IN-SITU INFILTRATION PERFORMANCE OF PERMEABLE CONCRETE BLOCK PAVEMENT – NEW RESULTS

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ABSTRACT

Since it is a design criterion for road drainage and sewer systems, the long-term infiltration performance of permeable interlocking concrete pavement (PICP) is of important significance during the service life of a road construction. New permeable pavements can regularly accommodate all rainfall intensities. However, due to the entrainment of mineral and organic fines into the aggregates used in joints or openings, the decrease of surface infiltration rates can be assumed. Research shows that the infiltration performance decreases significantly after a few years, but still infiltrates rainfall and runoff from high intensity storms.

In-situ field tests with a special infiltration-meter confirm these results. 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. Continuously repetition of these tests allow the observation of the long-term performance. After reviewing many sites of various ages, the reduction of surface infiltration over time is determined and an approximate correlation is developed.

This investigation presents new results from the last years of numerous testing sites for the first time and tries to initiate a discussion of a simple model that predicts the decreasing process of PICP infiltration performance over its service life.

KEYWORDS:

Permeable Pavements, Permeable Interlocking Concrete Pavement, Infiltration-meter Testing, Infiltration Performance, Influence of Aging, Clogging, Modelling the Infiltration Process, Stormwater Runoff Coefficient, Pavement Design

1 Introduction

For sustainable stormwater management the long-term infiltration performance of permeable pavements with PICP is the critical key factor for the reduction of surface runoff.

The modelling of process and behavior of the infiltration over the service years and the reliable prediction of the final and enduring infiltration value leads to accurate preliminary hydraulic determination for civil engineers (Yong and Deletic, 2012).

Research results of infiltration performance decrease in relation of the age of a PICP pavement because of clogging were published at the 8th International Conference on Concrete Block Paving in San Francisco (Borgwardt, 2006) and since then confirmed by numerous studies (Beeldens *et al.*, 2009; Pezzaniti *et al.*, 2009; Lucke and Beecham, 2011; Fassmann and Blackbourne, 2010; Boogard *et al.*, 2014).

With this paper, these studies are expanded, revised and updated by a database of a total 204 testing samples. In addition, a simple model that predicts the decreasing process of PICP infiltration performance over its service life is introduced.

2 Methods

While laboratory-based testing with simulated sediment accumulation and simulated rainfall intensities in order to provide timely results lead regularly to significantly higher and unrealistic infiltration rates than in field-based studies (Nichols *et al.*, 2015), in-situ field methods are preferred in this study.

To provide reliable and reproducible infiltration conditions, the infiltration-meter introduced in Borgwardt (2006) is used in this investigation. The results demonstrate that this equipment is effective in simulating actual rainfall events and the most accurate method (Borgwardt, 1998; Lucke *et al.*, 2013). Moreover, it includes the possibility of testing in realistic trafficked situations and allowing continuously repeated testing to observe the long-term performance at the same test location. Similar testing procedures are evaluated by Beeldens et al. (2009), Smith et al. (2011), Lucke et al. (2013), Nichols et al. (2014) and in Germany established in the *Guidelines for Permeable Pavements in Road Construction* (FGSV, 2013).

The basic scheme of the infiltration-meter is that a sealed single ring testing area of about 0.25 m^2 is homogeneously distributed with a constant intense model precipitation by a sprinkler container connected to a reservoir or a water connection (**Fig. 1**). The precipitation intensity is chosen for a minimal water level within the sealed testing area to prevent unrealistic vertical water pressure heads. A float switch in the testing area connected to a magnetic valve, which limits the water level within a few millimeters, controls the water level. An additional irrigation outside of the testing area prevents horizontal movement of the infiltrated precipitation. A flow meter records the infiltration by the change of flow. 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.

Fig. 1. Infiltration-meter

The testing results as an infiltration rate are shown of at least three measurements as regression curves of the averaged infiltration values in millimeters per minute [mm/min] or liter per second and hectare [l/(s × ha)]. This 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. 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 a infiltration in water-saturated conditions and can therefore construed as a permeability coefficient k in meters per second [m/s].

Based on the results and conclusions of Borgwardt (2006), this investigation includes additional 204 test locations. The tested pavements consist of installed PICP with widened joints, drainage openings (**Fig. 2**) and of porous paving blocks (**Fig. 3**) in traffic areas like roads, carparks or pedestrian areas. To allow the comparison of characteristic attributes the parameters $i_{(60)}$ and $i_{(10)}$ of the samples are divided in clusters of age, openings filling material and openings ratio (regardless if the openings are provided by widened joints or different openings, because the results show no difference in infiltration due to the layout of the openings.). They have a heterogeneous variability of site-specific and environmental influences and therefore cannot provide statistically applicable results like with continuous experimental testing scale conditions. However, the edited raw data is valuable for an extended and more accurate assessment of the long-term infiltration process of PICP.

