THE SLUDGEMATTRESS, A REMEDIATING ROAD

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ABSTRACT

In 2003 the Dutch Ministry of Public Works and Water Management called out a European contest: 'The Remediating Road'. In this contest, road infrastructure had to be used to remediate contaminated sludge. The combination GeoDelft and Royal Boskalis Westminster received an award with their concept 'De Baggerspeciematras' (The SludgeMattress). Realization and testing of a full scale pilot test took place between September 2005 and May 2007.

The SludgeMattress consists of a construction material from sludge which can be remediated during the lifetime of the road. The material is light so that settlements on soft soils are reduced. This makes The SludgeMattress economically competitive with sand. After removing crude materials the liquid sludge is converted into a strong and permeable stabilized foam using binding agents, foam and organic fibers. The SludgeMattress is permeable which makes remediation of the contaminated sludge possible. Rainwater percolates through the material washes out the contaminants. The contaminated leachate is cleaned in an ecological zone next to the road.

The paper describes the concept and its benefits. It provides a perspective over the economic and technical feasibility of large scale implementation of the concept. At PIARC 2007 the preliminary results of laboratory testing and the pilot test will be presented.

1. INTRODUCTION

The Netherlands have developed enormously during the past 50 years: The number of inhabitants has doubled to 16 million, the economy has expanded tremendously, standard of living has increased, and higher demands are posed on the environmental quality. The growing economy and the favorable geographic situation make the Netherlands a country of transport besides knowledge. These developments lead to mobility needs that require continuous attention for construction of new roads and broadening of existing ones, for increasing pressure on the environment, and for occupying the ever scarcely becoming space. The space is even decreasing further due to extraction of the primary building materials. Every year, 10-million cubic meters of sludge is dredged and for the greater part disposed off in large depots that require once more scarce space. No wonder that the reuse of sludge as a building material would save a lot of space and money for extraction and for storage. It would be even better if the dredging sludge could be cleaned during the life time of the road.

The Dutch Ministry of Public Works and Water Management initiated the innovation program “Roads to the Future”, in which “The Remediating Road” was part of. Roads to the Future aims on making road transport in the Netherlands perceptibly less congested, cleaner, safer, quieter, and more comfortable. By means of a competition, Roads to the Future called on market parties to provide ideas for a method by which contaminated dredged material could be used and cleaned under or next to road infrastructure [1].

In the spring of 2004 the Dutch Institute of Geo-engineering, GeoDelft and dredging contractor Royal Boskalis Westminster were one of the winners of the so called idea phase, with their concept ‘De Baggerspeciematras’ (The SludgeMattress). In the next phase the idea had to be worked out into a feasible design. With the patented design of The SludgeMattress [2] the consortium of GeoDelft and Royal Boskalis Westminster was one of two winners of The Remediating Road competition in the autumn of 2004. The winners of the design phase were offered to realize a full scale pilot to validate the design. The realization of the pilot is scheduled for the summer and autumn of 2005.

The SludgeMattress succeeds in realizing a durable, light weight road construction containing sludge as the elementary component. The SludgeMattress is built up using conventional working methods and routines while common biological principles remediate the contaminated sludge.

This paper first describes the basic principles of The SludgeMattress. The second section illustrates the stabilization into a light weight construction material. The following sections describe the remediation process of the SludgeMattress and the cleaning of the percolate water in an ecological shoulder zone. Finally the general benefits and a view on future developments and practices are given.

The poster at PIARC 2007 will give the preliminary results of laboratory testing and the pilot test.

2. BASIC PRINCIPLE

The concept of the SludgeMatress starts with the sludge itself, which with a type of vacuum cleaner is loosened from the water bed after which it is dredged or scooped up as a watery mixture. A dark yoghurt-like substance remains that is transported to the construction site by ship or pipeline.

