Settlement and slope stability analysis of landfill site for sustainable utilization

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Abstract. Waste accumulation in a landfill is often made a problem, especially when the landfill has reached the end of its service life, so there is a need for further utilization of the landfill, one of the things that can be done is to utilize the landfill as a place where a building can be built. In this research, a review of the waste settlement and slope stability uses the Plaxis Program to determine whether the landfill is able to withstand the burden of buildings. The research is located at Piyungan Yogyakarta Landfill. Material data in the form of the value of the friction angle, the volume weight of waste, and the modulus of elasticity obtained from previous research. From the results obtained, it is known that the deformation of waste that occurs shows a significant settlement up to 45 cm with load 1250 kg/m² so the foundation design at landfill area needs concern about high settlement, and this can be used as the basis for sustainable utilization of landfill.

1. Introduction
Waste is often a problem in the world, especially in developing countries. Consumption of the community that continues to increase without being balanced by good waste management causes accumulation of the amount of waste in landfills [1]. Landfilling is one of the most economical ways to process municipal solid waste (MSW). Public landfills can occupy areas ranging from a few hectares to hundreds of hectares [2]. Closed landfills are considered as suitable land use sites, such as parks and recreational facilities [3]. At present, no standards or guidelines exist on the performance and documentation of laboratory testing from MSW, and as a result, different approaches are used. In some cases, complete documentation about various aspects of testing not presented limits the value of the test results presented [4]. Garbage can experience geological disasters such as on land that causes buildings to sink (decrease), collapse, or tilt, cracked soil, landslides, and so on [5]. Therefore, it is necessary to conduct research to deal with possible disasters (landslides and landslides) in the landfill area if a building is built on it. Waste is a problem in several cities in Indonesia, one of that is Yogyakarta. Garbage in Yogyakarta per day can reach 2100 tons, of the total garbage is only 52% that can be handled and 32 percent of the garbage is carried to Piyungan because it is a residual waste. In the Piyungan landfill, the landfill is formed up to form a slope, the capacity of this landfill will eventually reach the end of the operation, so it is necessary to study the utilization of the Piyungan landfill when the service period has expired. To check this, it is necessary to do research on the decline that occurred in the area, whether the decline that occurred still included in the reduction of permits for a building. To model this,
A field investigation is needed. There are a number of technical problems in the construction and operation of waste, which is influenced by the technical properties of complex waste and landfill very easily becomes unstable due to external factors, the stability of the landfill is a significant problem in the operation of the landfill [6]. When the trash can stop operating because it has reached the service life it is very important to think about the utilization so that it is not neglected and produces a positive impact on the community, this research is expected to give an idea of how much settlement occurs when a landfill is burdened so that action can be taken certain in doing structure design especially foundation design.

2. Research methods

2.1. Settlement

Landfilling is one of the most economic of disposing municipal solid waste (MSW). Typical landfills may occupy an area ranging from several acres to hundreds of acres. Settlement estimation is a topic of concern in MSW landfill management. The landfill settlement continues over an extended period of time, with a final settlement that can be as large as 30%-40% of the initial fill height [2]. The design of foundations and other facilities above the landfill must be designed based on differential settlement. The decrease that occurs in the landfill is very random as shown in Figure 1.

![Figure 1. Settlement rate of landfill (wisconsin landfill, meruelo landfill, spadra landfill) [2].](image)

The settlement of waste is almost like soil, which is divided into immediate settlement, major settlement, and long-term settlement. The instantaneous settlement in waste can be due to the weight itself of the waste and the addition of load, this occurs within a few hours and results in significant strain [7]. Variations in the initial conditions of waste (composition, size, moisture content, volume weight, density, and amount of soil covers) and follow-up after the waste is piled up (aeration, the addition of water, and leachate circulation) are very influential in observing decreases [8,9]. If the settlement in waste is assumed to resemble the soil, then the settlement can occur when the waste is given a load so that it experiences strain and decline. Settlement in the soil itself due to changes in the composition of the soil or by reducing the pore water in the soil. The amount of strain along the layer depth is the total settlement in soil. The settlement due to expense is the sum of the immediate settlement and consolidation settlement [10]. Furthermore, the settlement in waste will be approached based on the settlement that occurs in the soil.
2.2. Landslide

Landslides can also occur in landfill. Landslides at landfills can also occur, while an amount of landslide incidents that have occurred can be seen in Table 1 [11]. The engineering properties of waste materials control many aspects from landfill design to issues regarding landfill stability. The stability and deformation response has implications for short-term and long-term stability, as well as landfill closure plans. For example, regarding short-term requirements, such as those in construction, knowledge of such responses is useful in assessing stability and in assessing potential changes in volume in the slope profile. Likewise, this knowledge is useful in assessing long-term stability regarding the additional volume that can be accommodated due to horizontal and vertical deformation in landfill mass [12]. Knowledge of shear strength is needed to assess the slope stability of the waste, and an understanding of the nature of compressibility is needed in the analysis of completion.

