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Variation of crack intensity factor in three compacted clay liners exposed to annual cycle of atmospheric conditions with and without geotextile cover

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ABSTRACT

Performance of compacted clay liners commonly used as landfill barrier systems can be subject to decline in terms of hydraulic conductivity if left exposed to atmospheric conditions for an extended period of time prior to placement of overlaying layers. The resulting desiccation cracking can lead to increased hydraulic conductivity. Desiccation crack intensity was studied for three clayey soils commonly used for construction of landfill barrier system in a relatively large scale test setup exposed to real time atmospheric conditions over a complete annual cycle. A white separator geotextile cover was presumed to be capable of reducing the intensity of desiccation cracking through absorbing and maintaining higher amounts of moisture and reducing the temperature of the soil surface in comparison to a directly exposed soil surface. Desiccation cracking was monitored using a digital imaging technique for three compacted clay liners in two sets, one open to air and the second covered with the white geotextile. Crack intensity factor approached a relatively stable phase after certain cycles corresponding to atmospheric dry wet cycles. The results indicated that the white separator geotextile was capable of reducing the crack intensity factor by 37.4–45.9% throughout the experiment including the cyclic phase of desiccation cracking. During the stable phase, the maximum reduction in crack intensity factor of 90.4% as a result of applying geotextile cover was observed for the soil with the lowest plastic index and clay content and therefore the lowest magnitude of crack intensity factor. The other two soils with similar clay content but different plastic index showed 23.6% and 52.2% reductions in crack intensity factor after cyclic phase when covered with geotextile.

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1. Introduction

Landfills are commonly employed as a major waste disposal option in many countries. Major concerns associated with landfilling of wastes are leachate and gas emissions to the environment. Leachate generation rate in particular could be considerably different from one landfill to another due to climatic conditions as well as waste characteristics and disposal practice. A variety of barrier systems are used to minimize or practically eliminate leachate migration to subsurface soil and consequently to underlying groundwater systems if present. Geosynthetic barrier systems typically comprised of High Density Polyethylene (HDPE) geomembranes overlain on Geosynthetic Clay Liner (GCL) or compacted clay liner (CCL) have been used in accordance to landfill standards in many countries. However CCL is used in a number of situations where geosynthetic barrier systems are not feasible in particular due to higher associated costs. It could also be used as an alternative base to GCL in composite barrier systems.

Amongst the critical properties of a CCL liner are its low hydraulic conductivity (i.e. <10^{-9} m sec^{-1}), adequate strength to cope with installation and operational conditions and minimal susceptibility to cracking and shrinkage. Desiccation cracking commonly occurring in clay can have a significant adverse effect on compacted clay liners in terms of its mechanical and permeability requirements (Phifer et al., 1995). Albrecht and Benson (2001)

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found that hydraulic conductivity of some clay liners was increased up to 500 times as a result of desiccation cracking. Boynton and Daniel (1985) and Rayhani et al. (2007) also showed that hydraulic conductivity was increased orders of magnitude in consequence of cracking. Furthermore, desiccation cracking which is induced as a result of shrinkage forms mechanically weaker regions within the soil structure in turn leading to a reduced mechanical resistance and consequently increased compressibility of soil (Tang et al., 2010).

Landfill barrier systems can remain exposed to atmosphere long before leachate drainage layer and waste are put in place. The time throughout which a given landfill barrier is left exposed can vary from months to even years depending on a number of technical and or administrative issues. Exposure of CCLs to atmospheric conditions including daily temperature cycles, precipitation and evaporation results in formation of desiccation cracks which in turn reduce the effective thickness of the CCL and increase its permeability (Hewitt and Philip, 1999). This is particularly important in arid and semi arid regions where high evaporation and low precipitation rates make the liner more susceptible to desiccation cracking.

