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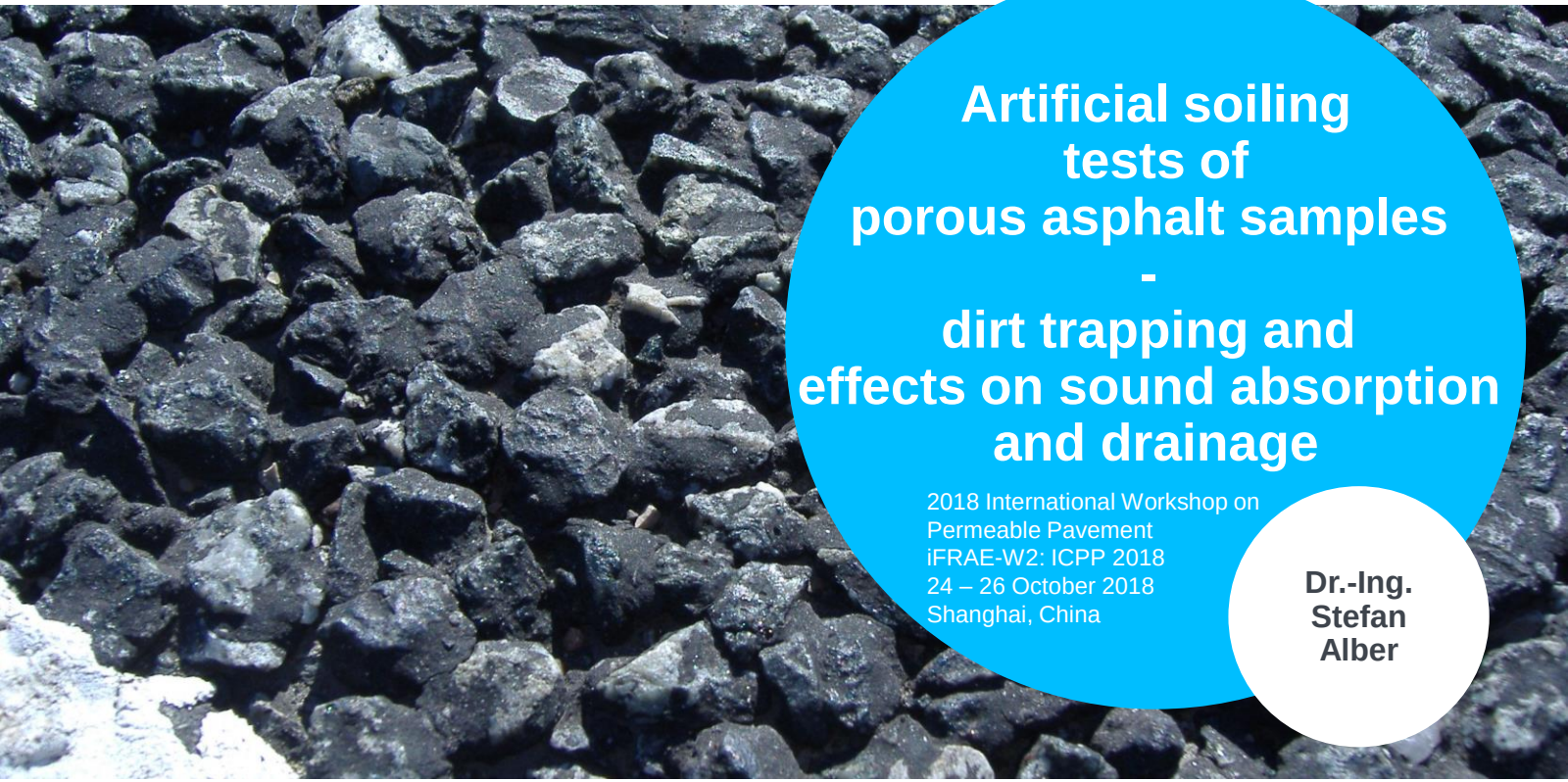
Institute für Road and Transport Science
Chair for Road Design and Construction



Artificial soiling tests of porous asphalt samples - dirt trapping and effects on sound absorption and drainage

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Abstract

Porous asphalt (PA) is an asphalt mixture with a very high void content. Therefore it has specific functional properties – especially concerning drainage and sound absorption.

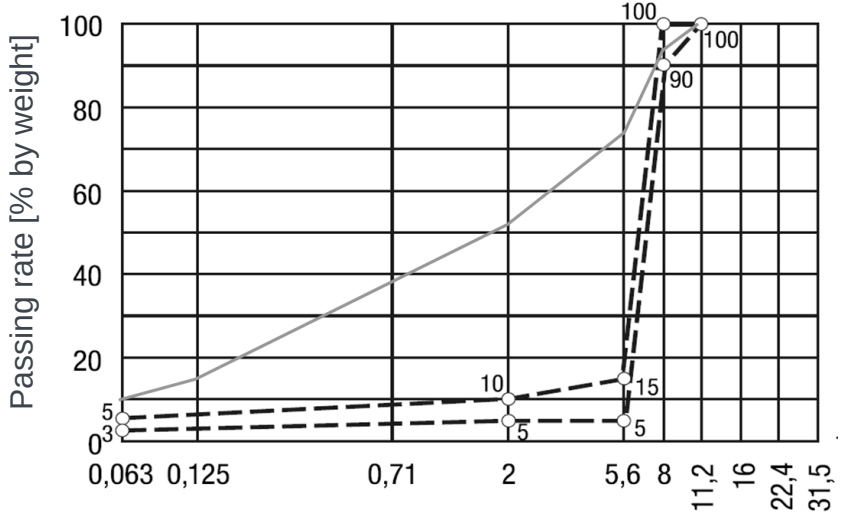
The high void content and the functional properties suffer from soiling. A soiling procedure using artificial rainfall in lab experiments has been applied on different PA structures regarding coarseness and layer thicknesses including twinlay concepts.

The retention of applied dirt particles is analyzed as well as effects on drainage and sound absorption behavior including air accessibility. Acoustical parameters describing the pore structure are back-calculated with sound absorption modeling.

The effect of PA soiling is an undesired effect which might be turned into an advantage if certain particles/contaminants could be trapped in the PA structure. Artificial soiling tests can deliver approaches for such analyses.

Introduction

- Porous asphalt (PA) is a special asphalt mixture with high inter-connected void content
  - Void content created by gap grading
  - 22 to 28 % (layer) according to German guidelines



Source (left picture/grading curve): Forschungsgesellschaft für Straßen- und Verkehrswesen (FGSV) (ed.): Technische Lieferbedingungen für Asphaltmischgut für den Bau von Verkehrsflächenbefestigungen – TL Asphalt-StB (free translation: German guidelines and terms of delivery for asphalt mixes) (2013) Ausgabe 2007/ Fassung 2013.

Introduction

- Porous asphalt (PA) is a special asphalt mixture with high inter-connected void content
  - Void content created by gap grading
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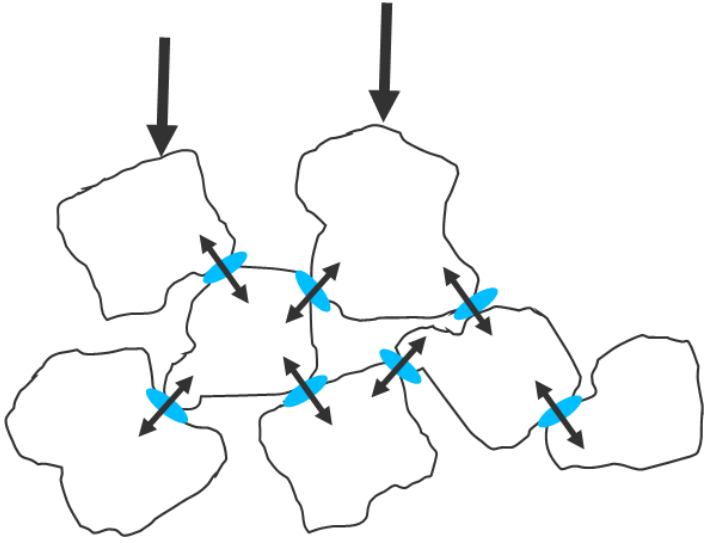
- **Special functional properties**
  - **Drainage**
  - Noise reduction
    - Reduction of aerodynamic noise-generating effects
    - **Sound absorption**
- …but also **special problems**

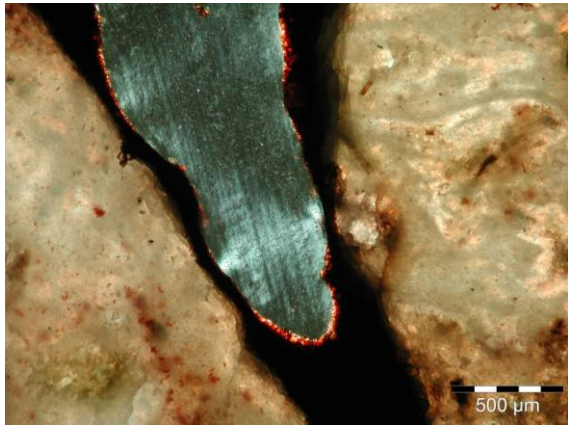
Introduction

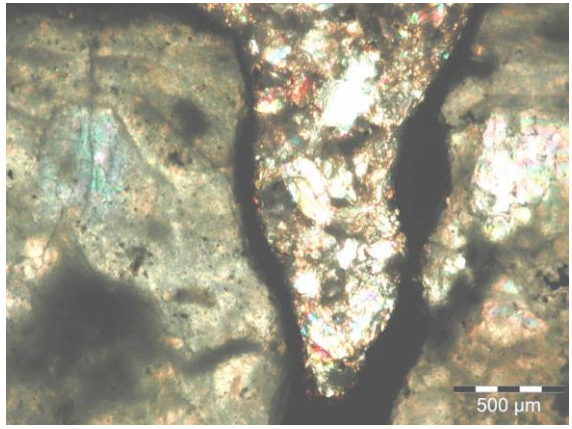
- Open-graded mix design is more susceptible to deterioration effects
- Increased ageing of binder by water and air infiltration
- Susceptibility to shear forces (braking, accelerating, cornering
  → Especially in urban traffic
- → Ravelling



Introduction

- Further problems in service
  - Winter maintenance (snow removal, snow chains, effectiveness of salt, temperature)
  - Drainage in built-up areas → usage of special gutters necessary
  - **Decreasing noise reduction capabilities**…
    - Because of raveling and the negative effects on surface texture
    - Because of **soiling and clogging effects**





Sources (picture): S. Alber, Veränderung des Schallabsorptionsverhaltens von offenporigen Asphalten durch Verschmutzung (Variation of sound absorption characteristics of porous asphalt due to clogging processes) (PhD thesis) German language, Veröffentlichungen des Instituts für Straßen- und Verkehrswesen, Universität Stuttgart, Heft 46 Stuttgart, 2013. http://dx.doi.org/10.18419/opus-489 .
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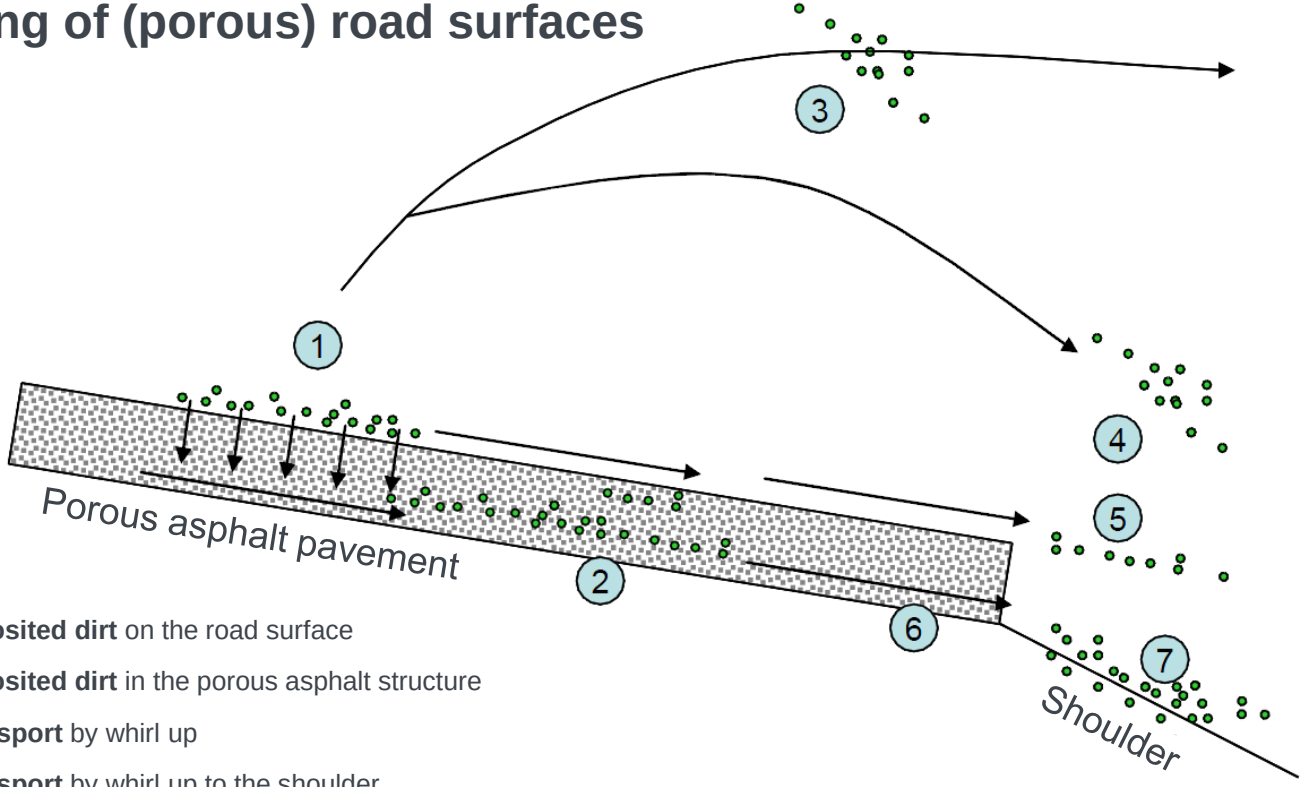
Soiling of (porous) road surfaces

