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Stability of an open dumpsite with ageing

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Abstract: Open dumping is the most commonly used method adopted in Sri Lanka as solid waste management. However, slope failures of open dump sites lead to environmental pollution as most of the open dumps are located near water bodies. Therefore, analysing the stability of open dumps is important in implementing mitigatory measures where required. Abandoned Udapalatha open dump site which is located near Gampola, Sri Lanka was considered as a case study to analyse the stability of its slopes consisting of old and new waste representing different degrees of decomposition. Shear strength parameters of the waste samples of the old and new waste sites were determined using box samples at different depths with particle size less than 9.5 mm. Specific gravity test, Oedometer test and Standard Proctor compaction test were performed to obtain Gs, primary and secondary consolidation parameters, maximum dry density and the optimum moisture content. In addition, direct shear test was carried out to determine the shear strength parameters of the fill. Slope stability analysis was carried out using Slope/W and Plaxis-2D software considering Mohr Coulomb and soft soil creep models respectively for waste material. Consideration of primary and secondary consolidation settlement within the landfill in the Plaxis-2D analysis resulted in an increase in the Factor of safety (FOS). Therefore, FOS values obtained from the slope stability analysis of the old site, was higher than that in the new waste site.

Keywords: Ageing, secondary consolidation, shear strength, slope stability.

1. Introduction

Municipal solid waste is a type of solid waste generated from community, commercial and agricultural operations. This includes wastes from households, offices, stores, industries and other non-manufacturing activities. Municipal solid waste removal is a major problem in all over the world. There are some methods available to remove solid wastes, such as engineering landfill, open dumping, recycle and reuse and ocean dumping. Historically, landfills have been the most common method of organized waste disposal and remain so in many places around the world. Some landfills are also used for waste management purposes, such as the temporary storage, consolidation and transfer, or processing of waste material (sorting, treatment, or recycling). An open dumping is defined as a land disposal site in which solid waste is disposed of in a manner that does not protect the environment and susceptible to open burning, exposed to the elements, scavengers, etc. There have been a number of landfill failures in the world with high loss of lives and properties. Stability of a slope is evaluated by the balance of shear stress and shear strength. A previously stable slope may be affected by many factors, making the slope unstable. Triggering factors of a slope failure can be a climatic event that can make a slope unstable leading to mass movements. Mass movements can be caused by increase in shear stress such as loading, lateral pressure and transient forces. Alternatively, shear strength may be decreased by weathering, changes in pore water pressure and organic material. In slope stability analysis, primary difficulty with analysis is locating most probable slip plane for any given situation, because most of the failure cases are analysed after the real failures. But nowadays slope monitoring using radar technology has been employed. Stability can be significantly improved by installing drainage path to reduce the destabilizing forces.

If the open dump sites undergo failures they can affect nearby water resources. There are number of landfill failures occurred in world with high loss of lives and properties such as landfill failure occurred in Ohio, USA on 9th March, 1996, Landslide at the Payatas dumpsite, Philippines on 11th July 2000 (Jafari et al.2013, [7]), Hiraya landslide in Iran on 1997. There are no slope failures in open dumpsites experienced in Sri Lanka, but most of them are located near river banks. Therefore, analysing the stability of this landfill is very important. In this research, a municipal solid waste landfill site at Udapalatha, Sri Lanka is considered as a case study. This site is adjacent to the "Mahaweli River", the longest river in Sri Lanka. It mainly consists of two distinctive areas such as new site and old site. Old site consists of MSW dumped at early stages of its operation and the new site consists of MSW dumped after the old site is filled to its capacity. After few years of operation dumping of MSW was stopped and the entire site was abandoned. These two sites consisting of MSW which have undergone different degree of decomposition are liable to undergo slope failure which could lead to severe environmental pollution mainly due to its close proximity to the river. Therefore, the research aim is to evaluate the stability of the slopes of old and new sites incorporating the spatial variation of shear strength properties within the fill.

2. Literature Review

The stability of waste mass is one of the major concerns associated with the design of landfill expansion. Past experience has shown that both vertical and lateral expansion of landfills can trigger waste mass instability. Vertical expansion generally involves a significant increase in landfill slope height (Zhan et al., 2008, [13]). For example, the postponed closure of the Payatas landfill in Philippines eventually caused a flow slide in 2000, which killed at least 278 persons (Kavazanjian and Merry, 2005).

