HEAVY METAL RETENTION WITHIN A POROUS PAVEMENT STRUCTURE

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ABSTRACT

Porous pavements with reservoir structure for infiltration of runoff from parking spaces and residential streets offer the opportunity to dispose water without using additional space in urban areas. However, pollutants in urban runoff endanger soils and groundwater, when pollutant retention in the structure is not sufficient. Porous pavement structures with four different subbase materials were tested in rigs. Additional tests were carried out in a pilot-scaled test bed. The pavements consisted of porous concrete blocks. All structures were loaded by sprinklers with synthetic runoff at *pH* 5, spiked with dissolved heavy metals. In most of the structures metal concentrations in effluent do not reach German limits for seepage water after simulation of 50 years. If porous pavements are planned and constructed carefully, groundwater seems not to be endangered by trace metals in the road-runoff.

KEYWORDS

heavy metals, infiltration, porous pavement, stormwater

INTRODUCTION

Porous pavements for retention and infiltration of runoff from parking spaces and small residential streets offer the opportunity to infiltrate water without the need of additional space. Therefore in urban areas with high building density, they are an alternative to classical and often used infiltration-devices. The use of these structures is widely discussed in Germany, because their effect on groundwater and bearing capacity is not well known. Runoff from rain and snowmelt contains significant loads of heavy metals and organic compounds. These constituents are generated by traffic activities, pavement degradation, car leakage and atmospheric deposition (Grottker, 1987, Muschack, 1989, Sansalone et al. 1996). Consequently groundwater can be endangered in the long run, if buffer-capacities are exceeded. Heavy metals are not degraded in soils like most organic constituents. So they have a high risk of being mobilised by changing physico-chemical behaviour. Especially lead, copper, zinc and cadmium show highest concentrations in runoff.

STUDY OBJECTIVES

The main objective of the study presented is to estimate the impact of pollutants to groundwater by infiltration of street runoff over porous pavements. To analyse the retention of heavy metals, tests with rigs of stainless steel and in a pilot-scale test-bed are carried out. Rainwater is spiked with heavy metals and given to the structures by different sprinklers. Concentrations of heavy metals in effluent and in different depth of the structures are analysed. All sediment-samples are extracted by different methods, including sequential extraction techniques to give a closer view to the partitioning and the mobility of the metals. Time periods of 50 years are simulated.

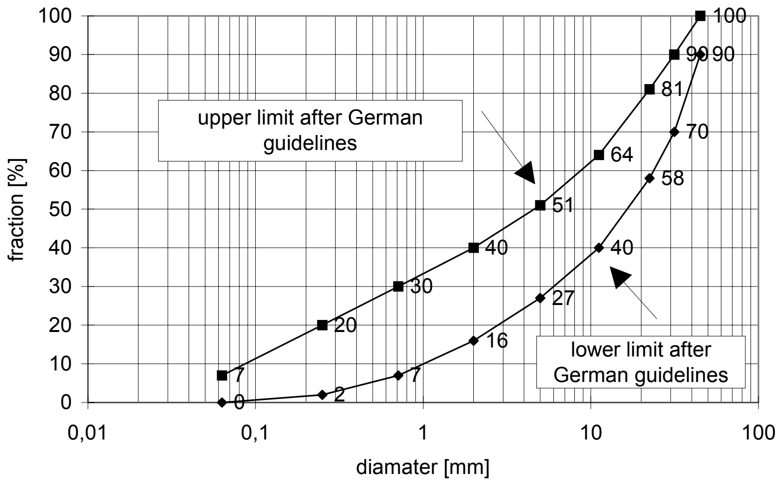

Fig. 1: Permissible German limits of grainsize-distribution of subbase material

The new German law about soil protection contains strict limits for infiltrated waters at the transition to the saturated zone. These limits are lower than limits for drinking water quality for some constituents. Many studies about the decontaminating effects of porous pavements with reservoir structure exist (Legret et al 1998, Pratt et al. 1998). Most of these studies are carried out on materials, which are not allowed to be used after German regulations. Often coarse subbase stones are used, that do not fulfil German regulations (see fig. 1). In most studies the pavement consists of a porous asphalt. This study concentrates on porous concrete blocks, which are mostly used in Germany for porous pavements. The whole subbase must trap the heavy metals effective enough, to reach concentrations of heavy metals in effluent that fulfil the limits of the new German guideline.

