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Utilisation of geological surplus masses in landfill cover: percolation results from pilot test

Utilisation de matériaux d'excavation dans les systèmes de recouvrement des sites d'enfouissement: résultats de percolation d'un essai pilote

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ABSTRACT: To minimize the generation of leachates and thus the contamination of the environment, landfills are usually closed using a cover system which includes a low-permeable hydraulic barrier. For landfills for ordinary and hazardous wastes, a common requirement is that the hydraulic conductivity of this layer must be less than $1x10^{-9}$ m/s. Compacted soil layers with natural dry crust clays have been used for this purpose in Norway. However, these soils are not always available within reasonable transport distances of landfills. An ongoing field-scale pilot test conducted at a landfill site in southern Norway therefore aims to evaluate whether a press filter residue from a soil-washing plant or an excavated cement stabilised clay could be used instead of natural-occurring clays. These two materials are normally considered wastes and currently have no application. Their reuse would therefore contribute to reduce the environmental footprint and the costs associated with their deposition in a landfill. Field results for a 6-month period (May 1st to October 31st, 2023) are presented and discussed in this article. These initial results indicate that the cover made of compacted dry crust clay is the most effective, but that the two alternative materials also fulfil the hydraulic conductivity target of 1×10^{-9} m/s. Overall, field measurements match well characterisation and hydraulic conductivity tests conducted in the laboratory. However, the difference in hydraulic conductivity between the dry crust clay and the reused materials is smaller in the field than in the lab. The environmental aspects regarding the reuse of these materials are yet to be evaluated.

RÉSUMÉ: Afin de minimiser la génération de lixiviats et donc la contamination de l'environnement, les décharges et sites d'enfouissement sont généralement restaurés au moyen d'un système de recouvrement comprenant une couche de faible perméabilité. En Norvège, les installations de stockage de déchets ordinaires et dangereux doivent normalement être recouverts d'une couche d'argile compactée ayant une conductivité hydraulique inférieure à 1×10^{-9} m/s. On emploie souvent des argiles glacio-marines altérées à cette fin, mais les matériaux adéquats ne sont pas toujours disponibles dans un rayon de transport raisonnable des décharges. Un essai pilote est donc en cours sur une décharge du sud de la Norvège afin d'évaluer si un résidu filtré provenant d'une usine de lavage de sols et une argile stabilisée au ciment excavée pourraient être utilisés à la place des argiles conventionnelles. Ces deux matériaux sont généralement considérés comme des déchets et n'ont actuellement aucune autre application. Leur réutilisation permettrait donc de réduire l'empreinte environnementale et les coûts liés à leur entreposage. Cet article présente les résultats de terrain pour une période de 6 mois, du 1er mai au 31 octobre 2023. Ces premiers résultats indiquent que la couverture constituée d'argile est la plus efficace, mais que les deux matériaux recyclés remplissent également le critère 1×10^{-9} m/s. Les résultats de ces essais de terrain confirment bien les caractérisations et tests de perméabilité réalises au laboratoire. Cependant, la différence de perméabilité entre l'argile et les matériaux recyclés est plus faible sur le terrain qu'au laboratoire. Les aspects environnementaux liés à la réutilisation de ces matériaux restent cependant à évaluer.

Keywords: Landfill; final cover; low-permeable barrier; compacted soil; reuse.

1 INTRODUCTION

Reducing the water percolation in a landfill is an important part of minimizing the generation of leachates and thus reduce the risk of contamination of the surrounding environment. Landfills are usually reclaimed using a cover system that includes a low-permeable hydraulic barrier, for example consisting of compacted clayey soil. For landfills for ordinary and hazardous wastes, the environmental authorities in Norway typically require this barrier to have a hydraulic conductivity lower than 1×10^{-9} m/s. This criterion is usually assumed to ensure that the annual percolation does not exceed 20 to 50 mm/yr (Avfall Norge, 2015).

A landfill for inorganic ordinary and hazardous industrial wastes, located in southern Norway, is currently planning its closure. Dry crust clays (DCCs), the weathered upper metres of marine clay deposits, have been used for the construction of a compacted soil layer (called sealing layer in previous associated papers) within the cover system for a closed part of the landfill. However, the availability of DCCs in the region is limited, and the landfill company therefore investigates possible alternative materials for the closure of the last part. Two clayey materials that are normally considered as wastes and deposited as such have been identified as potential alternatives. These include a clayey press filter residue (PFR) from a soil-washing plant, and a cement-stabilised clay (CSC) excavated from a construction site in the region. Several preliminary lab and field studies have, indeed, showed, that these two materials can achieve the target of 1×10^{-9} m/s, provided a sufficient compaction effort is applied (e.g., Kristensen, 2017; Pedroni et al., 2018; Ritter et al., 2023).