Slope stability of a MSW landfill mainly depends on the geotechnical properties of MSW, such as unit weight and shear strength. Although it is common to perform stability analysis with uniform shear strength parameters for MSW, it should be noted that the MSW properties vary spatially due to heterogeneous nature, overburden pressure, and degradation. (Canizal et al, 2011). Thus, spatial and temporal variation in geotechnical properties of MSW should be properly considered in the landfill slope stability evaluations (Babu et al., 2014, [1]). There are various researches and tests done to obtain shear strength characteristics of municipal solid waste (Strak et al., 2000, [12]; Dixon and Jones, 2005,[5]; Zhan et al., 2008, [13]; Reddy et al., 2011, [9]; Canizal et al., 2011; Jafari et al., 2013,[7]).They are laboratory tests, field measurements and back calculation of shear strength.

In laboratory testing methods, in most of the cases direct shear test, unconfined compression test and triaxial compression test are proposed to obtain shear strength parameters. Vane shear test, standard penetration test and cone penetration test are used as field testing methods and for back calculation analysis plate load test is also used (Dixon and Jones, 2005,[5]). However, it is common to use either direct shear test or triaxial test to determine shear strength parameters (Stark et al, 2000 [12]).

3. Methodology

The MSW samples were collected from two different locations in the landfill at Udapalatha. A Hydraulically operated rotary drilling machine was used for the drilling work. Dry percussion drilling was used to collect disturbed samples in the waste at PBH locations given in Figure 1 and rotary drilling was used to advance the boreholes below the waste layer into the subgrade at BH locations. Box samples were also obtained in the landfill site at various depths.

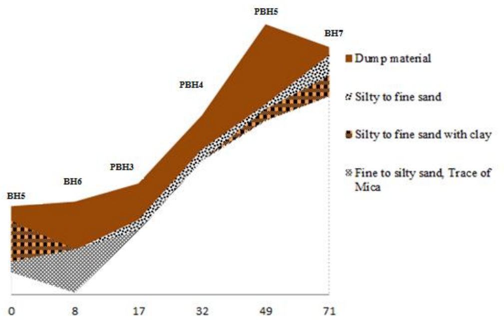


Figure 1: Cross section of old site of Udapalatha landfill

MSW is a heterogeneous material containing paper, polythene, plastic, clothes, organic matters, food particles, etc. It is difficult to analyse the geotechnical properties of MSW which contains materials such as polythene, plastic, etc. Normally fibrous materials present in the waste give additional strength to MSW in a sloped landfill. Therefore, fibrous materials were removed from box samples which were obtained at 0.5m, 1.5m, and 2.5m depths below the subgrade under the dump site. The maximum particle size selected for laboratory testing was selected as 9.5 mm as larger size particles, if present would induce a scale effect on direct shear test specimens.

In the laboratory, several parameters were measured in order to characterize its stability of slope and spatial variation of consolidation and shear strength parameters. These parameters are effective cohesion (c′), effective friction angle (ϕ′), Optimum moisture content (OMC), secondary consolidation parameters (λ*-Modified compression index, K*-Modified swelling index, μ*-Modified creep index) and unit weight (γ).

These parameters were evaluated by carrying out following tests;

1) Direct shear test-To determine c′&ϕ′
2) Consolidation test-To determine λ*, K*, μ*
3) Compaction test-To determine omc
4) Specific gravity test -To determine G_s

Slope stability analysis was done using different numerical software (Plaxis-2D and Slope/W) using different material models. Plaxis-2D with soft soil creep model and Slope/W with Mohr Coulomb model were used. Soft soil creep model is suitable for MSW materials because of its heterogeneity and the presence of more organic matters. This model tends to over predict the range of elastic soil behavior. Other material models do not take creep effects into account.

4. Results and discussion

Results were obtained from the Udapalatha old site samples. The optimum moisture content and the maximum dry density were obtained from Proctor compaction test.

Table 01: Maximum dry density and omc at different depths

Sample depth /m	0.5	1.5	2.5
Maximum dry density/ ρ_d (g/cm^3)	1.10	1.12	1.13
Optimum moisture content /w (%)	39.0	39.9	38.9

The secondary consolidation parameters were obtained from consolidation test. It was carried out in several load increments from 0.5 lbs to 64 lbs including the unloading stage. Figure 2 shows the consolidation test results of 1.5 m depth sample.

