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# Shear strength characterization of municipal solid waste at the Suzhou landfill, China

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**Abstract**

The current practice of slope stability analysis for a municipal solid waste (MSW) landfill usually overlooks the dependence of waste properties on the fill age or embedment depth. Changes in shear strength of MSW as a function of fill age were investigated by performing field and laboratory studies on the Suzhou landfill in China. The field study included sampling from five boreholes advanced to the bottom of the landfill, cone penetration tests and monitoring of pore fluid pressures. Twenty-six borehole samples representative of different fill ages (0 to 13 years) were used to perform drained triaxial compression tests. The field and laboratory study showed that the waste body in the landfill can be sub-divided into several strata corresponding to different ranges of fill age. Each of the waste strata has individual composition and shear strength characteristics. The triaxial test results showed that the MSW samples exhibited a strain-hardening and contractive behavior. As the fill age of the waste increased from 1.7 years to 11 years, the cohesion mobilized at a strain level of 10% was found to decrease from 23.3 kPa to 0 kPa, and the mobilized friction angle at the same strain level increasing from 9.9° to 26°. For a confinement stress level greater than 50 kPa, the shear strength of the recently-placed MSW seemed to be lower than that of the older MSW. This behavior was consistent with the cone penetration test results. The field measurement of pore pressures revealed a perched leachate mound above an intermediate cover of soils and a substantial leachate mound near the bottom of the landfill. The measurements of shear strength properties and pore pressures were utilized to assess the slope stability of the Suzhou landfill.


*Keywords:* Municipal solid waste; Shear strength; Fill age; Cone penetration test; Leachate level; Slope stability

## 1. Introduction

Significant growth in population and economy has occurred in most cities of China since the 1990s. This growth has resulted in a rapid increase in the quantity of municipal solid waste (MSW). At present the per-capita generation of MSW in China has reached about 1 kg/day, and the annual total generation is approximately 150 million tons. About 90% of the huge amount of MSW is disposed of in landfills. Most of the landfills in major cities were built in the early of 1990 and now have reached the design service life. The expansion of the existing landfills is presently being undertaken in many cities of China due to the social and political problems associated with identifying new landfill sites.

The stability of waste mass is one of the major concerns associated with the design of landfill expansion in China. Past experience has shown that both vertical and lateral expansion of landfills can trigger waste mass instability. Vertical expansion generally involves a significant increase in landfill slope height. For example, the postponed closure of the Payatas landfill in Philippines eventually caused a flow slide in 2000, which killed at least 278 persons (Kavazanjian and Merry, 2005). Lateral expansion may involve a large excavation adjacent to the side slopes of the existing landfill. The largest waste mass instability in the United States occurred in 1996 following lateral expansion of an existing landfill (Eid et al., 2000). Another potential failure mechanism associated with the landfill expansion in China is slippage alone the weak interface associated with the intermediate liner system sandwiched between the existing and expanded waste masses. It should be noted that most of the existing landfills in China were not lined with clay liner or

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HDPE geomembrane. According to new regulations (CJJ 17-2004), a composite liner system must be installed at the bottom of the expanded landfill.

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 (Landva and Clark, 1990; Singh and Murphy, 1990; Jessberger and Kockel, 1993; Kavazanjian et al., 1995; Gabr and Valero, 1995; Grisolia and Napoleoni, 1996; GeoSyntec, 1996; Manassero et al., 1996; Jones et al., 1997; Van Impe and Bouazza, 1998; Machado et al., 2002). 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 engineering 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. 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 and Jones, 2005). As far as the authors are aware, little experimental data are available to evaluate the aging effect.

Information on the leachate mound in a landfill is also required to evaluate the waste mass stability. This information is particularly important for landfills located in humid regions (e.g., in the south-east of China). Most of the existing landfills in China do not have effective facilities for rainwater interception and leachate drainage. Field reconnaissance has indicated that the leachate mound in landfills is quite high and leachate exits on the slope surface during the wet season. However, few field investigations have been carried out on this aspect.

This paper presents a field and laboratory study on the Suzhou landfill in China. The field study included drilling five boreholes, obtaining samples of MSW, driving cone penetration tests and monitoring of pore pressures. Borehole samples of the MSW were taken from various depths and taken to the laboratory for the determination of waste composition, volume-mass properties and shear strength properties. The waste strata within the landfill were dated to the fill age of waste. The changes in compositions and shear strength properties with the fill age were identified. The hydrogeological conditions of the landfill were discussed on the basis of the pore pressure measurements in the field. The cone penetration test results were interpreted on the basis of the measurements of shear strength properties and pore pressures. The stability of the existing landfill was also investigated by taking into account the variation in shear strength properties with depth and the height of leachate mound.

## 2. Landfill site and scheme of field study

The Suzhou landfill was put into operation in 1993. The landfill is located in a valley surrounded by hills about 13 km to the south of Suzhou city. The landfill was designed to contain 4.7 million $m^3$ municipal solid wastes and serve for about 15 years. At present, the landfill is receiving MSW at a rate of about 1600 tons/day. Fig. 1 shows the main cross-section of the landfill as of April 2006, when the field investigation was carried out. The landfill consists of a number of filled platforms that are set back at an embankment slope of 3H/1V. A rock-fill dam retains the lowest platform. It is anticipated that the landfill will reach its top design level (i.e., +80 m Ordnance Datum) by the end of 2008. 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 the vertical direction, and 400 m outward from the present landfill boundaries in the horizontal direction.

As shown in 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 leachate pond to limit downstream movement of leachate. The natural soil strata below the landfill bottom was composed of a layer of alluvial-colluvium deposit of Quaternary, highly-decomposed sandstone along with slightly-decomposed and fresh sandstone (lower–middle Devonian). 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 $\phi'$) measured for the gravelly clay were approximately 5 kPa and 31°, respectively. The water permeability for the gravelly clay was measured using double-ring infiltration tests, and it ranged from

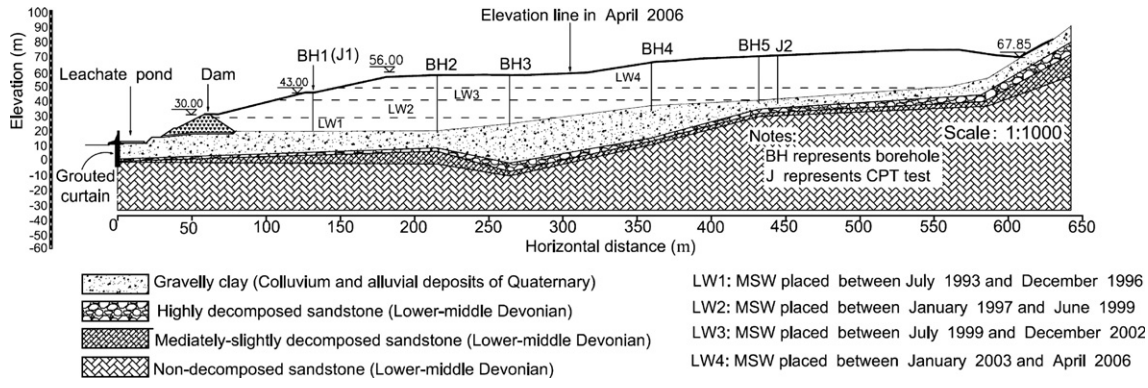


Fig. 1. Cross-section of the existing landfill in Suzhou of China and layout of boreholes and CPT locations.