A large-scale pilot test is therefore being conducted in the field, complemented by a laboratory characterisation test program, to evaluate the in-situ hydraulic conductivity and properties of these two alternative materials as well as a dry crust clay (DCC). Pilot design and field results are presented in this article.

2 METHODOLOGY

2.1 Materials

Three materials were evaluated in this research: the DCC, the PFR and the CSC. The DCC was obtained from a construction site in Oslo, Norway. The PFR was produced at a soil-washing plant, being the clay- and silt-fractions separated from the coarser fractions of various excavated lightly contaminated sediments. The CSC came from another construction project in Oslo. All three materials have been characterised as part of this study, and earlier by Ritter et al. (2023). The particle size distribution was determined by the falling drop method (NS-EN ISO 17892-4:2016; NS, 2016), water content by loss on drying (NS-EN ISO 17892-1:2014; NS, 2014), compaction properties were determined from the Standard Proctor test (AASHTO T99-10; AASHTO, 2022), consistency limits were evaluated by Atterberg tests (NS-EN ISO 17892-12:2018; NS, 2018), the shear strength was determined from fall cone (NS-EN ISO 17892-6:2017; NS, 2017) and minature vane (ASTM D4648; ASTM, 2016), whereas the hydraulic conductivity was measured in oedometer and triaxial cells (NS-EN ISO 17892-11:2019; NS, 2019). Table 1 summarises the results from these tests. All lab hydraulic conductivities presented herein were measured at 40 kPa, equivalent to the 1.8-2 m overburden the compacted soil layers were subjected to. The entirety of permeability test results are presented by the companion paper by Kim et al. (2024).

Table 1. Hydrogeotechnical properties of tested materials (partly adapted from Kim et al. (2024) and Ritter et al. (2023)). Averages are in parantheses (). DCC = dry crust clay, PFR = press filter residue, CSC = cement stabilised clay.

Parameter	**DCC**	***PFR***	**CSC**
Clay content	42-48% (45%)	19-30% (25%)	4.5 – 35% (31%)
Water content	27 – 30% (28%)	31-38% (35%)	23-30% (29%)
Optimum water content	~22-25%	~28-30%	~24-27%
Plasticity index	17 – 22% (20%)	25%	18 – 31% (25%)
Liquid limit	42 – 45% (43%)	53 – 56% (55%)	41 – 65% (53%)
Remoulded shear strength	95 kPa	20 kPa	-
Hydraulic conductivity at 40 kPa	2.4 – 3.0 $\times10^{-10}$ m/s (2.7×10^{-10})	1.0 – 4.9 $\times10^{-9}$ m/s (1.8×10^{-9})	1.9×10^{-7} – 6.2×10^{-10} m/s (4.3×10^{-8})

The used DCC had a clay content of around 45%, a shear strength of around 95 kPa and an average (of 3 oedometer samples) hydraulic conductivity at 40 kPa of 2.7×10^{-10} m/s. The clay content of the PFR varied between 19 and 30%, with an average at 25%. Its shear strength was considerably lower than that of the DCC, with an average of around 20 kPa. Its average hydraulic conductivity (6 oedometer and 2 triaxial samples) was 1.8×10^{-9} m/s. The CSC was characterized by a significant variability of both its geotechnical and hydrogeological properties. For example, the measured hydraulic conductivity of undisturbed samples from the field (5 oedometer and 2 triaxial samples) was between 6.2×10^{-10} m/s and 1.9×10^{-7} m/s, over 300 times higher.

This heterogeneity may be attributed to the nature of the material, a mixture of cement, cement stabilised clay lumps and non-stabilised natural clay. The various parts were mixed during excavation, handling, and transportation, but seemingly far from homogenised.

