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Influence of leachate pollution on mechanical properties of compacted clay: A case study on behaviors and mechanisms

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ABSTRACT

The environmental safety and engineering stability of landfills are always a concern of the public in view of its potential impact on public health. This study investigates the effect of leachate corrosion on the mechanical properties of a compacted clay. Batch tests were conducted to measure the permeability as well as the compressibility and the shear strength of the compacted clay that was polluted by landfill leachate under different concentrations. The influence mechanisms of leachate on the mechanical properties of compacted clay were investigated through microscopic experiments. The results showed that the hydraulic conductivity of compacted clay decreased because of the reduction in effective porosity resulting from the infiltration of leachate. Moreover, hydraulic conductivity decreased with the increase in leachate concentration and penetration time. The increase in leachate concentration respectively led to a decrease in the cohesion (C) and an increase in the internal friction angle (φ) of leachate-polluted compacted clay. The content of quartz and clay minerals in compacted clay decreased while albite increased after pollution. The compressibility of the compacted clay rises with pollution. An increase in compressibility and compressive deformation as well as a reduction in the compression modulus occurred as the leachate concentration increased. The maximum decline of void ratio was 9.7%.

1. Introduction

Landfilling is the most preferable method for the disposal of municipal solid waste in China today (Xue et al., 2011). A considerable amount of leachate is produced in landfills due to the biochemical reactions inside the buried solid wastes, with significantly high concentrations of heavy metals and organic pollutants (Guo et al., 2002; Kjeldsen et al., 2002). The migration of leachate can pollute the surrounding soil and groundwater, thereby causing serious health problems to human beings. Thus, an impermeable layer is established under every sanitary landfill to prevent leachate from leaking out of the landfills (Guyonnet et al., 2005; Touze-Foltz et al., 2006). Compacted clay is widely applied as a barrier material in the overburden layer and in the surrounding areas of a landfill (Yahia et al., 2005; Hamdi and Srasra, 2013). The compacted clay and surrounding soil will be soaked and eroded by leachate if leakage happens. Many scholars have conducted numerous studies on the impact of pollutants on the physical and chemical properties of soil (Liu et al., 2008a; Burgos et al., 2008). Soil properties can also be affected by leachate, given the large number of microorganisms, organic matter, and salts in leachate. Research results show that the adsorption of leachate components on the soil surface enhances the attenuation of heavy metals (Calace et al., 2001). Francisca and Glatstein (2010) studied the long-term permeability of compacted clay affected by leachate. The results showed that leachate reduced the hydraulic conductivity of compacted soil because the effective pores were clogged with microorganisms introduced by the leachate. Sunil et al. (2009) investigated the shear and chemical properties of leachate-polluted laterite and found that the cohesion, pH and cation exchange capacity (CEC) increased, while friction angle (φ) decreased as the concentration of leachate increased. However, the artificial leachate used by Sunil et al. (2009) deviated from the real field condition in a landfill. In addition, changes in hydraulic characteristics can directly affect the barrier performance of compacted clay, and an increase in the hydraulic conductivity of the impermeable layer can lead to leachate leakage in landfills (Çelik et al., 2009; Du et al., 2009). The weakening of the mechanical properties of compacted clay can affect the structural stability of landfills. In recent years, the occurrence of geo-disasters in landfills has been frequent (Zhang and Rao, 2005), thus urging many scholars to focus on the safety studies about landfills (Seed et al., 1990; Eid and Stark, 2000). Given the lack of available land area, numerous studies were conducted for the secondary development of the closed landfills. Examples of building constructions on closed landfills include the sports grounds built for the 1996 Olympic Games in South Korea, a supermarket in the USA, and the soon-to-be-built solid waste transfer station on the Jinkou landfill in Wuhan City, China (Yang et al., 2005). So, an in-depth understanding of the mechanical

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properties of buried waste, soil, and leachate-polluted compacted clay is necessary when using landfills as foundations for buildings.

This study investigates the effect of leachate corrosion on the mechanical properties of compacted clay. Typical clay and leachate in Wuhan, China were used as test samples. Batch tests were conducted to investigate the permeability, compressibility, and strength of compacted clay as leachate concentration changes. The erosion mechanisms of leachate on compacted clay were analyzed through microscopic experiments. The results of this study would provide guidelines and parameters for assessing, designing, and reusing of landfill.

2. Materials and methods

2.1. Research area

Compacted clay is used as a barrier and covering material in most landfills in China's central region. Clay is generally available in the vicinity of these landfills. In this study, the clay and leachate in Wuhan City were used to examine the effects of leachate on the permeability, compressibility, and strength of compacted clay. Compacted clay with a compaction degree of 95% was used as test samples, which meets the technical requirements for sanitary landfills in China.

