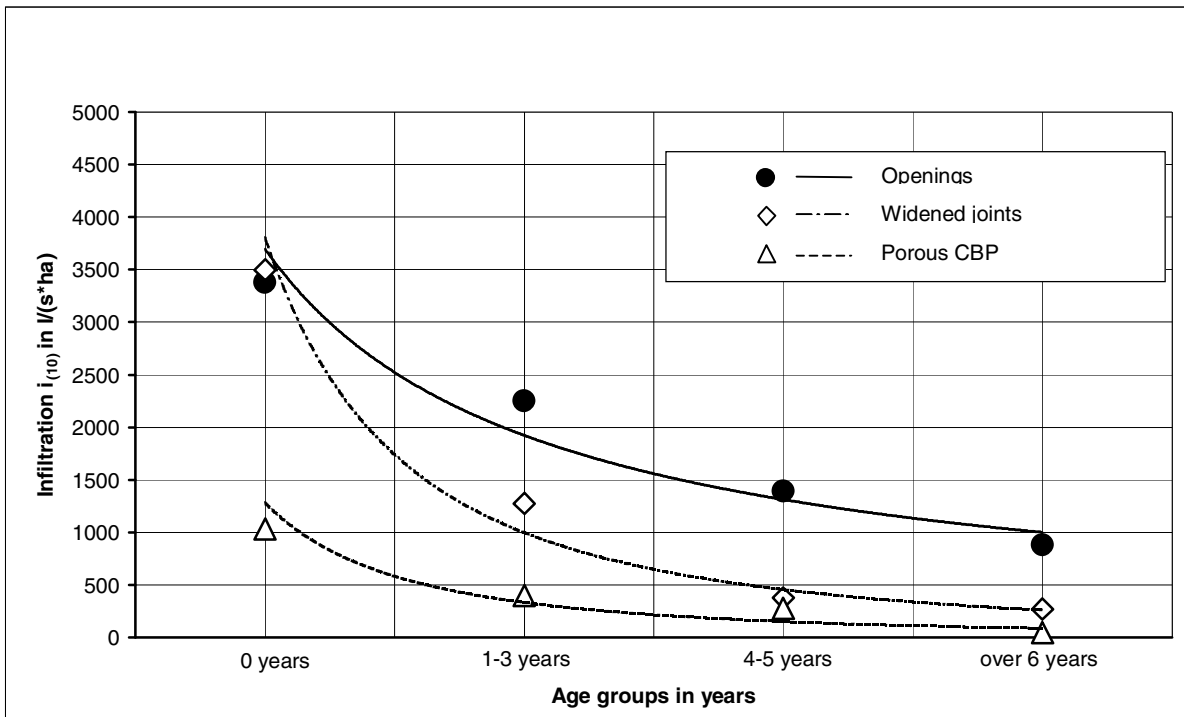


Figure 6. Infiltration performance in relation to age groups of different permeable CBP

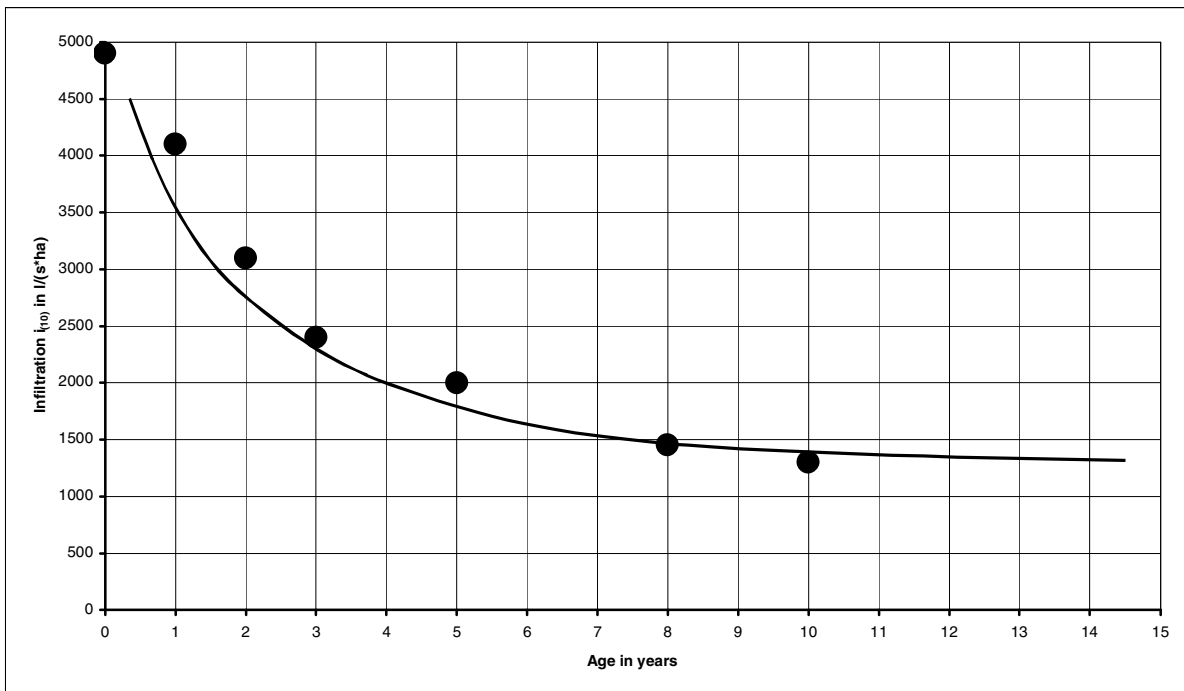


Figure 7. Aging process with a typical example

3. EVALUATION

The analysis of the infiltration tests leads to the following conclusions:

