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Laboratory investigation of artificial lumpy materials

X.S. Shi *, I. Herle [1]

Institute of Geotechnical Engineering, Technische Universität Dresden, D-01062 Dresden, Germany

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ABSTRACT

For the excavated clayey cover of a coal seam in open-pit mining, the shear strength is the most important issue after its deposition in landfills. For this purpose, an artificial lumpy material was investigated in this paper. A transition form between a reconstituted soil and natural lumpy soil governs the mechanics of the soils artificially deposited after the excavation. This paper presents triaxial and oedometer tests (including K_0 and isotropic consolidation tests conducted in triaxial cell) both on an artificial lumpy soil and its corresponding reconstituted form. Compression, permeability and strength of lumpy materials have been evaluated. When normalized by Hvorslev pressure, the shear strength of both lumpy materials and reconstituted soil lies on unique lines, with strength parameters of the lumpy materials lower than that of the reconstituted soil. Both the consolidation and triaxial test results indicate that the reconstituted soil, which exists in the inter-lump voids, plays a crucial role in the behaviour of lumpy materials.

1. Introduction

Large amounts of lumpy materials are generated in human activities, such as clayey landfills deposited in mining process (Masin et al., 2005; Najser et al., 2010), bentonite pellets used in HLR (high-level radioactive) waste isolation (Alonso and Hoffmann, 2005; Hoffmann et al., 2006) and dredged clay fills used in land reclamation (Karthikeyan et al., 2004; Robinson et al., 2005). A lumpy clay comprises two distinct pore systems: an inter-lump voids system created by clay lumps and an intra-lump voids system created by soil particles or aggregates.

A landfill of clayey overburden is an evident example associated with a double porosity system (Hollinderbaeumer and Kraemer, 1994; Bohac et al., 2003). In many parts of the world, the large-scaleopen-cast coal mining has resulted in depositing the clayey overburden in non-engineered landfills (Herbstova and Herle, 2009; Najser et al., 2012). These kinds of landfills usually reach depths of several tens of metres. The clayey overburden soils have been dumped without any compaction in the form of lumps and blocks ranging in size from millimetres up to about tens of centimetres (Figure 1(a)) (Masin et al., 2005). After several years from filling, mainly due to the influence of climate, gravitational effect and precipitation, the originally high inter-lump porosity clays in landfills tend to become relatively homogeneous soils (Figure 1(b)). However, even more than 10 years after filling, their corresponding double porosity still remains (Masin et al., 2005; Najser et al., 2010, 2012).

There are many factors which influence the stability and deformation of lumpy landfills, such as the shear strength of lumps and structure of fills. As investigated by Herbstova and Herle (2009), the shear strength of clay lumps is influenced by matric suction, overconsolidation and diagenetic processes. Naturally, there is an unsaturated zone in the clayfills, however, e.g. Herstus (1999) pointed out that the upper layer (8–22 m) is influenced by partial saturation and continuous air phase. When the rainfall is abundant, this zone would turn to be saturated due to the drainage path created by macrovoids. Therefore, this paper considers saturated soils only.

An artificial lumpy material is investigated in this paper. As a transition form between the reconstituted and natural lumpy soil, it plays an important role in explanation of the strength and permeability properties of natural lumpy materials. Compared with reconstituted soils, it has a double pore system. However, the shear strength of the tested material is lower than that of a natural lumpy material. There is no ageing effect in this artificially prepared soil; therefore the shear strength of lumps is controlled only by their porosity linked to overconsolidation.

Three topics will be investigated in this paper: (1) The permeability of the lumpy material, (2) the strength and compression behaviour of the lumpy material and its comparison with that of the reconstituted soil and (3) the structure transition of the lumpy material during compression and shearing processes.

2. Material properties and preparation of a lumpy sample

The material investigated in this study is a silty clay, which was sieved with a mesh diameter of 2 mm to exclude coarse grains from

* Corresponding author. Tel.: +49 351 463 34838.
E-mail addresses: Xiusong.Shi@mailbox.tu-dresden.de (X.S. Shi), Ivo.Herle@tu-dresden.de (I. Herle).
URL: http://tu-dresden.de/biwigt/grundbau/ (I. Herle).
[1] Tel.: +49 351 463 34248.

