OPTIMISED TECHNICAL SAFETY MEASURES FOR ROAD CONSTRUCTIONS

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ABSTRACT

Using „alternative materials“ such as industrial by-products, ash from the incineration of domestic waste or recycled building materials always means to survey environmental aspects. The materials may contain pollutants which might be leached by percolating water. To avoid contamination of soil and groundwater, they have to be tested. The results of the tests allow to differentiate the use of alternative materials in road construction in applications with or without technical safety measures (TSM). TSM aim to prevent the leaching of the pollutants. By example, the sealings of waste sites are most widespread. Due to different requirements, the TSM have to be adapted to road construction.

To reach this aim and to determine economically and environmentally optimised TSM for road constructions, the Federal Highway Research Institute (BASt) launched a study. In indoor and outdoor experiments with a lysimeter, parts of embankments will be constructed. Different kinds of TSM will be realised and tested with regard to the amount of percolating water and the leached pollutants. Until now a first prototype of that special kind of lysimeter has been constructed and first tests have been done. When the prototype passes all our tests, the testing of the different TSM under indoor and outdoor conditions will follow.

1. BACKGROUND

Based on the „law for Federation highways“ (Bundesfernstraßengesetz) [1], the requirements of the environmental laws [2-4] as well as the state-of-the-art technology have to be fulfilled by the road administration. The implementation of all requirements for highways is given in detail in special road construction regulations.

„Alternative materials“ such as industrial by-products, ash from the incineration of domestic waste or recycled building materials are good, economical and popular building materials.

The environmental aspects concerning their use in road construction have to be considered when working out the road construction regulations. As a general principle, in Germany all alternative materials have to be tested before they might be used. The contaminant concentrations in the eluate and the solids content have to be measured. The concentrations have to comply with reference values, otherwise the use of the materials won’t be regularly allowed.

For some alternative materials there are different classes of limitation values. Regarding road construction, three categories of recycled materials are given in the „Technical Terms of Delivery for aggregates in road construction“ (TL Gestein-StB), named RC-1, RC-2 and RC-3. These categories are subjected to special requirements for the use of the materials. In the class of low limit values (RC-1) the use of the material is allowed in highway construction without further requirements. The use of RC-2 material is submitted to special requirements regarding the location of the highway. Using RC-3 material requires technical safety measures (TSM). These measures are established to avoid or minimise the leaching of pollutants from the building materials and the pollution of soil and groundwater.

The sealings are the most widespread TSM. The technical know-how concerning sealings arised from the construction of waste sites. There are considerable differences between a waste site and the construction of a road, because both have to meet different demands. Most important are the technical aspects. The embankment of the road construction is much steeper than the embankments of dumpsites, which means that there is more run off at road embankments. For reasons of static and dynamic stability, the materials need to be compacted very well. This often causes a low water permeability. Finally, the materials permitted for construction have only a very low contaminant content. Therefore, TSM have to be adapted for road construction.

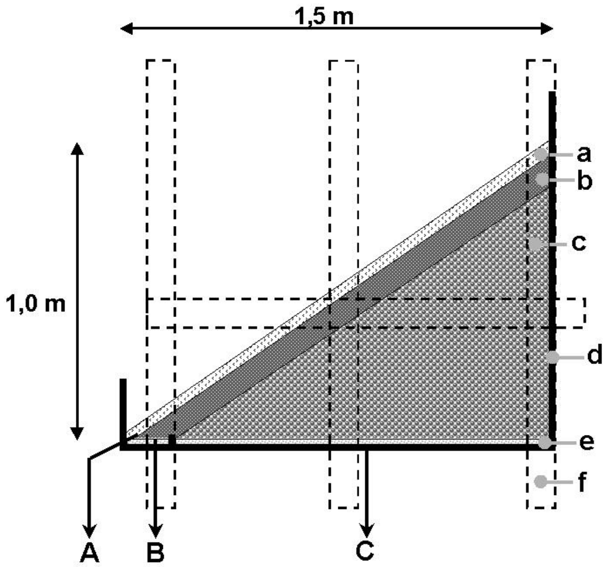
To reach this aim and to determine economically and environmentally optimised TSM for road construction, the Federal Highway Research Institute of Germany (BASt) launched a study. In indoor and outdoor lysimeter experiments parts of embankments be constructed. Different kinds of TSM will be realised and tested with regard to the amount of runoff and percolating water and the leached pollutants.

