Centrifuge model study of municipal solid waste landslide under high leachate

Y. J. Hou i), R. Peng ii) and C. Wang iii)

i) Professor, Department of Geotechnical Engineering, China Institute of Water Resources and Hydropower Research (IWHR), 20, Che-Gongzhuang West Road, Beijing 100048, China.
ii) Ph.D Student, Department of Civil Engineering, Beihang University, 37, Xuyuan Road, Beijing 100191, China.
iii) M.S. Student, Department of Geotechnical Engineering, IWHR, Beijing 100048, China.

ABSTRACT

A centrifuge model is designed based on a representative section of China Shenzhen Xiaping Landfill, to simulate its landslide in June 2008, due to the high water level of leachate. The model waste material is introduced in this paper for simulating the real waste material. A water tank was set up inside the model container to control the water level inside the model. Model was tested at centrifuge acceleration of 90g and the result shows that large horizontal deformation and tension cracks appeared on the model slope, although there was no extensive sliding failure observed.

Keywords: geotechnical centrifuge, landslide, municipal solid waste, leachate

1 INTRODUCTION

Leachate is generated by the liquid in the municipal solid waste (MSW) as it arrives at the landfill and is augmented by rainwater (or snowmelt) prior to placement of the final cover over the waste mass [Koerner & Soong 2000a]. Though the leachate collection and removal system at the base of an engineered landfill was used to collect the leachate being transmitted through the waste mass, the research has shown that low permeability layers within the waste, such as daily cover soils, may lead to a significant amount of perched leachate within the waste mass [Korfiatis et al. 1984]. Of the many technical papers on the quantity of leachate within landfills, almost all of them focus on its generation, collection, removal, and recently on its reinjection for the purposes of accelerated degradation of the waste mass [Wang et al. 2006]. Few papers have addressed the influence of leachate on the stability of the waste mass, the exception being a few forensic papers dealing with waste failures. For example, Hendron et al. (1999) and Caicedo et al. (2002) independently concluded that high pore water pressures in the excessively wet waste body were mainly responsible for the instability and failure at Dona Juana landfill in Bogota, Colombia. Koerner & Soong (2000b) present ten large solid waste landfills and analyze their failure patterns, found that all ten triggering mechanisms involved excessive liquids and the buildup of pore pressures, and four of them is due to the leachate build-up in the waste mass resulting in the failure surfaces occurring above the low permeable soil or geomembrane liner that was at the base of the landfill.

Because of the high component of kitchen waste on municipal solid waste in China cities, it leads to a high leachate production, especially when discharge guiding layer clogged, or long-term drainage facility impeded. The leachate accumulated in the landfill causes higher water level in the landfill, which is seriously challenging the stability of landfill as described by Zan at al. (2012). The survey suggested that some of the existing landfills have landslides owning to the problems of higher leachate water level. For example, the monitoring data of China Shenzhen Xiapiing Waste Landfill in 2008 showed that the water level is as high as 2m in depth when the slope fails in June, 2008, and sometimes, the leachate even overflows on the landfill surface. Therefore, it is necessary to study the deformation characteristics and failure model of landslides in the landfill with high levels of leachate, for the prediction, evaluation, and prevention of the landfill slope failure.

Geotechnical centrifuge modeling had been widely used for the study of slope instability and deformation nowadays. There were several published studies that reported on groundwater fluctuations induced slope instability in centrifuge tests (Merry et al. 2005, Timpong et al. 2007). Previous studies by the authors were based on simple hypothetical steep slope models of inclinations of 60–90° (i.e., initially unstable slopes).
However, recent studies have paid little attention to made reference to a full-scale landslide. This paper presents the centrifuge study of a model municipal solid waste slope under increasing water level inside. The main objective of this experiment is to understand the influence of water level due to heavy rainfall or leachate accumulation, on the landfill slope stability. The centrifuge model test was carried out with the 450g-ton geotechnical centrifuge in IWHR.

2 PHYSICAL MODELLING

2.1 Preparation of model slope

The MSW is usually highly heterogeneous and variable in its content. It is therefore preferable to be able to perform the experiments using a model waste that can be reproduced under laboratory conditions and whose properties closely match those of real MSW. A model waste that has the main relevant physical and dynamic properties of real MSW by using the mixture of Irish moss peat, clay, sand and water was produced by Thusyanthan et al. (2006). In the same way, a model MSW was developed in this study by using a mixture of Fujian standard sand, kaolin clay and peat, the mass ratio of the above mentioned materials is equal to 1:1:1. By adding water to the mixture, the moisture content of the model material is about 45% and matches that of the prototype. China Fujian standard sand is fine sand with mean diameter of 0.17 mm, and the kaolin clay has a liquid limit of 56% and plasticity index of 24. Peat was reproduced from Chang-bai Mountain in Jilin province, China. It is the product in the process of swamp development, the organic matter content is more than 30%, texture is soft and is easy to be broken, and the specific gravity is 0.7 to 1.05. The model MSW mixture had a specific gravity of 1.3. Its coefficient of hydraulic conductivity is 6.6e-4 cm/s, and the shear strength results obtained from consolidated-drained tests using saturated specimens were $\phi_f = 28^\circ$ and $C_f = 7.3kPa$. The same mixture material was adopted in the experiment study by Peng et al. (2014).