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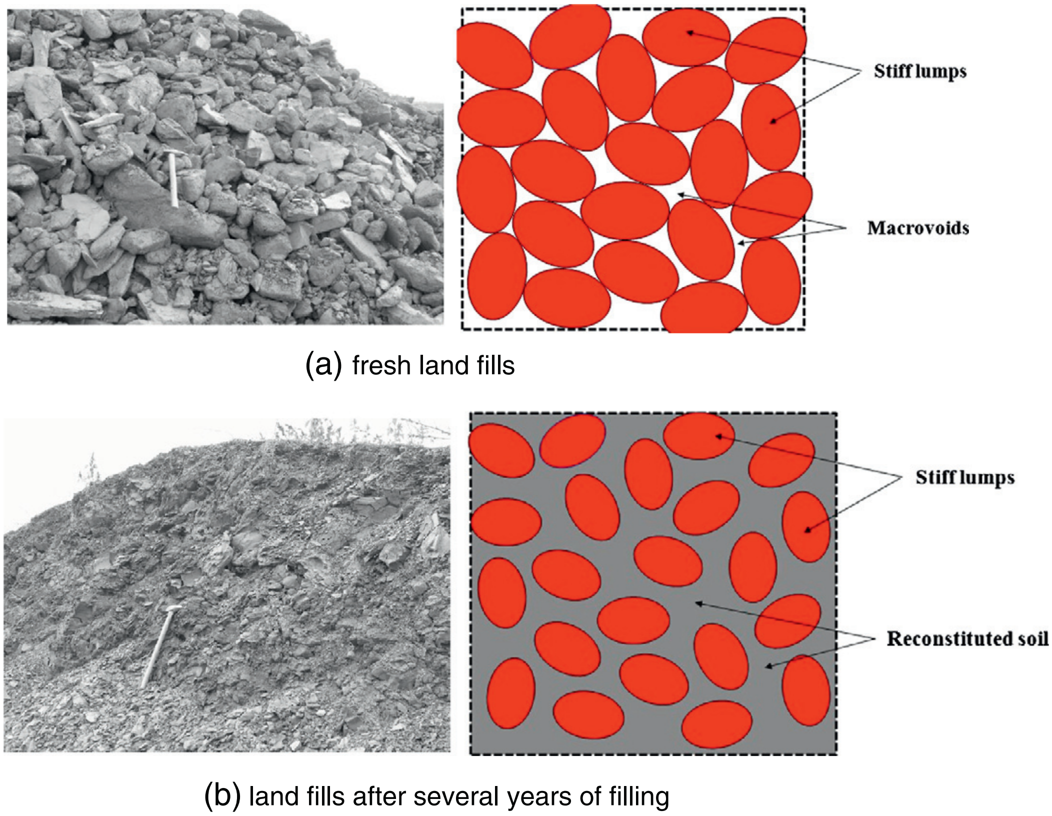

Fig. 1. Structure transition of natural landfills (Masin etal., 2005) and its simplified model (the stiff lumps in the lower right figure are smaller than the original sizes in the upper right figure). (a) Fresh landfills. (b) Landfills after several years of filling.

the natural soil. The silty clay was used in this study due to the fact that the unsaturated clay on the surface can disintegrate fast into a reconstituted soil, which reflects the structure processes of the natural landfill material in the field. In this way, time effect can be included in the laboratory. The basic physical properties of the soil are shown in Table 1. After being mixed with water, the slurry was poured into a consolidometer and then consolidated to 140 kPa by gradually adding slotted weights on the weight hanger. The duration of each load increment was 24–48 h.

The preparation of an artificial lumpy soil started by reconstituting of the soil and its consolidation in the consolidometer. After being fully consolidated, the specimens were extruded out from the consolidometer, and trimmed into 8 cm in height. In order to reflect the actual stress state of the stiff clay excavated from underground, a high pressure triaxial cell was used, which can reach a maximum cell pressure of 13 MPa.[2] The soil intended for the lumpy specimens was consolidated under an effective mean stress of 4000 kPa or 13,000 kPa respectively for 2 days, and then freely swelled under 30 kPa for 1 day, as shown in Fig. 2. Therefore, the swelling of the triaxial specimen took place before creating the lumps from it.

Finally, the soil was taken out from the triaxial cell and cut carefully into pieces with a maximum size of 5 mm. The cutting procedure can be seen in Fig. 3. In order to distinguish the particle grain sizes of the artificial lumpy material, the pieces were sieved through several different mesh sizes as shown in Fig. 4. For specimens used in the triaxial tests, the lumpy material was sieved through three different mesh openings (5 mm, 3 mm, 1 mm), while the pieces for oedometer tests were sieved with four different mesh openings (4 mm, 3 mm, 2 mm, 1 mm). The

Table 1
Basic physical properties of the reconstituted silty clay.

Density of particles g/cm^3	Liquid limit %	Plastic limit %	Clay %	Silt %	Sand %	Gravel %
2.70	32.6	19.4	18	70	10	2

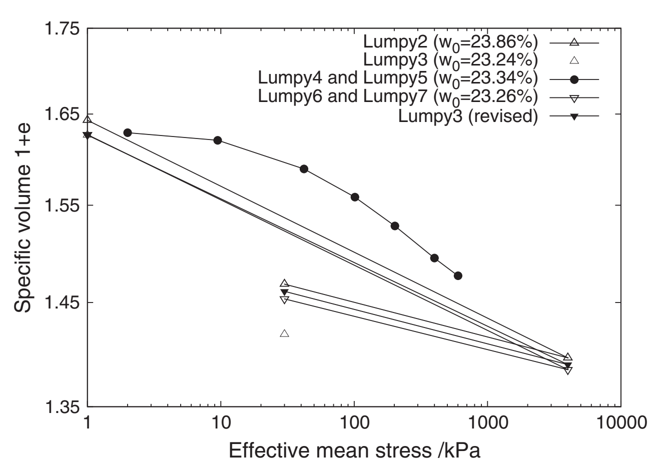

Fig. 2. Preconsolidation of specimens used for the preparation of an artificial lumpy soil in terms of specific volume–consolidation stress relationship in double logarithmic plot.

[2] E.g. in the Most Basin the original thickness of the sedimentary soil is as much as 550 m, and the subsequent denudation could range from 70 to 300 m. Hence, the preconsolidation pressure of the excavated claystones may surpass 10 MPa.