The preparation of the construction site starts with building of bunds for receiving the sludge mixture. Within the bunds, a plastic liner is put in place for preventing escape of contaminants to the surroundings. On top of the plastic liner, a drainage layer of coarse sand is applied. During transport or on the construction site, the sludge is mixed with binders, decelerators, foam, and organic fibers. After addition of the initiator, the mixture is now squirted into the bunds. Within a couple of days, the sludge mixture has reached its strength sufficiently for finishing the road construction. The road construction consists of a drainage layer on top of the sludge bed, a foundation layer and a traditional pavement. Along side the road, infiltration wells provide contact with the drainage layer of the road. An overview of the road construction and the drainage system is given in Figure 1.

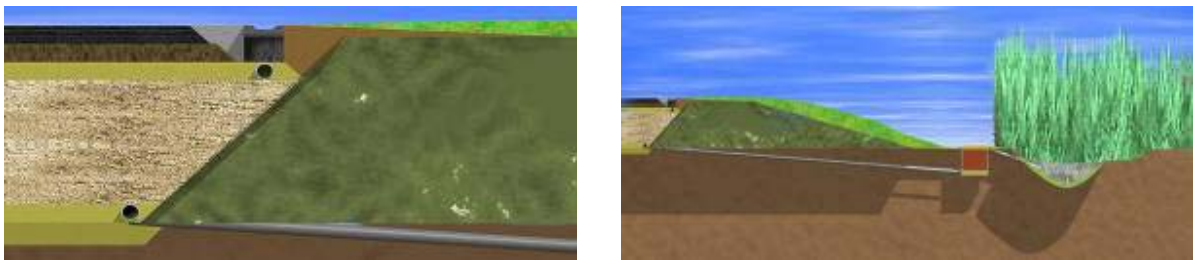

Figure 1 - Illustration of the road construction, drainage system and ecological zone

During the life time of the road construction the SludgeMattress is percolated with rainwater from the road surface. The water flow is driven through the system by gravitation. The drain construction collects the run-off water and distributes the water over the SludgeMattress. Water percolates through the canals and the micro-pores caused by the added foam and fibers respectively. The properties of the SludgeMattress allow remediation of the sludge. The binder in the mixture produces a high pH which initiates leaching and diffusion controlled processes. The percolating water collects the leached contaminants and the lower drainage layer takes care of further transportation into the ecological shoulder zone.

The shoulders of the road contain a maintenance-friendly and traffic-safe ecological zone, consisting of a filter construction with peat or turf, an anaerobic distribution ditch and a swamp area with accompanying vegetation. In this zone**,** the leached contaminants are adsorbed**,** immobilized or degraded so that finally clean water can be discharged to the surrounding surface water. The peat or turf filter neutralizes the pH and adsorb heavy metals and hydrocarbons. The final treatment in the anaerobic ditch and the swamp area (a halophyte filter) removes the remaining contaminants. Non-adsorbed heavy metals will be immobilized by the anaerobic phase of the ditch and the non-adsorbed organic compounds will be oxidized by a halophyte filter.

3. MATERIALS AND CHARACTERISTICS

3.1 Type of sludge

It is possible to vary the dosage of the additions in such a way that the mixture is tailored to the available sludge. Therefore the SludgeMattress is suitable for any type of sludge, even sludge with low sand and high silt contents.

3.2 Composition

The first mixing step exists of applying organic fibers, such as straws, hay or wood chips and applying foam. The organic fibers connect the micro-pores to the channels, produced by the foam. The foam makes the material light in weight. By adding the fibers in combination with the foam the permeability of the mixture increases significantly.

After this a binder and a decelerator is applied. The binder is a calcium oxide-based material. The decelerator is a surface-active compound that allows to process and pump the mixture during days. The sludge composition determines the mix ratio that ranges from 75 till 200 kg/m3 of binder, 3 till 4 kg/m3 of decelerator, 50 till 100 kg/m3 of foam, and 50 till 150 kg/m3 of organic fibers. After mixing, an initiator is added to bind the free amount of calcium oxide. The initiator and organic fibers also activate the leaching and diffusion controlled processes in the mixture.

