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STUDY ON A METHOD OF SLOPE STABILITY ANALYSIS USED FOR LANDFILL SLOPE

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ABSTRACT

Land filling is a widely used method for the disposal of wastes. With increased levels of urbanization and the location of landfills in close proximity to highly populated areas, a proper constructed landfill can avoid bad odour and hazardous leachate which can be as a result of instability of slope in the landfill. There are few methods available for checking the Factor of Safety (FOS) of the slope. In this analysis, slope is assumed to have translational failure where transitional method has been chosen for this study. This method is easy to develop and use as it allows the author to analyze the effect of waste properties by varying the different properties of waste in the assessment of FOS of landfill slope. A software program is written in MS Excel program to calculate the factor of safety based on properties of waste and Mambong Landfill Geometry that is located in Mambong, Sarawak. Analysis is performed on subgrade Cell number 2, which is currently in filling process. Height of the slope is 40 m with slope angle, α of 5.7°, angle of side slope, β of 18.4°, subgarde angle, θ of 1.15° and top width, B of 20 m were used for the present study. Waste and liner properties were varied in this analysis to see their effect on FOS. The analysis continues by maintaining a safe value of liner and soil properties at FOS equals to 1.35 and varying the geometrical properties of landfill. In addition to this analysis, a laboratory test on waste sample was performed; where the unit weight of waste obtained varies from 8 kN/m^3 to 10.5 kN/m^3. FOS analysis using Translational methods shows correct effects on FOS when the properties of waste, liner and geometry are varied.

ABSTRAK

Tapak pengumpulan sampah (Landfill) merupakan kaedah yang digunakan secara meluas untuk melupus sampah. Pada masa kini kadar urbanisasi kian meningkat dan ini mengalakan pembukaan kawasan perumahan baru yang semakin menghampiri lokasi pengumpulan sampah ini. Dengan itu, pembinaan tempat pengumpulan sampah yang terancangan mampu mengatasi masalah bau busuk dan bahan larut resap (leachete) yang berbahaya. Beberapa kaedah telah diaplikasikan untuk menguji kestabilan (FOS) cerun. Dalam kajiselidik ini,cerun dianggap mengalami kegagalan 'translational'. Kaedah 'translational' telah dipilih kerana ia senang untuk diaplikasikan dan boleh menunjukkan kestabilan (FOS) mengikut perubahan nilai didalam cerun. Ms. Excel telah diprogramkan untuk mengira kestabilan (FOS) untuk nilai-nilai sampah dan tapak pengumpulan sampah di Mambong, Sarawak. Analisa telah dilakukan terhadap 'subgrade cell' kedua di tapak pengumpulan sampah Mambong yang kini dalam proses pengisian. Ketinggian cerun (H) adalah 40 m, sudut cerun belakang (β) 18.4º, sudut 'subgrade cell'(α) 1.15º dan dataran puncak sampah (B) adalah 20 m telah di gunakan dalam kajian ini. Nilai-nilai sampah dan liner di pilih melalui analisa ini untuk melihat kesannya terhadap kestabilan cerun. Analisa di teruskan dengan mengekalkan nilai selamat untuk 'nilai liner' dan nilai sampah serta menguji geometri tapak pengumpulan sampah apabila nilai kestabilan bersamaan dengan 1.35. Sebagai tambahan untuk kerja analisa, ujian makmal terhadap sampel sampah telah dilakukan. Analisa kestabilan (FOS) menggunakan kaedah 'translational' memberikan kesan yang betul untuk analisa kestabilan apabila nilai-nilai sampah,'liner' dan geometri dipelbagaikan.

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LIST OF NOTATIONS

b = Width of slice

c' = Cohesion coefficient

e = Void ratio

I = Length of slices

m = Moisture content

n = Porosity

u = Pore pressure force

w_d = Dry gravimetric moisture content

C_m = Mobilized cohesion

E_{HP} = Normal force from the active wedge acting on the passive wedge (unknown in magnitude, but with the direction perpendicular to the interface of the active and passive wedge)

E_{VP} = Frictional force acting on the side of the passive wedge (unknown in magnitude, but with the direction parallel to the interface of the active and passive wedges);

E_{HA} = Normal force from passive wedge acting on the active wedge (unknown in magnitude, but with the direction perpendicular to the interface of the active and passive wedges), $E_{HA} = E_{HP;}$

