ARTICLE IN PRESS

Waste Management xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Waste Management

journal homepage: www.elsevier.com/locate/wasman

Geotechnical properties of municipal solid waste at Laogang Landfill, China

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ARTICLE INFO

Article history:
Received 29 January 2016
Revised 13 August 2016
Accepted 14 September 2016
Available online xxxx

Keywords:
Municipal solid waste
Landfill
Geotechnical properties
Shear strength
Hydraulic conductivity

ABSTRACT

Landfills have been widely constructed all around the world in order to properly dispose municipal solid waste (MSW). Understanding geotechnical properties of MSW is essential for the design and operation of landfills. A comprehensive investigation of geotechnical properties of MSW at the largest landfill in China was conducted, including waste composition, unit weight, void ratio, water content, hydraulic conductivity, and shear behavior. A large-scale rigid-wall permeameter and a direct-shear apparatus were adopted to test the hydraulic conductivity and shear behavior of the MSW, respectively. The composition of the MSW varied with age. With the depth increasing from 0 to 16 m, the unit weight increased from 7.2 to 12.5 kN/m^3, while the void ratio decreased from 2.5 to 1.76. The water content ranged between 30.0% and 68.9% but did not show a trend with depth. The hydraulic conductivity of the MSW ranged between 4.6×10^{-4} and 6.7×10^{-3} cm/s. It decreased as the dry unit weight increased and was sensitive to changes in dry unit weight in deeper layers. Displacement-hardening was observed during the whole shearing process and the shear strength increased with the normal stress, the displacement rate, and the unit weight. The friction angle and cohesion varied from (15.7°, 29.1 kPa) to (21.9°, 18.3 kPa) with depth increasing from 4 to 16 m. The shear strength of the MSW obtained in this study was lower than the reported values in other countries, which was caused by the less fibrous materials in the specimens in this study. The results in this study will provide guidance in the design and operation of the landfills in China.

1. Introduction

A large amount of municipal solid waste (MSW) is generated everyday around the world. Landfills have been widely constructed to dispose MSW (Dixon and Jones, 2005; Zhan et al., 2008; Reddy et al., 2009a, 2011; Machado et al., 2010). For example, approximately 54% (USEPA, 2007) and 90% (Zhan et al., 2008) of waste are landfilled in the United States and China, respectively. Design and operation of landfills are challenging in geotechnical engineering. The complex geotechnical properties and mechanical behavior of MSW have caused some geotechnical problems in landfills, such as slope stability, cracking, settlement, and leachate seepage (Stark et al., 2000; Koelsch et al., 2005; Merry et al., 2005; Zekkos, 2005). Understanding the geotechnical properties of MSW is essential to address the above problems.

Geotechnical properties of MSW, such as composition, unit weight, hydraulic conductivity, shear strength, and compressibility, are essential for landfill design. Landva and Clark (1990) were the pioneers to study the geotechnical properties of MSW. In the past decades, great efforts have been made to investigate these properties (Jessberger, 1994; Gabr and Valero, 1995; Kavazanjian et al., 1995; Powrie and Beaven, 1999; Pelkey et al., 2001; Zhu et al., 2003; Vilar and Carvalho, 2004; Dixon and Jones, 2005; Zekkos, 2005; Jain et al., 2006; Zhan et al., 2008; Bray et al., 2009; Reddy et al., 2009a, 2009b, 2011; Stark et al., 2009; Machado et al., 2010; Castelli and Maugeri, 2014; Babu et al., 2015). The properties were mainly determined through in-situ tests, laboratory tests, and back-analysis.

The geotechnical properties can differ substantially from one region to another due to different waste compositions, climate conditions, operation styles, testing methods, and so on. The values reported in the literature vary over a wide range. For example, the friction angle and cohesion reported by Landva and Clark (1990) were 24–42° and 16–23 kPa, respectively, those by Eid et al.

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http://dx.doi.org/10.1016/j.wasman.2016.09.016
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(2000) 35° and 0–50 kPa, respectively, those by Bray et al. (2009) 36° and 15 kPa, respectively, and those by Reddy et al. (2009a) 26–30° and 31–64 kPa, respectively, based on direct shear tests. The hydraulic conductivity can vary from 3.0×10^{-9} to 0.8 cm/s (Korfiatis et al., 1984; Chen and Chynoweth, 1995; Powrie and Beaven, 1999; Jang et al., 2002; Penmethsa, 2007; Reddy et al., 2009b). Obviously, it is necessary to study the properties of MSW for different regions.

