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GEOTECHNICAL CHARACTERISTICS OF BANTARGEBANG SOLID LANDFILL WASTE USING A LABORATORY TEST ON ARTIFICIAL WASTE SAMPLES AND A FIELD TEST

Erly Bahsan[1*], G.S. Boedi Andari[1], Sarah Pramiarsih[1], Syahrizal A. Latief[1]

[1]*Department of Civil Engineering, Faculty of Engineering, Universitas Indonesia, Kampus UI Depok, Depok 16424, Indonesia*

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ABSTRACT

To analyze the stability of landfill waste, it is necessary to know the geotechnical characteristics of the solid waste material, especially the parameters related to the stability calculation such as the strength parameters (cohesion and friction angle). The physical properties of the materials are also important, as well as the composition of the waste. This study conducts laboratory and field tests to obtain the aforementioned characteristics from a typical urban landfill in Indonesia. The case study is taken to be the TPST Bantargebang landfill. Due to the difficulties in obtaining an undisturbed sample from landfill waste, a laboratory test was conducted using artificial solid waste samples. The strength parameters of the artificial waste samples were determined using a direct shear test. Besides the laboratory test, field tests (cone penetration test (CPT) and dynamic cone penetrometer test (DCPT)) were also conducted on the closed landfill zones in TPST Bantargebang to obtain the typical bearing capacity of the fill materials. The results of the direct shear test show that the cohesion value of the waste material aligns with the initial compression: higher compression results in higher cohesion, while the contrary applies to the friction angle. The cohesion values range from 0 to 41 kPa, and the friction angle ranges from 0 to 26°. The cone resistance value (q_c) up to a depth of 10 m is in the range of 2 to 10 MPa. The equivalent CBR (California Bearing Ratio) value from the DCPT ranges from 4% to 21%. Despite the large variability of the bearing capacity at the top layers, as shown by the DCPT results, the CPT results in the field reveal that the bearing capacity (also the strength characteristics) of the waste materials shows linear increase in line with the depth.

Keywords: Artificial sample; Geotechnical characteristics; Landfill; Solid waste; Stability

1. INTRODUCTION

Landfill remains the preferred method of managing non-recycled solid waste in Indonesia. An example is the Integrated Waste Treatment Site (*Tempat Pengolahan Sampah Terpadu*, TPST) Bantargebang, Bekasi, West Java, which processes all of the waste collected from the Jakarta area (e.g., Basyarat, 2006). After years of operation the height of the landfill is increasing, reaching heights in excess of 10 m in places. The high piles of waste in this landfill pose a risk of failure. The latest incident of landfill failure occurred in January 2016, resulting in one casualty (e.g., Qodir, 2016). Hence, it is important to analyze the stability of the landfill waste in order to avoid further accidents in the future.

To analyze the stability of the landfill, it is required to know the typical strength parameters of

*Corresponding author's email: erlybahsan@eng.ui.ac.id, Tel: +62-21-7270029, Fax: +62-21-7270028
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the material, such as cohesion (c), friction angle (ϕ), and also the physical parameters such as unit (ϕ) and water content (w). It is also necessary to know the typical bearing capacity of the landfill, in order to obtain the correlations between the parameters and the actual condition in the field. In this paper, these considerations are referred to as the geotechnical parameters of the landfill. Stark and Huvaj-Sarihan (2009) wrote that the geotechnical parameters of landfill are related to the physical characteristics of the waste material, such as its composition and age. James et al. (2017) studied the way in which industrial solid waste used as blended fill materials can influence the strength of embankments. Another study by Zhan and Ling (2008) involved a specific investigation of the shear strength characteristics at the Suzhou Landfill in China. Many studies have been conducted to examine the geotechnical characteristics of solid waste material, as summarized by Dixon and Jones (2005), for example, but such studies have rarely been carried out in Indonesia. This study aims to discover the geotechnical characteristics of samples of solid waste material in Indonesia.

