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Approaches to investigate the crack formation of mineral landfill liner systems

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Abstract
The municipal landfill in Rastorf (Schleswig-Holstein) is covered with a temporary till based capping system. Investigations of structural changes (water conductivity, pore function, shrinkage behaviour) were carried out with undisturbed soil cores and two- and three-dimensional measurement techniques.

The usage of different techniques to evaluate the soil volume changes resulted in variations of the available water capacity (ver>ver+hor>3D) and the unsaturated hydraulic conductivity.

In summary, a critical matric potential between -500 and -1000 hPa in conjunction with a low shrinkage tendency (V_s < 5 %) could be seen as main argument for the utilization of till as sealing substrate.

Keywords: landfill capping system, shrinkage behaviour, critical matric potential

Introduction

In its function as pollutant sink, landfills still represent the major option for global waste disposal (Hoornweg and Bhada-Tata, 2012). In Germany, the qualitative criteria of landfills are legally binding and define the technical standards for engineered barriers according to the German landfill directive (2009).

At the end of the active sedimentation phase, the pollutant potential of the waste makes it necessary to immediately apply a temporary or final surface covering system.

The main requirements for a landfill capping system include the minimization of rainwater input (groundwater protection) and the prevention of landfill gas emissions (protection of the atmosphere) with regard to long-term functioning (Horn, 2002, Rowe, 2011). Therefore, (a) the recultivation layer in its function as vegetative layer and (b) the sealing layer as water and root barrier are essential components of the capping system to prevent the atmosphere and the groundwater of various pollutants.

A basic prerequisite of functional landfill capping systems is the hydraulic stability of the sealing layer due to weather-induced shrinkage processes that can lead to crack formation resulting in higher infiltration rates and leachate generation with environmentally degrading materials.

Consequently, the sealing layer in its function as last barrier above the waste body must exhibit hydraulic stability during drier periods by suitable selection of materials and the water content during installation (Horn & Stepniewski, 2004). The functionality of the sealing layer is decreasing due to crack inducing critical matric potentials when the mineral substrates dry out with matric potentials more negative than the driest field conditions and exceeded the pre-shrinkage stress (Horn and Baumgartl, 2002).

Material and Methods

The sealing layer of the Rastorf landfill (Schleswig-Holstein) consists of a compacted till (69 % sand, 24 % silt, 7 % clay) with an average dry bulk density between 1.67 and 1.84 g cm^{-3}.

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Therefore, the shrinkage induced volume change was estimated with undisturbed soil cores of 100 cm^3 at the drying stages of quasi-saturated, -30, -60, -150, -500 hPa with a suction plate and at -15000 hPa with a pressure pot and the soil cores were subsequently dried with 105°C for 24 hours.

Several non-destructive methods were used to quantify the soil volume change at the different drying stages according to Peng et al. (2006) and Seyfarth et al. (2012). These include:

- caliper (only vertical direction = ver),
- calliper and 2D image analysis (vertical and horizontal direction = ver+hor) in Fig. 1,
- 3D laser triangulation, considering the geometry of crack formation (3D) in Fig. 2.

Fig.1: Estimation of soil shrinkage via digital image analyses (Software Image J Version 1.4).

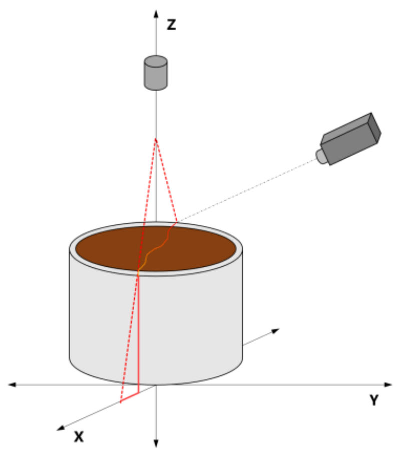

Fig.2: Estimation of soil shrinkage via laser triangulation device Soil LT 100TM (UGT, GmbH).

The volume shrinkage index (V_s) was calculated as follows:

$$\frac{V_{0\,hPa} - V_{105°C}}{V_{0\,hPa}} \qquad \textbf{(Eq. 1)}$$

where V_{0hPa} is the soil volume at the quasi-saturated stage and $V_{105°C}$ is the soil volume at 105°C (oven dried).

The shrinkage tendency (V_s) can be ranked into four classes: low (< 5 %), moderate (5-10 %), high (10-15 %) and very high (> 15 %) according to Vogt et al. (2013).

Results and Discussion

The results in Fig. 3 show significant differences between the only caliper method (ver) and the extended 2D image analysis (ver+hor) as well as the 3D laser triangulation (3D) with a V_s of 1.68, 3.74 and 4.24 %, respectively. So, the shrinkage tendency could be classified as low.