The unit weight, water content, void ratio, and compressibility of MSW highly depend on waste composition. Shear strength is important for the design of lateral and vertical expansion of landfills, and is a function of waste composition, unit weight, water content, void ratio, degradation rate, and stress level (e.g., Dixon and Jones, 2005; Zhan et al., 2008; Babu et al., 2015). Hydraulic conductivity is important since it affects leachate circulation, and hence the distribution of pore-water pressure and effective stress, and consequently shear strength (Dixon and Jones, 2005; Hossain and Haque, 2009). Therefore, most existing studies focus on shear strength (e.g., Zhan et al., 2008; Bray et al., 2009; Babu et al., 2015) and hydraulic conductivity (e.g., Powrie and Beaven, 1999; Hossain et al., 2009; Reddy et al., 2009b). It is important to have a comprehensive understanding of the geotechnical properties of MSW.

The objective of this study is to conduct a comprehensive investigation of the geotechnical properties of the MSW at the largest landfill in China. Geotechnical properties, including waste composition, unit weight, void ratio, water content, hydraulic conductivity, and shear behavior were studied by field investigations and laboratory tests. A large permeameter and a direct-shear apparatus were adopted to determine the hydraulic conductivity and shear behavior of the MSW, respectively.

2. Landfill site and sample collection

Laogang Landfill is located in the Pudong District of Shanghai, approximately 60 km from the center of Shanghai. It is China's largest landfill, receiving about 5000 tons of MSW on a daily basis, approximately 70% of the MSW disposed in Shanghai (Wu and Wang, 2013).

In this study, tested materials were sampled directly from Laogang Landfill. Leachate used in the hydraulic conductivity tests was collected from a drainage pipe at the leachate collection sump (Fig. 1a). MSW samples of different ages were collected and tested. At Laogang Landfill, the MSW at a depth from 0 to 7 m was approximately 0.3 year old; 7.5 m to 14.5 m, 2 years old; and below 15 m, 4 years old. Therefore, the samples collected at depths of 0, 4, 11 and 16 m were 0, 0.3, 2 and 4 years old, respectively (Table 1). Three fresh MSW samples were collected from the working phase of the landfill. The landfilled MSW was sampled when installing the gas collection well. Each sample was 0.3 m^3. A schematic of the sampling positions is shown in Fig. 2. Three boreholes were used for sampling. The borehole was drilled using a large-diameter bucket auger rig (0.8 m in diameter and 1.5 m in length). Once completing each advancement, the bucket was retrieved from the boring and emptied near the drill rig. Considering the age of the MSW, the MSW at depths of 4, 11, and 16 m were collected for determining in-situ unit weight and further testing. When the auger rig reached the desired depth, the MSW in the bucket was weighed. The volume of the MSW was determined by the borehole diameter and the advance depth. The in-situ unit weight was then easily determined. Due to various compositions and particle sizes, some MSW was torn out from the borehole wall, resulting in the calculated unit weight being somewhat larger than the real value.

The components of the fresh sample could be easily recognized (Fig. 3a). The 0.3-year old sample decomposed slightly, and the fibers were finer than those of the fresh sample (Fig. 3b). The 2-year old sample was notably darker, and the moisture content was higher (Fig. 3c). It was difficult to identify components of the 4-year old sample (Fig. 3d) since the sample has experienced long-term degradation.

3. Testing apparatus and method

3.1. Waste composition and physical properties

The in-situ unit weight of the MSW could be determined based on the volume and weight of the material taken out from the borehole. Some of the MSW was collected (0.3 m^3 for each sample), sealed in plastic bags and taken to the laboratory for further testing. Hence the samples for the later tests were reconstituted. The

Fig. 1. Sampling process at Laogang Landfill: (a) leachate sampling; (b) MSW sampling.

Please cite this article in press as: Feng, S.-J., et al. Geotechnical properties of municipal solid waste at Laogang Landfill, China. Waste Management (2016), http://dx.doi.org/10.1016/j.wasman.2016.09.016