Wastes Cover Wastes: A Novel, Scientific and Environmentally Friendly Approach for Landfilling

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ABSTRACT: For environmental protection and sustainability, the use of plants and recycled wastes have been investigated in a landfill site located at Xiaping, Shenzhen under humid climates. The main objective was to validate a novel vegetated three-layer landfill cover system using recycled construction waste without the need of geomembrane in the field. One section was transplanted with Bermuda grass while the other section was left bare. To assess the landfill cover performance, the test site was heavily instrumented and monitored for a period of 13 months under natural climatic conditions. The cumulative rainfall depth was about 2950 mm over the whole monitoring period. At the end of monitoring period, the measured cumulative percolation was only 27 mm and 20 mm at the bottom of the bare and grassed cover, respectively. It is evident that the vegetated three-layer landfill cover system using recycled concrete without geomembrane can be effective in minimizing percolation at humid climates.

Keywords: three-layer landfill cover, recycled concrete, vegetation, field monitoring, water infiltration.

1. INTRODUCTION

With an increasing population worldwide and a high urbanization rate mainly in developing countries, the production of municipal solid waste (MSW) also increases. Many of these MSW are construction wastes. Landfilling is perhaps the simplest, cheapest and most cost-effective method to dispose MSW. In most developing countries, a very high percentage of MSW goes to landfill. Even in developed countries, many MSWs are also landfilled. For example, more than half of the member states in the European Union still dispose in excess of 50 percent of their waste to landfills (EEA 2013). In the United States, 50 percent of total waste generated are also disposed in landfills (US EPA 2015).

To minimize rainfall infiltration of water into the waste and hence to minimize leachate to contaminate groundwater, most modern landfill cover systems utilize geotextile composites and geomembranes due to their low permeability. However, geomembranes are highly susceptible to interface instability and defects/holes which can compromise their reliability (Daniel 1994; Koerner and Daniel 1997; Amaya et al. 2006).

Alternative cover systems such as cover with capillary barrier effects (CCBE) have been proposed (Ross 1990; Khire et al. 2000; Iryo and Rowe 2005; Bouazza et al. 2006; McCartney and Zornberg 2010; Siemens and Bathurst 2010; Zornberg et al. 2010; Rahardjo et al. 2012). A CCBE typically consists of a layer of fine-grained soil such as silt or clay over a coarse geomaterial. Field studies have shown that CCBEs can be effective for arid and semi-arid regions in minimizing rainfall infiltration into underlying MSW (Benson and Khire 1995; Khire et al 1999; Khire et al. 2000; Zornberg and McCartney 2003). However, the performance of CCBEs under humid climates have not been satisfactory (Morris and Stormont 1999; Khire et al. 2000; Albright et al. 2004; Rahardjo et al. 2006). A new three-layer landfill cover system was proposed and verified for humid climates theoretically and experimentally (Ng et al. 2015a and b; Ng et al. 2016). This new system is to add a layer of fine-grained soil (i.e., clay) underneath a two-layer barrier with CCBE (i.e., a silt layer overlying a gravelly sand layer). Based on one-dimensional (1D) water infiltration test in a soil column (Ng et al. 2016) and two-dimensional flume model tests and numerical simulations (Ng et al. 2015a and b), it is found that no percolation was observed after 48 hours of constant water ponding, which is equivalent to a rainfall return period of greater than 1000 years in Hong Kong.

To promote environmental protection and sustainability, the use of plants and recycled wastes as landfill cover materials have been investigated in a landfill site located at Xiaping, Shenzhen in a humid climatic region of China (see Figure 1). The main objective was to validate a novel vegetated three-layer landfill cover system using recycled construction waste without the need of geomembrane in the field. Unsieved completely decomposed granite (CDG) and coarsely crushed recycled concrete (CC) was used for the top and intermediate layer while sieved CDG was used as the bottom layer. One section was transplanted with Bermuda grass while the other section was left bare (refer to Figure 1). To assess the landfill cover performance, the test site was heavily instrumented and monitored for a period of 13 months under natural climatic conditions.