2.2 Pilot design, construction and instrumentation

Four test cells were constructed as one continuous final cover about 14 m wide and 35 m long, with a cross-section as shown in Figure 1. A lysimeter, consisting of a permeable gravel placed on top of an impermeable geomembrane with a drain at the bottom, was installed at the base of each cell. All lysimeters were nearly quadratic and varied from about 11.5 m^2 to 14.5 m^2. The percolated water volumes were measured using tipping buckets (Campbell Scientific, 2023). The compacted soil layer was constructed (in three lifts/layers) by laying out the loose materials and compacting with a Cat D6 bulldozer (Caterpillar, 2023). A 13-ton rolling machine was then used to further compact and smoothen the surface of the third lift. The surface of the compacted soil was slightly inclined (approx. 1:16) towards the side of the cells (not towards the neighbouring cell). The compacted soil was covered by a 1.8-2.0 m thick protection layer of crushed limestone against climatic conditions and exterior alterations (freeze/thaw and drying/wetting cycles especially). The four different compacted soil layer designs consisted of (1) the DCC, (2) the PFR, (3) one lift of PFR and two overlying lifts of CSC, and (4) CSC alone.

A tipping bucket and temperature sensor was installed on top of the protection layer to measure the precipitation and air temperature. Teros 12 and 21 sensors (Teros, 2023) and a PT100 temperature sensor were installed at different depths in all cells to monitor temperature, volumetric water content, electrical conductivity, and matric suction. The construction and design of the pilot tests are described in more detail by Ånes et al. (2023).

Daily monitoring data from the 6-month period May 1st to October 31st (2023) were collected and analysed. Measured field percolation was compared with the laboratory characterization conducted on undisturbed samples (Kim et al., 2024).

3 RESULTS

Percolation volumes measured by the tipping buckets were normalised by the lysimeter area and expressed in equivalent millimetres.

The total precipitation during the considered 6-month period was 390 mm. The weather through the period was variable (Figure 2). Only 35 mm of precipitation were recorded in May and June, i.e., 1/5 of the total precipitation for the period. In contrast, July and August were particularly wet with 260 mm in total, while September-October experienced 95 mm. The average temperatures for the three two-month periods were 14.7, 15.9 and 10.9°C, respectively.

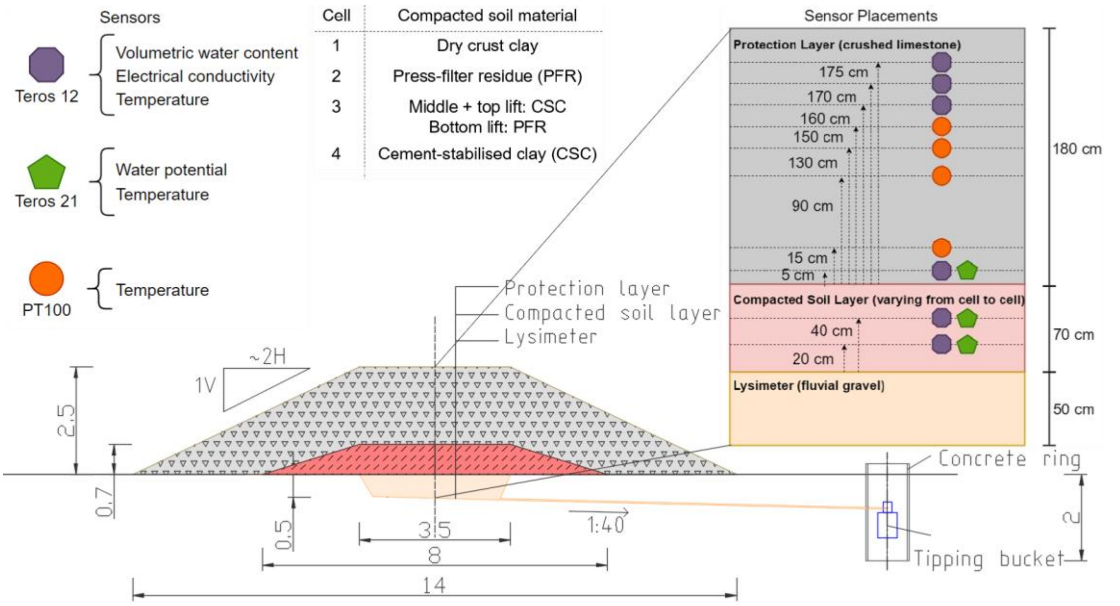

Figure 1. Cross-section drawing of the pilot final cover, including instrumentation. Dimensions for the final cover are in meters. Modified from Ånes et al. (2023).

The percolation through the alternative compacted soil layers (cells 2, 3 and 4) was around 7 mm (1.8% of precipitation), more than 2 times greater than in the cell with DCC (3 mm, 0.8% of precipitation). With an annual precipitation around 1000 mm (2.5 times the recorded precipitation for the monitoring period), the total percolation in cells 2, 3 and 4 was therefore expected to be between 8 and 18 mm/yr, i.e., below the target criteria (Avfall Norge, 2015).