To compare the accumulated results and to develop a simple model that predicts the decreasing process of PICP infiltration performance over its service life the achieved infiltration rates of PICP with widened joints and drainage openings are converted to percent openings ratio (to this reason, here porous paving blocks are excluded) and then processed further.

3 Results and Discussion

As stated in Borgwardt (2006) the long-term infiltration performance of PICP is highly affected by the age of the pavement because of the entrainment of mineral and organic fines in upper 20 mm of joint or openings filling or the pores of porous paving blocks. Illgen (2008), Lucke and Beecham (2011), Yong and Deletic (2012) verify the effect of clogging. This leads the hypothesis to a reduction of a minimum value between 10 and 25 % of its original infiltration performance during the service life of a permeable pavement. Beeldens et al. (2009), Pezzaniti et al. (2009), Fassmann and Blackbourne (2010) and Boogard et al. (2014) observe similar reductions.

The overall examination of all data – regardless of openings ratio or openings filling material – shows in **Figure 4** the degression of infiltration by different age groups. In extension to previous experience and as a spin-off the comparison of PICP and porous paving block (joint filling material sand 0/2 and 0/5 mm) delivers no evidence of significant difference (**Fig. 5**).

Furthermore, the results still show that aggregates with a coarse particle size exhibit a higher infiltration than others do with fine-grained aggregates (**Fig. 6**). With the added new examples for this investigation, the now higher results can be explained by tendentially higher opening ratios, the more competent usage of aggregates and improved building skills over the last decade.

To compare the infiltration performance of PICP with different openings ratio, the data of the samples are class-divided into the three different openings filling materials with aggregate size 2 to 5 mm, 1 to 3 mm and 0 to 2 mm. Then the results are converted into infiltration per percentage openings ratio. This allows a general comparison and an extrapolation to a given openings ratio.