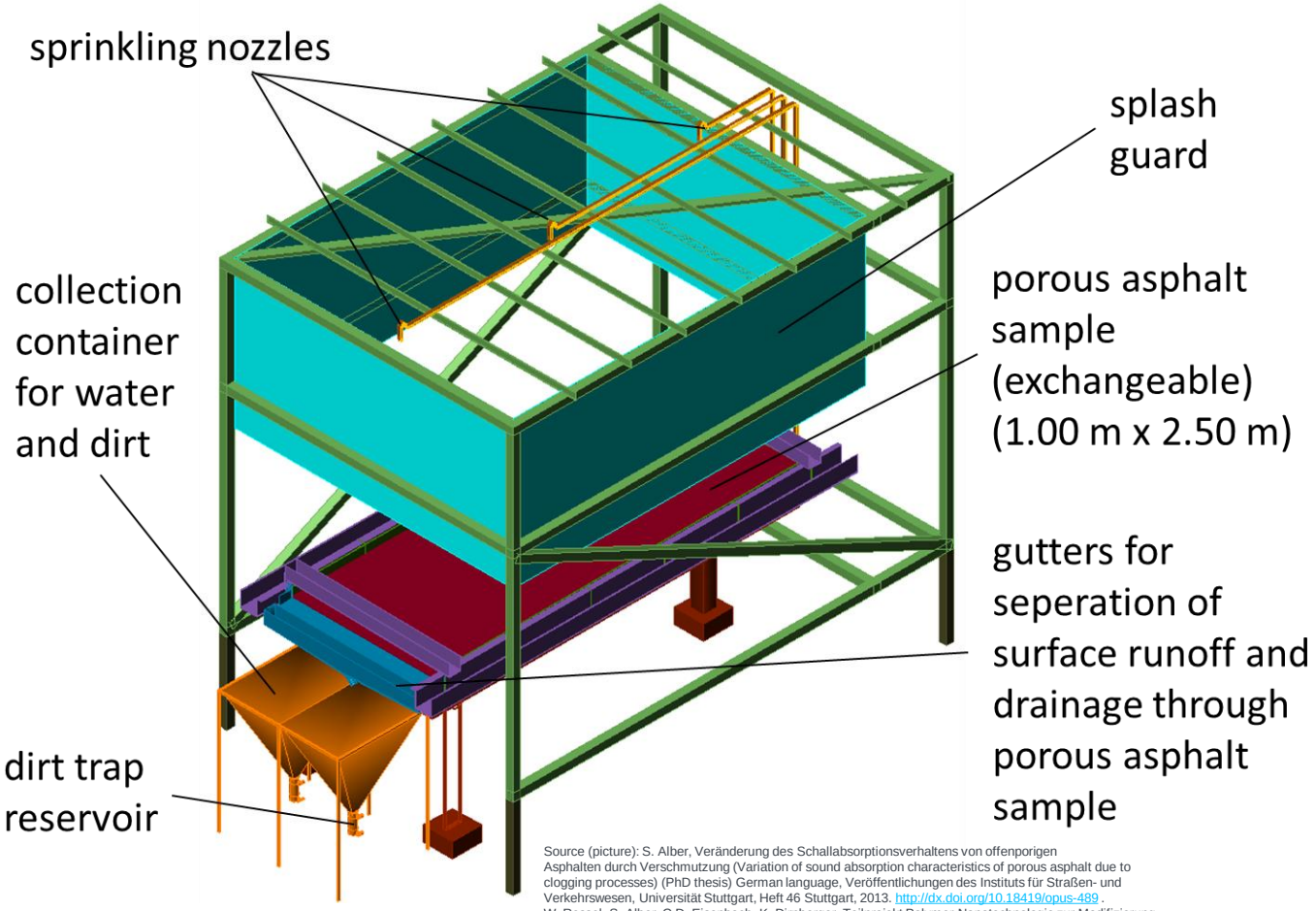


1. **Deposited dirt** on the road surface
2. **Deposited dirt** in the porous asphalt structure
3. **Transport** by whirl up
4. **Transport** by whirl up to the shoulder
5. **Transport** by rain on the surface to the shoulder (rather non-porous surfaces)
6. **Transport** through the porous structure
7. **Deposited dirt** on the shoulder

Source (picture): S. Alber, Veränderung des Schallabsorptionsverhaltens von offenporigen Asphalten durch Verschmutzung (Variation of sound absorption characteristics of porous asphalt due to clogging processes) (PhD thesis) German language, Veröffentlichungen des Instituts für Straßen- und Verkehrswesen, Universität Stuttgart, Heft 46 Stuttgart, 2013. http://dx.doi.org/10.18419/opus-489 .

„Typical road dirt“ composition

Experimental set-up for artificial soiling tests (AST)



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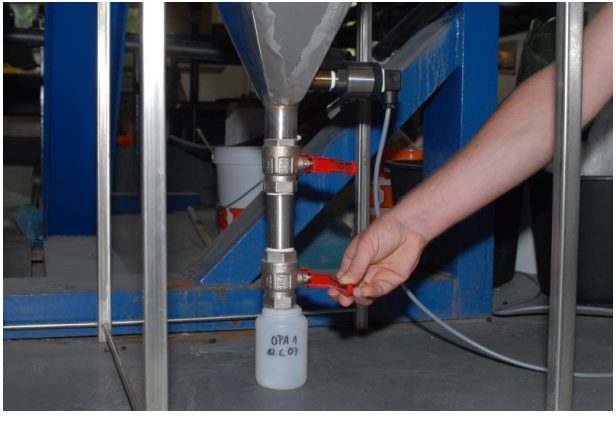
Experimental set-up for soiling experiments



Pictures partly also in: Alber, Stefan; Ressel, Wolfram; Liu, Pengfei; Wang, Dawei; Oeser, Markus (2018): Influence of soiling phenomena on air-void microstructure and acoustic performance of porous asphalt pavement. In: Construction and Building Materials 158, S. 938–948. DOI: 10.1016/j.conbuildmat.2017.10.069.

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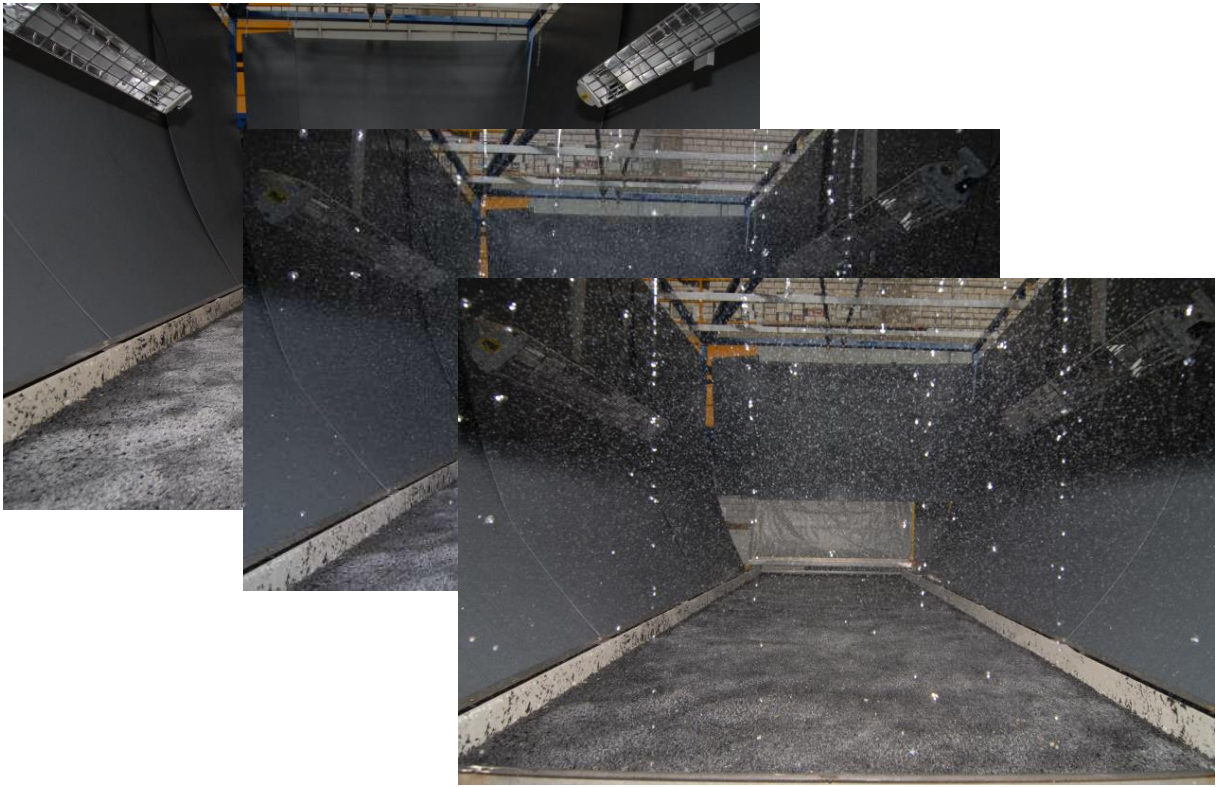

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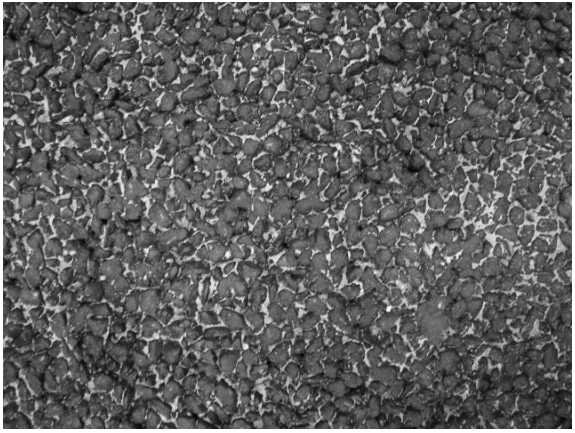
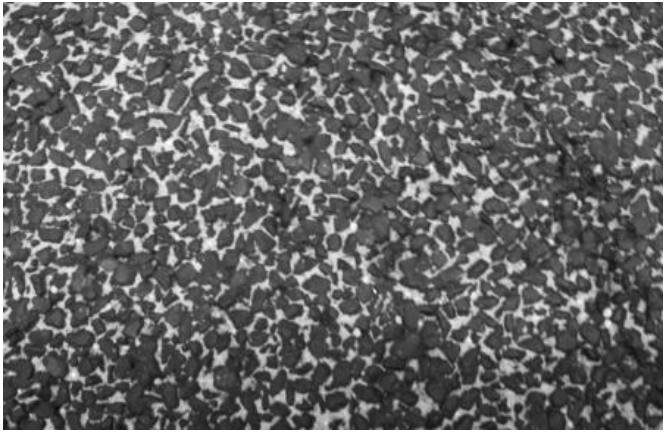
Soiling states

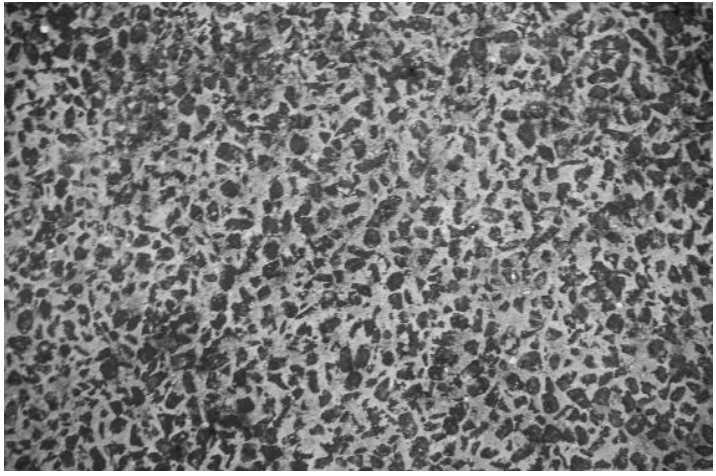
Repeated soiling procedure (9 to 10 repeatitions)