2. REALISATION

2.1. The Prototype of the lysimeter

Originally, the lysimeters were constructed to answer questions of agriculture optimisation and for water balance studies. The general lysimeter is a barrel which contains soil. It is open on top and at the bottom so that it is possible to collect the percolating water at the bottom of the lysimeter. Some instrumentation can be integrated in the lysimeter, for example to measure temperature or water content of the soil. The lysimeters are used by environmental researchers because they offer the opportunity to receive information about the properties of soil, for example the retention of pollutants.

For TSM related to road construction the lysimeter has to achieve new aspects. It is necessary not only to test the alternative building materials, but also to implement the typical form of embankments. The lysimeter has to have a size that corresponds to actual conditions to achieve represenative results. On the other hand it is not easy to perform full-scale test facilities because of the difficulties resulting from the preparation. So, after having analysed the documentation [5-16], the lysimeter shown in figure 1 could be realised.



a: lawn
b: topsoil
c: material to be tested
d: waterproof frame construction
e: drainage course
f: supporting structure

A: run off
B: interflow
C: percolating water

Figure 1- Prototype of the lysimeter, construction principles

2.2. The sprinkler irrigation facility

In the field different kinds of rainfall can occure. The amount of percolating water not only depends on the amount of rainfall but also on the intensity. Rainfall with a low rain yield factor normally causes a higher percentage of percolating water than rain with high rain yield factor. The sprinkler irrigation facility has to give the possibility to simulate different kinds of rainfall. Another condition on the sprinkler irrigation facility was to give a consistent rainfall intensity for the whole surface of the lysimeter.

Therefore, a facility consisting in a supporting structure and in a sprinkler head meeting the above conditions, was realised.

The sprinkler head serves as a water supply reservoir, which has the same size as the lysimeter. Water comes out through small cannulas, normaly used in medicine for syringes. Different rain yield factors can be chosen using two kinds of pumping systems, one for small ones and one for the higher ones. With this facility, rain yield factors from 7 l/s*ha (liter per second and hectare) up to nearly 900 l/s*ha can be reached, which is a very wide range of potential occurrences.

2.3. Drainage course

In the field, embankments are much higher than the small sample tested by the lysimeter. The soil in the lysimeter has only a relativ small height. Under real soil conditions - especially with soils of fine materials - exists a hanging water column, which reaches down to the ground water. To simulate the flow paths of water in the lysimeter near to real conditions, it is necessary to have the possibility to replace the connection to the ground water respectively the connection to this hanging water column. The arrangement to reach this aim is given in figure 2.