Furthermore, the estimated critical matric potential in a range of -500 to -1000 hPa should not be occurred, especially during dry summer months, to prevent crack formation in the mineral liner.

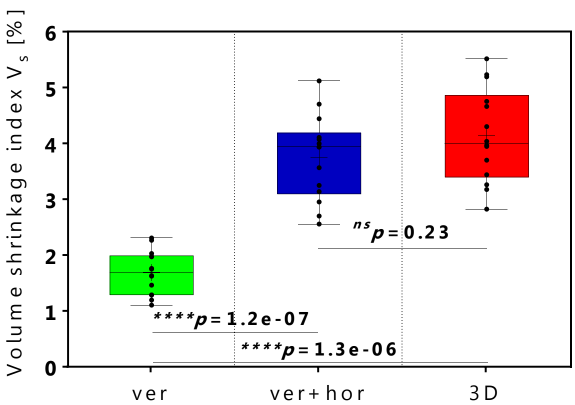

Fig.3: Volume shrinkage index (V_s) with significant differences (p<0.05) between the measurement methods.

Therefore, any desiccation being higher than the previously highest one (ψ_{mcrit}) moreover leads to irreversible shrinkage components and the crack formation will lead to higher infiltration rates and the leachate will increase and thus the transition to the proportional shrinkage phase should be avoided (Horn & Baumgartl, 2002).

The till shows a decreasing AWC with 6.78, 6.75 and 6.55 cm^3 cm^{-3} (ver>ver+hor>3D) with increasing soil volume change (ver<ver+hor<3D) (Fig. 3, 4).

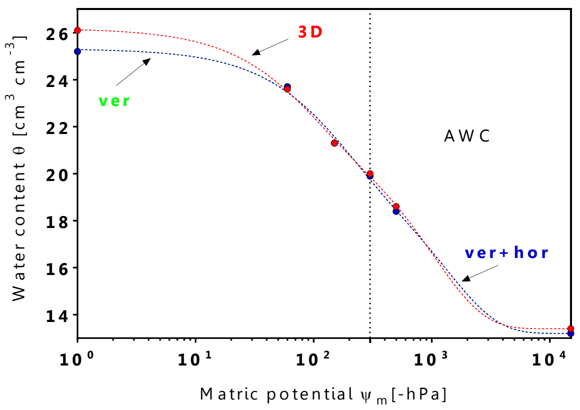

Fig.4: Effect of soil shrinkage on the available water capacity (AWC) of the mineral liner derived from sandy till with measured and fitted data (ver, ver+hor, 3D) by VAN GENUCHTEN formula (1980).

The curve patterns based on the VAN GENUCHTEN parameters (α, n, m) also underline the effect of soil volume changes on the hydraulic conductivity according to the applied measuring method (Fig. 5). In that regard, the parameter "α" increased and "n" decreased with increasing soil volume change.

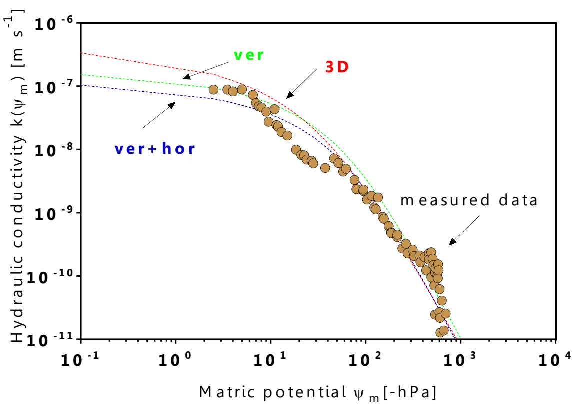

Fig.5: Effect of soil shrinkage on the hydraulic conductivity k(ψ_m) of the mineral liner derived from sandy till with measured and fitted data (ver, ver+hor, 3D) by VAN GENUCHTEN formula (1980).

Conclusion

The changes of the soil physical properties due to shrinkage processes cannot be excluded and are mostly irreversible. Therefore, deeply drained landfill capping systems quickly lose their hydraulic stability in combination with increasing leachate rates or rather a higher hazard potential for the groundwater.

In our case, the estimated critical matric potential between -500 and -1000 hPa should not be occurred, especially during dry summer months, to prevent crack formation in the mineral liner (Horn & Stepniewski, 2004). Therefore, the mentioned non-destructive methods were useful to quantify the soil volume change, especially the 3D laser triangulation, considering the geometry of crack formation according to Seyfarth et al. (2012).

Due to the verified volume change of the till, non-rigidity of soils should not be assumed, even for highly compacted soils with low shrinkage tendency, but the degree of the rigidy depends on the historical hydraulic stresses (Horn & Baumgartl, 2002).

An underestimating of the occurrence of soil shrinkage may result in incorrect data for modelling of hydraulic functions or changes of hydraulic properties of mineral liners due to climate change (Alaoui et al., 2011).

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