EXPERIMENTAL METHODOLOGY

Test rigs

The test-rigs consist of stainless steel and have dimensions of 40 cm in length and 60 cm in height. The subbase is build of a geotextile, 39 cm of different crushed stones from 0 to 32 and 45 mm, respectively, 5 cm of a pea-gravel from 2 to 5 mm and porous concrete blocks with dimensions of 20 cm length, 10 cm width and 8 cm height (fig. 2). The joints are filled with sand from 0 to 2 mm. The rigs are loaded by a sprinkler consisting of injection-needles. Runoff is pumped into the sprinkler by a peristaltic pump. The volume of water is measured by electronic scales.

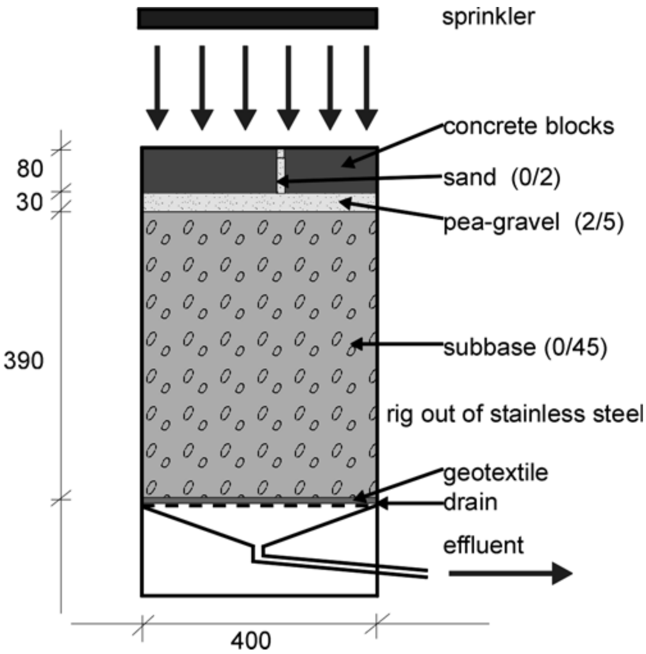

Fig 2: Test rig filled with a porous pavement with reservoir structure after German regulations

The rigs are loaded with a synthetic runoff at *pH* 5, that is spiked with dissolved heavy metals. The concentrations were chosen from literature data and were multiplied by 10 to study the structure under worst case conditions. Altogether 4000 mm of rain were simulated, that reflect 5 years of rain in Germany.

Pilot scale tests

To investigate the behaviour of the structure under more representative conditions, a test-bed out of stainless steel was build, that is 2,80 m long and 1,50 m wide (fig. 3). It also consist of stainless steel. Surface water and effluent can be sampled separately. The fluxes are measured by electronic scales and are logged online by a PC. *PH* and electric conductivity of seepage water are also measured online. TDR-probes and tensiometers analyse the volumetric water content and the suction in different depth.

The sprinkler consists of 1300 injection needles. Stormwater from a roof is stored in a tank and is spiked with heavy metals. It is pumped into the sprinkler by a peristaltic pump. Rain intensity is measured by a flow-meter. Altogether 4000 mm of rain were simulated during the tests. Rains were reflected by a rain intensity of 25 l/(s·ha). Heavy metals were detected in the rainwater and in the effluent. After 4000 mm of rain were loaded to the structure during 50 simulated storms, tests with high rain intensities were carried out to find out, if the rain-intensity influences the metal retention in the structure.