2. METHODS

2.1. Characteristics of Urban Solid Waste

To obtain the mechanical properties of solid waste material, an undisturbed sample of material should be taken and tested in the laboratory. However, due to the difficulties involved in obtaining undisturbed samples from the field, this study used artificial solid waste samples. The characteristics of Indonesian solid waste are thus required in order to construct the artificial waste samples to be tested in the laboratory. According to Dixon and Jones (2005), urban solid waste is typically generated by domestic and commercial activities. In general, these materials can be classified into organic and non-organic. The typical composition of waste materials in Indonesia can be accessed from several sources (e.g., Dhokhikah & Trihadiningrum 2012; State Ministry of Environment the Republic of Indonesia, 2008; Kardono, 2007). Most of these sources reveal that organic content accounts for the largest part (about 40% to 60%). Non-organic materials typically include plastics, paper, rubber, wood, glass, and dust. Several studies also mention the significant amount of absorbent hygiene products within the composition of urban solid waste (e.g., Gerina-Ancane & Eiduka, 2016; Rawtec, 2013).

2.2. Preparing the Artificial Waste

Artificial waste samples were made for use in the direct shear test to obtain typical values for the cohesion and friction angle of the landfill material. The composition of the artificial waste samples was 52% organic materials, 20% plastics, 11% paper, 5% fabrics, 6% absorbent hygiene products, and 2% wood. Two different methods were used to make the artificial waste: (1) the fresh organic components were stored separately for 6 months before being mixed with the non-organic materials, denoted as Type A; and (2) the organic and non-organic components were mixed together and then stored for 6 months, denoted as Type B. The 6-month period was required to allow decomposition of the organic content.

2.3. Direct Shear Test

Direct shear tests were conducted on the artificial waste samples using the combinations shown in Table 1. The effects of the different methods of preparing the artificial waste samples can be observed by comparing the results from the Type A and Type B samples. Different initial compressions were used in a bid to simulate the effects of the depth of waste material in a landfill. By assuming the unit weight of landfill waste material to be 5 kN/m^3, an initial compression of 40 kN/m^2 represents the material at a depth of around 8 m, while 80 kN/m^2 represents the material at a depth of around 16 m in the landfill. The effects of the size of the non-organic components can be seen by comparing the samples with large (0.25 cm^2) and small (4.0 cm^2) non-organic components.

Table 1 Combinations for direct shear test on artificial waste

Waste Type	Initial Compression	Size of Non-organic Components	
		Large	Small
Type A (Organic materials decomposed separately for 6 months)	40 kN/m^2	×	×
	80 kN/m^2	×	×
Type B (Organic and non-organic materials stored together for 6 months)	40 kN/m^2	×	×
	80 kN/m^2	×	×

2.4. Field Test and Field Sampling

Field tests and field sampling were conducted at TPST Bantargebang, specifically at the closed landfill Zones IVB and V, as indicated by the highlighted areas in Figure 1. Disturbed samples were taken from the landfill using an excavator to a depth of 2.0 m. These samples were then used for analysis of the composition and the physical properties of the waste material.

A cone penetration test (CPT, as described in ASTM D3441) was conducted at four points in Zone IVB and at another four points in Zone V. A dynamic cone penetrometer test (DCPT, as described in ASTM D6951) was also conducted near the CPT locations, at four points in Zone IVB and four points in Zone V (each triangle mark in Figure 1 indicates the location of 1 CPT and 1 DCPT).