E_{VA} = Frictional force acting on the side of the activity wedge (unknown in magnitude, but with the direction parallel to the interface of the active and passive wedges), $E_{VA} = E_{VP;}$

F_b = Factor of safety

FOS = Factor of safety

F_A = Frictional force acting on the bottom of the active wedge (parallel to the bottom of the active wedge);

F_P = Frictional force acting on the bottom of the passive wedge (parallel to the bottom of the passive wedge);

FS_P = Factor of safety for the passive wedge;

FS_A = Factor of safety for the active wedge;

FS = Factor of safety of the entire solid waste mass

F_i = Shearing force acting on the slices

ΔH_{total} = Total settlement

ΔH_i = Immediate settlement

ΔH_c = Consolidation settlement

ΔH_α = Secondary compression or creep

N_i = Normal force acting at the base

N_A = Normal stress acting on the bottom of the active wedge;

N_P = Normal force acting on the bottom of the passive wedge;

P_i = Normal forces acting on the slices

T_i = Resisting shear force mobilized at the base

ΔT = changes in shearing forces ($T_n - T_{n+1} = \Delta T$)

U_i = Pore water force

U_i = Pore water pressure acting at the base of the i^{th} slice

V = Total volume of solid waste

V_w = Volume of water

W = Weight of slice

Wi = Weight of the i^{th} slice

W_A = Weight of the active wedge;

W_T = Total weight of the active and passive wedges;

W_P = Weight of passive wedge;

W_s = Dry weight of solid waste

W_{wt} = Weight of water

W_w = Weight of the sliding soil wedge

τ = Shear strength

τ_f = Average shear strength of soil

τ_d = Average shear stress developed along the potential failure surface

ϕ_m = Mobilized friction angle

α = Inclination of the failure plane

α_b = Angle between radius and vertical

γ = Unit weight of soil

ϕ = Angle of internal friction

σ_n = Total normal stress

μ = Pore pressure

θ_v = Volumetric moisture content of solid waste

δ_P = Minimum interface friction angle of multi-layer liner components beneath the passive wedge;

ϕ_{sw} = Friction angle of solid waste;

α_{sw} = Angle of solid waste slope, measured from horizontal, degrees;

θ_{sw} = Angle of the landfill cell subgrade, measured from horizontal, degrees;

δ_A = Minimum interface friction angle of multi-layer liner components beneath the active wedge;

β = Angle of the side slope, measured from horizontal, degrees;

γ_d = Dry density

γ_b = Bulk density

CHAPTER 1

INTRODUCTION

1.1 General

Slope stability analysis is very important in landfill slopes as slope failure can cause big damage and increase the cost of maintenance. To perform the slope stability analysis is not an easy task. Engineers should carefully examine the types of waste, its seepage condition and slip potential before construction, during construction and after construction (maintenance) of landfill. As stated by Bromhead (1992) there are three factors that affect the stability of the slope. That are:-

a. Geologic and hydrologic conditions

b. Topography

c. Climate weathering

In landfill, there are several ways performed to construct landfills which are used to manage wastes as there are enormous amounts of solid waste generated.

According to the Consumers' Association of Penang, at present, the per capita generation of solid waste in Malaysia varies from 0.45 to 1.44kg/day depending on the economic status of an area. In general, the per capita generation rate is about 1kg/day. Malaysian solid wastes contain very high organic waste and consequently high moisture content and bulk density of above 200kg/m^3. A recent study conducted in Kuala Lumpur has revealed that the amount of organic wastes for residential area range from 62 to 72%. Disposal of solid waste is done almost solely through landfill method. These waste materials can be classified into (a) municipal waste (b) industrial waste (c) hazardous waste (d) low –level radioactive waste.

1.2 Project Objective

The main purpose of this project is to evaluate method of slope stability analysis applied to landfill slopes and investigating the unit weight of waste using Standard Proctor Test. Municipal Solid Waste (MSW) landfill is going to be the types of landfill that will be analyzed in this project as the MSW are the highest disposal generated by human everyday especially in Malaysia. The aim of this study is to find out the effectiveness of transitional method (two-wedge method) on analyzing the factor of safety of landfill and the unit weight of local waste.