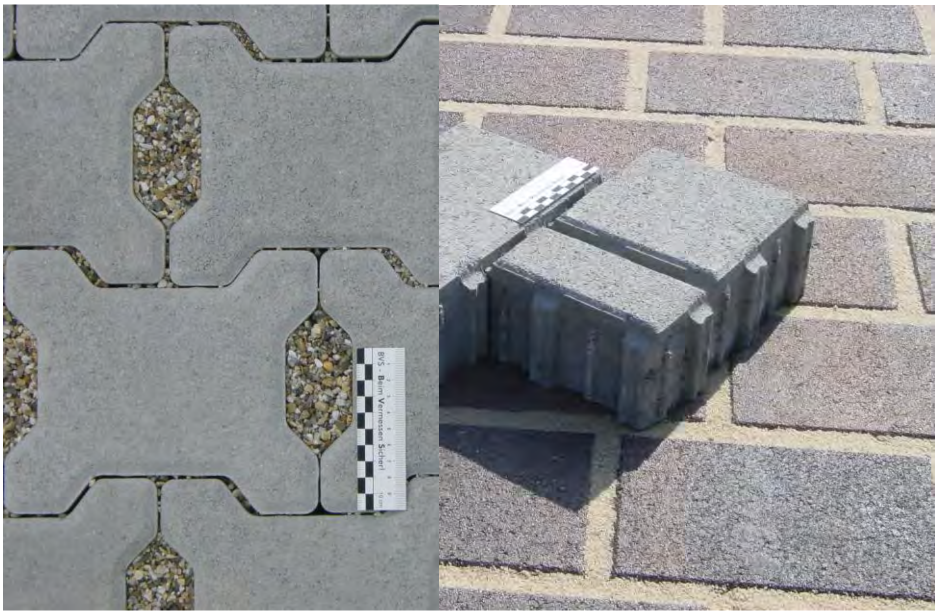

Fig 2. Example for PICP with widened joints and drainage openings

Fig. 3. Example for porous paving block

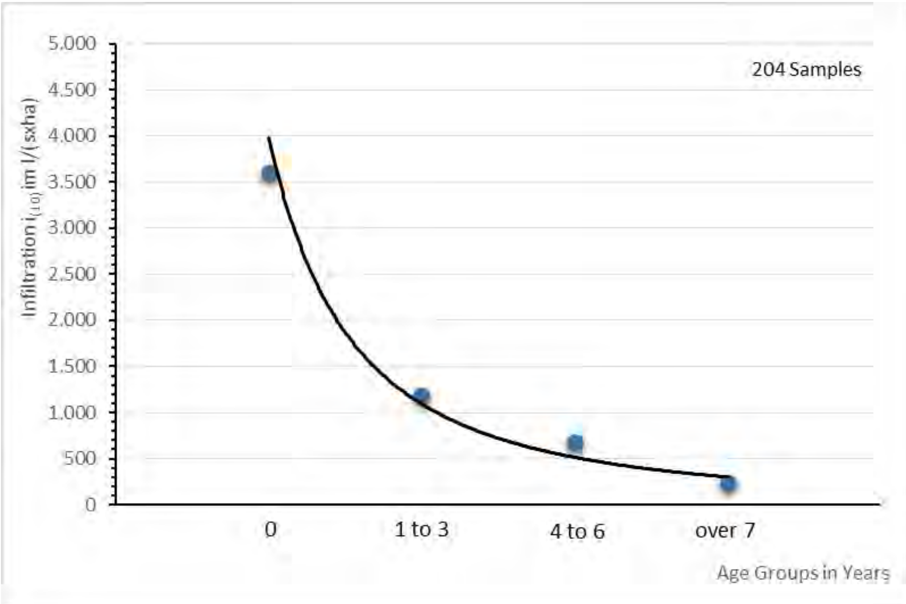

Fig. 4. Infiltration performance by different age groups

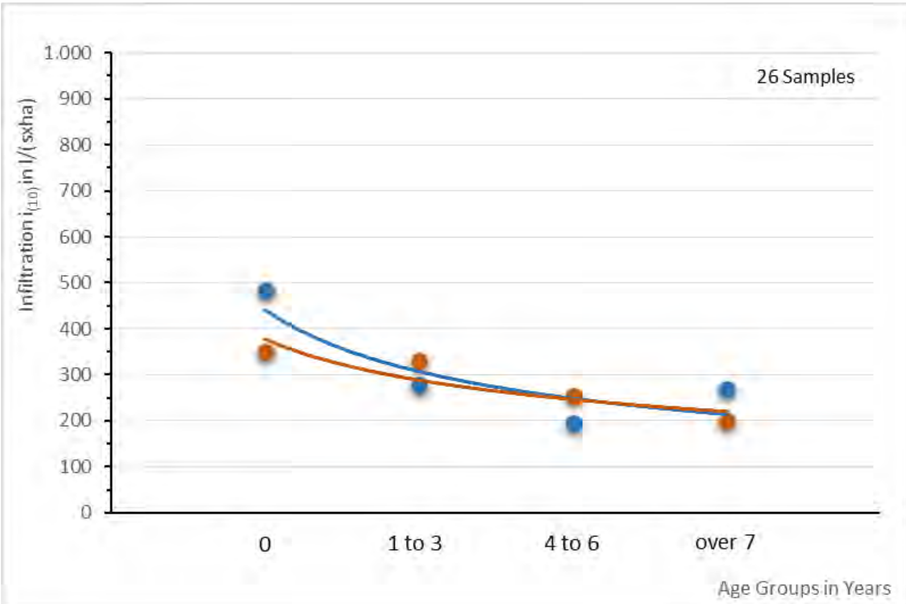

Fig. 5. Comparison of infiltration progress of PICP and porous paving blocks

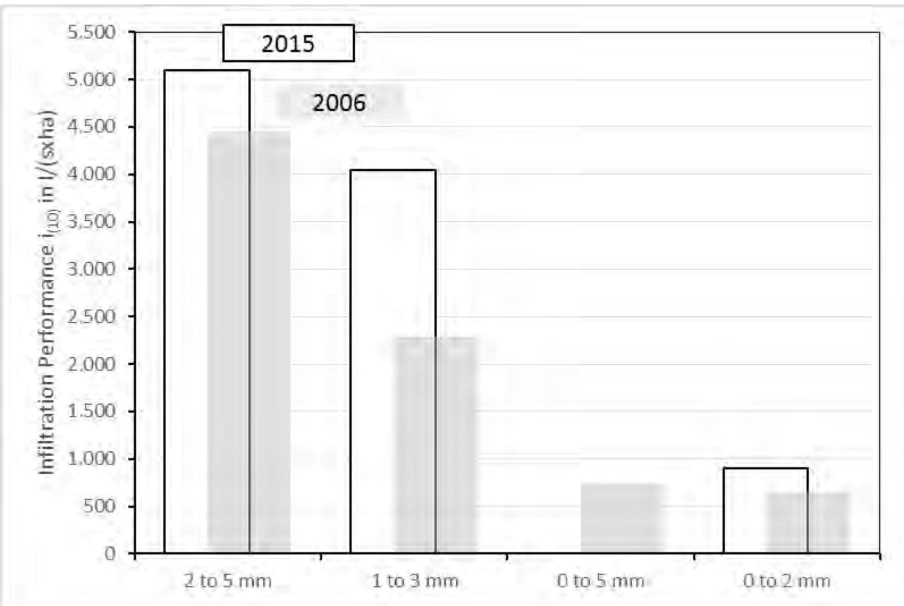

Fig. 6. Infiltration performance of different aggregates for openings fillings (in comparison to Borgwardt, 2006)

