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Field and laboratory investigation on geotechnical properties of sewage sludge disposed in a pit at Changan landfill, Chengdu, China

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ABSTRACT

In order to find a proper treatment method for a sewage sludge disposal pit, field and laboratory investigation were conducted on the geotechnical properties of the sludge at the Changan landfill in Chengdu, China. The field investigation included borehole sampling, cone penetration tests and vane shear tests. The laboratory study involved the measurements of volume–mass relation, hydraulic conductivity, compressibility, coefficient of consolidation and shear strength for the borehole samples taken from the field. The field investigation revealed that the sludge in the disposal pit could be subdivided into three layers, i.e., top crust layer, middle fluid-like layer and deep soft plastic layer. The vane shear strength for the sludge was less than 1 kPa at the fluid-like layer, and 1 and 3 kPa at the deep soft plastic layer, being significantly lower than that of soft clay. Laboratory test results demonstrated that the sludge was high in organic content (18.5% to 51.8%) and water content (from 210% to 790%), and both of them exhibited a decreasing trend with depth. The variation in the organic content indicated a difference in the degree of biodegradation for the sludge at locations. The consolidation property and shear strength of the sludge exhibited a non-linear relationship to the applied consolidation pressure. The coefficient of consolidation of sewage sludge, decreasing with increasing consolidation pressure, was in an order of 10^{-5} cm^2/s to 10^{-6} cm^2/s, being 1–2 order lower than that of soft clay. The friction angle for the sludge increased from 10° for the pressure range from 0 to 100 kPa to 15° for the pressure range from 100 to 400 kPa.

1. Introduction

Significant growth in population and economy has occurred in China since the 1990s. This growth has resulted in a rapid increase in the quantity of municipal solid waste and sewage sludge. Sewage sludge is the colloidal sediments generated from wastewater treatment, and it contains harmful pollutants of microorganism, pathogen and heavy metals. Fig. 1 shows the annual generation of dewatered sewage sludge with a solid content of 20% in China over last decade. It is estimated from the amounts of annual treated municipal wastewater (China EPA, 2011) and a survey of dry sludge generation ratios by Zhu et al. (2005). The disposal methods of sewage sludge in different countries include landfilling, incineration, composting, air-drying and stockpiling (Arulrajah et al., 2012). It is estimated that about 65% of the mechanical dewatered sewage sludge in China was disposed in landfill (Wang et al., 2010). The landfill disposal of sewage sludge in China includes two ways, i.e., mono-landfilling and co-landfilling.

In 2000s, co-disposal of sewage sludge in the landfills of municipal solid wastes was quite popular in China. The common-used procedures include finding a depression, building an embankment, and then dumping the fluid-like sludge in the pit. Sometimes the filled-up of municipal solid wastes were used as the embankment, and the sludge pit was adjacent to the waste mass. This kind of co-disposal was observed in many landfills in China, e.g., Shenzhen Xiaping landfill, Suzhou Qizishan landfill, Chengdu Changan landfill.

Fig. 2 shows two sludge pits located within the dumping area of Chengdu Changan landfill. The dumped sludge was high in water content (about 550%) and low in undrained shear strength (less than 1 kPa). The sludge pits were usually deeper than 10 m, and exposed to atmosphere and rainfall without any cover. This way of co-disposal will cause safety problem to the landfill operation. The waste mass adjacent to the sludge pits may lose stability, and hence the operation near the pits is dangerous. In addition, the further filling of municipal solid wastes on the closed sludge pits is very dangerous. Most of the sludge pits were temporary set-up, and the landfill operators tried to use the pits as a further dumping area to reach the design height of the landfill. An accident was reported to have been happened to the Shenzhen Xiaping landfill in 2009 due to the above reasons (Zhan et al., 2010). The filling of 15 m thick municipal solid wastes on an untreated sludge pit caused a movement of the downstream embankment, and resulted in 40,000 m^3 sludge surging out like a volcano and flowing to the downstream area. After the accident, many landfill operators were seeking effective treatment methods for the extremely soft sludge pits. Characterization of engineering properties for the disposed sludge is the first step to find a proper treatment method. This is the background for the field and laboratory investigation of the sludge pit at the Chengdu Changan landfill presented in this paper.