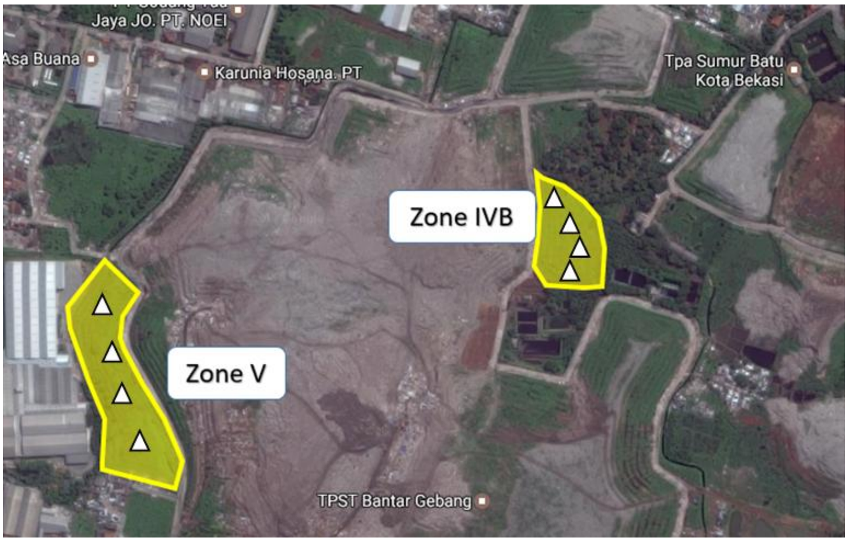
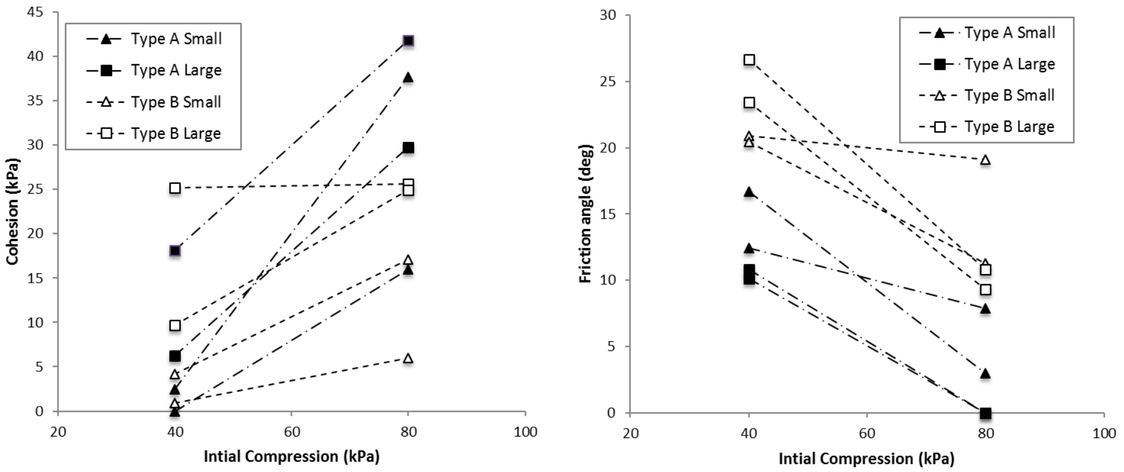


Figure 1 TPST Bantargebang and the locations for field sampling

3. RESULTS AND DISCUSSION

3.1. Effects of the Initial Compression and the Preparation Method

In general, a higher initial compression will produce higher cohesion, but in contrary it also produces a lower friction angle, as seen in Figure 2. For example, in Figure 2 the “Type A Small” mark shows the test results for the Type A sample (organic and non-organic materials prepared separately) with a smaller size of non-organic material. The “Type B Large” mark in Figure 2 shows the test results obtained from the Type B sample (organic and non-organic materials prepared together) with a larger size of non-organic materials. Figure 2 also shows the effects of the different preparation methods of the artificial waste. The waste material tends to be more cohesive if the organic and non-organic components are mixed and stored together (Type B). In general, the cohesion of the artificial waste material ranged from 0 to 41.8 kPa, and the friction angle ranged from 0 to 26.7°. As a comparison, Dixon and Jones (2005), in their study, found a range of 0 to 28 kPa for cohesion, and 15 to 42° for the friction angle. Zhan and Ling (2008) had a wider range for cohesion, from 0 to 70 kPa, with the friction angle ranging from 10 to 41°. In general, the cohesion and friction angle results obtained in this study are in agreement with the range of parameters found in previous studies.