The model was designed for simulating the slope failure of Shenzhen Xiaping landfill in China, with its geometry given in Figure 1. It consists of two layers. The upper layer is the model MSW, with bed rock on the bottom layer. Between those two layers, there is a simplified composite liner, which is made of geomembrane and nonwoven geotextile similar as in the field. The geomembrane was stuck on the bedrock and the nonwoven geotextile was laid over on the geomembrane. A rigid aluminum container with inner dimension of $135 \times 40 \times 90$ cm (length $\times$ width $\times$ height) was adopted for the model set up. The model bedrock was made of concrete and relatively impermeable. The model waste was placed on the bedrock layer by layer and slightly compacted to the required density. After the final compaction, the model waste was cut into a designed slope. At the upstream side of the model, there is a water tank to constantly supply water to the model waste. A toe drain was provided at the downstream of the slope inside the container to permit extra water releasing outside the container into the centrifuge chamber during the test.

Based on the geometry of prototype, the centrifugal acceleration is designed to be 90g, to simulate a prototype landfill with the maximum thickness of 39.6m.

For measuring the surface settlements of the slope, three laser displacement transducers were placed above the slope. Four pore pressure transducers were installed at the bottom of the model waster to measure the variation of pore water pressure during test. One pore pressure transducer P0 was placed at the bottom of water tank to indicate the water level of the reservoir. A high resolution camera was installed against the model section for observing and picture recording. Pictures token can be analyzed after the model test with the help of particle image velocimetry (PIV) technique.

![Test setup of the waste slope model](image)

**Fig. 1** Test setup of the waste slope model (unit: mm).

2.2 Test procedures and results

The centrifuge was subjected to a stepwise increased to the acceleration of 90 g where the model slope represents an approximately 108m length in prototype scale. Figures 2 and 3 present the monitored time histories of the surface settlements and pore water pressures during the centrifuge flight, respectively. The rapid increase of surface settlement and the pore water pressure of seepage tank were observed during the increase of acceleration level from 1 g to 60 g (from beginning to t1) and 60g to 90g (t1 to t2). Upon reaching the testing acceleration, raising the water level was simulated by introducing water into the water tank (at t2). The buildup of positive pore water pressure can be clearly observed as given in Figure 3, the inlet water supply was kept constant at 800ml/min (t2 to t3) and then the ground water level was raised up, it lasted approximately 7 min. Then the inlet water supply rate was raised up to 1,400 ml/min (t3 to t4). The ground...
water level was rapidly raised again, and the increases of surface settlement continue to develop. But the pore water pressure near the toe of the slope does not continue to increase, because the seepage water released from the toe of the slope. This process lasted for about 8min. When the inlet water supply rate was raised up to 2,000ml/min (t4), a significant increase of surface settlement was observed (L1) during this time. The rapid increase in the surface settlement was monitored just before the slope failure as given in Figure2, which is an interesting indication for predicting the occurrence of slope failure.

That the water gushed out from the tension cracks and caused flooding.

Due to the space limitation in the centrifuge basket, the camera can only be installed on the position to capture the middle area of the slope, as shown in Figure 5. Vectors of total displacement were plotted with PIV software, which reveals the landslide final slip surface and sliding area. It is clear that the displacement near the slope is significantly larger than that at the bottom of the slope. Figure 6 and Figure 7 illustrate the slope failure mode in the model after the test. Although the slope did not experience a large sliding failure, the tension cracks developed in the landfill also indicating the onset of sliding. The deep slip surface along the interface of geotextile and geomembrane in liner system was also observed. The slip distance is about 1 cm, when convert to the prototype, slip distance is up to 90 cm. And in central location of the model, Figure 6b shows that the lateral or horizontal displacement is the primary deformation of the waste body. With the rising of the water level inside the slope, the waste moves along the weak zones inside the slope at the beginning and finally sliding along the bottom interface. Large deformation accumulated at downstream of the slope, and a little uplift was observed at the slope toe.

Back calculations were performed using the measured pore water pressure data from the P1, P2, P3 and P4 to establish the variations of ground water level in the model slope, as shown in Figure 4. The buried depth of the water level is about 2.5cm (2.25m in prototype) when raising the water level by introducing water into the inlet supply at 2000ml/min. It is noted that flooding was observed near the toe of slope (t3 to t4) thus the back-calculated ground water level seems to be higher than the slope surface. This is probably due to the fact...
3 REMARKS

Centrifuge model was designed and tested to simulate the landslide of Shenzhen Xiapng Landfill. The high leachate level was found to be closely correlated with the slope failure of the landfill in June, 2008. The test results in this paper show that the water level rising in the model was the main reason that leads to large displacement in the model waste. The tension cracks on the slope also indicate the onset of instability. The test results will compare with the field monitoring data and may gain more understanding with the help of numerical analysis.

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