Slope stability associated with expansion of MSW landfill in China

La stabilité de la pente associée à l'expansion des déchets solides municipaux (DSM) en Chine

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ABSTRACT
Expansion of municipal solid waste (MSW) landfill is now under practice in many cities of China. The landfill expansion generally involves a significant increase in landfill slope height, which may trigger waste mass instability. Another potential failure associated with the landfill expansion in China is slippage alone the weak interface within the intermediate liner system, which is sandwiched between the existing and expanded waste masses. In this paper, an attempt has been made to to investigate the major factors influencing the slope stability of landfills, including shear strength of MSW, leachate level and interface shear strength within a composite liner. These issues are discussed based on experimental results and theoretical analysis for the Suzhou landfill, which is under design for vertical and lateral expansion.

RÉSUMÉ
Actuellement, l'expansion des déchets solides municipaux (DSM) se pratique dans beaucoup de villes de Chine. L'expansion des déchets comprend généralement une augmentation significative dans la hauteur de la pente des tas d'ordures, qui suscite peut-être l' instabilité de la masse des déchets. Un autre échec potentiel associé à l'expansion des déchets en Chine est le ripage tout le long de l'interface faible à l'intérieur du système de la double étanchéité intermédiaire, qui est inséré entre la masse des déchets existante et expansée. Dans cette thèse, une tentative a été faite pour investiguer les facteurs majeurs influençant la stabilité de la pente des déchets, y compris la résistance au cisaillement des déchets solides municipaux (DSM), le niveau du produit de lixiviation et la résistance au cisaillement d'interface à l'intérieur d'une double étanchéité composite. Les problèmes sont discutés sur la base des résultats expérimentaux et des analyses théoriques pour la mise en décharge des déchets de Suzhou, qui est en cours de la conception pour l'expansion verticale et latérale.

Keywords : Municipal solid wastes ; Landfill expansion ; Shear strength ; Leachate level ; Interface shear strength of liners

1 INTRODUCTION

Several lethal failures at the uncontrolled landfills took place in Asia during the last decade. The tragedies remind us that landfill stability is an issue that should not be overlooked. Blight (2006) conducted a survey on three lethal failures at the uncontrolled landfills in Asia. The survey suggests that the primary factor in all of the failures was lack of knowledge and technique regarding the effects of water and slope angle on the stability of waste mass. The secondary factor was the low strength of MSWs due to an absence of compaction or an abundance of plastic sheets. Koerner & Soong (2000) also pointed out that excessive moisture was invariably the triggering mechanism in all the landfill failures they had investigated. Hendon et al. (1999) reported a catastrophic landfill failure caused by leachate recirculation. At modern controlled landfills, composite liners, consisting of soil and geosynthetic materials, are widely used to prevent the contamination of the surrounding environment. The shear resistance at soil-geosynthetic and geosynthetic-geosynthetic interfaces is generally low, and the low interface strength has led to slippage and slope failure at many landfills (Koerner & Soong 2000). This paper tries to address the major factors influencing the slope stability associated with one of the expanded landfill expansion in South China, namely the Suzhou landfill (see Fig.1). The major factors included shear strength of municipal solid wastes (MSWs), leachate level and interface shear strength within a composite liner.

The Suzhou landfill was put into operation in 1993, and was located in a valley surrounded by hills about 13 km to the south of Suzhou city. It is anticipated that the landfill will reach its top design level (i.e., +80 m Ordnance Datum) by the end of 2010. Vertical and lateral expansion of the existing landfill is under design. The preliminary design involves expanding the existing landfill from a level of 80 m to 120 m in vertical direction, and 400 m outward from the present landfill boundaries in the horizontal direction (see Fig.1). The bottom of the existing landfill was not lined with any form of engineered barrier. An injected grout curtain was installed under the retaining wall of the leacate pond to limit downstream movement of leachate. The natural soil strata below the landfill bottom was comprise of a layer of alluvial-colluvium deposit, highly-decomposed sandstone along with slightly-decomposed and fresh sandstone. The alluvial-colluvium deposit was composed of gravelly clay with a thickness ranging from 5 to 27 m. The mean values of shear strength parameters (i.e., c' and ϕ') measured for the gravelly clay was approximately 5 kPa and 31°, respectively. The water permeability for the gravelly clay was measured using double-ring infiltration tests, and it ranged from 1×10^{-6} m/s to 5×10^{-6} m/s. The decomposed sandstone below the gravelly clay had a high shear strength. Joints were well developed in the highly-decomposed sandstone, resulting in a high hydraulic conductivity. However, the fresh rock at the bottom had a high integrity and a water permeability less than 1×10^{-9} m/s. The grout curtain was made to extend to the underlying fresh rock. The grout curtain and the fresh rock were expected to constitute a closed barrier system against the leachate in the landfill. However, groundwater monitoring downstream of the grout curtain indicated that the barrier system was not perfect. In accordance with the new regulation,