3.3 Characteristics

A PMF (Polarization Fluorescent Microscopy) as shown in figure 2, reveals the mineralogy and the microstructure. The material contains quartz, carbonates, organic fibers, and Blast furnace slag cement. The material has a homogenous structure, and the pores are clearly visible.

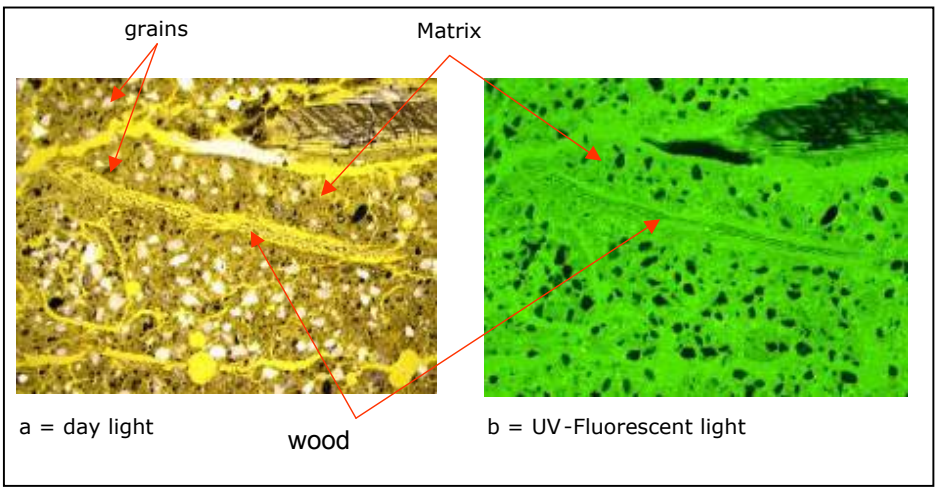

Figure 2 - PMF–picture 5,4 mm x 3,5 mm of Sludge Mattress material [3]

For feasibility, different sludge materials were tested containing different contamination levels from light to heavy according to Dutch regulations (class 1 and 3), and a low or high sand content. The final products were tested in triaxial cell on pressure strength, E-modulus, and permeability. Besides the triaxial test, the density was measured. The strength varied from 400 till 900 kPa (at 2% strain) and the E-modulus from 20 till 130 kPa dependent on amount of binder. The density varies between 1.100 till 1.300 kg/m^3 dependent on the amount of foam. The amount of organic fibers decreased the E-modules. With enough organic fibers, a permeability of 1 x 10^{-5} m/s could be obtained.

3.4 Remediation process

With the aid of Fick's Law [4] a first estimation of the efficiency, the remediation efficiency can be obtained. This shows that the available fraction for PAH can be leached in 2 years. For the available fraction of Zn, this can take up to approximately 18 years. Therefore, during the life cycle time of a road construction (>50 years) the SludgeMattress is remediated and turned into a regulated construction material.

3.5 The ecological zone

In the ecological zone leached contaminants are adsorbed, immobilized or degraded so that clean water can be discharged to the surrounding surface water. The ecological zone contains of three elements: a peat or turf filter, a connecting anaerobic ditch and halophytes filters. Figure 3 provides an overview of the remediation process.