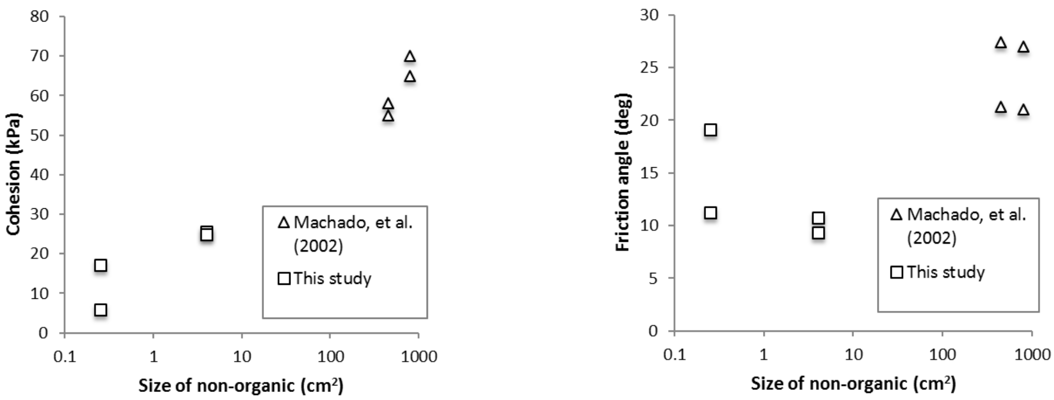


(a) (b)

Figure 2 Effects of initial compression on: (a) the cohesion; and (b) the friction angle of artificial waste material

3.2. Effects of the Size of Non-organic Components

From the direct shear tests carried out on the artificial waste samples, it is shown that a larger size of non-organic components corresponds to higher cohesion. Figure 3a shows the results from a previous study by Machado et al. (2002), revealing a higher cohesion for the larger size of non-organic components. However, there is no such clear trend in relation to the friction angle.



(a) (b)

Figure 3 Effects of the size of non-organic components on: (a) the cohesion; and (b) the friction angle of artificial waste material

Figure 3b shows that from this recent study the friction angles of the sample with larger non-organic components may be lower than those found in the sample containing smaller non-organic components. Yet this pattern is not consistent when compared to the results from Machado et al. (2002), which had larger non-organic components and also higher friction angles.

3.3. Composition of the Bantargebang Landfill Waste Material

The composition of the solid waste at Bantargebang is obtained from the waste samples taken from Zones IV and V at TPST Bantargebang. The typical percentages for each component are shown in Figure 4. Organic content is the largest component, accounting for around 34% of the total weight of the waste. Plastic is the second largest component, comprising around 29% of the total weight. This plastic material can be classified into plastic films (28%) and dense plastics (1%). Other significant materials that account for more than 10% of the total weight of the waste are wood (14%) and fabrics (11%).