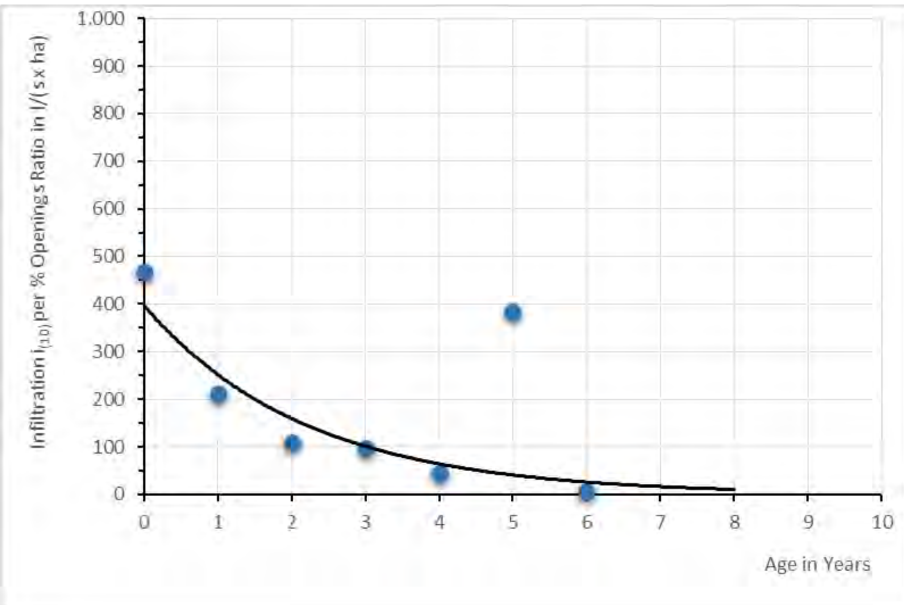

Fig. 7. Infiltration progress of PICP with openings filling material 2 to 5 mm

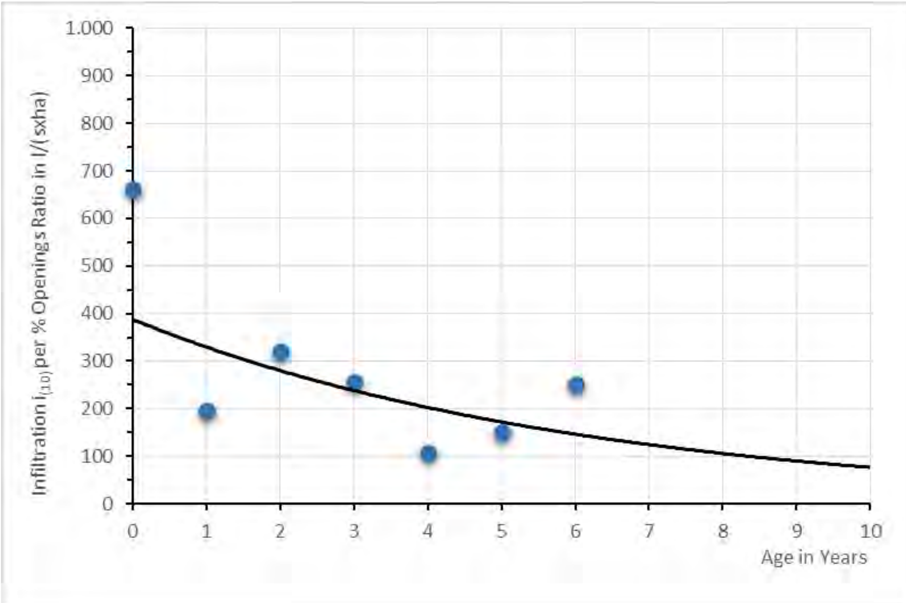

Fig. 8. Infiltration progress of PICP with openings filling material 1 to 3 mm

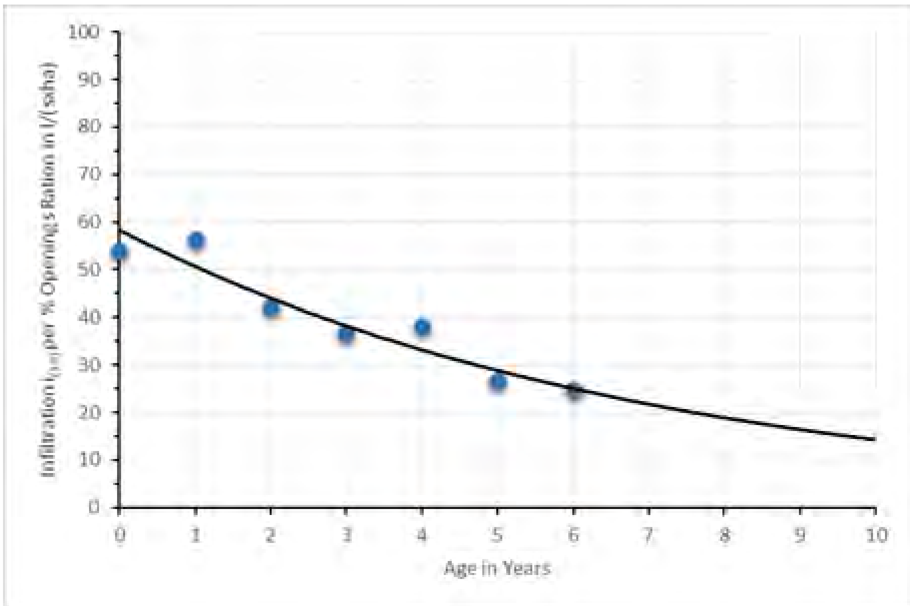

Fig. 9. Infiltration progress of PICP with openings filling material 0 to 2 mm

PICP with openings filling materials with aggregate size 2 to 5 mm show a infiltration performance $i_{(10)}$ per percentage openings ratio of about 400 l/(s × ha) or 198 mm/h in new condition and decreases in the period under review of 6 years to app. 40 l/(s × ha) or 14 mm/h (**Fig. 7**). The respective results for aggregate size 1 to 3 mm and 0 to 2 mm are in **Fig. 8** and **9**.

