

Behavior and influence of desiccation cracking in loess landfill covers

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Abstract: In the northwest region of China, loess was the main closure cover material of local landfills. Tests in a full-scale testing facility were conducted to investigate the behavior and influence of desiccation cracking in loess landfill covers. The desiccation cracks in the loess landfill cover intersected with T-shape, and the intersection angles were close to 90 degrees. The desiccation cracks formed as a result of drying, and would heal with the increase of moisture content of the loess. In addition, desiccation cracking in loess covers would promote the formation of preferential flow channels. As a consequence, the gas permeability of the loess cover was improved, and methane emissions increased obviously.

1. Introduction

Loess, widely distributed in the northwest region of China, was the main closure cover material of local landfills. As the loess landfill covers were exposed to the atmosphere, the unprotected loess layer was prone to damage from desiccation [1]. Moisture content in earthen covers would undergo significant changes due to seasonal variations in precipitation and evapotranspiration, and the wet-dry cycles were detrimental to the structure and service performance of the earthen covers [2-3]. Furthermore, drying causes shrinkage and subsequent cracking of soil.

Cracks not only reduced the strength and stability of soils, but also formed preferential flow channels for the transport of fluids. As a consequence, the hydraulic conductivity and gas permeability coefficient of the soil would be significantly promoted [4]. Desiccation cracking was dependent on various factors including moisture and density conditions, cycles of wetting and drying, temperature and fines content [5-7]. Drumm et al. (1997) indicated that the hydraulic conductivity of compacted clay barrier could be improved by wetting and drying cycles, and the hydraulic conductivity was increased by two orders of magnitude after two cycles of wetting and drying [4]. Yu et al. (2011) demonstrated that the hydraulic conductivity of soils would decrease along with the increase of dry density, and the permeability coefficient of basalt residual soil tended to be stable after 7 cycles of wetting and drying [8].

A full-scale testing facility, mainly composed of a compacted loess layer and a gravel layer, was constructed in northwest China. One and a half years after exposure to the open atmosphere, the geometric characteristics and distribution of cracks in the loess cover were measured and recorded. Furthermore, the contributing factors of crack formation and the effects of vegetation on soil cracking were discussed in this paper. In addition, methane (CH₄) emissions from the loess landfill covers were measured, and the influence of desiccation cracking on methane migration was analyzed.



2. Materials and methods

The testing facility was constructed on the slope between the 7th and 8th platform in the Jiangcungou landfill, which accepted all the municipal solid wastes from Xi'an. The test site occupied an area of 30 meters long and 20 meters wide, and followed a slope of 3H: 1V. The landfill cover consisted of 900 mm compacted loess layer and 600 mm gravel layer. Due to the limitations of the length of this thesis, a detailed introduction to the test facility was expounded by Zhan et al. (2016) [9].

The length and width of the cracks were measured by a steel tape, and the characters of branches of the cracks were recorded at the same time. It was pretty hard to measure crack depths directly, a thin iron wire was used as a test reference. The wire was inserted into the crack until part of the wire stuck into the soil, then the wire was pulled out to measure the length below the surface of the earth (L_0), and the crack depth was obtained using the L_0 minus the length of the wire which was wrapped up by loess.

The landfill gas, provided by the vertical wells in the landfill, was pumped to the base of the cover with a flux of $0.25 \text{ m}^3 \text{ LFG}/(\text{m}^2 \text{ h})$ and the volumetric concentration of CH_4 was about 30%. The methane emissions were measured by using static flux chambers with a laser methane detector (LMD, TGE-SA3C32A). And 9 test points were evenly arranged throughout the test area. The chamber used in this paper was made from polymethyl methacrylate, with a diameter of 0.5 m and a height of 0.5 m. And the portable LMD was placed at the side of the chamber. The methane emission flux was calculated using equation as follows

$$J_{out} = \frac{V}{A} \left(\frac{dC}{dt} \right) \quad (1)$$

Where J_{out} was the methane emission ($\text{m}^3 \text{ CH}_4 \text{ m}^{-2} \text{ min}^{-1}$), A was area (m^2) covered by the chamber, V was the volume of the chamber (m^3), and dC/dt was the slope of methane concentration versus time curve ($\text{m}^3 \text{ CH}_4 \text{ m}^{-3} \text{ air min}^{-1}$). The methane emissions measured by the portable LMD was consistent with the results of gas chromatograph (GC9800) as shown in validation tests in laboratory.

3. Results and discussion

Figure 1 shows the typical surface structural morphology of cracks in loess cover, and the contour of cracks is marked with red lines to make it easier to observe. The cracks intersected with T-shape, and the most intersection angles were close to 90 degrees. As there were no obvious parallel cracks in the loess cover, the crack type was identified as desiccation cracks. The length of the desiccation cracks in the loess landfill cover was mostly 0–150 cm, the width was 0–2 cm, and the depth was 2–26 cm. In addition, vegetation had obvious influence on the desiccation cracks. The growth of desiccation cracks was negatively related to the degree of vegetation abundance, and the extension of the desiccation cracks could be blocked by the root system of the grass. Furthermore, the desiccation cracks would heal with the increase of moisture content of the loess.