1.3 Organization of Thesis

Chapter one is mainly about the slope stability and landfill. Slope stability and standard proctor test are briefly discussed. In Chapter two, a presentation of literature review is made as to review some of the methods of slope stability applied on earth and landfill slopes. From this chapter, study is made on the different types of slope stability analysis to obtain FOS and the types of waste, its classification and properties are also included. Apart from that, reviews of other research works on landfill slopes are also included at the end of the chapter. In Chapter three, the main concern is on the translational method that is used on landfill and discussion on Standard Proctor Test in compaction test. Data involved in FOS analysis is obtained from Trienekens (SARAWAK) Sdn. Bhd. In Chapter four, the results and the discussion of data obtained from FOS analysis and compaction test are presented. Finally, Chapter five contains an outline of the conclusions drawn from the project and the recommendations for further study.

CHAPTER 2

LITERATURE REVIEW

2.1 General

A review of existing literature review on method of slope stability analysis is discussed here, followed by description of different types of landfill and its stability analysis. The first part of the literature review deals the factor of safety of the preexisting study on man-made slope while the second part describes the various method of slope stability analysis that are performed to determine the FOS of slope and the final part will cover landfill and its properties and explanation on its stability analysis.

2.2 Factor of Safety

According to Bromhead (1992), the ratio between the actual strength available, and that mobilized, gives an index of relative stability called the *factor of safety*. Factor of safety is defined as:-

$$FOS = \frac{\tau f}{\tau d} \qquad \text{....2.1}$$

Where,

FOS = factor of safety with respect to strength

τf = average shear strength of soil

τd = average shear stress developed along the potential failure surface

The factor of safety compensates for the uncertainties of engineering analysis. The lower the factor of safety, the greater the risk involved. This is because the factor of safety is not remaining valid and can be manipulated by the change in the condition of:-

(a) Change in pore water pressure.

(b) Weathering of spoil or coal waste.

(c) Departure from the assumed conditions of the analysis during field construction.

(d) Conditions can change overnight due to climate. It is difficult to assign realistic properties to an analysis.

The value factor of safety can be seen from the Table 2.1. This is the value of the factor of safety that varies with the details of the slope.

FACTOR OF SAFETY	DETAILS OF SLOPE
<1.0	Unsafe
1.0 - 1.25	Questionable safety
1.25 – 1.4	Satisfactory for routine cuts and fills, questionable for dams, or where failure would be catastrophic
>1.4	Satisfactory for dams

Table 2.1 Factor of safety which related to detail of slope (Terzaghi and Peck, 1967)

2.3 Method of General Slope Stability Analysis

The various procedures of stability analysis of such slopes may, in general, be classified into three major groups' namely whole mass procedure, method of slices and finite element method.

2.3.1 Whole Mass Procedure

In this procedure the mass of the soil above the surface of sliding is taken as a unit. This procedure is useful when the soil forming the slope is assumed to be homogeneous. The method that uses this procedure for the analysis of slope stability is Culmann's method.

2.3.1.1 Culmann's Method

This method is used for the stability analysis of homogenous soils possessing cohesion. The analysis is based on the assumption that the failure will occur along a plane that passes through the toe of the fill. A sliding mode of failure will occur along a resumed failure surface when the applied shearing force exceeds the resisting shearing forces. The failure surface can be of any combination of plane and curved surfaces, but for simplicity, all failure surfaces are assumed to be planes which form the bases of wedges the failure mechanism is illustrated in Fig. 2.1. By referring to the Fig 2.1, the tangential force, T tending to cause sliding is given by,

$$T = W_w \sin\alpha \qquad \text{…2.2}$$

Where, T = tangential force;

W_w = weight of sliding soil wedge;

α = inclination of the failure plane.

Similarly the resisting to sliding, Rs, from the cohesion and angle of internal friction of the soil is given by

$$Rs = C_m L + W\cos\alpha\tan\phi_m \qquad \text{….2.3}$$

Where, C_m = mobilized cohesion; ϕ_m = mobilized friction angle, α = inclination of the failure plane and

$$C_m = \frac{c}{F_c} \quad \text{and} \quad \tan\phi_m = \frac{\tan\phi}{F_\phi}. \qquad \text{….2.4}$$

Where, F_c and F_ϕ are factor of safety against cohesion and angle of internal friction.

Solving for H, we get

$$H_c = \frac{4C_m}{\gamma_w}\frac{\sin\beta\cos\phi}{1-\cos(\beta-\phi)} \qquad \text{….2.5}$$

Where, H_c = height of mass; γ_w = unit weight of water; β = side slope angle.