To develop a simple model that predicts the decreasing process of PICP infiltration performance over its service life a power regression of the infiltration progress in relation to the age is introduced. It is bases on the presented infiltration rates $i_{(10)}$ in l/(s × ha) of 204 test locations and is provided with an empiric observed range of approximated ±20 % for new condition and +25 % and -20 % for final condition because of the variability of the achieved infiltration rates (**Tab. 1**). To verify the validity of this approach, the correlation between infiltration rate and openings ratio is tested and shown in **Fig. 10 to 12**.

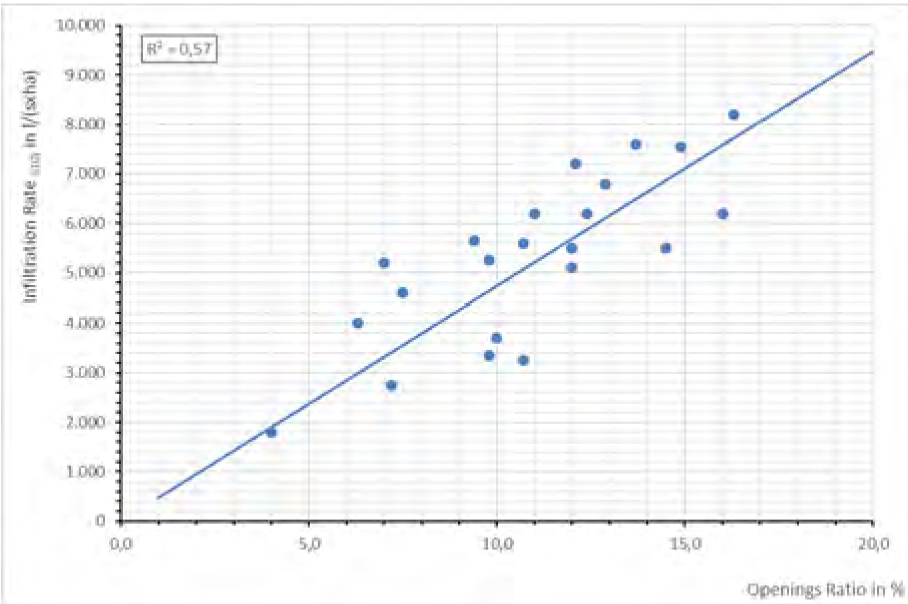

Fig. 10. Correlation of **i**nfiltration performance and openings ratio of PICP with openings filling material 2 to 5 mm