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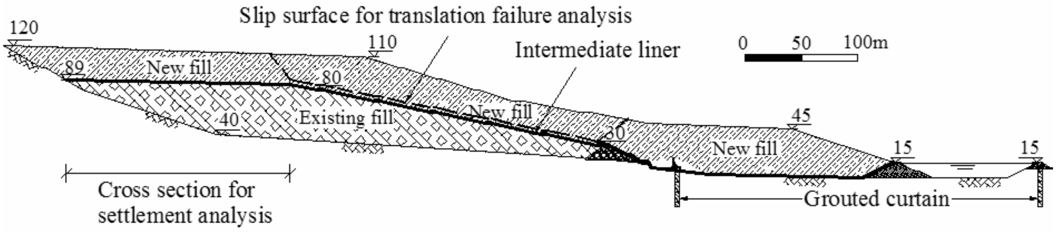

Figure 1. A preliminary design of landfill expansion in Suzhou, China

the bottom of the expanded waste body will be lined with a composite liner system including a leachate collection layer and sealing layers. According to the preliminary design, the sealing liner is made of HDPE geomembrane and geosynthetic clay liner (GCL). The potential slippage alone the intermediate liner system sandwiched between the existing and expanded waste masses one of the major concerns associated with the design of the landfill expansion.

2 SHEAR STRENGTH CHARACTERISTIC OF MSW

Information on the shear strength of the MSW is required for the assessment of slope stability since failures usually occur entirely or at least partially within the waste material. Numerous data on the shear strength of MSW have been obtained from both experimental measurements and back-analysis of field case histories over the last two decades (Machado et al. 2002; Feng et al. 2005). However, the shear strength values reported in the literatures vary widely, with internal friction angle varying from 10° to 53° and cohesion varying from 0 to 67 kPa (Machado et al. 2002). The selection of appropriate shear strength parameters remains a challenging design issue for a site-specific landfill. Variability in the shear strength parameters is due to the variableness of MSW compositions, the strain level at failure, the choice of representative samples and testing methods. The abundant fibrous materials in MSWs lead to a stain-hardening behavior upon shearing. Hence, the shear strength of MSWs is highly dependent on the strain level experienced by the waste mass. An additional factor affecting shear strength is the change in shear strength with the fill age of waste because of the biodegradation of the organic component (Dixon & Jones 2005). As far as the authors are aware, little experimental data are available to evaluate the aging effect.

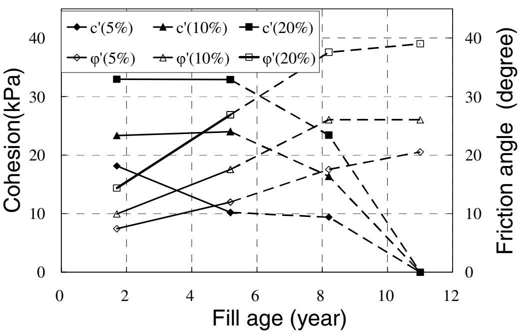

Figure 2. Relationships of shear strength parameters to the fill age of MSW (Zhan et al. 2008)