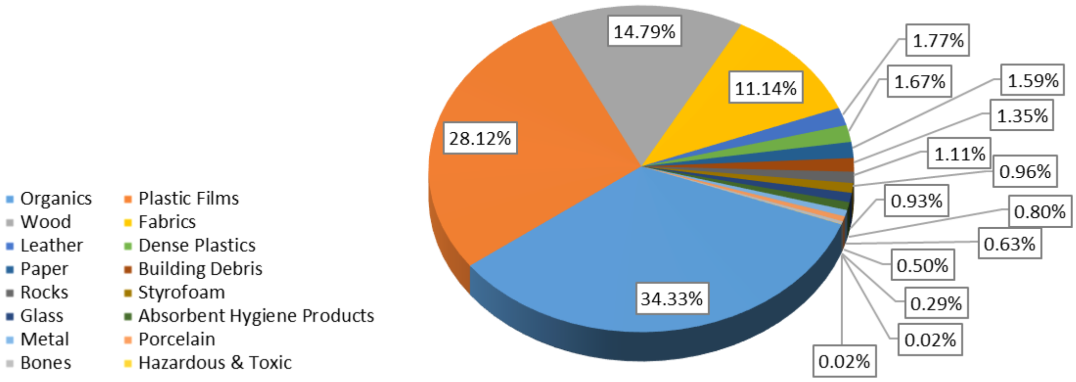


Figure 4 Composition of waste material at TPST Bantargebang

Table 3 Average speed and percentage share of vehicles at study sections

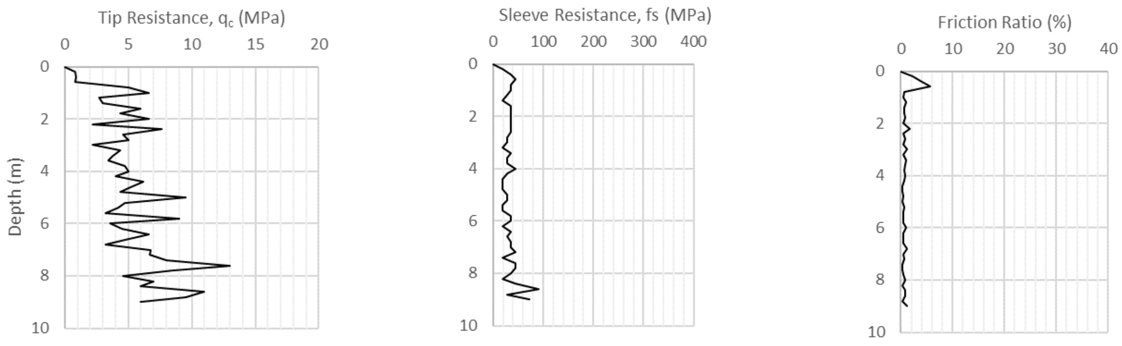
Vehicle Type	Section-I		Section-II		Section-III	
	Average Speed (km/h)	Proportional Share	Average Speed (km/h)	Proportional Share	Average Speed (km/h)	Proportional Share
CS	66.59	0.32	64.5	0.20	83.3	0.22
CB	69.80	0.07	67.0	0.06	75.1	0.10
LCV	49.80	0.03	47.6	0.07	60.1	0.04
HCV	46.70	0.04	42.1	0.07	51.9	0.08
TW	50.02	0.45	45.1	0.45	56.5	0.49
3W	39.50	0.05	40.8	0.12	49.4	0.02
B	50.47	0.04	45.2	0.03	66.1	0.05

The average water content of the solid waste at Bantargebang ranges from 29% to 36%, and the average unit weight ranges from 4.2 to 4.6 kN/m^3. These values are lower than the results obtained in other studies, due to the use of disturbed samples. The actual water content obtained in the field by Zhan and Ling (2008) was in the range of 50 to 100% and, according to Dixon and Jones (2005), the actual unit weight of landfill waste material should be in the range of 6 to 20 kN/m^3.

3.4. Results of the CPT

A CPT can only be conducted to a maximum depth of 8 to 11 m below the surface due to difficulties in penetrating beyond that depth. The results of a CPT for tip penetration (q_c), sleeve resistance (fs), and friction ratio (Figure 5 shows an example from 1 CPT in Zone IVB) have a similar pattern to the CPT results found by Zhan and Ling (2008) at Suzhou Landfill, China

(Figure 6) despite the lower sleeve resistance. The q_c value increases with depth from about 2.0 MPa near the surface to a maximum of 10.0 MPa at a depth of around 11 m (Figure 7 shows all the q_c from all CPT points in Zones IVB and V). The sleeve resistance is relatively constant along the depth, at an average value of 0.03 MPa.