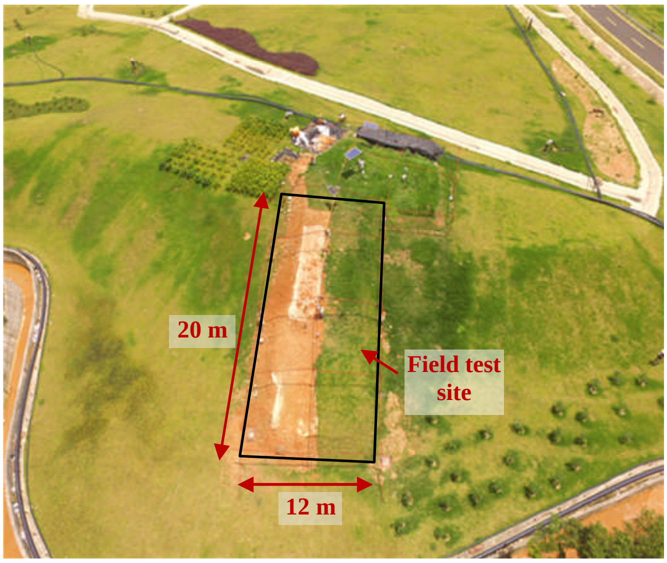

Figure 1 The field test site at the Xiaping landfill, Shenzhen, China (Ng et al. 2018a)

2. DESCRIPTIONS OF THE TEST SITE

The test site was selected and constructed at the Xiaping landfill, which is located in Shenzhen City, China. Currently, the Xiaping landfill having a total area of 149 ha, is Shenzhen's biggest landfill. The test site is located in a humid subtropical climate region, with approximately 80% of rainfall occurring between May and September.

Figure 2 shows the cross section of the test site. The landfill cover consisted of three-layers, namely a 0.8 m thick sieved CDG (dry density of 1.73 Mg/m^3), a 0.2 m thick recycled CC (dry density of 1.89 Mg/m^3) and a 0.6 m thick unsieved CDG (dry density of 1.77 Mg/m^3) from the bottom to the top. The slope was 12 m wide, 20 m long and it inclined at 30° to the horizontal. Half of the test site (6 m width) was transplanted with Bermuda grass turfs while the other half was left bare.

3. MATERIAL PROPERTIES

The CDG soil used to construct the three-layer landfill cover system was excavated from a slope near the test site. For the low permeability layer, the CDG soil was sieved to recover only the fraction less than 10 mm. The recycled CC was sourced from a recycling plant in Shenzhen and delivered to the Xiaping landfill. The basic properties of the cover materials are summarized in Table 1. Figure 3 shows the particle size analyses which were obtained from sieve analysis

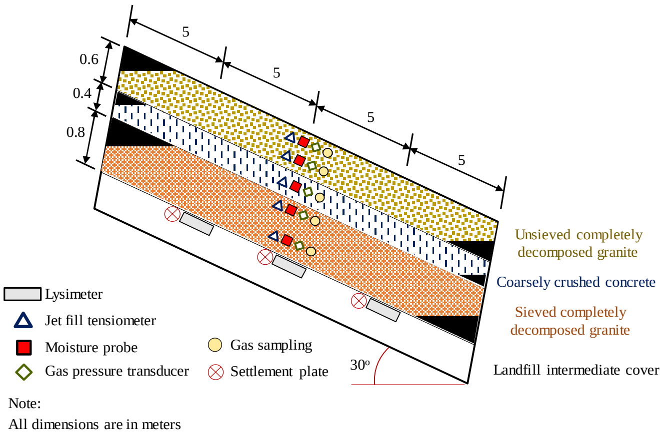

Figure 2 Typical cross section view and layout of instrumentation in the test site (Ng et al. 2018a)

Table 1 Basic Properties of Soils and Construction Wastes Used

PROPERTY	Unsieved CDG	Recycled CC	Sieved CDG
Unified soil classification system	SC	GP	SC
Specific gravity, G_s	2.63	2.45	2.61
Atterberg limits			
Liquid limit, LL	37	-	37
Plastic limit, PL	20	-	20
Plasticity Index, PI	17	-	17
Standard compaction curve			
Maximum dry density (kg/m^3)	1860	1890	1820
Optimum moisture content (%)	12.6	-	14.4
Saturated water permeability (m/s)	5.7x10^{-5}	7.5x10^{-2}	8.1x10^{-8}