Figure 2 shows the relationships of shear strength parameters (c' and ϕ') to fill age, which were measured from the borehole samples taken at different depths of the existing Suzhou landfill. It should be noted that the values of fill age for the data points were equal to the middle age of the four ranges (i.e., 0-3.3, 3.3-6.8, 6.8-9.3 and 9.3-12.8 years). As expected, both cohesion and friction angle increase with the strain level as a result of the strain-hardening behavior of theMSW. For a given strain level, it was found that the value of cohesion decreases with an increase in fill age, and the value of friction angle increasing with fill age. The trends for the three strain levels are all consistent. The data show that the MSW with a fill age of about 11 years poses zero cohesion and a friction angle up to 39°. For the recently-filled MSW, the values of cohesion and friction angle corresponding to a strain level of 10% are 23 kPa and 10°, respectively. The four sets of shear strength parameters (strain level =10%) corresponding to the four ranges of fill ages (i.e., 0-3.3, 3.3-6.8, 6.8-9.3 and 9.3-12.8 years) were used for the slope stability analyses of the exsiting Suzhou landfill. The calculated minimum values of factor of safety (Fs) were 1.31, 1.77, 2.06 and 1.45, corresponding to the four sets of parameters. It demonstrates that the variation of shear strength parameters compressibility with the fill age of MSW should be taken into account in the slope stability analyses.

3 EFFECT OF LEACHATE MOUND ON WASTE MASS STABILITY

A high leachate level is present in most of uncontrolled landfills in the South of China. The influence of leachate level on the slope stability of the Suzhou landfill (before landfill expansion) was investigated by performing slope stability analyses by the use of the Bishop simplified method. The overall inclination at the sloping part of the landfill is 4H:1V (i.e., about 22°). The measurements of shear strength parameters at the two strain levels (10% and 20%) were used for the analyses (refer to Figure 2). Figure 3 shows the change in Fs with the normalized height of leachate level (i.e., h/H), where H is the maximum thickness of the landfill. When the leachate level is located at the bottom of the landfill (i.e., totally unsaturated condition), the minimum Fs of the landfill is close to 3 (i.e., corresponding to the shear strength parameters at a strain level of 10%). An increase in the normalized height of the leachate level results in a significant decrease in the Fs. When the leachate level reaches the top surface of the landfill (i.e., totally saturated condition), the minimum Fs for the landfill is close to 1. The analysis results suggested that the leachate level in the landfill with a slope angle of 22° should be controlled at a height less than 70% of the landfill thickness if the Fs value is required to be greater than 1.4. The analyses also indicate that the use of shear strength parameters corresponding to a strain level of 20% seem to overestimate the factor of safety. On the basis of comparative analyses, Feng et al. (2005) suggested that a strain level of 10% is appropriate to define the shear strength parameters of MSWs for the evaluation of landfill stability.

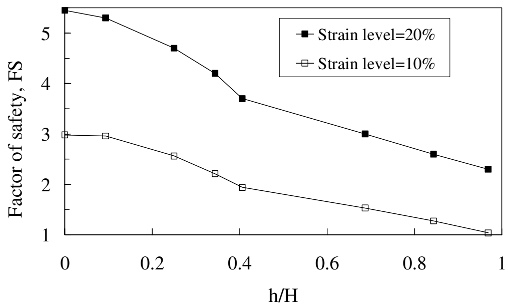

Figure 3. Influence of leachate level on the slope stability of the Suzhou landfill

4 SLIDE OF WASTE MASS ALONG WEAK LINERS

For a controlled landfill lined with a composite liner system, landfill failure tends to be controlled by the weak shear strength at soil-geosynthetic and geosynthetic -geosynthetic interfaces. Figure 4 shows a comparison of stress-deformation curves for different materials and interfaces, which are commonly found in landfills. The interfaces include textured geomembrane/compacted clay (GM/CL), textured geomembrane/non-woven geotextile (GM/GT) and textured geomembrane/geosynthestic clay liner (GM/GCL). It can be seen that the MSW, exhibiting a strain-hardening behavior, poses higher ultimate shear strength than the compacted clay and the interfaces. The peak values of shear strength of the interfaces are close to that of the compacted clay. However, all the interfaces show a strain-softening, and hence have lower shear strength than the compacted clay when the shear displacement is large. A difference in the shear strength is also observed among different interfaces, particularly at a large shear displacement. The GM/GCL interface at a hydrated state has the lowest strength and exhibits a more significant strain-softening at a higher stress level. This is attributed to bentonite extrusion from GCL to the interface.