(a) (b) (c)

Figure 5 Typical CPT results from the TPST Bantargebang landfill: (a) tip resistance; (b) sleeve resistance; (c) friction ratio

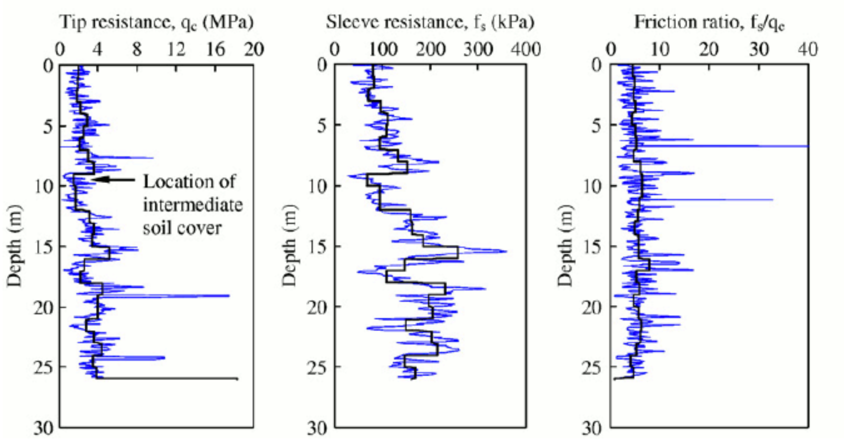
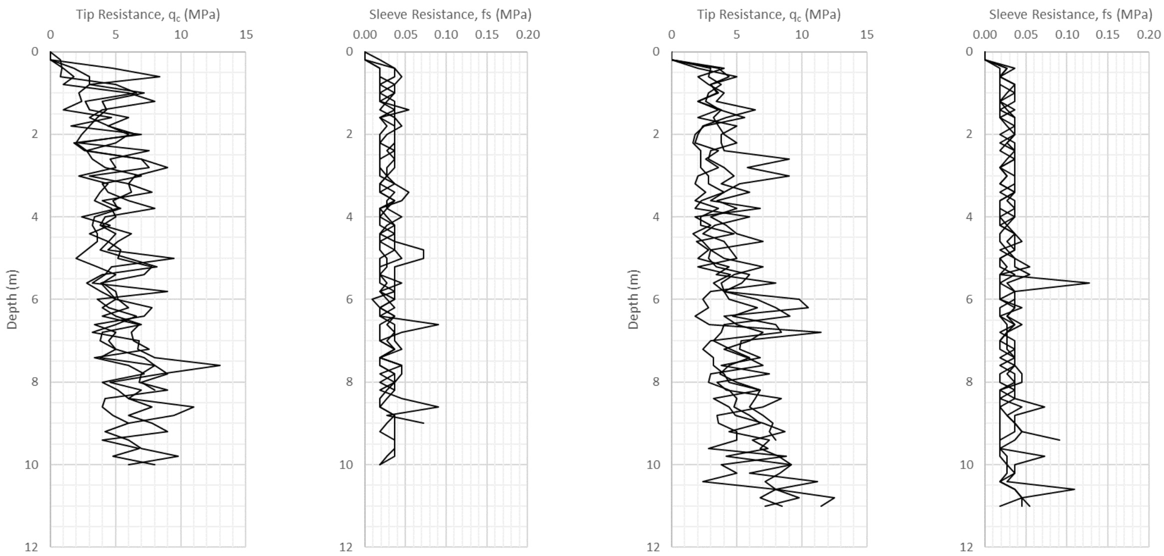


Figure 6 Typical results of CPT at Suzhou Landfill, as shown in Zhan and Ling (2008)



(a) (b) (c) (d)

Figure 7 Results of CPT from four points at Zone IVB: (a) tip resistance; (b) sleeve resistance; and from four points at Zone V: (c) tip resistance; (d) sleeve resistance

The lower sleeve resistance may be seen as an indication that the landfill at Bantargebang is less compacted in comparison to that at Suzhou.