480 g/m²



960 g/m²



1440 g/m²

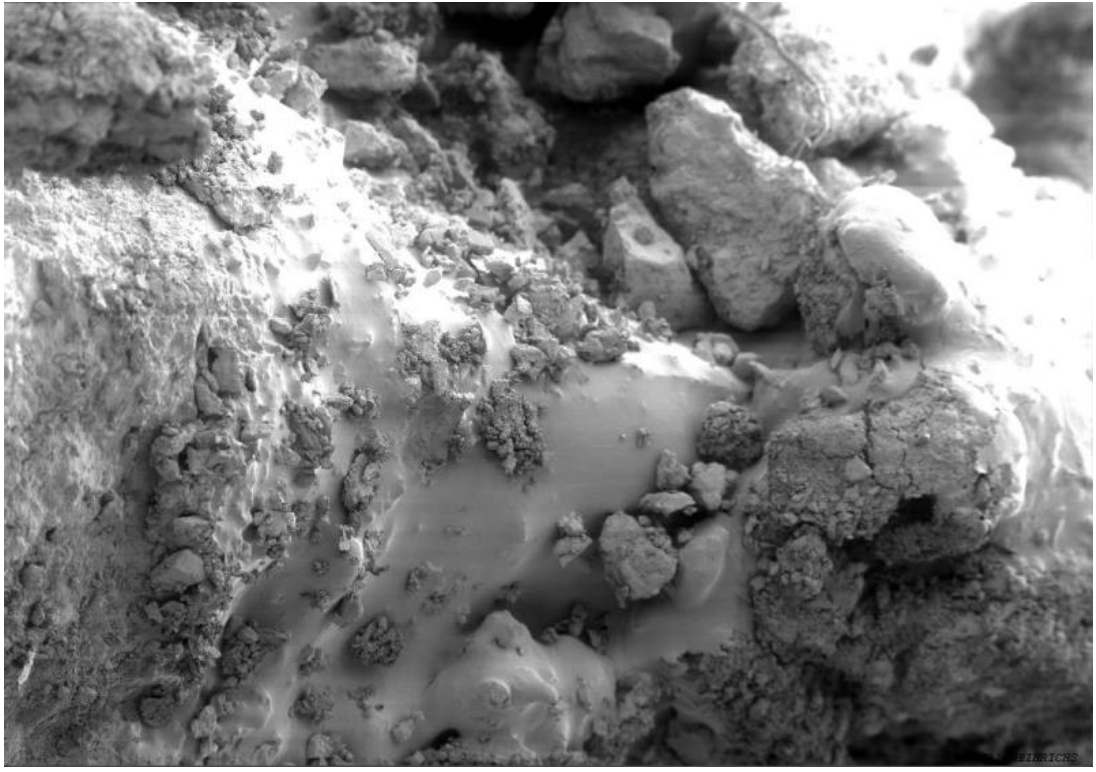
Soiling and clogging of porous asphalt (PA)

Mechanisms of soiling and clogging

- 1) Adhesion of particles to the pores‘ surface
  - Single particles
  - Agglomerations of dirt
  - Partly closely glued and connected to the bitumen film in the pores
  - Effect of agglomeration and clumping is increased by heat and probably salt (winter maintenance)
  - Effect of internal soiling
- 2) Constriction of pores/narrow pore channels
- 3) Partly clogging of narrow pore channels (while pores itself are not clogged yet)
- 4) Clogging of whole pores

Soiling and clogging of porous asphalt (PA)

Adhesion of dirt at the (bituminous) pores‘ surfaces



100 µm

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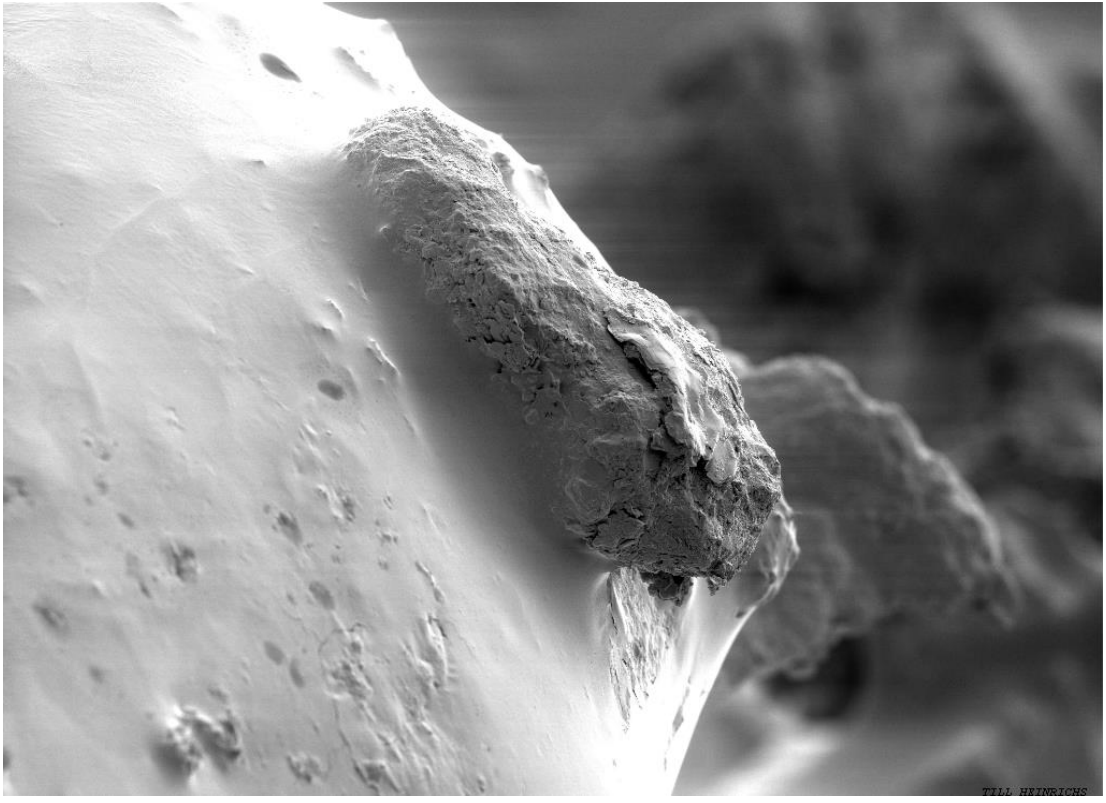
Soiling and clogging of porous asphalt (PA)

Glueing of dirt particles on bituminous film in a pore



10 µm

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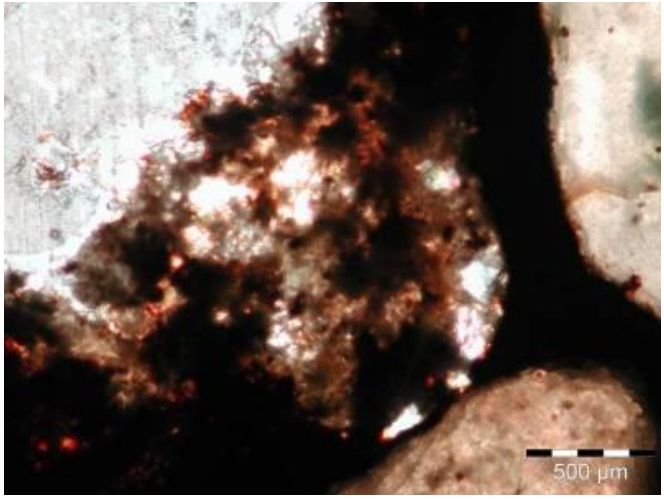
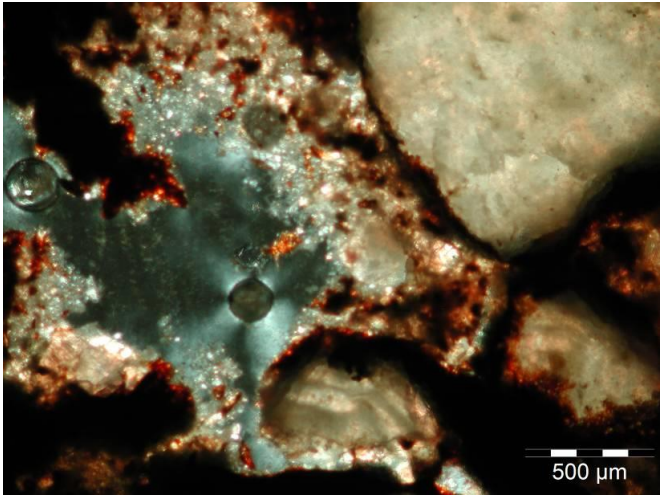
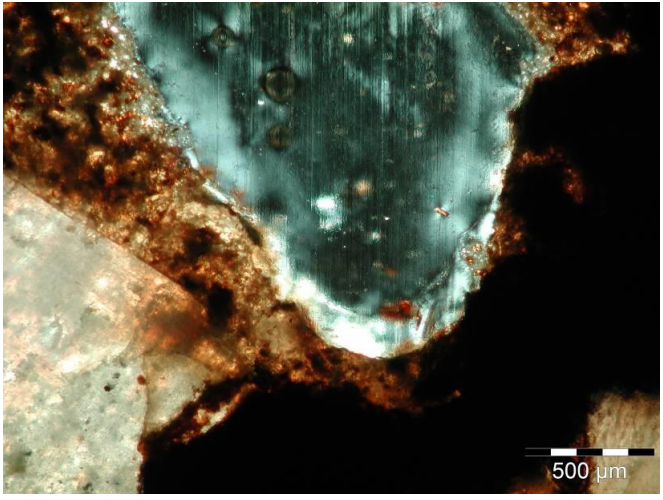




- Effect of internal soiling
- Filler and bituminous mortar particles (rather unbound)



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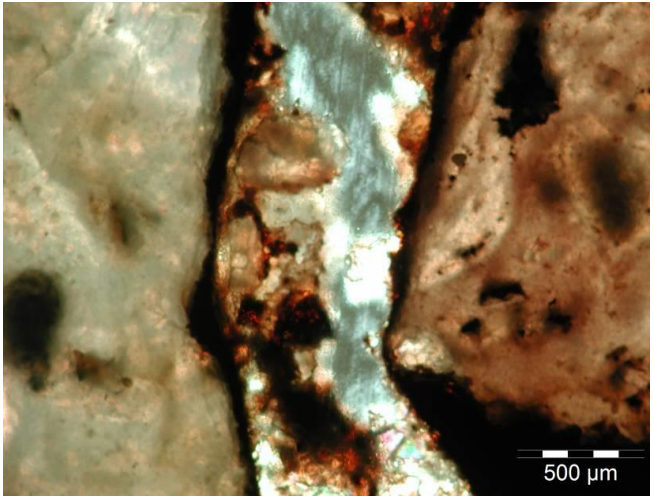
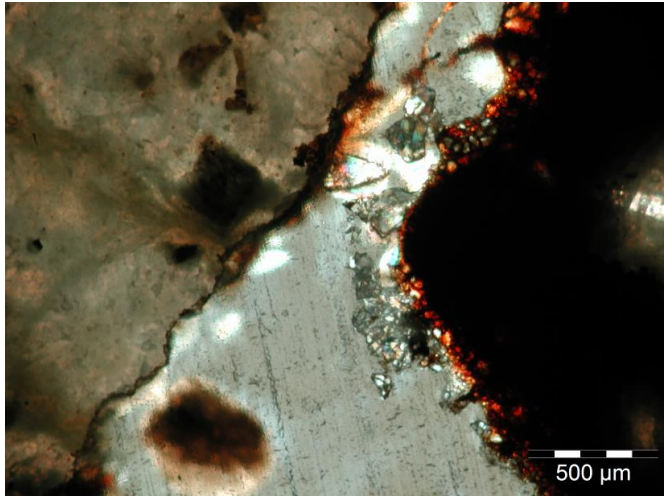
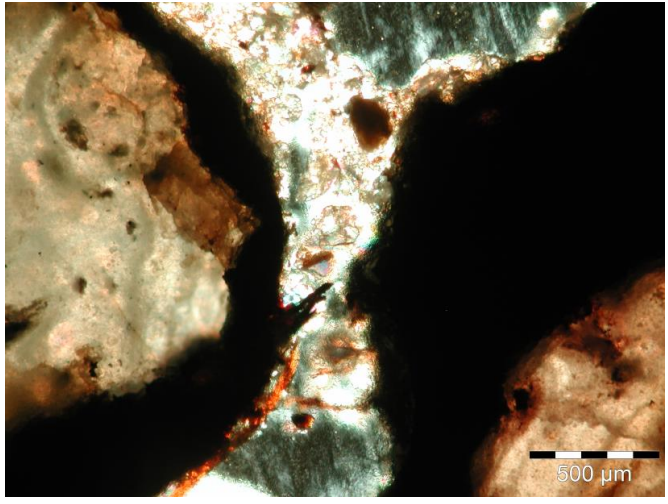




- **Constriction** of pores/narrow pore channels
- **Partly clogging** of narrow pore channels
- (while pores itself are not clogged yet)