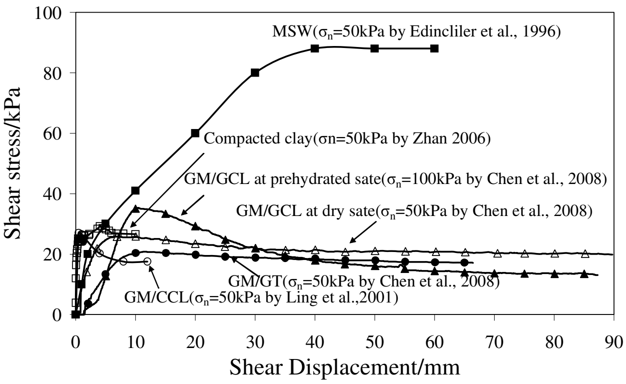

Figure 4. Shear stress-displacement relationships for MSW, compacted clay and interfaces within composite liners

Experiment results (Chen et al. 2008) indicate that there exist two major factors affecting bentonite extrusion from hydrated GCL to the textured GM surface. One is the extrusion of bentonite due to excessive pore-water pressure during rapid loading (see Fig. 5(a)) and the other is due to plowing effect of GM asperities during shearing (see Fig. 5(b)). When the prehydrated GCL specimen is subjected to rapid one-dimensional loading, an excessive pore-water pressure tends to build up in the GCL. Then the seepage force drives bentonite extruding through the geotextile and attaching on the GM(see Fig. 5(a)). The bentonite extrusion mechanism during shear involves the interaction between the GT and the textured GM. When the GCL/GM interface is subjected to shearing, the GM asperities tend to plow across the woven geotextile of GCL. The interaction tends to enlarge the voids in the geotextile, and hence allow hydrated bentonite to come in contact with the GM surface(see Fig. 5(b)). Then, the bentonite is more easily extruded onto the GM as shearing continues.

The experimental results demonstrated that the quantity of bentonite extrusion during shearing is much more than that due to excessive pore-water pressures during one-dimensional loading. The bentonite extrusion mechanism associated with shearing exerts a dominant effect on strength reduction at the hydrated GCL/GM interface.

Shear resistance versus normal stress is plotted in Fig. 6 to show the effect of bentonite extrusion on changes in shear strength parameters. For simplicity, it is assumed that the cohesion intercept is equal to zero and a linear regression can be made for each of the shear strength envelopes. The values of interface friction angle at peak (φ_p) were 24.4° and 20.9° for the dry GCL/GM interfaces and the hydrated GCL/GM interfaces, respectively. The values of interface friction angle at large displacement (φ_{ld}) were 16.9° and 9.3° for the dry GCL/GM interfaces and the hydrated GCL/GM interfaces, respectively. A comparison of the two shear strength envelopes corresponding to the large displacement conditions indicates that the bentonite extrusion at the large shear displacement caused a strength loss with a magnitude of 7.6° in terms of interface friction angle. The magnitude of strength loss is comparable to the combined effects of strain-softening, geotextile damage and geomembrane asperity removal on the post-peak strength reduction of the dry GCL/GM interfaces, which showed a magnitude of 7.5° in terms of interface friction angle. The influence of bentonite extrusion on the peak shear strength showed a magnitude of 3.5° in terms of interface friction angle. As compared with the peak strength envelope of the dry GCL/GM interfaces, the hydrated GCL/GM interfaces at the large shear displacement experienced a total strength loss with a magnitude of 15.1° in terms of interface friction angle. It is acknowledged that more data points would be beneficial in confirming the above quantification.