Figure 1. The surface structural morphology of cracks in loess cover

Figure 2 and Figure 3 illustrate the volumetric water content distribution in the loess landfill cover and the CH_4 emissions of 9 test points, respectively. The volumetric water content (VWC) in loess cover varied greatly in different seasons, and the VWC in summer was much lower than that in winter because of evapotranspiration (Figure 2). As a consequence, there were a number of desiccation cracks in the loess landfill cover in summer, while few cracks came into being in winter. As shown in Figure 3, the methane emissions from the loess landfill cover in summer were higher than that in winter. This was mainly due to the negative correlation between the gas permeability and the water content in the loess cover. In addition, the methane emission at test point 6 was much higher than the results of other test points, indicating the existence of preferential flow. Furthermore, as a result of the desiccation cracking of the loess cover, the methane emissions at test points 1, 6 and 8 increased significantly with the decrease of VWC in loess cover.

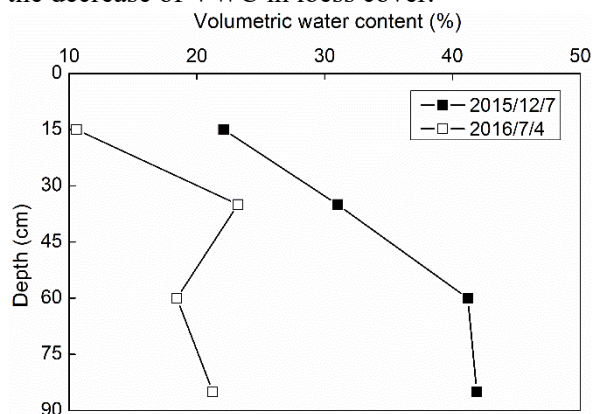


Figure 2. Volumetric water content profiles in the loess landfill cover

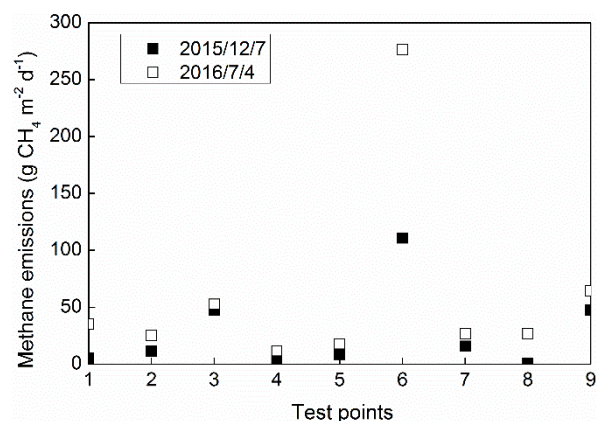


Figure 3. CH_4 emissions of 9 test points in the test area

4. Summary

The loess landfill cover, exposed to the atmosphere, would crack as a result of desiccation. However, the desiccation cracks would heal with the increase of moisture content of the loess. In this test, the extension of the desiccation cracks could be blocked by the root system of the grass, and the growth of desiccation cracks was negatively related to the degree of vegetation abundance. The desiccation cracks facilitated the formation of preferential flow channels for the transport of fluids. As the gas

permeability was improved by desiccation cracks, methane emissions from the loess landfill cover increased obviously.

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References

- [1] Daniel, D. E., and Wu, Y. K. (1993). Compacted clay liners and covers for arid sites. *Journal of Geotechnical Engineering*, **119**(2), 223-237.
- [2] Wan, Y., Xue, Q., Chen, Y. J., Zhang, Q., Zhao, Y., and Liu, L. (2013). Construction of consistent stability analysis model of landfill cover system and its application. *Chin J Rock Soil Mech*, **34**(6), 1636-1644.
- [3] Khire, M. V., Benson, C. H., and Bosscher, P. J. (1997). Water balance modeling of earthen final covers. *Journal of Geotechnical and Geoenvironmental Engineering*, **123**(8), 744-754.
- [4] Drumm, E., Boles, D., and Wilson, G. (1997). Desiccation cracks result in preferential flow. *Geotech. News*, **15**(2), 22-25.
- [5] Morris, P. H., Graham, J., and Williams, D. J. (1992). Cracking in drying soils. *Canadian Geotechnical Journal*, **29**(2), 263-277.
- [6] Nahlawi, H., and Kodikara, J. K. (2006). Laboratory experiments on desiccation cracking of thin soil layers. *Geotechnical and Geological Engineering*, **24**(6), 1641-1664.
- [7] Yesiller, N., Miller, C. J., Inci, G., and Yaldo, K. (2000). Desiccation and cracking behavior of three compacted landfill liner soils. *Engineering Geology*, **57**(1), 105-121.
- [8] YU, P., ZHANG, Z. F., WEI, H. Z., and MENG, Q. S. (2011). Experimental Study on Permeability Coefficient of Basalt Residual Soil Considering Influence of Drying and Wetting Cycle. *Journal of Water Resources and Architectural Engineering*, **5**, 014.
- [9] Zhan, L. T., Qiu, Q. W., Xu, W. J., and Chen, Y. M. (2016). Field measurement of gas permeability of compacted loess used as an earthen final cover for a municipal solid waste landfill. *Journal of Zhejiang University-SCIENCE A*, **17**(7), 541-552.