Table 1. Landslide accident of landfill around the world [11].

| Location                          | Year | Victims |
|-----------------------------------|------|---------|
| Payatas, Manila, Philippines      | 2000 | 278     |
| Leuwigajah, Bandung, Indonesia    | 2005 | 147     |
| Belo Horizonte, Brazil            | 1992 | >100    |
| Istanbul, Turkey                  | 1993 | 39      |
| Bantargebang, Bekasi, West Java, Indonesia | 2006 | 28 |

2.3. Shear Strength

The Mohr-Coulomb criteria are generally used to describe soil strength. The main hypothesis is based on the statement that the combination of normal and shear stresses forms a more critical boundary state than if only the principal stress or the maximum shear stress must be considered individually [13]. The shear strength of the waste is very much needed in analyzing the stability of the landfill during the service life or after the service life is completed. The shear strength parameters described by the Mohr-Coulomb collapse criteria (c = cohesion, φ = friction angle) are often used to calculate shear strength parameters in the waste. This shear strength parameter can be measured directly through laboratory testing, scale testing in the field, and back calculations of existing or failed slopes. The soil shear strength parameter influences the decomposition process, but the significant effect is the friction angle parameter (φ), while the cohesion value (c) does not show a correlation with the decomposition process [9]. The shear strength parameters (c and φ) from standard laboratory tests must be reduced by 15-25% [14]. The shear strength parameters for waste in the Piyungan landfill have been conducted, with the results shown in Table 3 [15].

Table 2. Shear strength parameter value at Piyungan landfill [15].

| Depth (m) | Hydraulic conductivity k(cm/sec) | Density ρb(kg/cm³) | Friction Angle φ (°) | Cohesion (c) |
|-----------|---------------------------------|--------------------|----------------------|--------------|
| 0-12      | 4.32 × 10⁻⁵                    | 0.85               | 35.02°               | 0 kPa        |
| 12-30     | 4.43 × 10⁻⁵                    | 1.50               | 36.10°               | 0 kPa        |
| 30-60     | 3.27 × 10⁻⁵                    | 1.45               | 41.98°               | 0 kPa        |

2.4. Modulus Elasticity

The stiffness modulus values determined by different methods are consistent with each other and reinforce the fact that typical values for MSW are low. These values are between 0.4 - 2 MPa for an average confinement stress of around 50 kPa, and tend to increase linearly with increasing confinement stress as shown in Figure 2 [16].
2.5. Finite element method
The conventional boundary equilibrium method is usually used to assess embankment stability. The finite element method, as an alternative to limit equilibrium method, is increasingly being used in the deterministic stability analysis of slopes or embankments. In this paper, a practical procedure for integrating the finite element method and the boundary equilibrium method into the probabilistic stability analysis for the embankment [17]. In recent years, finite element methods have increasingly been adopted to study slope stability or embankments. One of the programs for calculating the finite element method is Plaxis.

2.6. Methodology

2.6.1. Research location. The research location is in Yogyakarta Piyungan Landfill as shown in Figure 3.

2.6.2. Data. The data used are secondary data from previous research. Contour data such as Figure 4 is used as geometry input in the Plaxis program. Then the input parameter data is used as in Table 3.
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Figure 4. Cross section of Piyungan Landfill.

Table 3. Analyses data for plaxis input.

| Depth (m) | Hydraulic conductivity \( k (cm/s) \) | Density \( \gamma_b (g/cm^3) \) | Friction Angle (\( \varphi \)) | Cohesion (c) | Modulus Elasticity (E) |
|----------|-------------------------------------|-------------------------------|-----------------------------|--------------|----------------------|
| Sample 1 | 4.32 \times 10^{-5}                | 0.85                          | 35.02°                      | 0 kPa        | 1200 kPa             |
| Sample 2 | 4.43 \times 10^{-5}                | 1.50                          | 36.10°                      | 0 kPa        | 1800 kPa             |
| Sample 3 | 3.27 \times 10^{-5}                | 1.45                          | 41.98°                      | 0 kPa        | 1800 kPa             |

2.6.3. Research procedure. The procedure of this research is to conduct finite element analysis using the Plaxis program by entering secondary data from Figure 5 and Table 3. Then do the calculation of immediate settlement and slope stability analyzes were carried out using the Plaxis program by entering evenly distributed loads with equal loads 250 kg/m\(^2\), 750 kg/m\(^2\), 1250 kg/m\(^2\). The results obtained in the form of pictures and graphics that will be compared changes that occur.

3. Results and discussion

3.1. Settlement

Settlement analysis is carried out using a Plaxis program based on the finite element method. Figure 5, Figure 8, and Figure 9 show the settlement that occurs in landfills due to the load that occurs varies.