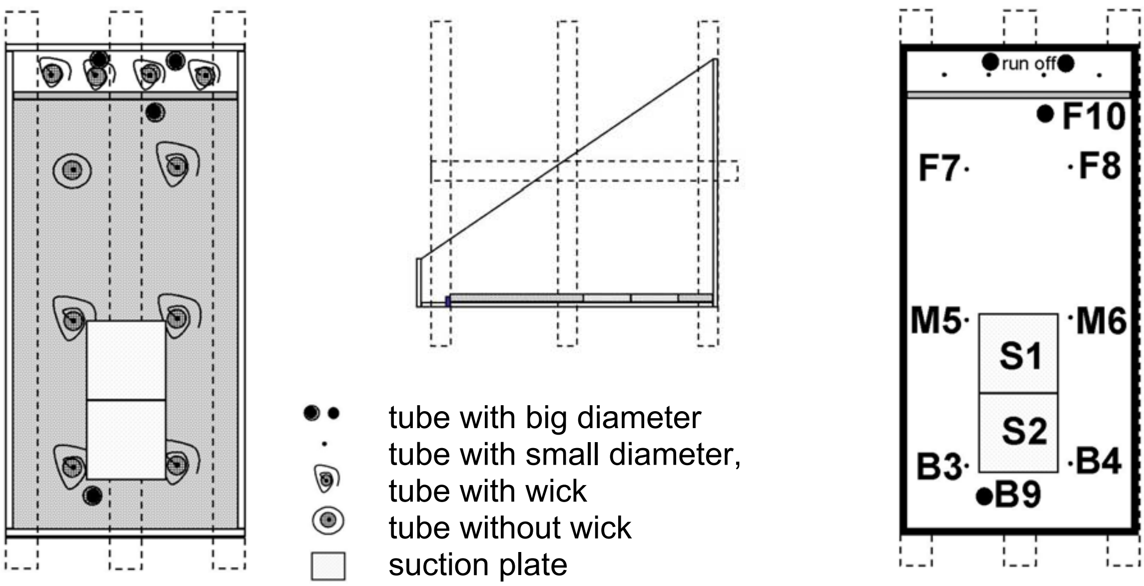


Figure 2 - Arrangement of drainage bed with tubes and suction plates at the bottom of the lysimeter

Two alternatives were tested with the protoype of the lysimeter. One method consisted in realising a sandy drainage bed under the soil. Percolating water gets out of this bed through tubes. Before the soil was filled in and compacted, the bed and the tubes are filled with water. The tubes end half a meter below the lysimeter. After the installation of the soil the tubes are opened. The aim is to connect the hanging water column of the soil to the hanging water column of the tubes.

14 tubes were connected with the bottom of the lysimeter. The task of the six tubes in the front of the lysimeter is to drain the run off. The task of the other tubes is to catch the percolating water.

Four tubes have a bigger diameter in order to make sure that high amounts of water can flow, to avoid retaining water at the bottom of the lysimeter (like F10 and B9). All small tubes except one (F7) got a wick to avoid that the hanging water column breaks.

The second alternative to catch the percolating water is to use suction plates. At the beginning of the study it was unsure that the suction plates could withstand the pressure for the compaction of the soil. The first tests were passed successfully.

2.4. Flow paths - border problems

The size of the soil particles used is 0/45. That might lead to the problem that percolating water takes untypical paths especially along the walls of the facility. To avoid this effect, the narrow gap along the border of the lysimeter was filled with quartz silt resp. bentonite as sealing.The principle is shown in figure 3.

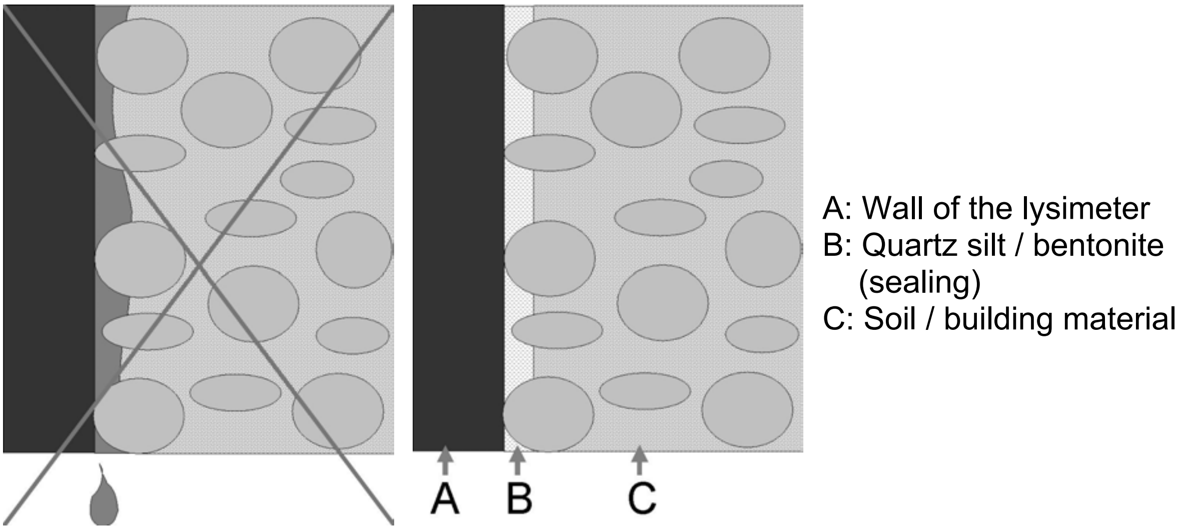


Figure 3 - Sealing with quartz silt / bentonite

2.5. Description of the soil

The soil used to test the lysimeter consists of gravel, sand and silt. The grading curve is given in figure 4.