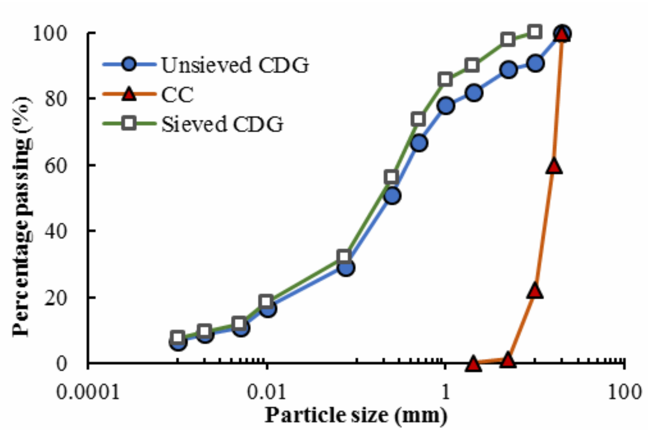

Figure 3 Particle size distribution of the unsieved completely decomposed granite (CDG), coarsely crushed recycled concrete (CC) and sieved completely decomposed granite (CDG)

4. FIELD INSTRUMENTATION AND MONITORING

The field performance was assessed by measuring percolation through the landfill cover by lysimeters and also by monitoring the variations of pore water pressure and volumetric water content within the landfill cover under natural climatic conditions. Percolation through the bare and grass covered landfill cover was monitored from June 2016 to July 2017. Six lysimeters (1 m diameter each) for the bare and grassed landfill covers spaced at 5 m apart were installed at 1.8 m depth to monitor water percolation through the three-layer landfill cover (see Figure 2). Each lysimeter was connected to an independent drainage pipe to allow gravity flow of the percolated water.

The variations of pore water pressure and volumetric water within the landfill cover were monitored from May 2017 to July 2017. To assess the variations of pore water pressure and volumetric water content in both the bare and grass covered three-layer landfill cover, jet fill tensiometers (JFTs) and moisture probes were installed at different depths (i.e., 0.2 m, 0.4 m, 0.8 m, 1.2 m and 1.6 m) within the mid cross-section of the slope.

The JFTs fitted with pressure transducers were used to measure pore water pressure within the range of 100 kPa to -90 kPa at an accuracy of ± 1 kPa. Changes in volumetric water content were measured using SM300 moisture probes. Before installation, all moisture probes were calibrated for the different cover materials. In addition, an automated weather station was installed on top of the slope to measure the atmospheric parameters including rainfall, relative humidity, air temperature, wind speed and wind direction. It is noted that details regarding gas monitoring and settlement of the landfill cover will not be described herein as they are beyond the scope of this paper.

5. MONITORING RESULTS

5.1 Pore water pressure response

In this extended abstract, only monitored results from the grassed landfill cover (see Figure 2) are reported. Other results are reported by Ng et al. (2018a). Figure 4 shows variations of measured pore water pressure at different depths in the grass covered three-layer system from 1 May 2017 to 18 July 2017 during the wet season of the year. As expected, the maximum changes in pore water pressure occurred near the surface (i.e., 0.2 m depth) and the magnitude of changes were much smaller at depths between 0.4 m to 1.6 m. Pore water pressures near the surface (i.e., 0.2 m depth) were the first affected by the onset of rainfall significantly. At the start of the monitoring period, the measured pore water pressure was about -25 kPa. The high negative pore water pressure in this shallow depth was due to evapotranspiration. Other similar field measurements were also reported by Lim et al. 1996; Garg et al. 2015 and Ng et al. 2018b. Upon monitoring under natural variations, it was observed that pore water pressure at 0.2 m depth was -20 kPa on 24 May 2017. This was before the occurrence of a rainfall event with a total depth of 78 mm. After the rainfall event, the measured pore water pressure increased to -15 kPa. This retained high negative pore water pressure also reduced water permeability (Ng and Menzies 2007). At 4 June 2017 (i.e., after 10 days of drying period with minimal rainfall), the measured negative pore water pressure at 0.2 m depth was found to be -33 kPa. Even after the grassed slope being subjected to a heavy rainfall event with a total depth of 149 mm, pore water pressure was still retained at -17 kPa. During the entire monitoring period (1 May 2017 to 18 July 2017), the presence of grass helped in retaining lower negative pore water pressure due to transpiration, as compared to the bare soil slope (Ng et al., 2018a & 2018b).

It can be seen from Figure 4 that the variations of measured pore water pressure at 0.4m or deeper were much less affected by weather. The observed changes in pore water pressure range from -9 to -2 kPa during the wet season. This suggests that there was no water infiltrated through the three-layer capillary barrier cover system during entire monitoring period. More solid evidence can be illustrated from the measurements by six lysimeters installed at the bottom of the three-layer cover system.