- (1) The infiltration performance is highly affected by the age of the pavement because of the entrainment of mineral and organic fines in the upper 20 mm of joint fillings or the pores of porous paving blocks. An overall trend of the infiltration performance during the service life of a permeable pavement allows constructing the hypothesis of a decrease to 10 to 25 % of its original output power (Fig. 8).
- (2) Permeable pavements are able in new and partly in aged condition to infiltrate storms that normally are beyond the rainfall measures for the hydraulic design of road drainage systems. The verification for the whole service life is at the moment not finally clarified.
- (3) This leads to the recommendation for a runoff coefficient of 0.3 to 0.5 for permeable CBP during the whole service life compared with non-permeable CBP with 0.8 (Borgwardt 1994).
- (4) A significant correlation between infiltration performance and permeability of the aggregates of joint fillings is given. Aggregates with a coarse particle size exhibit a higher infiltration than others with fine grained aggregates.
- (5) There is only a limited correlation between the infiltration performance and the openings ratio. A mathematical calculation of the actual infiltration performance because of permeability-coefficient and opening ratio is not acceptable. For that reason the openings ratio of permeable CBP is not as important as the selection of highly permeable aggregates for the joint filling.
- (6) The overall variance of all results leads to the conclusion that the infiltration performance of permeable CBP depends in the first place on the quality of the aggregates for the joint filling and mainly on the quality of the construction execution.

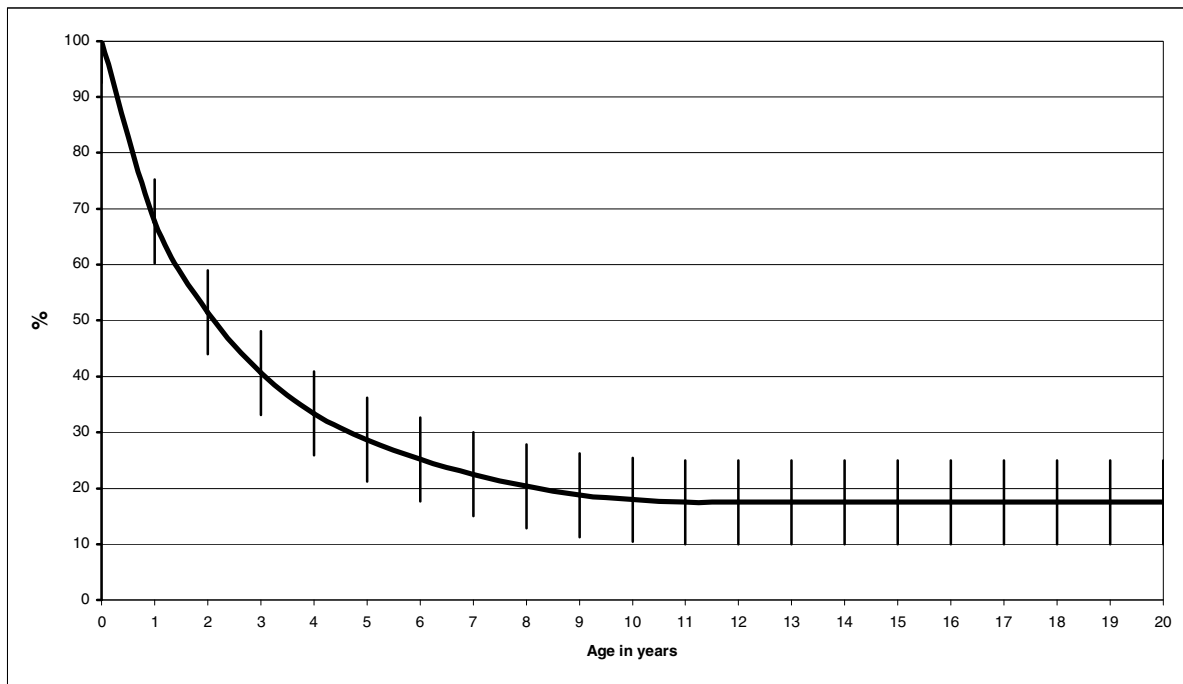


Figure 8. Overall trend of the infiltration performance

For the adequate implementation of permeable concrete block pavements it is vital that besides the hydraulic performance the structural requirements have to be matched at the same time (Borgwardt, Gerlach and Koehler 2000). This means in the first place a pavement design with a view to traffic

loads and frequencies In addition amongst others the assessment of legal requirements, suitable locations, pavement design considerations and maintaining a proper drainage has to be considered. Long lasting experience with the practical application of permeable CBP (Borgwardt, Gerlach and Koehler, 2000) leads to the knowledge that – under the consideration of the precondition of a lasting structural function – only the adequate choice of hydraulic effective aggregates and the accurate installation of the whole pavement in a monitored building process guides to a long-term performance with a durable high-level infiltration rate for a low surface runoff and consequently a important part for a sustainable and environmental useful management of affordable drainage and sewer systems.

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