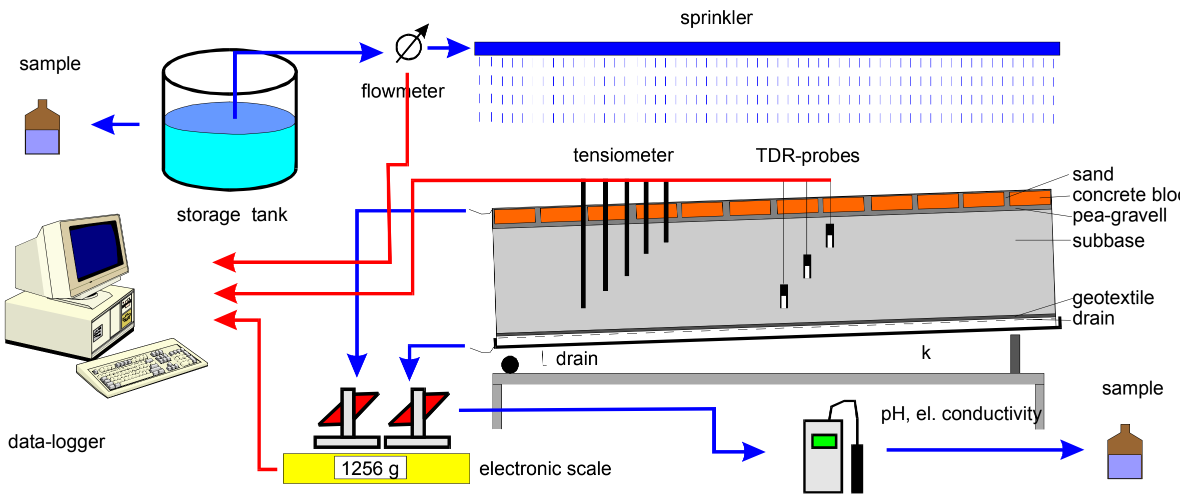

Fig. 3: Setting of pilot-scaled tests with porous pavements

Heavy metal extractions

After the tests all materials of the rigs and the test-bed were sampled at different depth to obtain information about the destination of the heavy metals. Pseudototal contents of metals were extracted by aqua regia after German guidelines for soil analysis. Available contents of metals were extracted with 0,5 m EDTA-solution. To determine operational species of the metals and to make an estimation of mobility a four step sequential extraction procedure after SM&T regulations was carried out (Ure et al. 1993).

RESULTS

Characterisation of the materials

In the rigs four different materials are investigated. Three crushed stones (0-45 mm), including a basalt, a sandstone and a limestone, which is the mostly used material in Germany, and one gravel (9-32 mm) are used. Each material fulfils regulations for street-construction in Germany. Proctor-densities are between 2,07 g/cm^3 and 2,17 g/cm^3. *PH* is between 8.3 and 8.8. The measured hydraulic conductivities vary from $3 \cdot 10^{-4}$ m/s (gravel) up to $2 \cdot 10^{-2}$ m/s for the sandstone. The limestone is situated in the middle of the conductivities. The concentrations of Pb, Cu, Zn and Cd were in the range of natural soils.

Heavy metal concentrations in effluent

The rigs were charged with synthetic rainwater containing mean concentrations of 180 µg/l Pb, 470 µg/l Cu, 660 µg/l Zn and 30 µg/l Cd and *pH* was at 4,9 (see table 1). In effluent at the beginning of the tests *pH* was at 8,0 at all rigs, except of the basalt with a *pH* of 8,7. At the end of the tests *pH* has lowered to 7,3 in the sandstone rig, up to 8,0 in the basalt rig. Red-Ox-Potential in the effluent was between 235 mV and 240 mV. So after the infiltration of 4000 mm of rain effluent was still in an intermediate *pH*-range and red-ox was high, so there are no indications for high metal mobility. Cadmium-concentrations in the effluent rose linear during the tests. In the basalt rig and in the gravel rig they could not be detected after

4000 mm of rain. In the limestone rig cadmium reached the limit for seepage-water of 5 µg/l after about 3000 mm. In the column with the sandstone the limit was decreased after about 1000 mm. Copper concentrations in effluent were rising in the beginning of the tests and stay at one level after about 1500 mm. For the basalt and the gravel about 15 µg/l to 20 µg/l were detected. In the rigs with the limestone concentrations reached about 30 µg/l to 40 µg/l , and at the sandstone column concentrations of about 60 µg/l were analysed. So in the sandstone the limit of 50 µg/l is surpassed. Zinc and lead-concentrations were found very low. Lead could not be detected in effluent. Zinc was detected in concentrations up to 300 µg/l in the sandstone. All mean concentrations of effluents of the tests are shown in table 1. The main reason for the different behaviour of the materials is connected to the part of grains smaller than 2 mm. The results from the pilot-scaled test look very similar to the rigs. Here the concentrations in the effluent were even lower, because of lower the rain-intensities used for infiltration.

Results of soil analysis

After the tests, samples were taken in different depths. To obtain a balance of metals retained in the column, masses of metals that are trapped in one layer were calculated.