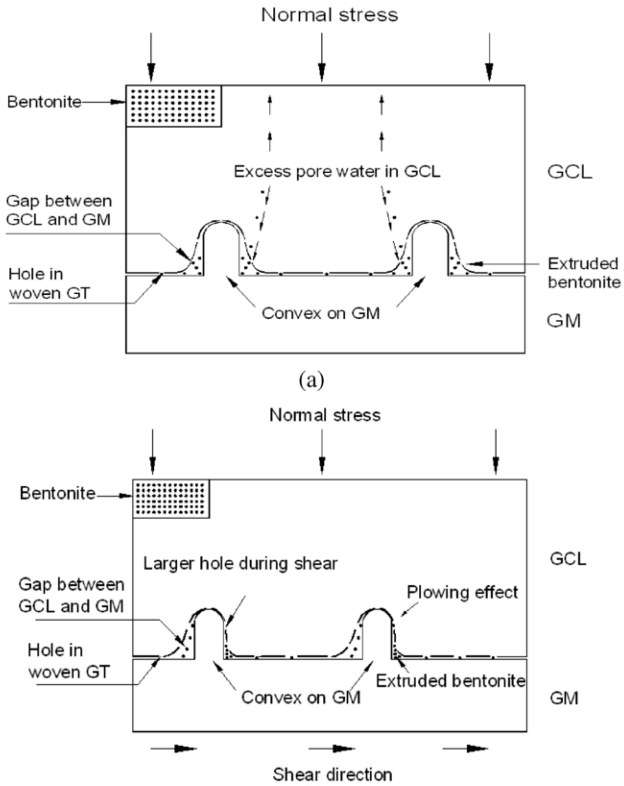

Figure 5. Bentonite extrusion mechanism of GCL: (a) Excessive pore-water pressure during rapid loading; (b) Plowing effect during shearing

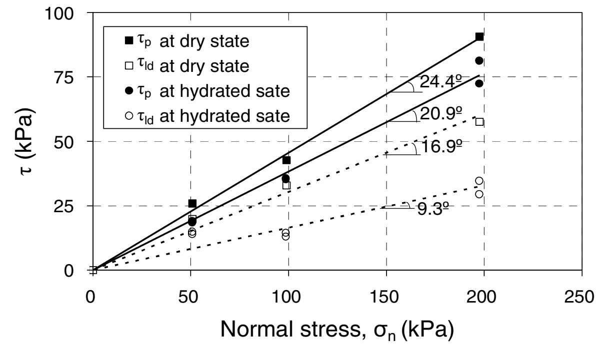

Figure 6. shear strength envelopes for the GCL/GM interfaces

Table 1. Factor of Safety for the Slide Along the Intermediate Liner at the Suzhou Landfill.

Interface	State	Shear strength parameters corresponding to large displacement		Factor of safety
		c (kPa)	φ (°)	
GM/GT	Dry	5	12.8	1.247
GM/CCL	Dry	11.4	23.6	2.141
GM /GCL	Dry	0	16.9	1.487
GM /GCL	Hydrated	0 (peak value)	20.9 (peak value)	1.746
		5	9.3	1.017

Note: GM: being textured with grains sprayed-on on both sides with a material identical to that of which the geomembrane is made (Textured, GSE Lining Technology, Inc., Houston, Tex.); GCL: having an intermediate layer of granular sodium bentonite with a mass per area of 4500 g/m^2, which held between a woven slit-film polypropylene geotextile (109 g/m^2) and a nonwoven needle punched polypropylene geotextile (204 g/m^2); GT: a polypropylene geotextile with a mass per area of 400 g/m^2

The interface shear strength parameters in Table 1 were used to evaluate the stability of the expanded waste body at the Suzhou landfill (see Figure 1). For the purpose of comparison, a fixed slip surface mainly along the intermediate liner system was assumed for the translation failure analyses. The three-part wedge method proposed by Gao et al. (2006) was employed for the analyses. The analysis results are also shown in Table 1. When the shear strength parameters at a large shear displacement are used, the factor of safety for the slippage against the hydrated GM/GCL interface is the lowest (i.e., FS = 1.126), followed by the GM/GT, the dry GM/GCL, and GM/CL in succession. It can be seen the factor of safety against the GM/GCL interface is significantly affected by both the hydration state of GCL and the shear displacement occurring to the interface. The analysis results indicate that the use of GM/GCL as a liner on the sloping ground should be very careful, particularly in a landfill absence of an effective water management system.

5 CONCLUSIONS AND SUGGESTIONS

(1) As a result of the biological decomposition process of the organic components, the mechanical properties of the MSWs tend to change with the age of fill. The aging effect should be taken into account when assessing the performance of MSW landfills.
(2) Water management and control of leachate level are a matter of the utmost concern with the current practice of MSW landfills in the Asian developing countries. High leachate level has caused several lethal landfill failures, and resulted in a high level of environmental pollution risk. Retro-fitted measures should be taken to lower down the high leachate level within the existing uncontrolled landfills.
(3) Expansion of the existing uncontrolled landfills usually involves the design an intermediate liner system in between the existing and expanded waste fills. The stability of the expanded landfill along the weak interfaces within the intermediate liner system should be concerned, especially when the GM/GCL liner are used.

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