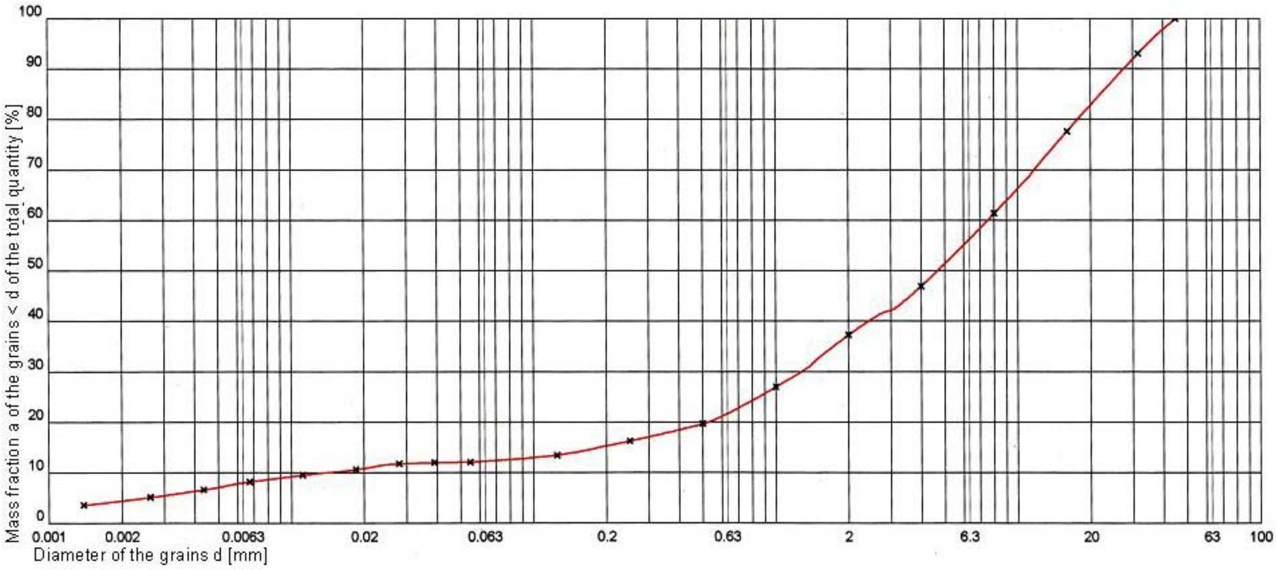


Figure 4 - Grading curve of the test soil

The permeability of the soil at proctor density is $3,7 \bullet 10^{-7}$ m/s. The aim was to obtain a compaction of 100% proctor density in the lysimeter. This was done by hand using sort of a masher as a compacting device. The thickness of the single layers was restricted to at most 12 cm to obtain a good compaction. The compaction was measured twice with a densitometer and determined with 98% proctor density and 102% proctor density, which corresponded to the above mentioned condition.

The lysimeter was covered with cultured lawn sods after the installation of the soil.

3. FIRST RESULTS

The first tests had to answer two main questions. The first aim was to test the lysimeter so that the results of the measurements could be plausible. The second aim was to find out the best way to collect the percolating water. For that the yield of the several outflow possibilities had to be analysed.

Two first tests were made to test the lysimeter and the sprinkler irrigation facility. One test was run with high rain yield factors but only short rain intervals, the second test was run with a low rain yield factor but a long raining interval. The rain yield factors, the duration of the rainfall and the amount of water that was collected at the bottom of the lysimeter are listed in Table 1.

Table 1 - Operating data of the first tests

Test 1			
rain yield factor (l/s*ha)	duration of rain (min.)	amount of rained water (l)	
887	2	10	(= 100%)
500	20	67	
115	30	23	
deplete the sprinkler head	after one day	13	
Test 2			
rain yield factor (l/s*ha)	duration of rain (min.)	amount of rained water (l)	
34	480	102 (= 100%)	

The run off and percolating water were collected and observed until steady state conditions. The results are given in table 2.