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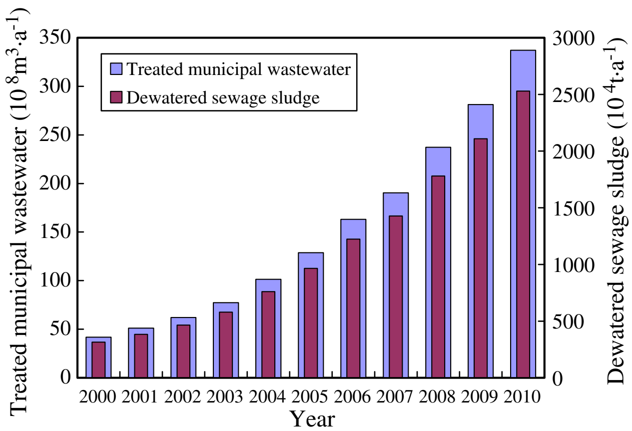

Fig. 1. Generation of municipal wastewater and dewatered sewage sludge in China.

Previous investigation on engineering properties of sewage sludge was mostly performed in the laboratory and on the fresh sludge samples. Wang et al. (1992), Klein and Sarsby (2000) and Lo et al. (2002) carried out laboratory investigation on the shear strength property of dewatered sewage sludge for the slope stability of sludge landfill. O'Kelly (2008a) studied the consolidation behavior of sludge to determine the proper dewatering level required for an efficient disposal. Moo-Young and Zimmie (1996), Kraus et al. (1997) and Diliūnas et al. (2010) measured the hydraulic conductivity of different kinds of sludge to investigate the viability of using them as impermeable landfill final covers. Karla et al. (2011) measured the hydraulic conductivity and shear strength of a paper mill sludge to investigate the feasibility of using it as an alternative impermeable landfill liner. Chu et al. (2005) conducted a model test to study the consolidation behavior of cement-treated sewage sludge using vertical drains. Arulrajah et al. (2011, 2012) studied chemical and engineering properties of wastewater biosolids, which refers to dried sludge with water content of 48%–57%. Disfani et al. (2013) investigated the possible risks of using biosolids in road embankment fills and the relevant parameters for determining the biodegradation settlement, such as organic content, pH and electricity conductivity of the biosolids. As far as the authors are aware, field investigation on the sludge dumped in a pit for several years has not been reported. In addition, the properties of sludge quite depend on the wastewater source and treatment methods, and hence the site-specific study is required.

This paper presents a comprehensive field and laboratory investigation on the geotechnical properties of the sewage sludge filled in the pit at Chengdu Changan landfill. The field work included borehole sampling, vane-shear tests and cone-penetration tests. The laboratory tests involved the measurement of physical properties, hydraulic conductivity, compressibility, coefficient of consolidation, and shear strength on the 56 samples taken from different depths of 5 boreholes.

2. Site description

The Changan landfill is located in Luo-dai of Chengdu, China. It was put into operation in 1993, and was designed to serve for 17 years. The Changan landfill was designed as two phases: the first phase was located at south-west of the landfill (See Figure 2), and had a storage capacity of 11.35 million m^3. Until August 2009, the first phase of the landfill reached its design capacity. The second phase was located at north-east of the landfill and had a storage capacity of 20.74 million m^3. It was put into operation in 2009. To May 2011, the landfill was receiving MSW at a rate of about 3000–5000 t/day.

Within the design dumping area of the second phase, two temporary pits were built for disposing sewage sludge in 2008. As shown in Fig. 2, the large one, being about 350 m in length, 100 m in width, 15 m in depth, has a storage capacity of 530,000 m^3. Its bottom and inwall was lined with HDPE geomembrane and GCL. The sludge pit was put into use in 2009, and received sewage sludge at a rate of about 400 t/day. The sewage sludge with a water content of about 560% was directly dumped at the east corner of the pit and spread out by gravity flow (shown in Figure 2). Until May 2011, the sludge pit was filled with about 450,000 m^3 sludge. The sludge pit was exposed to atmosphere and rainfall without any cover. The local climate belongs to subtropical moist climate, and annual rainfall in Chengdu is about 1000 mm. The small pit has a size about 1/3 of the large one, and it is not the object of this study.

In 2015, the dumping of municipal solid wastes will be performed on the large sludge pit because no other space is left in the second phase of the landfill (see Figure 3). Owing to the safety problem, the landfill operator tried to treat the extremely soft sludge in the pits to meet the strength requirement. There are many ground improvement methods for the soft clay. However, the engineering properties of the sewage sludge were supposed to be quite different from that of a soft clay, i.e.,

Fig. 2. Aerial view of Changan landfill and layout of sludge pits.