2.2. Clay

The silty clay used in the tests was collected from a subway excavation site in Wuhan City in disturbed state. The clay was dried, ground, and then sieved through a 2 mm screen before use. The main mineral composition and physical–mechanical indexes of clay are shown in Tables 4 and 1, respectively. The mineral components of the soil samples were determined by D8 Advance X-ray diffractometer from the Brooke Company. Other physical and mechanical properties were obtained by standard methods based on the Chinese "Standard for soil test method." The light proctor compaction method was adopted in the compaction test. The soil was prepared with 19.5% water (optimum moisture content) for 24 h before used for tests.

2.3. Leachate

The leachate used in the tests was obtained from a landfill in Wuhan City, and its chemical indexes are shown in Table 2. The heavy metal concentrations in the leachate were determined by Optima 4300DV ICP-OES from PerkinElmer, Inc., USA; the chemical oxygen demand was determined through the potassium permanganate method. Three kinds of solutions with different concentrations were used in the test: 0% concentration of leachate (deionized water only), 100% concentration of leachate (leachate only), and 50% concentration of leachate (volume ratio of deionized water and leachate is 1:1).

Table 2
Chemical characteristics of leachate used in tests.

No.	Index	Concentration
1	pH	8.03
2	COD	3625.5
3	NH_3-N	26.8
4	Pb	0.055
5	Zn	0.066
6	Cr	0.212
7	As	0
8	Cd	0.007
9	Cu	0.009

All parameters are expressed in mg/L except for pH.

2.4. Leachate permeability test

Permeability is one of the key indicators affecting the barrier performance of the compacted clay. To simulate the effect of leachate permeation on the permeability of compacted clay, landfill leachate was used as the permeant, and the change of hydraulic conductivity with different leachate concentrations and permeation time was studied. A cylindrical mold with an inner diameter of 50 mm and height of 100 mm was used to make the samples. Clay (with 19.5% moisture content) was compacted into molds for three layers, and 95% of the maximum dry density values were established for the soil samples. The hydraulic conductivity of the leachate-polluted compacted clay was measured according to the American test standard ASTM D 5084, and the constant head test was performed on a PN3230M flexible-wall permeameter from Geoequip Corporation, USA. The confining pressure of the sample was maintained at 100 kPa to ensure that the film clings to the sample and to prevent the side leakage of the solution. The water head and room temperature were set to 80 kPa and 25 °C, respectively. The test samples were pre-saturated in a vacuum saturator for 24 h using different solutions and then tested with different solutions. The experimental conditions are shown in Table 3.

The hydraulic conductivity values were calculated using the following equation:

$$k = \frac{Q \cdot L \cdot \rho \cdot g}{A \cdot t \cdot P} \times 10^{-5}$$

where k is the coefficient of permeability in cm/s, A is the cross-sectional area of the sample in cm^2, Q is the collected leachate at time t in cm^3, t is the permeation time in s, P is the applied water head in kPa, ρ is the density of water in kg/m^3, and g is the ratio of gravity and quality in N/kg.

2.5. Consolidation test

Samples were prepared by isostatic pressing method with cutting rings (internal diameter: 60.8 mm; height: 20 mm) at 95% of standard proctor maximum dry density (Table 1). Before the tests, the specimens were saturated with different concentrations of leachate (0%, 50%, and 100%) for seven days. The consolidation test method was based on the Chinese "Standard for soil test method." A GZQ-1 automatic pneumatic odometer from the Nanjing Soil Instrument Company was used in the tests. Three parallel tests were conducted for each case.

2.6. Shear test

The sample preparation was the same as that in Section 2.5. Before the tests, the specimens were saturated with different concentrations of leachate (0%, 50%, and 100%) for seven days. The test method was also based on the Chinese "Standard for soil test method", with a shear rate at 0.02 mm/min. A quadruple electric direct shear apparatus from Nanjing Soil Instrument Company was used for the tests, and each test was conducted thrice.

Table 1
Basic physico-mechanical properties of clay used in tests.

Moisture content/%	Density/(g/cm^3)	Specific gravity	Void ratio	Liquid limit/%	Plastic limit/%	Optimum moisture content/%	Grain-size distribution/%			Maximum dry density/(g/cm^3)
							Sand	Silt	Clay	
20.78	1.89	2.72	0.74	41.6	21.8	19.5	3.45	62.27	34.28	1.72