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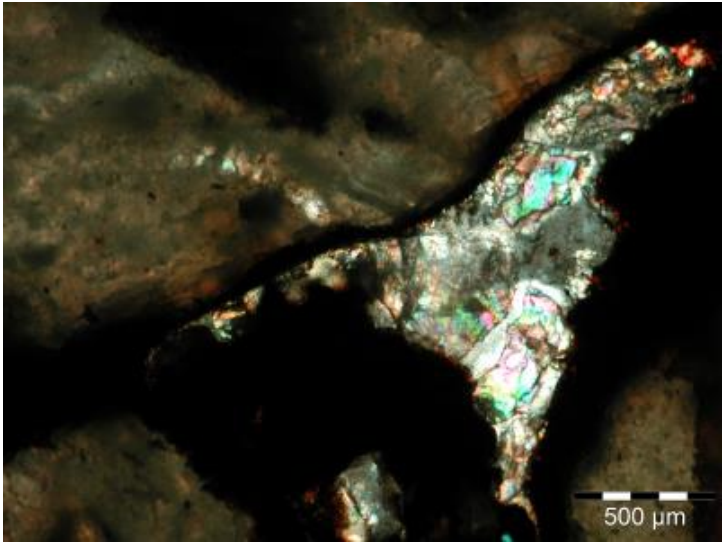
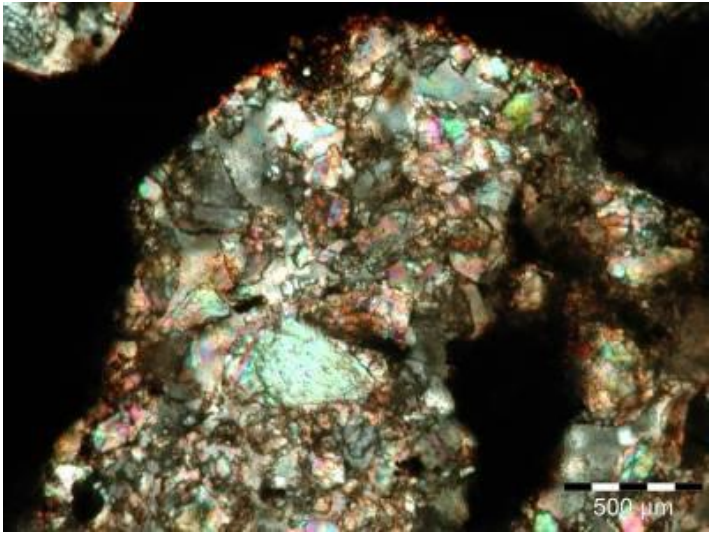


- **Clogging** of whole pores



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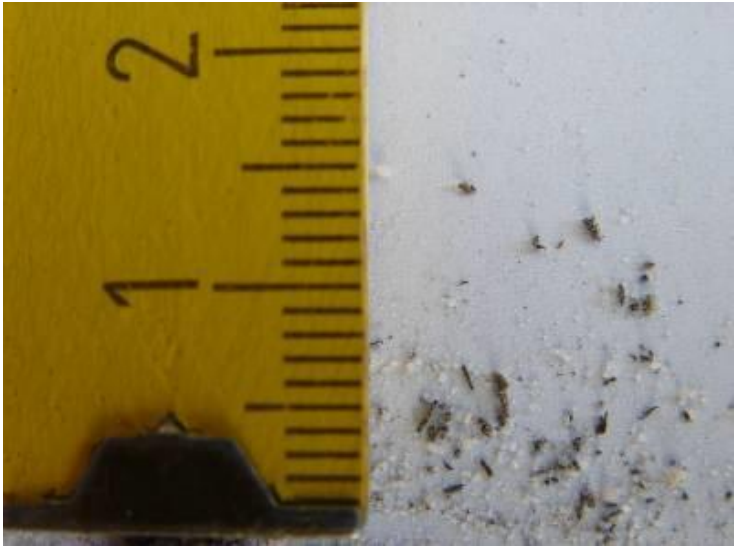
Soiling and clogging of porous asphalt (PA)

Washing out of artificial dirt after soiling

- External soiling and internal soiling (fibers and „bituminous“ particles)



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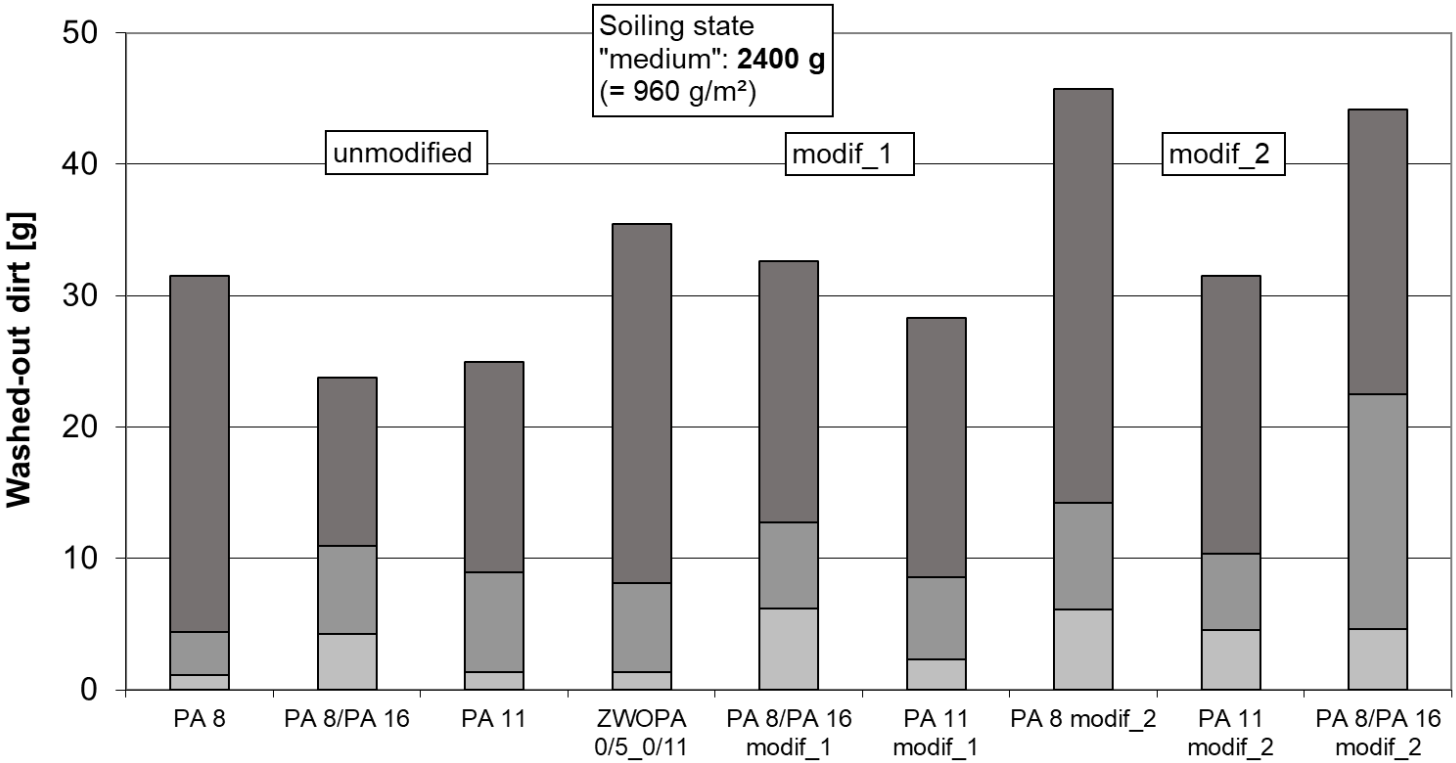
Soiling and clogging of porous asphalt (PA)



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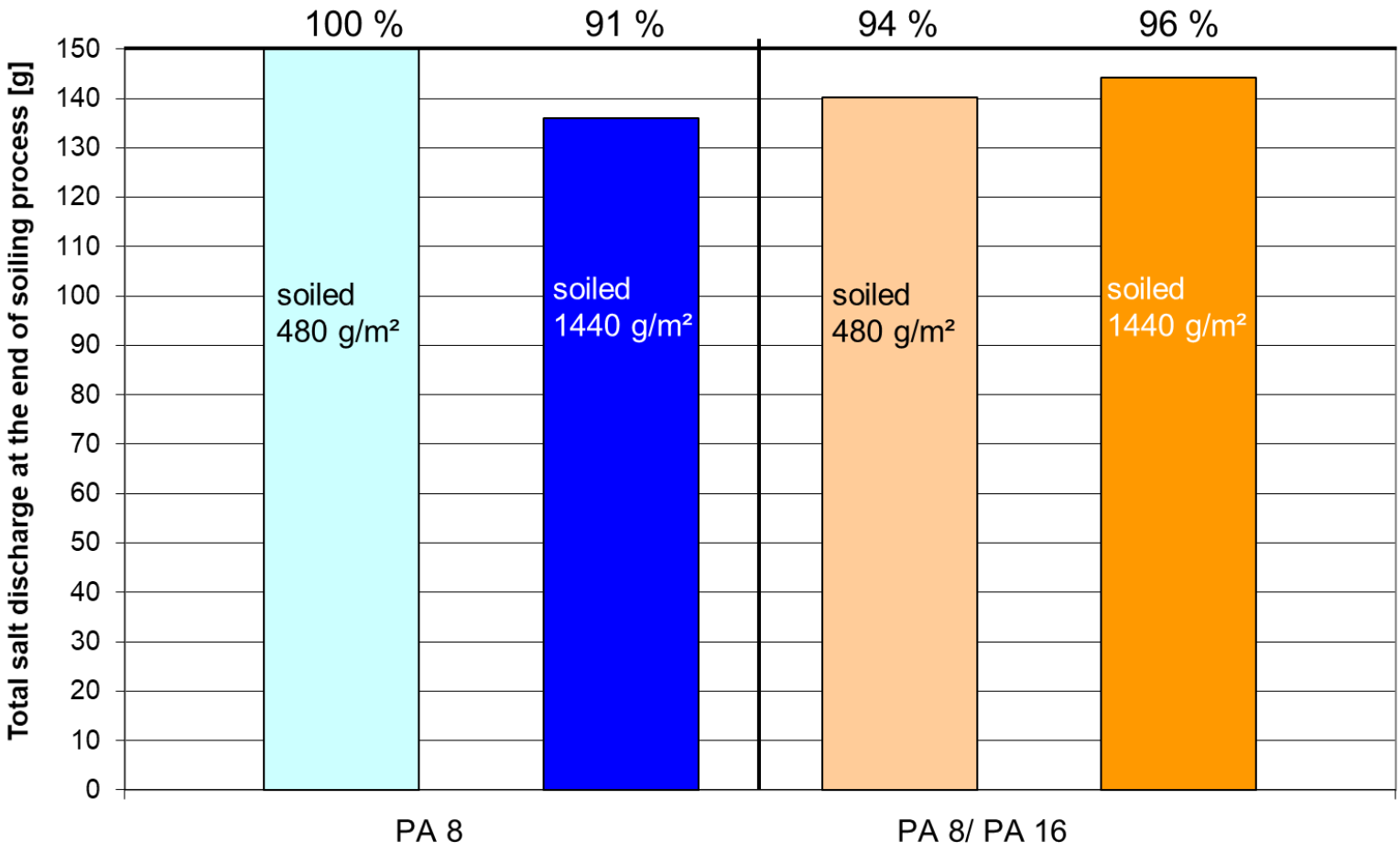