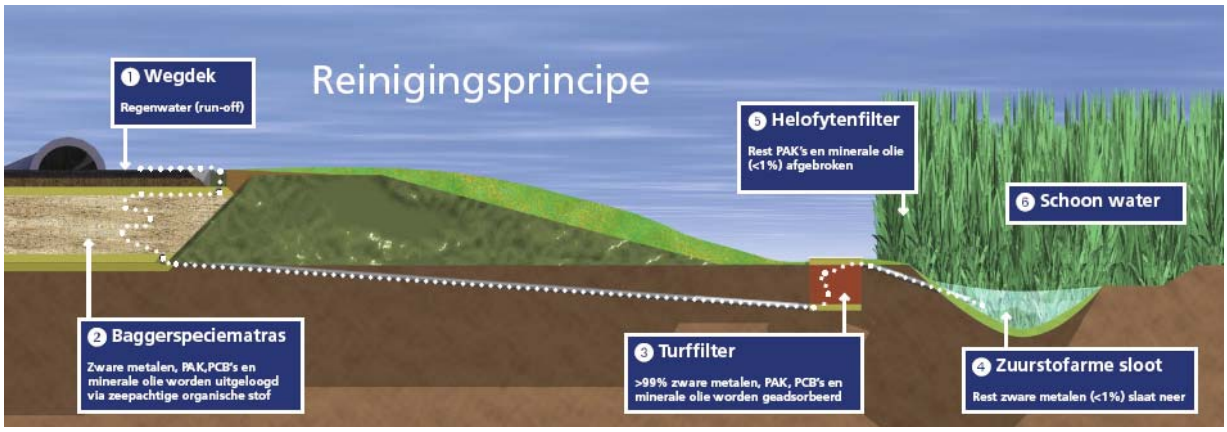

Figure 3 - Overview of the cleaning process

After leaving the SludgeMattress, using common used drainage techniques, the peat or turf filter neutralizes the pH to natural values. While the pH decreases, the organic colloids with the organic contaminants flocculate from the solution onto the peat. As shown by a calculation with Ecosat [8], the peat will also adsorb 99% of the heavy metals leached from the SludgeMattress. Although Arsenic is not expected to be leached from the SludgeMattress [9], Arsenic shows no adsorption in these calculations. If necessary, iron oxide can be added to the peat to enhance adsorption properties. In time, the peat needs replacement due to spend

buffer capacity. The peat material can be burned in regular waste incinerators. The heavy metals will concentrate in the incinerator ash.

The heavy metals which are still transported through the peat filter are treated in the anaerobic ditch. In this ditch, sulfate-rich organic manure is added. Sulfate reducing bacteria such as *Desulfovibrio* and *Desulfobacter* will grow under such conditions and reduce Sulfate to Sulfide. These sulfides remove heavy metals by precipitation from the ditch water. This concept has been demonstrated in the USA [10]. After this the anaerobic ditch distributes the water over the halophyte filters. These are sand filters planted with reed. In the halophyte filter, the root zone is used [11] to adsorb and/or biodegrade organic contaminants in an aerobic zone. Halophyte filters are already commercially used to clean household waste water.

3.6 Full scale pilot

During the summer of 2005 a full scale pilot started nearby the city of Beesd (the Netherlands), intended to be a part of the future broadening of Highway A2. The geotechnical conditions in this area are poor; with a traditional road construction significant settlements are expected to occur. The light-weight concept of the SludgeMattress can be tested fully in this way.

Figure 4 - Impression of the full scale pilot of the SludgeMattress (H. de Bont, Boskalis Dolman)

The pictures show, left to right, up to down the following: (1) realization of the drainage layer, (2) mixing installations, (3) bringing in the sludge, (4) the anaerobic ditch and halophyte filter, (5) peat filter, (6) the definitive road structure.

In total 800 m^3 of sludge is used. This resulted in approximately 1.200 m^3 of mixture. An increase of volume of around 50%. This 50% consists of 60% foam and 40% additives. The dry weight varies between 900 kg/m^3 and 1.100 kg/m^3 (saturated 1.100 kg/m^3 and 1.300 kg/m^3).

4. GENERAL BENEFITS

The general benefits of the SludgeMattress can be summarized as follows:

- The SludgeMattress combines a reuse of secondary materials (sludge) with savings of primary construction materials which are scarce in the Netherlands.
- Functional use of road infrastructure by adding remediation functionalities.
- Calculations for typical Dutch soil conditions show that the material is competitive with sand in an economic manner.
- Settlements of the road construction in soft soil regions can be reduced by 25%, compared to the traditional used sand as construction material.
- The total construction time on soft soils can be reduced by 30% when using the light weight SludgeMattress in stead of traditional construction methods.

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