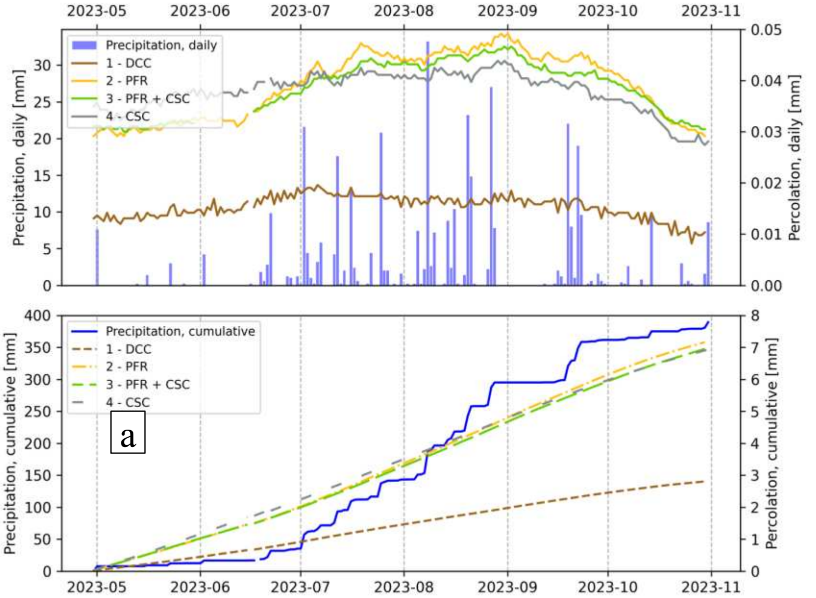

Figure 2. (a) Daily and (b) cumulative percolation and precipitation in each of the instrumented pilot cells from May 1st to October 31st. DCC = Dry crust clay, PFR = Press filter residue, CSC = Cement stabilised clay.

Considering the daily variations (Figure 2a), it may be noted that the effect of precipitation was different for the various compacted soil layers. The percolation through cell 1 plateaued early after the onset of the wet period (beginning of July), whereas the percolation through cell 2 and 3 continued to increase until the end of August when the wet period ended. The percolation in cell 4 varied less than in cell 2 and 3, being higher in the dry period May-June, and lower in July-October. It is not clear what caused this, but differences in material properties and degrees of saturation, and continuous reactions involving cement in the stabilised clay, are possible explanations. Additional tests and analyses are currently ongoing to further investigate potential mechanisms.

The degree of saturation of the compacted soil layers, measured using the water content probes installed in the pilot, was between 85% and 95%. Based on suction measurements, a conservative downward hydraulic gradient of 1 was assumed for all cells, leading to an estimation of the hydraulic conductivity between 2×10^{-10} m/s (cell 1) to around 4×10^{-10} m/s (cell 2-4).

The difference in hydraulic conductivity between the DCC and the PFR and CSC in the pilot was around 2 (towards 3 during the summer and fall), i.e. lower than in the laboratory where the average measured hydraulic conductivity of PFR and CSC were, respectively, 7 and 159 times greater than that of the DCC. The variability of the materials (especially CSC) may at least in part be the cause for these differences between lab and field results. The slightly lower degree of saturation in the field and/or variations in porosity in the laboratory may also be part of the explanation. Further investigations may be required to evaluate if the representativity of the lab samples and their size may be another reason for the observed differences.

4 CONCLUSION

A pilot test has been constructed at a landfill site in Norway to quantify the field-performance of final cover compacted soil layers consisting of various reused clayey soils.

Percolation and precipitation results from May 1st to October 31st showed that all the proposed compacted soil layers had a hydraulic conductivity lower than 1×10^{-9} m/s, and thus satisfied the criteria of hydraulic conductivity for compacted soil layers. The compacted soil layer with dry crust clay had the lowest hydraulic conductivity, which corresponded well with hydraulic conductivity tests conducted in the laboratory (Ritter et al. (2023) and Kim et al. (2024)) as well as with the higher clay content compared to the other materials. The compacted soil layers with the press filter residues and excavated cement stabilised clay were slightly more permeable than the DCC, but suitable, nevertheless. The hydraulic conductivities of CSC evaluated in the field were notably lower than the lab average, most probably because of the heterogeneity of the materials and scale effects influencing the lab results. Additional lab tests are ongoing to further assess the variations in field and lab, as well as the variation between lab samples of the same material.

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