Results of the soil analysis are shown in fig. 4. Here the distribution of EDTA-extractable zinc is shown for five rigs with different subbase materials in relation to depth. Most of the EDTA-Zn was found in the concrete-pavement itself. In the pea-gravel of the bedding the concentrations decrease rapidly, and they increase again in the upper five centimetres of the subbase stones. This development looks similar at each of the examined metals. For cadmium and zinc the concentrations show an increase of concentrations up to a depth of about 30 cm. For copper and lead it can be seen only to a depth of 20 cm. The concrete blocks itself show a steep gradient for the concentration of the metals. Especially copper and lead show high concentrations only in the upper 2 cm of the blocks. Zinc and cadmium have higher concentrations also in depth up to 8 cm. The metal-contents of the materials do not exceed the permissible limits for soils under the German regulations.

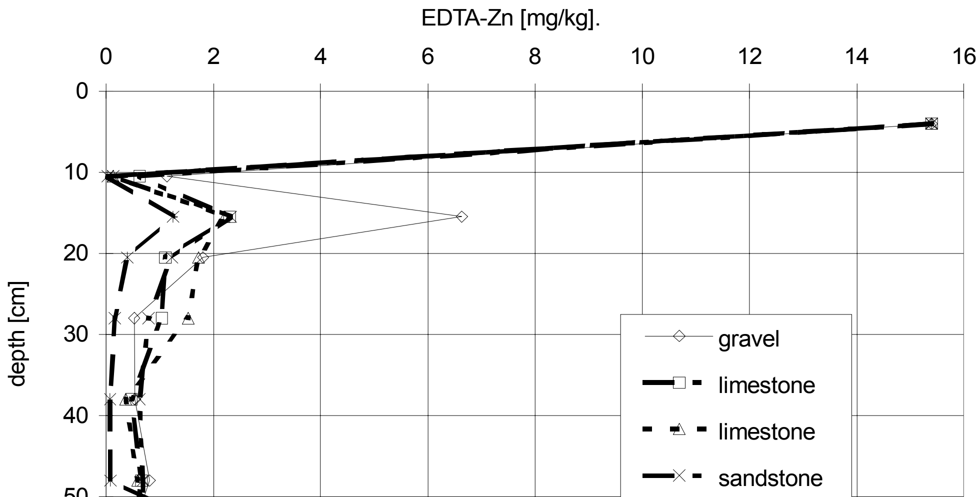

Fig. 4: Concentrations of ETDA-extractable in relation to depth after infiltration of 50 years loads in five test rigs with different subbase materials

The balance of the total metal masses is shown in table 1 for all rigs and for the four metals. The highest effectivities show basalt and gravel, which is an effect of the big part of small grainsizes. The sandstone shows the lowest effectivity for retention and it has the highest hydraulic conductivity. The lowest metal retention was found for cadmium and zinc. Lead and copper were trapped more effectively in the structures.

	lead	cadmium	copper	zinc
synthetic runoff	180 µg/l	30 µg/l	470 µg/l	660 µg/l
effluent (mean conc.)				
gravel	< 4 µg/l	0,7 µg/l	18 µg/l	19 µg/l
basalt	<4 µg/l	0,7 µg/l	16 µg/l	18 µg/l
limestone	< 4 µg/l	3,2 µg/l	29 µg/l	85 µg/l
sandstone	< 4 µg/l	10,5 µg/l	51 µg/l	178 µg/l
retention				
gravel	98 %	98 %	96 %	97 %
basalt	98 %	98 %	96 %	98 %
limestone	98 %	88 %	94 %	88 %
sandstone	89 %	74 %	89 %	72 %
limits for seepage	25 µg/l	5 µg/l	50 µg/l	500 µg/l

Table 1: Concentrations of metals in the synthetic runoff and in the effluent of the test rigs, percentage of metals retained in the columns after infiltration of the loads of about 50 years and permissible limits for seepage after the new German law for soil-protection

Results of sequential extraction

A sequential extraction was carried out on the concrete blocks after the infiltration of the loads of dissolved metals corresponding to 50 years to get an idea of the partitioning of the heavy metals. Therefore the block was cut into 4 layers of 2 cm each. In figure 5 the different behaviour of the four metals in relation to the depth can be seen clearly. Cadmium and zinc were found up to 80 % in the first fraction (acid soluble and exchangeable) in the upper two centimetres of the block. Even to a depth of 6 cm the part of metals in the acid-soluble fraction is above 20 %. For copper and lead there is no significant change for the partitioning of the metals below a depth of 2 cm. The acid-soluble fraction is here below 10 %. For lead and copper the third fraction of oxydable species is more important than for zinc and cadmium. Copper also shows the highest part of metals in the residual fraction. The results of the sequential extraction has to be interpreted very carefully. They only can be used to compare the different layers of the block, but they give an idea of the processes taking place. Zinc and cadmium mostly are trapped in the most mobile fraction and are transported into depth, while copper and cadmium are retained very effective and stronger in the upper 2 cm.