Table 2 - First Results

	run off	amount percolating water	amount of rained water	Calculated Rest
Test 1	51,5 %	29,0 %	100 %	19,5 %
Test 2	14,0 %	49,7 %	100 %	36,3 %

The run off in the first test is much bigger than that in the second test. The difference between the quantity of the collected water (run off and amount of percolating water) and the amount of rained water arises probably because of the evaporation of water. This probably had a much bigger importance in the second test.
The flow paths of the percolating water and the performance of the two different types of sealing will be tested with a dye tracer experiment soon.
The difference of run off in both tests is not quite unexpected. It is generally known that long time precipitation with small rain yield factors cause more percolating water and less run off. The longer raining time in the second test led to higher evaporation, which should be minimised in the future.

The second result of the tests is more important: The construction principle itself seems to be adequate for answering the questions. The lysimeter proved to be an efficient means to test different TSM.

Regarding the second question, different possibilites of collecting the percolating water were tested. First there were different sizes and positions of tubes. The tubes and their position in the lysimeter are shown in figure 2. The table 3 gives the results of the tests. In the first test the water caught by the small tubes (B3, B4, M5, M6, F7, F8) is collected together. Furthermore the water of the two suction plates and the water of the bigger tubes (B9, F10) is collected. So the outflow of the the big and small tubes as well as this of the suction plates could be evaluated separately. One can observe that the suction plates collected nearly the same amount of water (about 80%) as all tubes together (B3, B4, M5, M6, F7, F8, B9, F10) despite of having compared only the small sizes with the whole size of the lysimeter bottom .

Table 3 - Results of the collected percolating water

	S1/S2	B3/B4	M5/M6	F7 (without wick)	F8	B9/F10
Test 1	12,9 %	13,2 %				3,2 %
Test 2	20,6 %	1,0 %	0,2 %	27,0 %	0,1 %	0,7 %
		28,3 %				

In the second test each small tube outflow was collected separately. The results show, that most of the water is collected from tube number 7. This tube is the one without a wick. The position of this tube in the lysimeter is comparable to tube number 8. So it seems that the wicks in the tubes avoid the collection of water. The tubes number 9 and 10, which have a bigger diameter than the others don´t collect much water. So a small size seems to be useful. One can also see, especially in the second test, the good performance of the suction plates. Obviously, none of them had been damaged during compacting the soil.

Looking at the temporal distribution of the collected water during the testing time, more details can be found out. The figure 6 points out the stop of water when rainfall stops. The bigger tubes only collect water during the time of rainfall and shortly after, but not over a longer period. So do the smaller tubes. Only the suction plates collect water during the whole time of test 1. So, the suction plates seem to work properly even though the amount of avaible water becomes smaller.

The good work of the suctions plates is confirmed in the second test. The suction plates are the only collectors of water after the first day. The separated collection of the tubes‘ outflow clarifies the results of the first test. The bigger tubes only collected water for a short time, probably at the time most of the water has seeped through the soil of the lysimeter, so that there is a lower soil moisture tension. This effect is nearly the same for all other tubes. Even the tube F7, which collected the highest amount of water, stopped after the first day.
So, regarding the drainage of the lysimeter, it seems to be useful to install suction plates across the whole bottom of the lysimeter.