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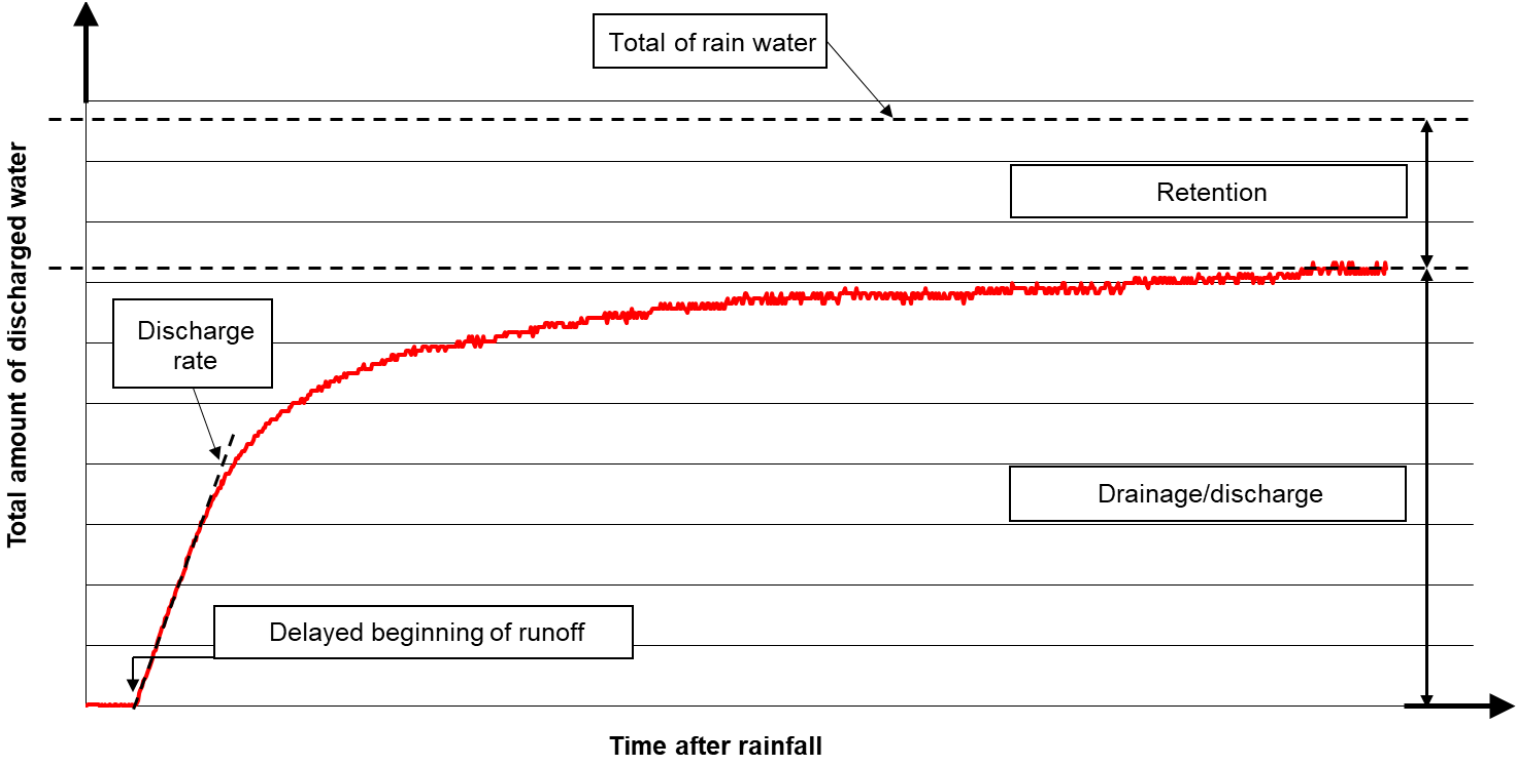
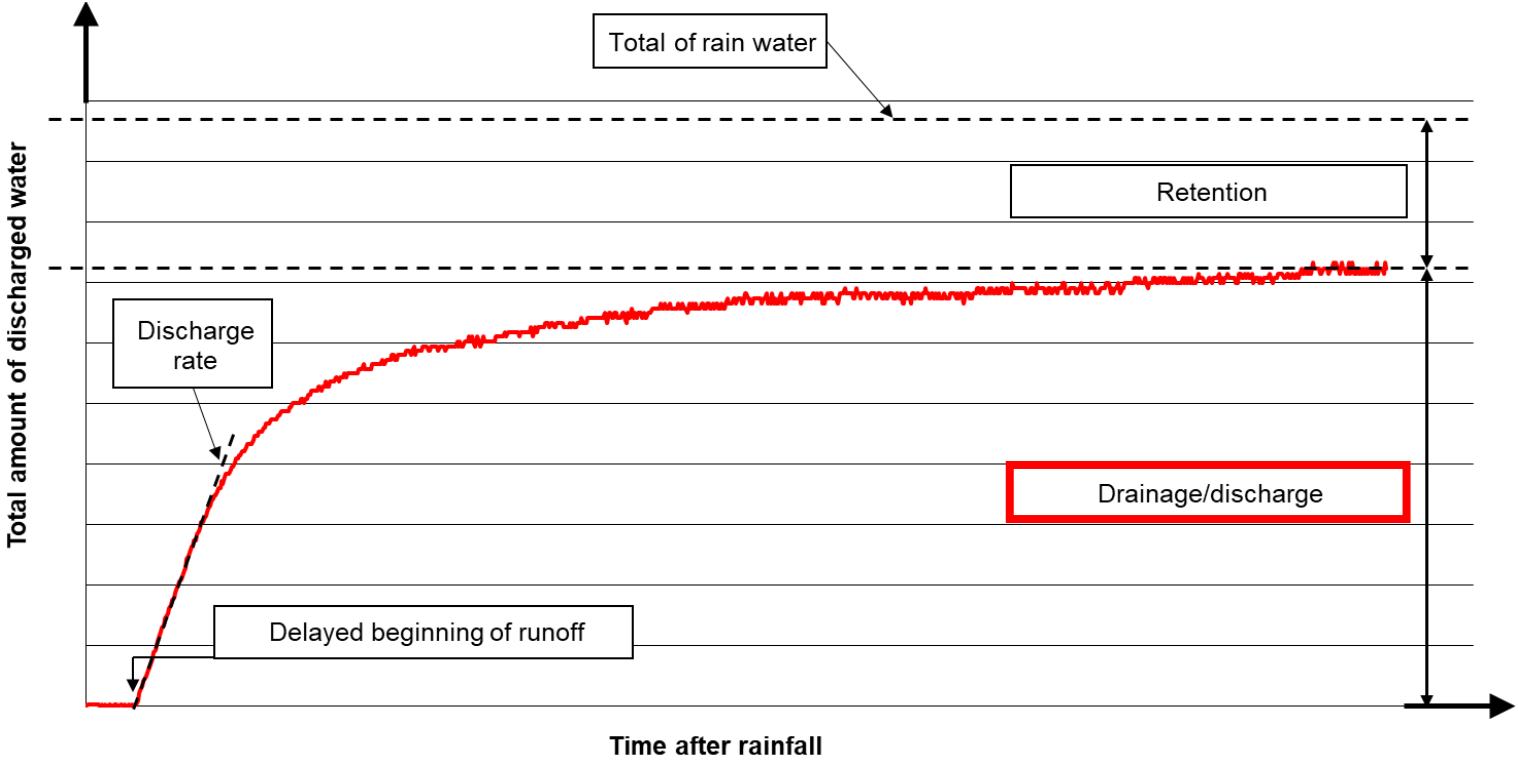
Drainage properties

Typical development of runoff of PA

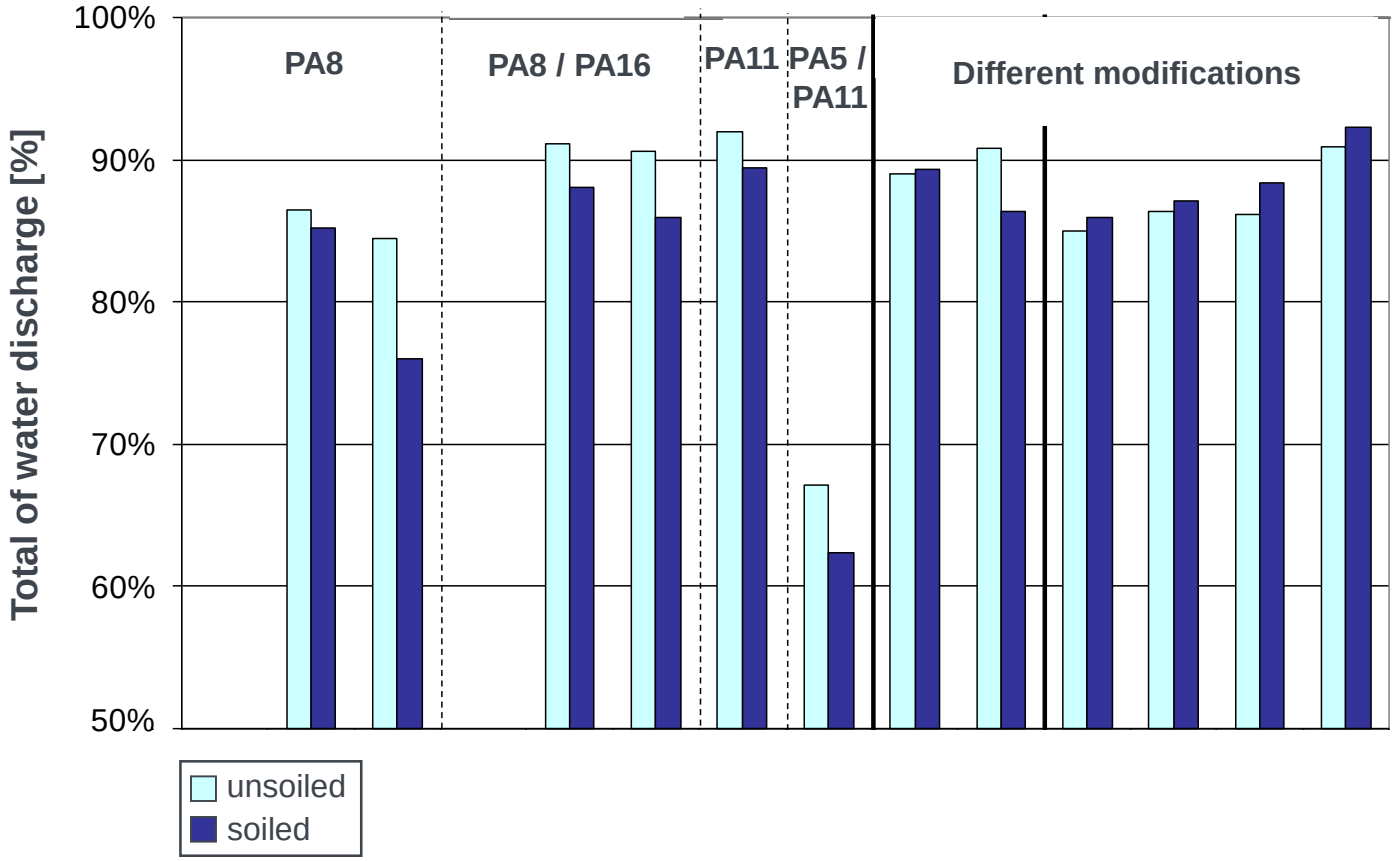


Drainage properties

Typical development of runoff of PA



Drainage properties – total amount of discharge



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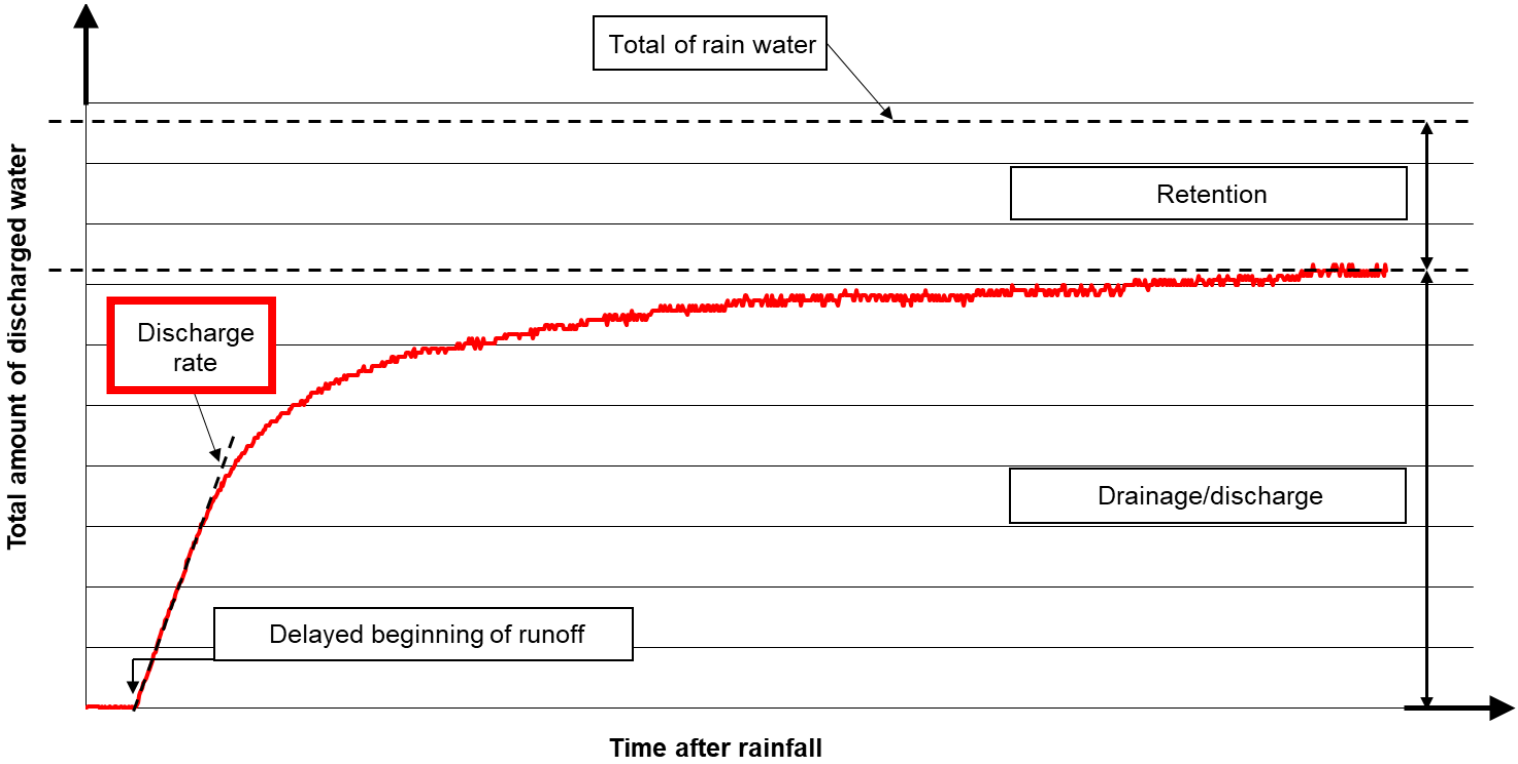
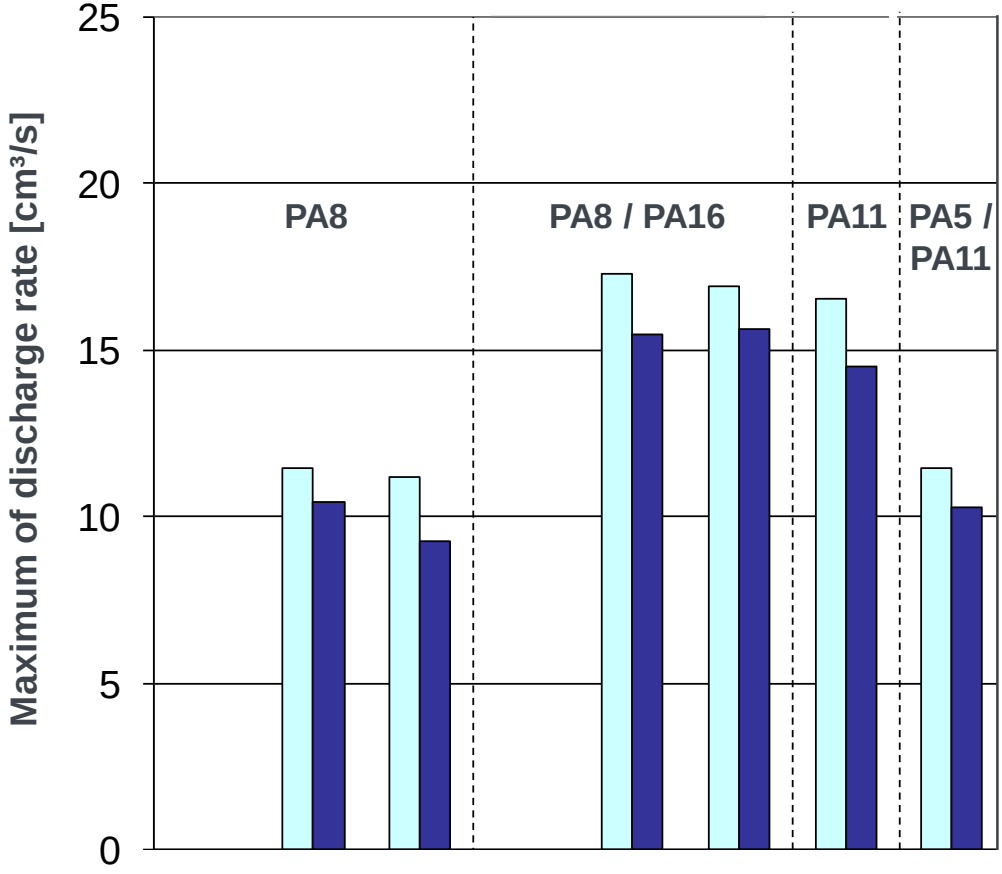