Desiccation cracking rate and crack dimensions have been shown to be governed by several parameters including pore water suction, grain size distribution, elastic properties, moisture content during compaction, temperature and wet–dry cycles (Hewitt and Philip, 1999). According to Fredlund and Rahardjo (1993), capillary forces resulting from loss of moisture can cause shrinkage in the soil mass thus facilitating suction. The suction in turn results in inter-particle tensions and reduces the soil volume consequently forming cracks. It was shown by Daniel and Wu (1993) that a four percent reduction in soil volume could result in initiation of cracks. Accordingly, adding coarse grains to clayey soils can reduce the extent of shrinkage and consequently size of the cracks (Hewitt and Philip, 1999; Holtz and Kovacs, 1981; Kleppe and Olson, 1985). However in cases where the soil is to serve as landfill barrier, this cannot be considered a desirable option to reduce crack intensity as it can in turn increase hydraulic conductivity of the soil.

After wet–dry cycles, hydraulic conductivity of clayey soil is increased with increasing plasticity index (Othman et al., 1994; Rayhani et al., 2007). In contrast to low plasticity soils showing only minor alteration of hydraulic conductivity due to wet–dry cycles, higher plasticity can result in formation of cracks leading in turn to increased hydraulic conductivity (Rayhani et al., 2008). Furthermore, clogging of cracks can also occur in low plasticity soils by particles washed through infiltrating liquid (Eigenbrod, 2003). However it was shown by Yesiller et al. (2000) that the percentage of fines in a soil is more important compared to plasticity index in terms of causing desiccation cracking.

Moisture content during compaction of clayey soils also affects the drying behavior and consequently desiccation cracking. Lower moisture content along with higher compaction energy minimizes the potential for cracking in the dry areas (Daniel and Wu, 1993; Hewitt and Philip, 1999).

Majority of studies on the effect of wet–dry cycles on liner performance indicated that hydraulic conductivity of clayey liners remains relatively constant after three cycles of wetting and drying (Albrecht, 1996; AlWahab and El-Kedrah, 1995; Omidi et al., 1996). This is while the first drying cycle in clayey soils results in irreversible alteration of soil texture since the interparticular bounds are broken and soil structure is weakened leading to shrinkage specifically after subsequent wetting (Yesiller et al., 2000; Yong and Warkentin, 1975).

Loss of moisture being the key parameter in desiccation cracking varies with temperature and relative humidity. The higher the temperature, the lower is the relative humidity of ambient air which in turn increases the moisture gradient between soil and adjacent layers of air resulting in increased evaporation and consequently increased potential for cracking (Tang et al., 2010).

The main objective of this study was to evaluate desiccation cracking in clayey soils typically used as landfill liners, when exposed to a full cycle of atmospheric conditions. Three clayey soils commonly used to construct landfill barriers were studied in a pilot scale experiment. Soils were compacted in relatively large volumes and were exposed to real atmospheric conditions over an entire annual cycle. Desiccation cracking was analyzed in three pairs of compacted clayey soils one of each covered with a commercially available geotextile. The effect of geotextile cover on desiccation cracking of the soils was evaluated. Results of the study are presented in this paper in details.

2. Material and methods

2.1. Soil properties

Three clayey soils were selected for this study in accordance with their dominant landfill applications in the semi-arid region of southern and western Tehran. The soils were acquired from borrow pits in three geographically distant cities of Kahrizak, Karaj and Varamin. Properties of the clayey soils are presented in Table 1.

2.2. Experimental setup

In order to evaluate desiccation cracking in compacted clayey material and analyzing the effect of geotextile cover on crack formation and properties, a relatively large scale pilot was designed

Table 1
Properties of three clayey soils studied.

Property	Test method (ASTM, 2001)	Unit	S1 Kahrizak	S2 Karaj	S3 Varamin
Specific gravity	ASTM-D854	–	2.75	2.7	2.75
Sand content	ASTM-D422	%	18	5	4
Silt content	ASTM-D422	%	49	81	72
Clay content	ASTM-D422	%	23	14	24
Liquid limit (LL)	ASTM-D423	%	55	29	39
Plastic limit (PL)	ASTM-D424	%	29	21	20
USCS* classification	ASTM-D2487		CH	CL	CL
Optimum water content	ASTM-D1557(A)	%	19.7	13.7	22.0
Maximum dry unit weight		kN/m^3	15.5	18.5	15.9
Hydraulic conductivity	ASTM-D5856	m/s	1.2E−7	2.5E−9	1.5E−8

CH: fat clay with sand.
CL: lean clay.
* Unified Soil Classification System.

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