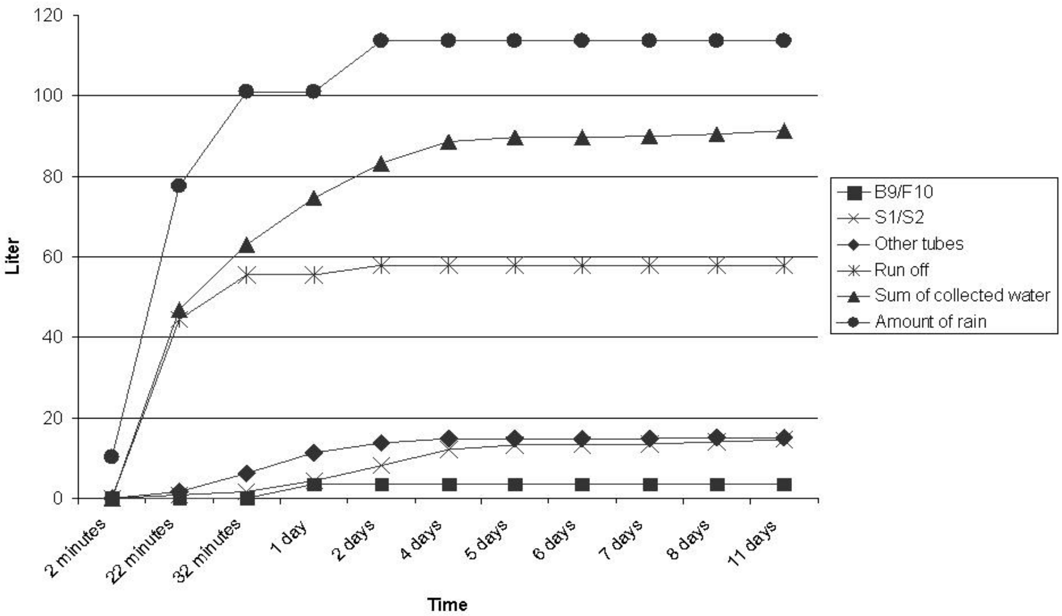


Figure 6 - Temporal distribution of the collected water - test 1

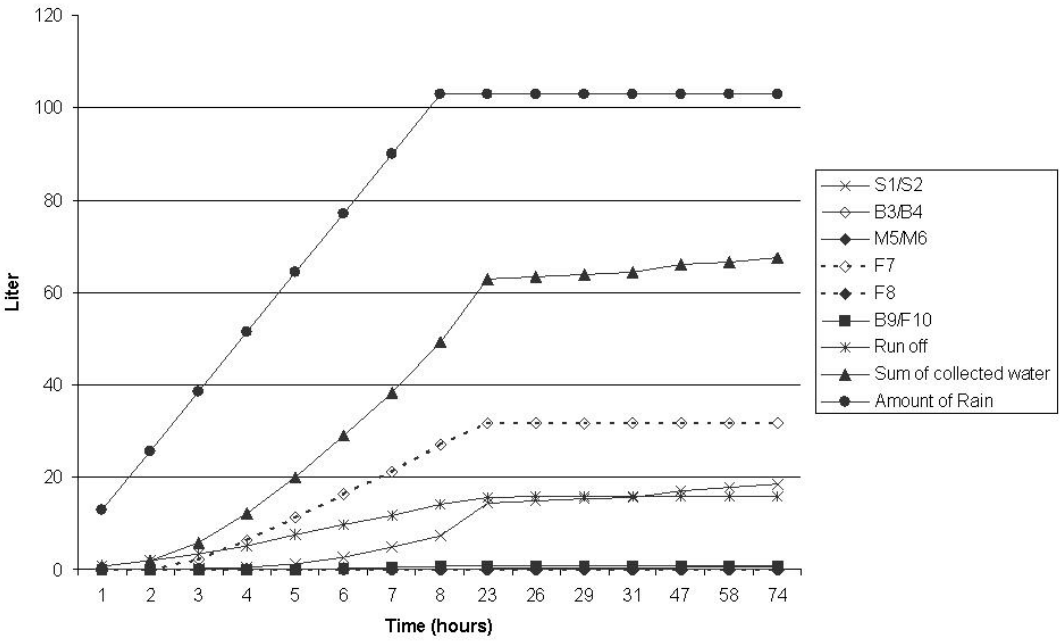


Figure 7 -Temporal distribution of the collected water - test 2

3. CONCLUSIONS

Using alternative materials in highway embankments might need the implementation of technical safety measures (TSM). A method for the comparison of different TSM and their optimal coordination according to the special requirements of highway construction will be developed. In the Federal Highway Research Institute of Germany a study has been started for the investigation of this topic. A lysimeter was designed to reproduce a section of a highway embankment. By the first tests that have been carried out it was possible to show the performance of a newly designed lysimeter. The results of the tests give hints how to optimise the lysimeter. Especially the protection against evaporation during the rainfall experiments and the collection of percolating water with suction plates are to be mentioned here. Indoor and outdoor lysimeter experiments will follow to test different TSM.

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