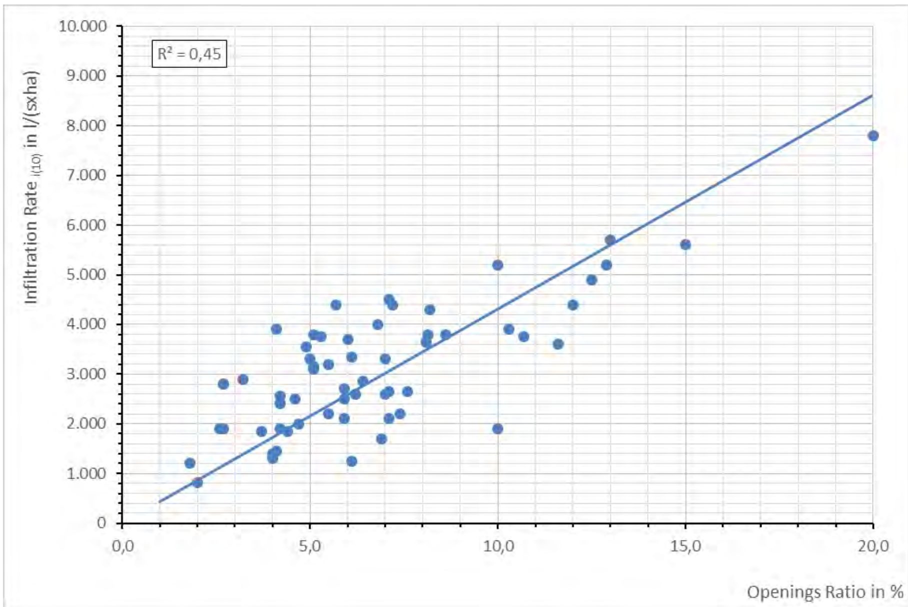

Fig. 11. Correlation of **i**nfiltration performance and openings ratio of PICP with openings filling material 1 to 3 mm

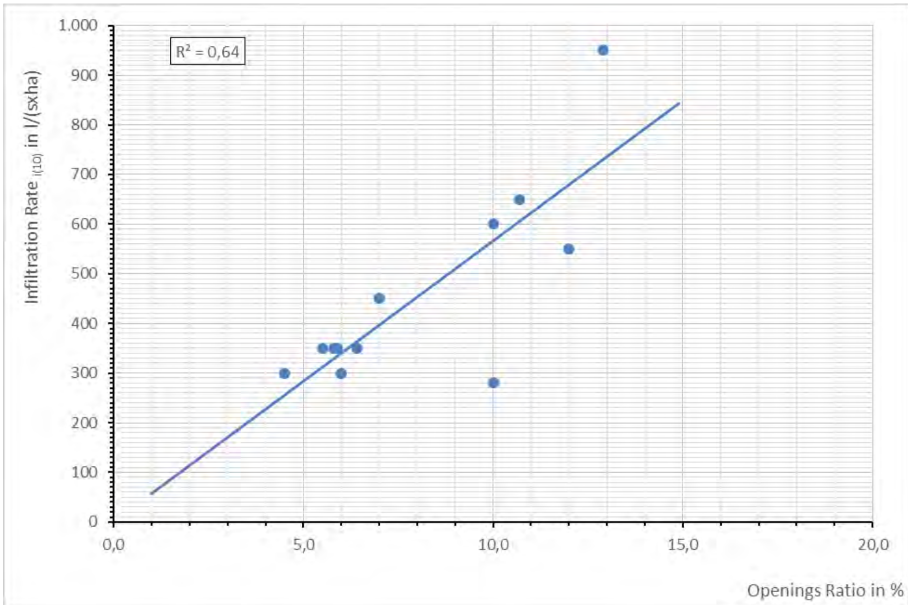

Fig. 12. Correlation of **i**nfiltration performance and openings ratio of PICP with openings filling material 0 to 2 mm

Tab. 1. Infiltration performance per percentage openings ratio

Openings Filling Material	New Condition	Final Condition
Aggregate Size in mm	$i_{(10)}$ in l/(s × ha)	
2 to 5	600-400	150-40
1 to 3	480-320	120-30
0 to 2	70-50	20-5

The Infiltration Process Model of PICP features a distinctive range of infiltration performance $i_{(10)}$ per percentage openings ratio with a high value in new condition, power functional degression with an asymptotic approximation to an end value after 8 to 12 years.

With openings filling material 2 to 5 mm there is an infiltration rate per percentage openings ratio of 600 to 400 l/(s × ha) (216 to 144 mm/h) in new condition which decreases to an end value between 150 to 40 l/(s × ha) (54 to 14 mm/h) (**Fig. 13**)

The values for for aggregate size 1 to 3 mm are in the beginning with 480 to 320 l/(s × ha) (173 to 115 mm/h) per percentage openings ratio lower but the final infiltration seems to be similar to 2 to 5 mm aggregates (**Fig. 14**).