![Figure 5](image)

Figure 5. Settlement with load (a) 250 kg/m\(^2\), (b) 750 kg/m\(^2\), 1250 kg/m\(^2\).

Table 4. Settlement result.

| Load (kg/m\(^2\)) | Settlement (cm) |
|-------------------|-----------------|
| 250               | 8-12            |
| 750               | 22-24           |
| 1250              | 36-48           |

Based on Table 4, it can be seen an increase in the settlement in the area burdened due to additional load. The settlement in the burden of 1250 kg/m\(^2\) reached 36-48 cm, this settlement in intermediate
settlement where the settlement occurred instantaneously when burdened. Safety factor of waste embankment ± 1.24 before adding load and changing to 1.16 after adding load. The addition of the load is not too expensive in the stability of the slope, this is probably due to the loading given a safe distance to the edge of the slope and the angle of the slope ± 26° which is not too steep.

4. Conclusion
Utilization of landfill for construction is very possible, but keep in mind there is a significant settlement when added to the load. The biggest settlement reached 36-48 cm when loaded with 1250 kg/m², this indicates the need for special measures in the design of foundations in this area considering that the settlement is very large and the buildings built must be able to withstand any differential settlements that might occur. The stability of the slope does not show a significant change because it is given a safe distance when under load and the slope is not too steep. The data used in this modelling is secondary data and parameter approach, so that in the future it is necessary to test directly in the field so that it gets more realistic data in modelling. The results of this research can illustrate how likely it is to settlement when the waste is loaded, making it easier to for foundation design, and this can be used as the basis for sustainable utilization of landfill.

References
[1] Basoka I W A and Sinarta I N 2019 Kapasitas Dukung Fondasi Diatas Tanah Timbunan Sampah Sebagai Usaha Mitigasi Bencana Seminar Nasional Teknik Sipil 3 (Denpasar)
[2] Ling H I, Leshchinsky D, Mohri Y and Kawabata T 1998 Estimation Of Municipal Solid Waste Landfill Settlement J. Geotech. Geoenviron. Eng. 124 21–8
[3] Kissida J and Beaton N K 1991 Landfill park: From eyesore to asset Civ. Engrg 61 49–51
[4] Athanasopoulos G A 2008 Laboratory Testing of Municipal Solid Waste Int. Symp. Waste Mech.
[5] Sinarta I N and Ariyana Basoka I W 2019 The potential of liquefaction disasters based on the geological, CPT, and borehole data at southern Bali Island J. Appl. Eng. Sci. 17 535–40
[6] Huang Y and Fan G 2016 Engineering geological analysis of municipal solid waste landfill stability Nat Hazards 84 93–107
[7] Fei X and Zekkos D 2013 Factors Influencing Long-Term Settlement of Municipal Solid Waste in Laboratory Bioreactor Landfill Simulators J. Hazardous, Toxic, Radioact. WASTE 174 259–71
[8] Bareither C A, Benson C H and Edil T B 2012 Compression behavior of municipal solid waste: Immediate compression J. Geotech. Geoenviron. Eng. 138 1047–62
[9] Bareither C A B, Craig H. and Edil Tuncer B. 2012 Effects of Waste Composition and Decomposition on the Shear Strength of Municipal Solid Waste J. Geotech. geoenvironmental Eng. ASCE. 10 138
[10] Hardiyatmo H C 2014 Mekanika Tanah 2 (Yogyakarta: Gadjah Mada University Press)
[11] Lavigne F, Wassmer P, Gomez C, Davies T A, Hadmoko D S, Iskandarsyah, M T Y W, Gaillard J, Fort M, Texier P, Heng M B and Pratomo I 2014 Catastrophic Waste Avalanche At Leuwigajah Dumsite, Bandung, Indonesia Geoenvironmental Disasters a SpringerOpen J. 1
[12] Ering P and Babu G L S 2016 Slope Stability and Deformation Analysis of Bangalore MSW Landfills Using Constitutive Model 16 1–9
[13] Abramson L W, Lee T S, Sharma S and Boyce G M 2002 Slope Stability and Stabilization Methods (New York: John Wiley & Sons, Inc.)
[14] Bagchi A 2004 Design of Landfills and Integrated Solid Waste Management (Canada: Jonh Wiley & Sons, Inc.)
[15] Rifa’i A, Basoka I W A and Faris F 2018 Slope Stability Analysis of Integrated Municipal Disposal Site Based on Organic Content Change to Optimize Embankment Capacity 8th Int. Conf. Geotech. Constr. Mater. Environ.
[16] Gomes C C, Consultants E, Lopes M D L and Oliveira P J V 2014 Stiffness parameters of municipal solid waste
[17] Xu B, Low B K and Asce F 2006 Probabilistic Stability Analyses of Embankments Based on Finite-Element Method 132 1444–54