Drainage properties – discharge rates



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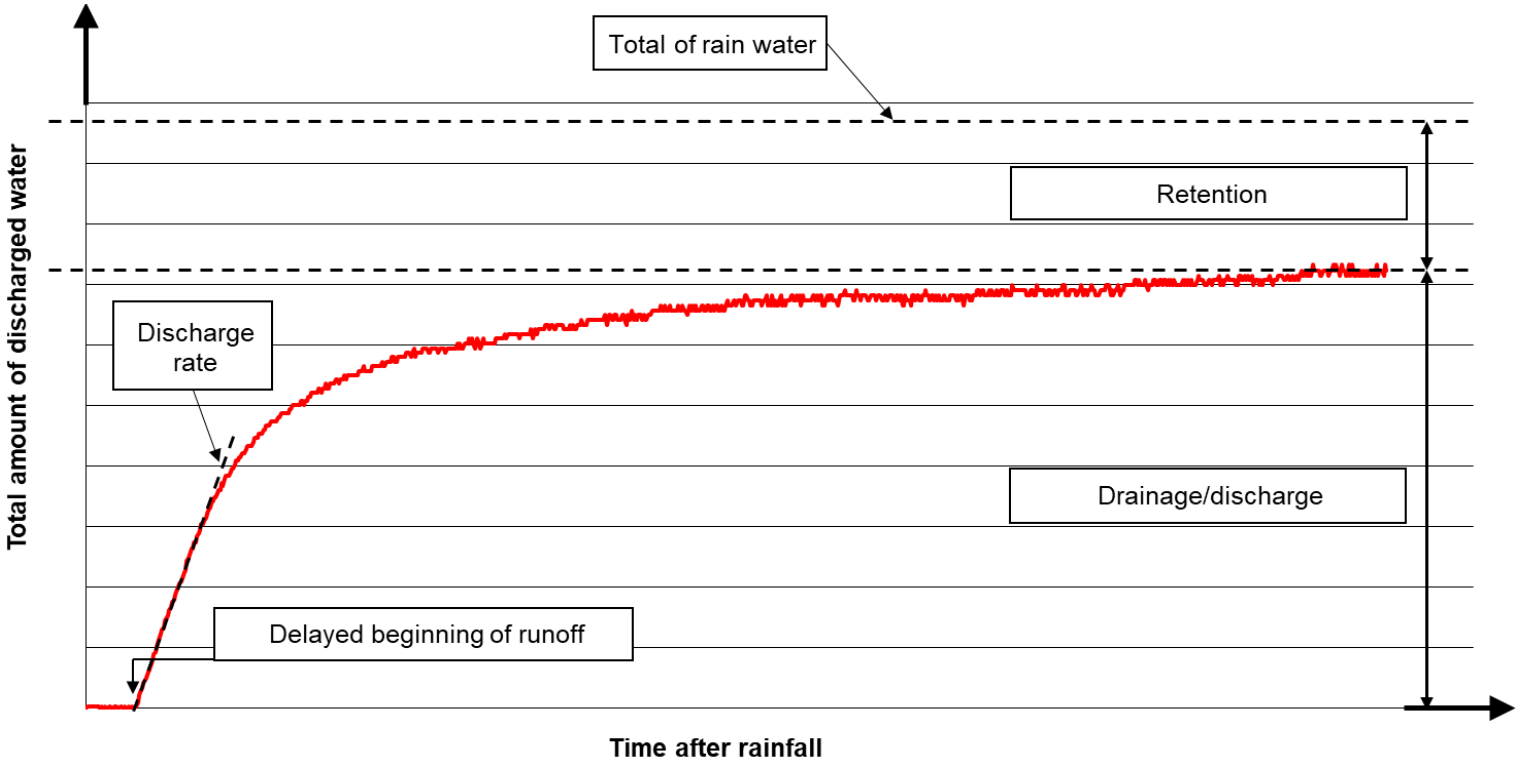
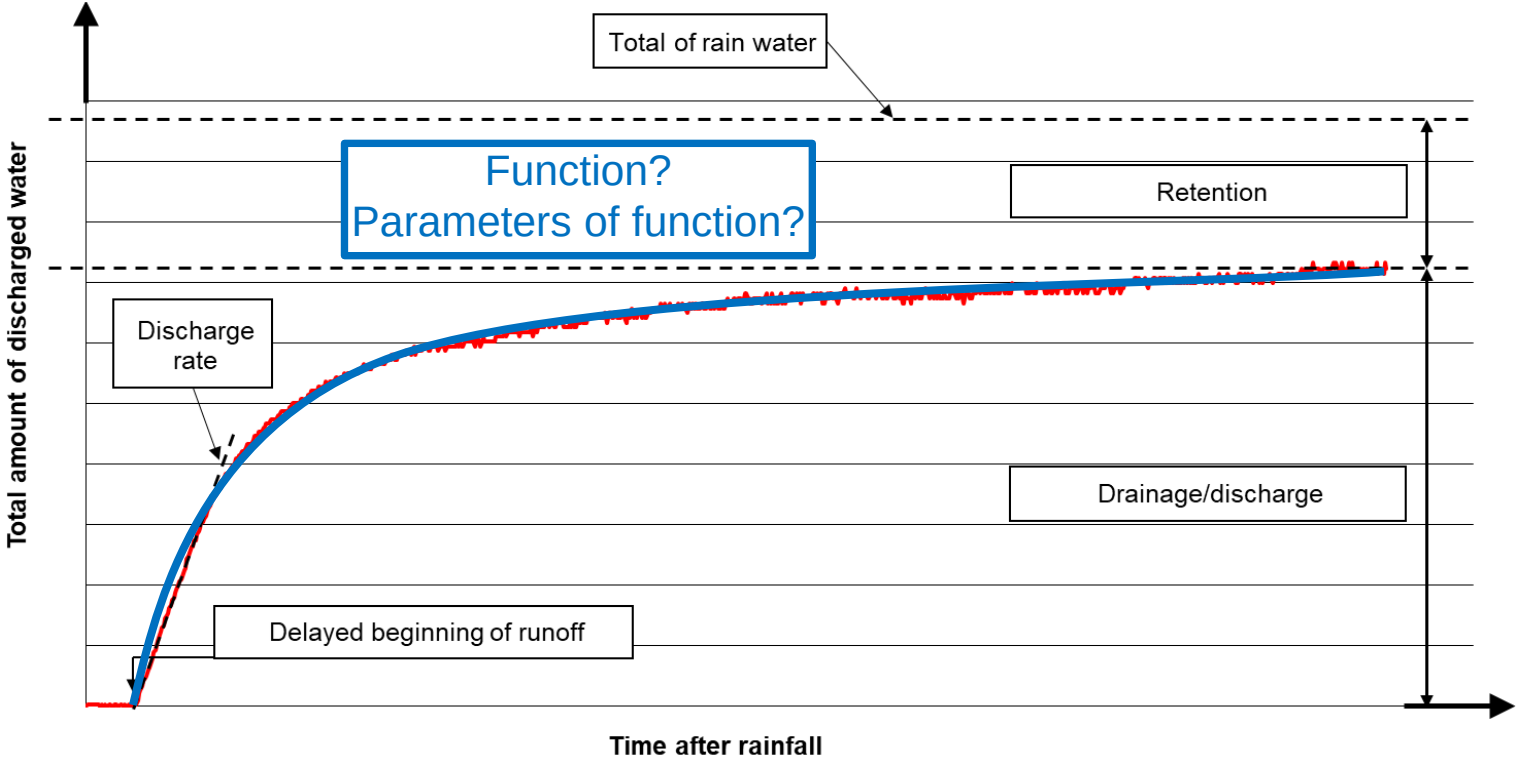
Drainage properties

Typical development of runoff of PA



Drainage properties

Typical development of runoff of PA



Drainage properties

Hydrological approach – linear reservoir model

$$S(t) = K \cdot q(t)$$

$$q(t) = \frac{S(t_0)}{K} \cdot e^{\frac{-t}{K}}$$

$$Q(t) = \int_{t_{0=0}}^{t} q(t) = S(t_0) \cdot (1 - e^{\frac{-t}{K}})$$

q(t): runoff flow rate [l/min]

K: storage constant [min]

S(t): stored water volume in reservoir [l]

t: time [min]

$S(t_0)$: initial water volume in reservoir/porous asphalt [l/min]

Q(t) : total amount of discharged water volume at a certain time t [l]

Drainage modelling

Hydrological approach – linear reservoir model

- Smaller values of K → „faster“ ouflow
- Questions:
- Typical storage constants K from the artificial rain experiments (2.5 m² sample with maximum of flow path of 2.5 m)
  - Dependent on **PA type**: coarser PA have smaller K than finer ones
  - Dependent on **rainfall intensity**: higher K for lower rainfall intensities
  - Dependent on **retained water** within the porous structure…
  - Dependent on **soiling state**…

  - → Paper submitted to „Road Materials and Pavement Design“
  - …Extrapolation for bigger PA areas possible?

Drainage modelling

3D drainage model

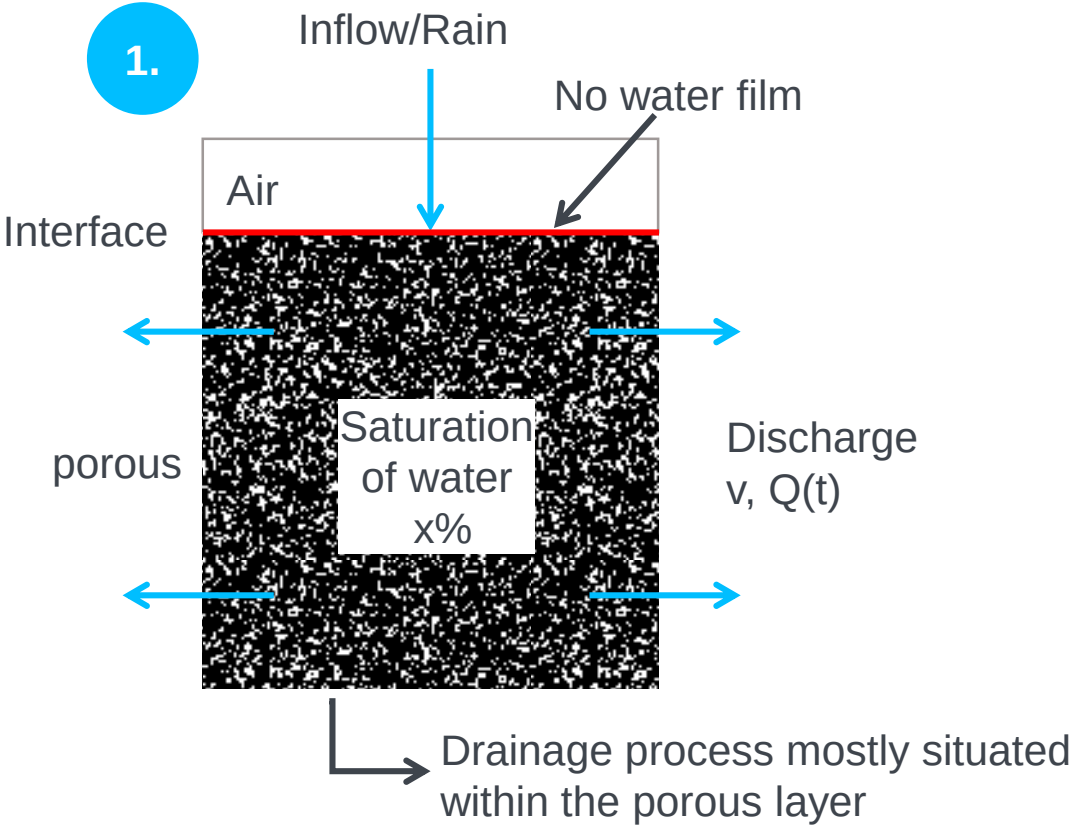
- DFG: German Research Foundation
- FOR 2089: research group
- Subproject: Development of a 3D drainage model of pavements
- Drainage model based on (physical) principles of hydromechanics