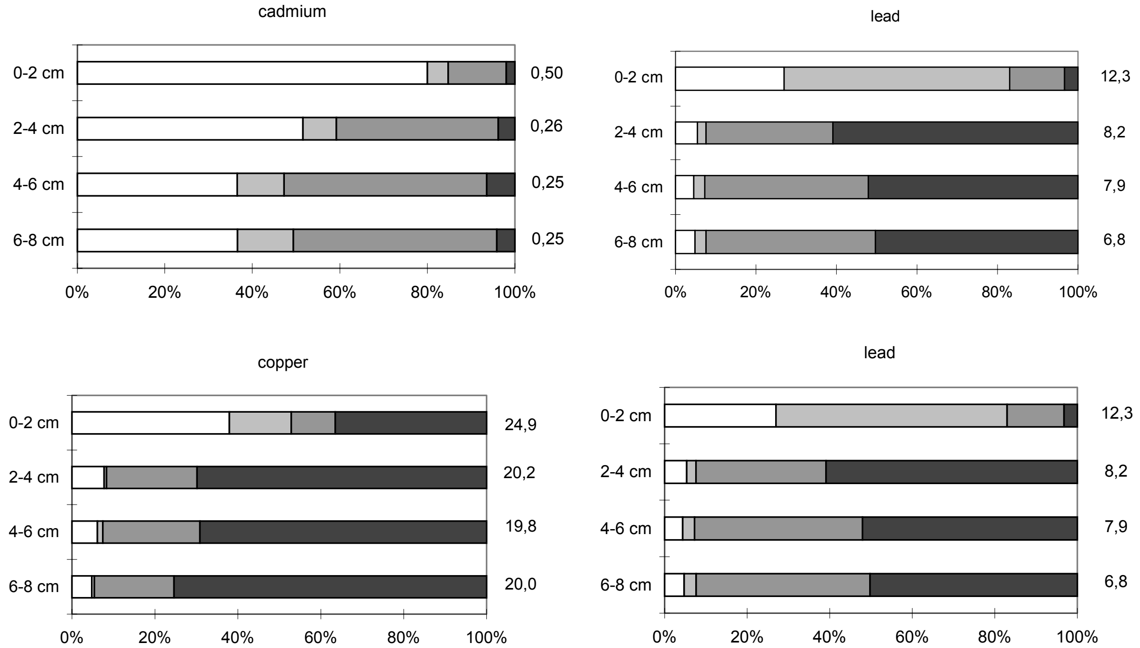

Fig. 5: Results of the sequential extraction of the porous concrete block after infiltration of 50-years loads of dissolved heavy metals in a test-rig

CONCLUSIONS

Porous pavements for stormwater infiltration from parking lots and residential streets show a very high effectivity to trap dissolved heavy metals in the runoff. Especially the pavement itself is responsible for the highest part of retention. Most metals are precipitated in the upper 2 cm of the porous concrete and can be mobilized by acids in the rain. But *pH* in effluent shows, that the buffer capacities of the concrete are very high, so that there is no danger of a mobilisation. In the subbase higher concentrations of metals were found to a depth of 20 cm for cadmium and lead and to a depth of 10 cm for copper and lead after charging the loads equivalent to 50 years in reality to the rigs. Metal concentrations in the effluent only reach the permissible limits at cadmium and copper, when very coarse material for the subbase is used. Most structures show no danger of groundwater contamination during the tests. So porous pavements out of concrete blocks constructed after the German regulations could be used without fear of a breakthrough of metals in a period of 50 years. Using other pavements like blocks with bigger joints or grass-filled blocks, the retention of metals in the structure should be less, because most metals were found in the pavement itself. With field tests over longer time periods the results have to be improved.

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