3.5. Results of the DCPT

The typical results of the DCPT are shown in Figure 8 from one point in Zone IVB and another point in Zone V. The CBR value of this landfill material is obtained from the relationship to the rate of penetration per blow on the DCPT results (e.g., Kementerian Pekerjaan Umum, 2010):

$$Log_{10}(CBR) = 1.352 - 1.125 Log_{10}(mm/blow) \quad (1)$$

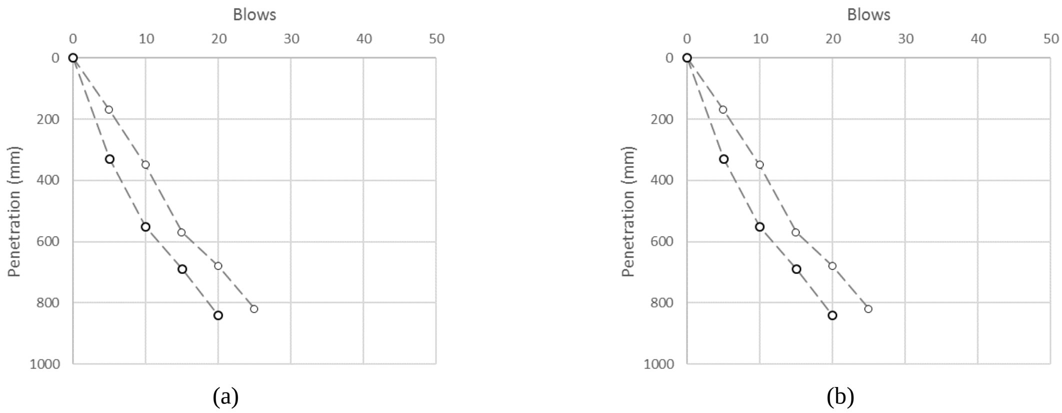


Figure 8 Example of the DCPT results from: (a) one point in Zone IVB; and (b) one point in Zone V

The CBR values from each DCPT point are summarized in Table 2. The CBR values all fall within the range 4.55–21.4%; the results from Zone V are more consistent than the results from Zone IVB. These values show that the landfill material can be considered as the medium category for subgrade (e.g., NCHRP, 2001).

Table 2 CBR values from DCPT

Zone	Point	CBR (%)
IVB	1	11.6
	2	21.4
	3	4.55
	4	5.1
V	1	7.9
	2	8.75
	3	7.75
	4	9.35

4. CONCLUSION

This paper summarizes the results of laboratory and field tests designed to obtain the geotechnical characteristics of typical landfill waste in Indonesia. A laboratory test was carried out on artificial waste samples to obtain typical shear strength values using a direct shear test.

The direct shear results show a very wide range of strength parameters: in general, the cohesion of the artificial waste material ranged from 0 to 41.8 kPa, and the friction angle ranged from 0 to 26.7°. These values are in agreement with the typical results obtained in previous studies from other countries. The initial compression applied to an artificial waste sample has a significant effect on its shear strength parameters: a higher initial compression results in higher cohesion but a lower friction angle. This may indicate that the waste material in the lower part of the landfill may have higher cohesion but that the friction angle, in contrary, may be lower than the near-surface materials.

The field test was carried out on the closed landfill Zones IVB and V at TPST Bantargebang to obtain the typical bearing capacity profiles of solid landfill waste. A CPT was carried out to a maximum depth of 11 m, wherein the cone resistance increased linearly from 2 MPa near the surface to around 10 MPa at a depth of around 11 m, while the sleeve resistance remained constant at around 0.03 MPa. The results of a DCPT conducted at the surface of the landfill waste show correlated CBR values ranging between 4.55% and 21.4%. Compared to the condition of landfill waste in other countries, the Bantargebang landfill seems to be less compacted. Yet its condition remains safe; as subgrade material the landfill is able to bear the load of heavy equipment. The results of this study may be used as an input in the optimization of landfill design.

5. ACKNOWLEDGEMENT

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