- State of the art: 2D drainage of dense pavements
- Surface runoff, no infiltration
- Pavement Surface Runoff Model (PSRM)*

*) A. Wolff, Simulation of pavement surface runoff using the depth-averaged shallow water equations (PhD thesis), Veröffentlichungen des Instituts für Straßen- und Verkehrswesen, Universität Stuttgart, Heft 45, Stuttgart, 2013. http://dx.doi.org/10.18419/opus-488

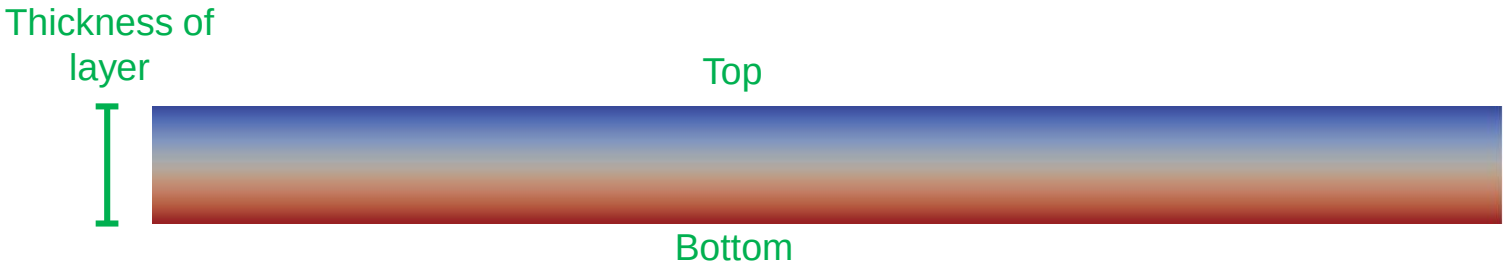
Drainage modelling

3D drainage model



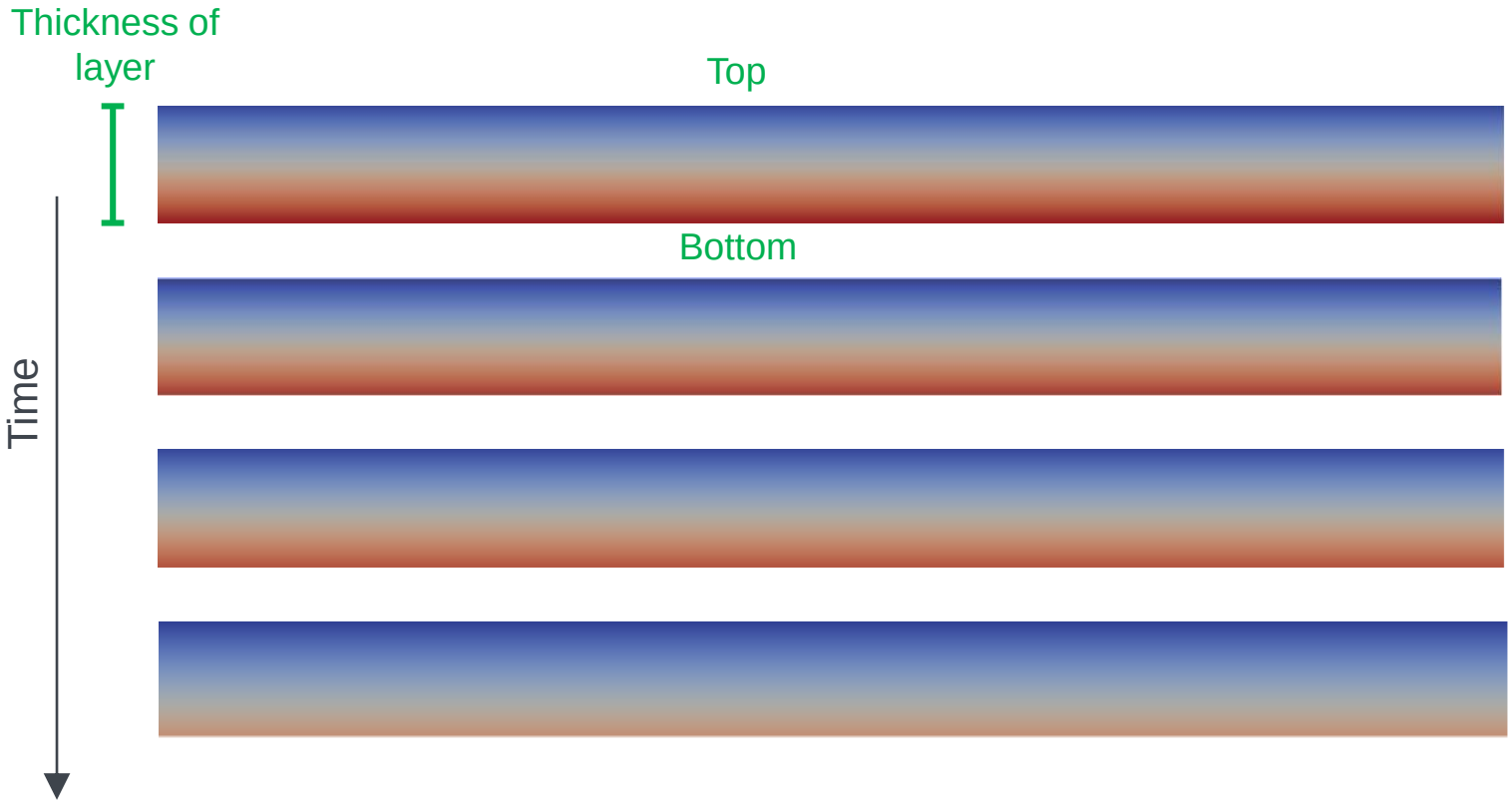
Drainage modelling

Example - Development of saturation in a PA layer



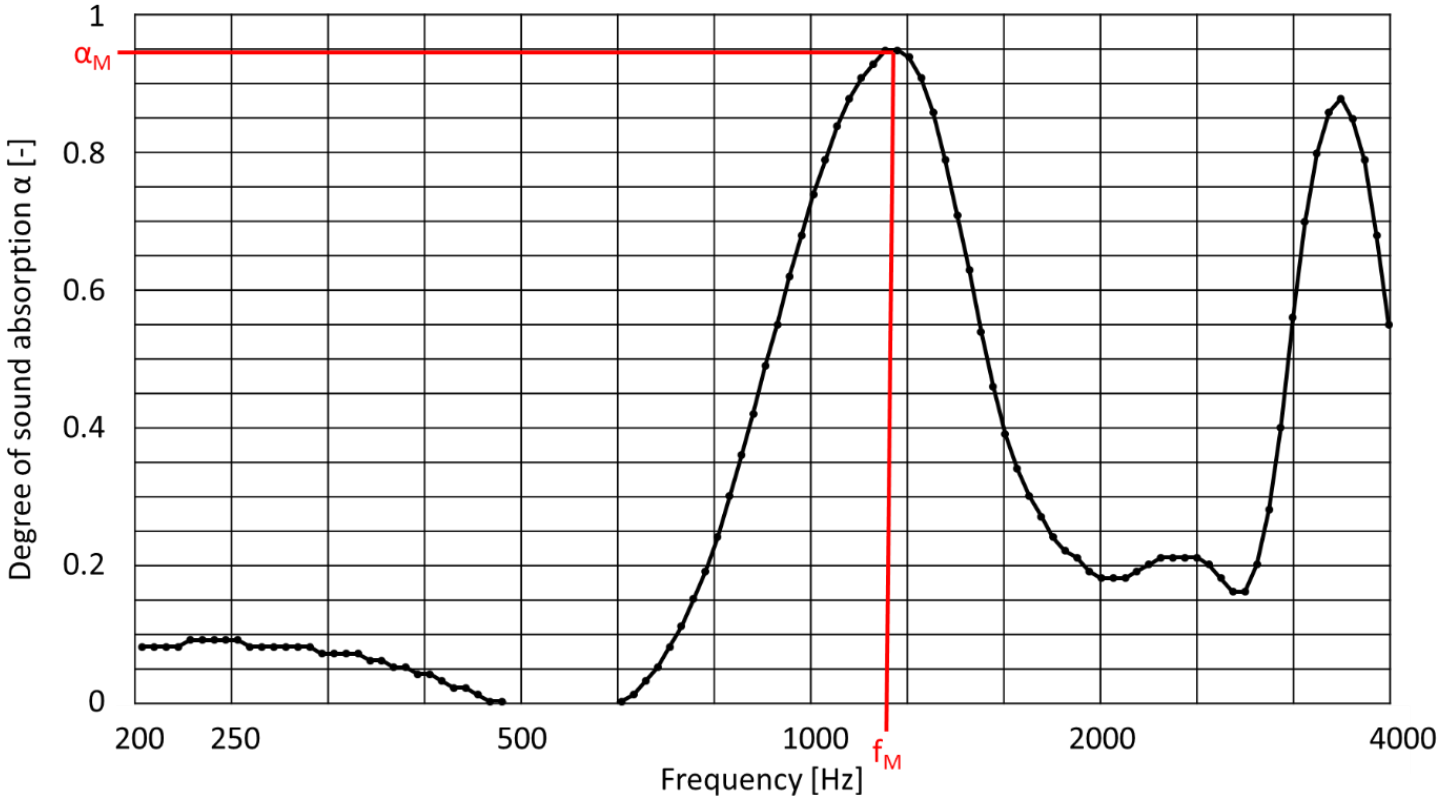
Drainage modelling

Example - Development of saturation in a PA layer



Sound absorption

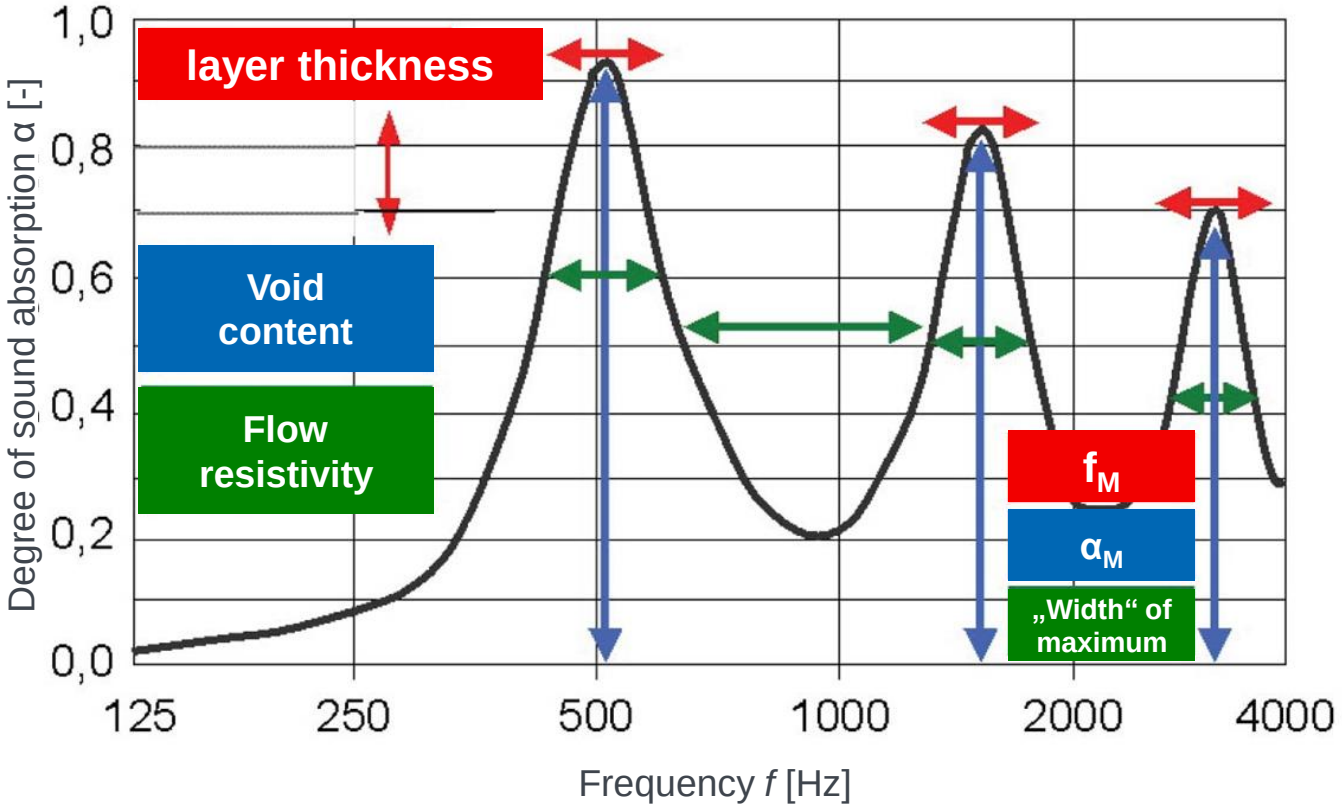
Typical shape of PA sound absorption degree



Source (picture): Alber, Stefan; Ressel, Wolfram; Liu, Pengfei; Wang, Dawei; Oeser, Markus (2018): Influence of soiling phenomena on air-void microstructure and acoustic performance of porous asphalt pavement. In: Construction and Building Materials 158, S. 938–948. DOI: 10.1016/j.conbuildmat.2017.10.069