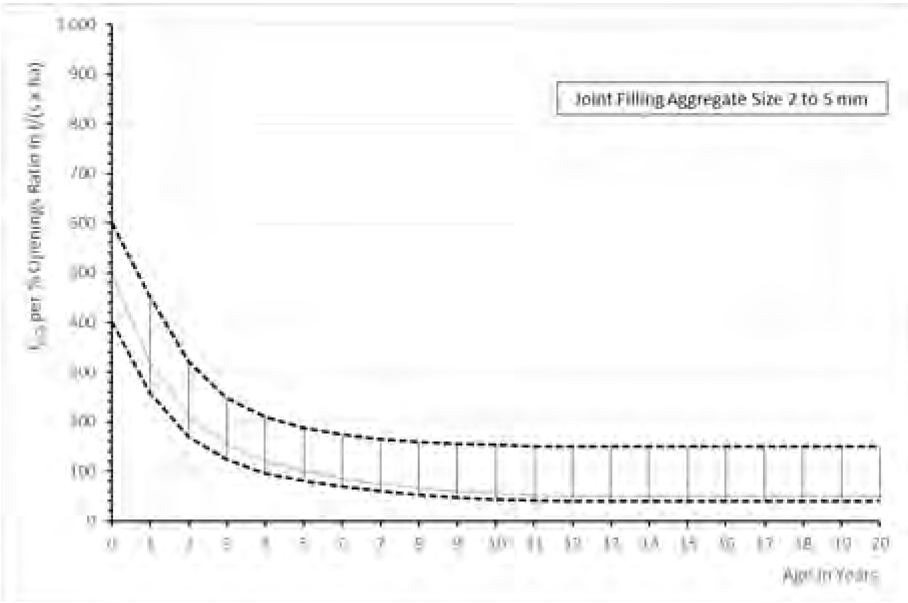

Fig. 13. Infiltration Process Model of PICP with openings filling material 2 to 5 mm

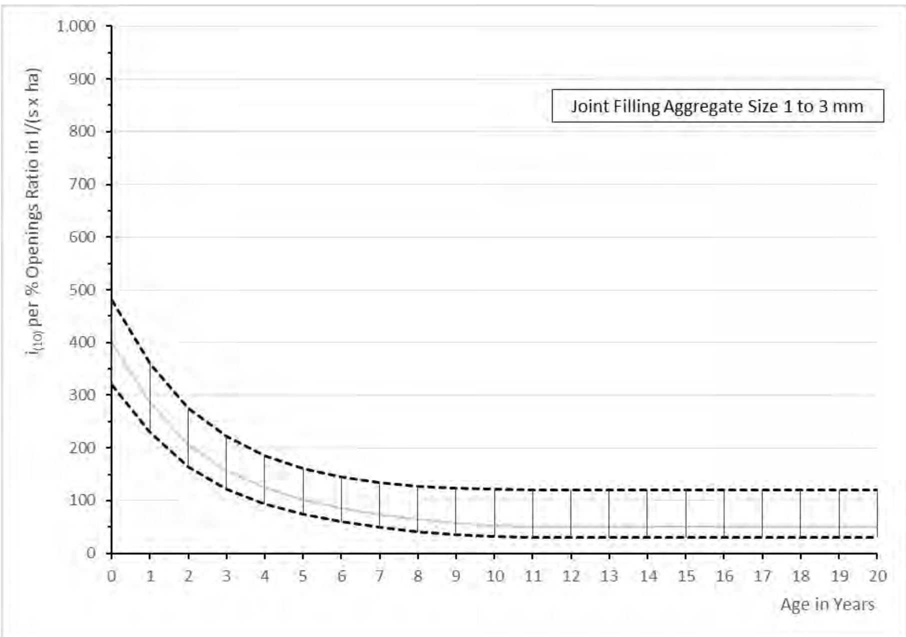

Fig. 14. Infiltration Process Model of PICP with openings filling material 1 to 3 mm

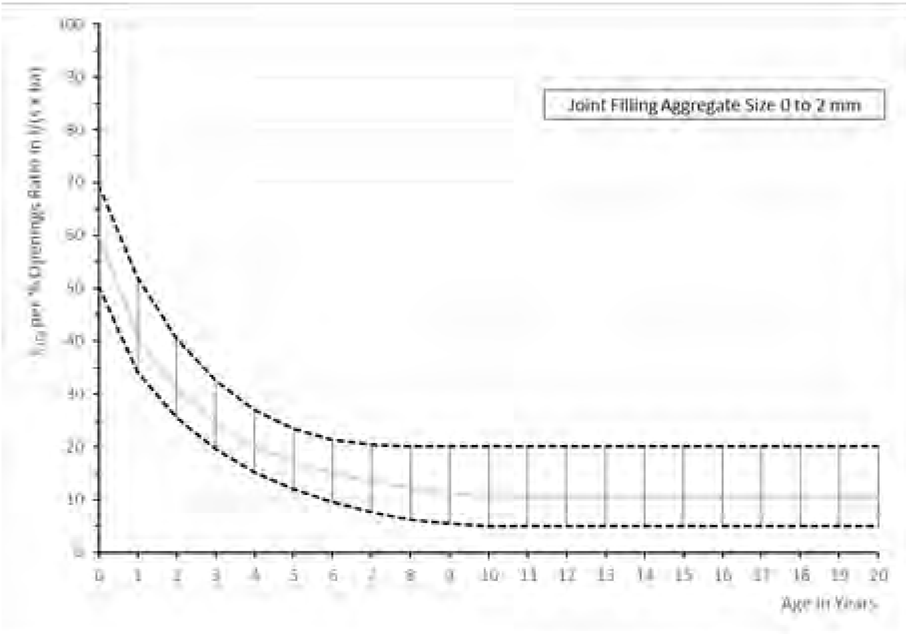

Fig. 15. Infiltration Process Model of PICP with openings filling material 0 to 2 mm

The infiltration capacity can vary significantly (Boogard *et al.*, 2014; Lucke and Beecham, 2011) and single location can have a different infiltration behavior (**Fig. 16**), mainly because of (Borgwardt *et al.*, 2000)

- in practice considerably varying permeability of joint filling material,
- partly poor construction work and
- very different intensity of maintenance.