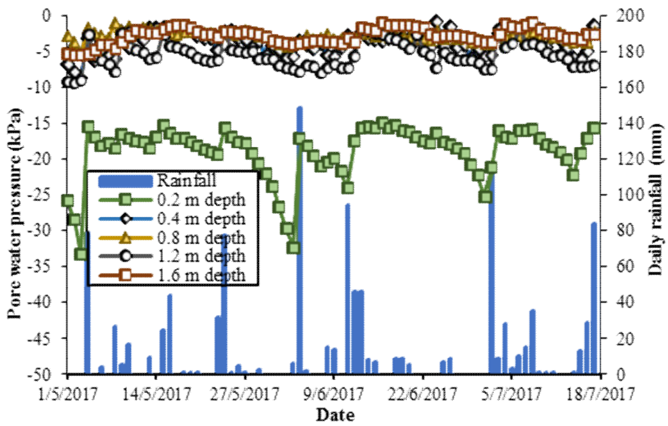

Figure 4 Variations of pore water pressure at different depths in the grass covered three-layer landfill cover system

5.2 Cumulative percolation measured by lysimeters

Figure 5 shows the measured cumulative percolation in the bare and grass covered three-layer landfill cover from June 2016 to July 2017. Cumulative percolation at three different locations (i.e., crest, middle, toe) in both slopes are included. For ease of comparison, the measured cumulative rainfall depth with a total amount of 2,950 mm is also provided in the figure. During the first 6 months of monitoring (i.e., June 2016 to November 2016), measured percolation increased at a relatively steady rate and showed little variation in response to daily rainfall events, even those in excess of 200 mm (i.e., 19 October 2016). This indicates the effectiveness of the three-layer landfill cover system in preventing excessive percolation through the cover. No sign of preferential flow was observed through both the bare and grass covered landfill covers. However, following a long drying period (i.e. December 2016 to May 2017), percolation increased steadily by about 10 mm for both landfill covers. This may be due to some desiccation cracks which were observed on the soil surface at the end of this long drying period. Similar findings were also described by Albright et al. (2006). At the end of 13-month monitoring period, the maximum percolation measured for the bare and grass covered landfill cover, was 27 mm and 20 mm, respectively. Both landfill covers meet the recommended design criterion of 30 mm/year for compacted clays (Benson et al. 2001). It is clear that the newly proposed three-layer landfill cover system using recycled concrete without geomembrane can be effective in minimizing percolation at humid climates.

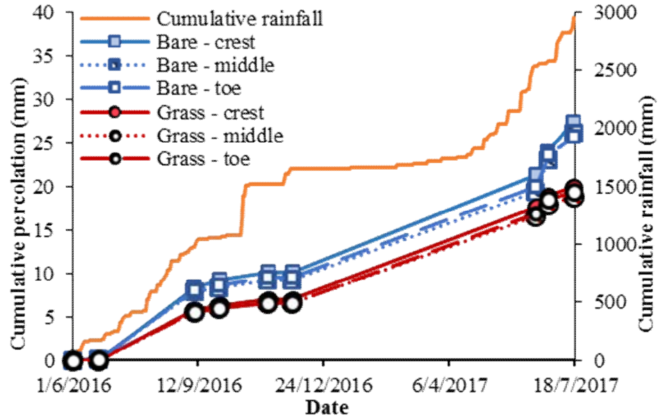

Figure 5 Cumulative percolation in the bare and grass covered three-layer landfill cover system from June 2016 to July 2017

3. CONCLUSIONS

A newly proposed three-layer landfill cover system was constructed and tested in Shenzhen, China. Based on field monitoring of the full-scale test over a period of 13 months (i.e., June 2016 to July 2017), the following conclusions may be drawn:

a) Under natural weather variations, pore water pressure at shallow depth (i.e., 0.2 m) was mostly affected by rainfall events. However, negative pore water pressure was retained at all depths (i.e., 0.2m, 0.4m, 0.8 m, 1.2 m and 1.6 m) in the cover after heavy rainfall events.
b) At the end of 13-month monitoring period, the measured cumulative rainfall was 2,950 mm, whereas the corresponding amount of percolation was 27 mm and 20 mm for the bare and grass covered landfill cover, respectively. The measured percolation in the new cover system clearly meets the recommended criterion of 30 mm/year for conventional compacted clay covers in the US.
c) The results of the field monitoring validated the potential use of a grassed three-layer landfill cover system using recycled concrete without geomembrane as a promising alternative landfill cover system for humid climates.

4. ACKNOWLEDGEMENT

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