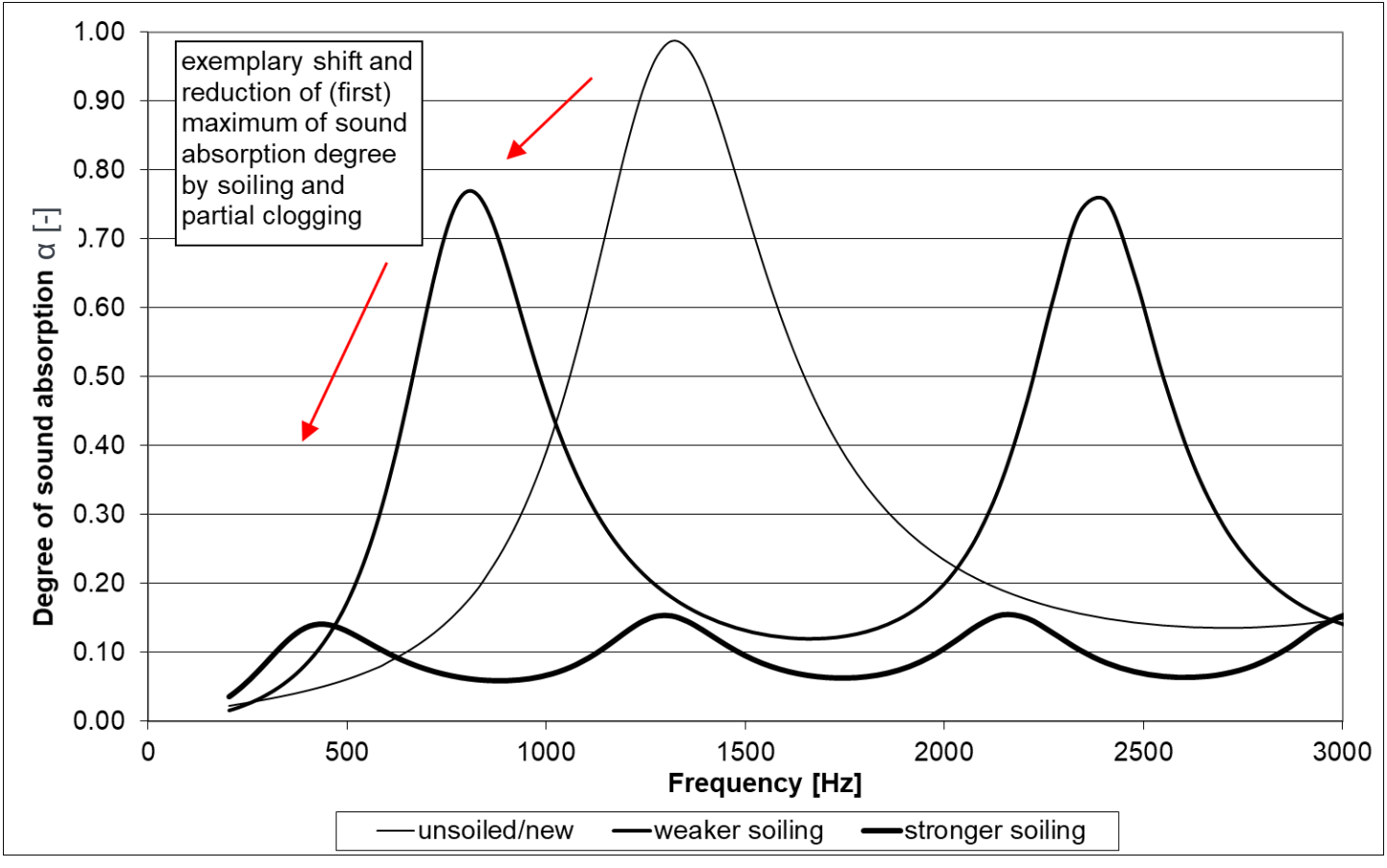
Sound absorption of PA - parameters

Degree of sound absorption - influencing parameters



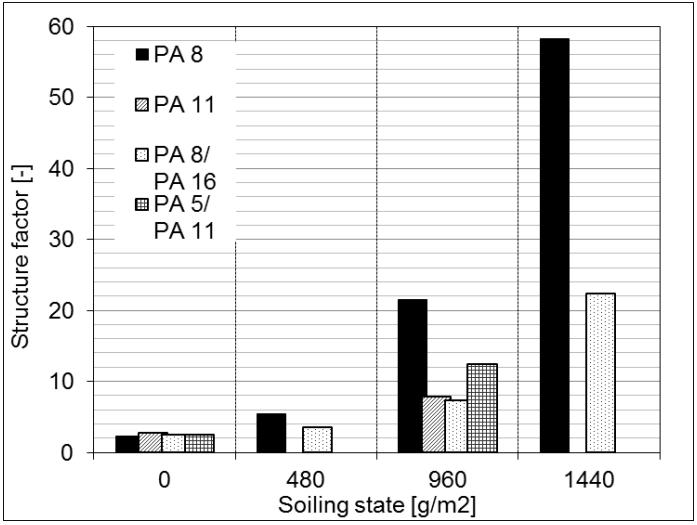
Source after: FGSV (ed.): Merkblatt für Asphaltdeckschichten aus Offenporigem Asphalt (M OPA) (free translation: Code of practice for porous asphalt wearing courses), Ausgabe 2013

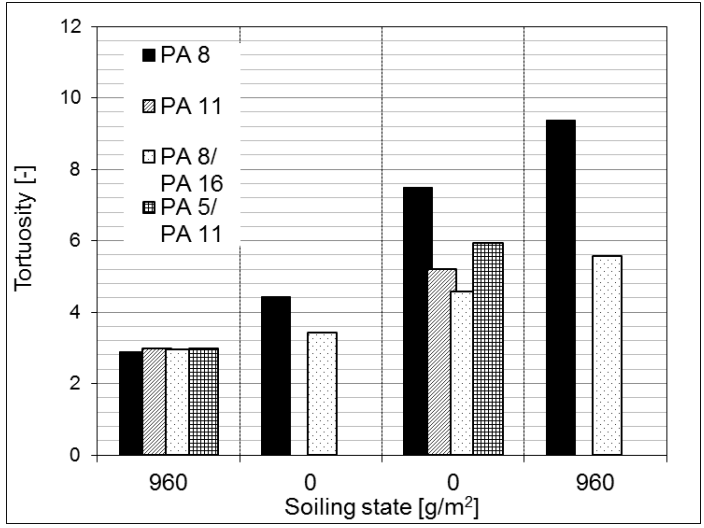
Sound absorption of PA – effect of artificial soiling



Picture: S. Alber, Veränderung des Schallabsorptionsverhaltens von offenporigen Asphalten durch Verschmutzung (Variation of sound absorption characteristics of porous asphalt due to clogging processes) (PhD thesis) German language, Veröffentlichungen des Instituts für Straßen- und Verkehrswesen, Universität Stuttgart, Heft 46 Stuttgart, 2013. http://dx.doi.org/10.18419/opus-489
English illustration: Alber, Stefan; Ressel, Wolfram; Liu, Pengfei; Wang, Dawei; Oeser, Markus (2018): Influence of soiling phenomena on air-void microstructure and acoustic performance of porous asphalt pavement. In: Construction and Building Materials 158, S. 938–948. DOI: 10.1016/j.conbuildmat.2017.10.069 .

Sound absorption of PA – effect of soiling





- Back-calculation of acoustical parameters related to morphological structure
- Structure factor κ and tortuosity τ increase with higher soiling states with the effects on sound absorption shown above
- **Unsoiled** state, **independent** from mix type, layer thickness and coarse or fine structure
  - $\kappa \approx 2.5$
  - $\tau \approx 3$

Picture: Alber, Stefan; Ressel, Wolfram; Liu, Pengfei; Wang, Dawei; Oeser, Markus (2018): Influence of soiling phenomena on air-void microstructure and acoustic performance of porous asphalt pavement. In: Construction and Building Materials 158, S. 938–948. DOI: 10.1016/j.conbuildmat.2017.10.069 .
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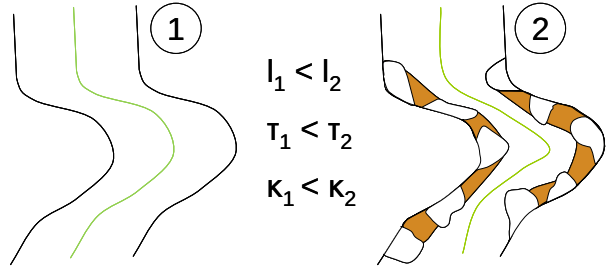
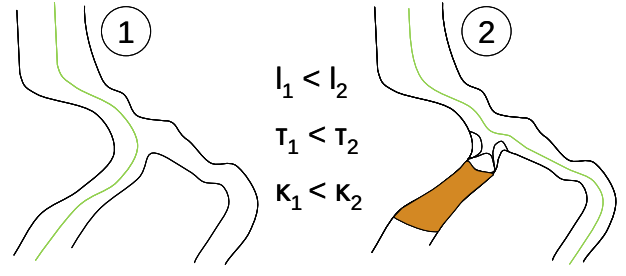
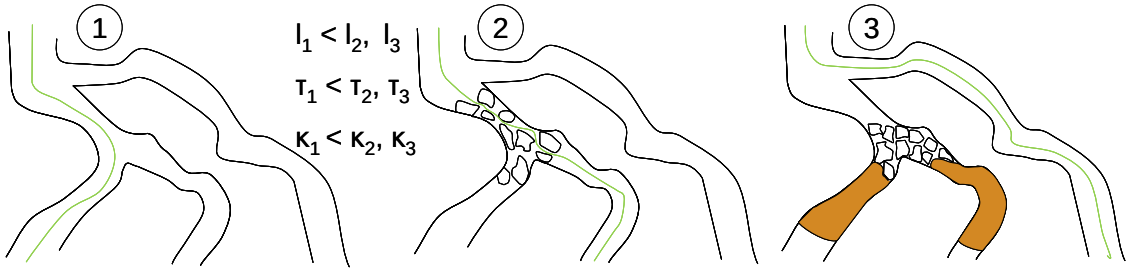
Sound absorption of PA – effect of soiling

Constriction of pores



Clogging of pore channels





Air flow paths

Areas where air cannot be accelerated

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Summary

- **Artificial soiling tests**
  - Artificial dirt
  - Artificial rainfall
  - Experimental set-up with
    - Time-dependent drainage measuring
    - Collecting and analyzing washed-out dirt
  - Soiling mechanisms
  - →…Possible approaches for capturing contaminants…
- **Effects of soiling on**
    - Drainage
    - Sound absorption
- **Modelling approaches explaining the empirical results**

Related (own) literature

- Alber, S.; Ressel, W.; Liu, P.; Wang, D.; Oeser, M. (2018): Influence of soiling phenomena on air-void microstructure and acoustic performance of porous asphalt pavement. In: Construction and Building Materials 158, S. 938–948. DOI: 10.1016/j.conbuildmat.2017.10.069.
- Alber, S.; Ressel, W.; Liu, P.; Hu, J.; Wang, D.; Oeser, M. et al. (2018): Investigation of microstructure characteristics of porous asphalt with relevance to acoustic pavement performance. In: International Journal of Transportation Science and Technology. DOI: 10.1016/j.ijtst.2018.06.001.
- Alber, S. (2013): Veränderung des Schallabsorptionsverhaltens von offenporigen Asphalten durch Verschmutzung (Variation of sound absorption characteristics of porous asphalt due to clogging processes) (PhD thesis) German language, Veröffentlichungen des Instituts für Straßen- und Verkehrswesen, Universität Stuttgart, Heft 46 Stuttgart, 2013. http://dx.doi.org/10.18419/opus-489
- Ressel, W.; Wolff, A.; Alber, S.; Rucker, I. (2017): Modelling and simulation of pavement drainage. In: International Journal of Pavement Engineering 82 (2), S. 1–10. DOI: 10.1080/10298436.2017.1347437.
- Wolff, Anne: Simulation of pavement surface runoff using the depth-averaged shallow water equations (PhD thesis), Veröffentlichungen des Instituts für Straßen- und Verkehrswesen, Universität Stuttgart, Heft 45, Stuttgart, 2013. http://dx.doi.org/10.18419/opus-488

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- Kuti, H.: Verschmutzungsprozess von offenporigen Asphaltdecken Soiling Process of Porous Asphalt Wearing Courses (Diploma thesis), Institute for Road and Transport Science (in cooperation with the Department of Structural Geology and Geodynamics of the University of Göttingen, Germany), University of Stuttgart, 2006.
- Maróthy, E.: Untersuchung der Rauheit von Poreninnenwandungen inoffenporigen Asphalten (free translation: Roughness of pore surfaces in porous asphalt) (Diploma thesis), Institute for Road and Transport Science(in cooperation with the Department of Structural Geology and Geodynamics of the University of Göttingen, Germany), University of Stuttgart, 2006.

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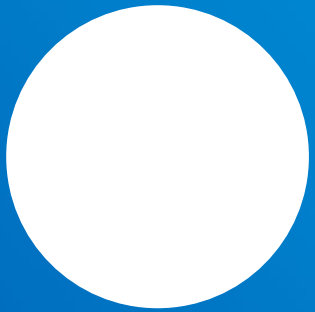
Thank you!



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