To this conclusion, this model can now only be used as a rough approximation, within the openings filling's range of permeability of **Table 2** and has to be confirmed by field measurements with the actual pavement.

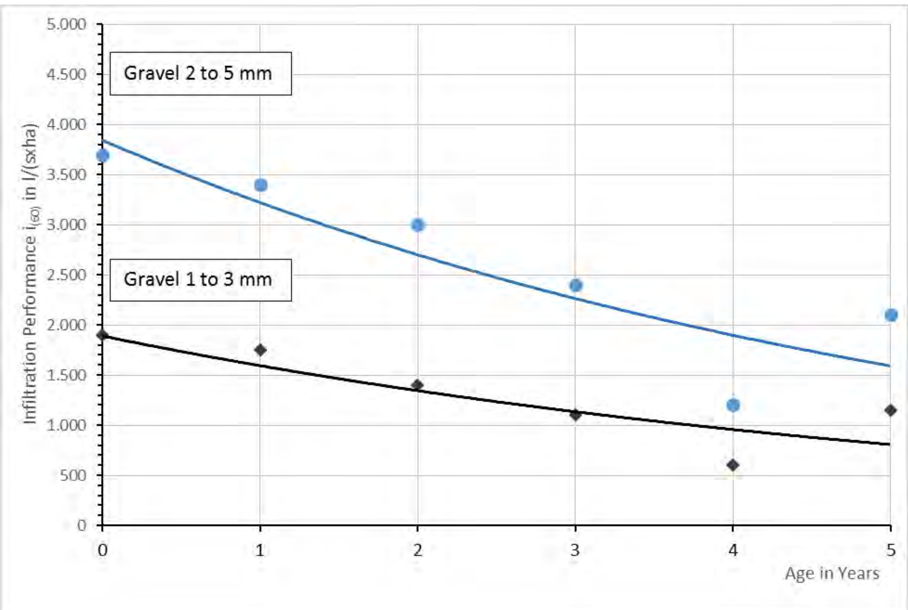

Fig. 16. Example of a variant aging process

Tab. 2. Permeability of aggregates for openings filling (after Borgwardt, 2006)

Particle Size	**k [m/s]**
2 to 5 mm	1×10^{-2} - 1×10^{-3}
1 to 3 mm	1×10^{-3} - 1×10^{-4}
0 to 2 mm	1×10^{-4} - 1×10^{-5}

PICP with aggregates 0 to 2 mm with a regularly poorer permeability start in new condition with infiltration rates per percentage openings ratio of 70 to 50 l/(s × ha) (25 to 18 mm/h) and end with 20 to 5 l/(s × ha) (7 to 2 mm/h).

The different extent of degression within the classes of openings filling material can be traced to the different range of permeability and supports the hypothesis of Nichols et al, 2015 of different clogging processes.

4 Conclusion

The infiltration process of pavements with PICP is highly affected by the age of the pavement because of the entrainment of mineral and organic sediments retained in the aggregated for openings fillings. The infiltration performance with newly built pavements depends consequently for one on the openings ratio and at the same time on the permeability of the aggregates used for the openings (Borgwardt, 2006).

At this, infiltration rates of new installed permeable pavements are not convincing for proper design. Instead, a clogging factor needs to be applied to the incremental clogging that occurs (Beecham *et al.*, 2009). This can lead to the recommendation for a general runoff coefficient, for example of 0.3 to 0.5 for PICP (Borgwardt, 1994).

With increasing age, the clogging process proceeds with the initial infiltration performance and leads to a decrease with an asymptotic approximation to the end value, which is regularly reached after 8 to 12 years and presents ultimately the reliable operand for the efficiency of PICP.

Based on the data of numerous test locations the accumulation in categories of openings filling materials and the conversion to the same openings ratio them helps to predict the infiltration process with the actual numbers for the infiltration rate and the empiric observed deviation in new and final condition.

This is a first model and therefore represents a rough approximation. Further investigation – especially under controlled test conditions – have to confirm and extent this model and all researchers concerned are invited to discuss the findings in this study.

Note

When Brian Shackel visited me his last time at the George Hotel in Hamburg, he encouraged me to publish this paper. Thanks!

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