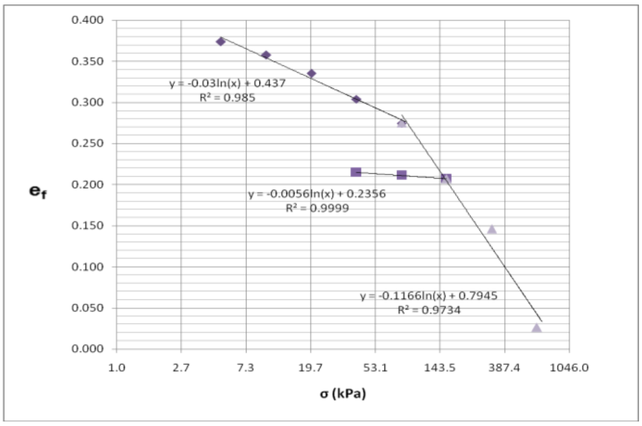


Figure 2: Variation of void ratio with σ

The modified compression index (λ* = 0.1166) was found from Figure 2 loading part and the modified swelling index (κ*=0.0056) was found from the unloading curve. Figure 3 shows the variation of void ratio with time from that graph.

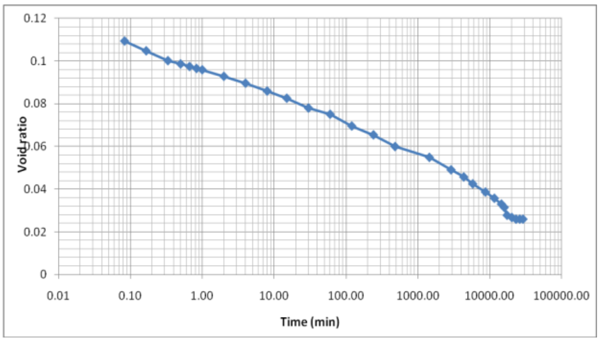


Figure 3: Variation of Void ratio with time

Secondary compression index (Cα) was obtained using the void ratio-time relationship beyond the primary consolidation. Cα was found to be 0.008 from Figure 3. Modified creep index (μ*=0.0024) was found using Cα and initial void ratio (e).

The shear strength parameters were obtained using direct shear test. Figures 4, 5 and 6 show the results of the direct shear test for samples obtained at depths of 0.5 m, 1.5m and 2.5m respectively. A displacement of 20 mm was taken as ultimate strength and corresponding shear stress and normal stress were used to draw the graphs. The shear strength parameters obtained from the direct shear test are listed below in Table 2.

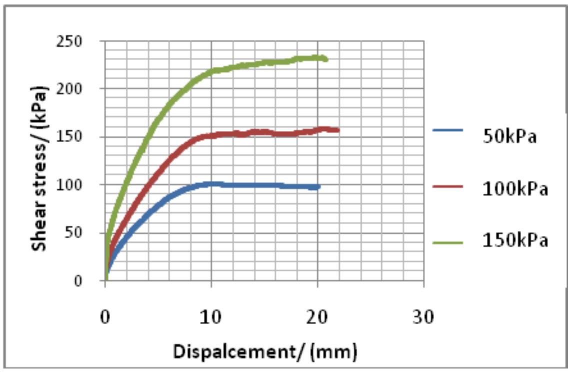


Figure 4: Variation of shear stress with shear displacement for 0.5 m depth sample

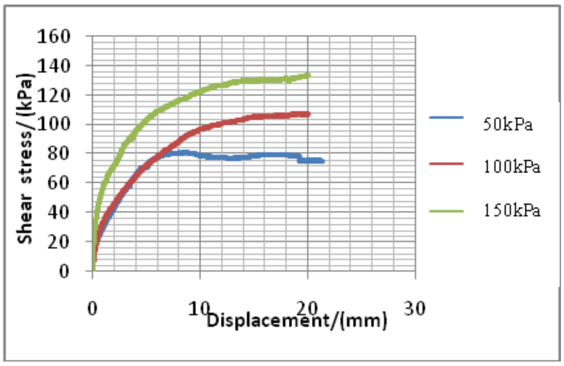


Figure 5: Variation of shear stress with shear displacement for 1.5 m depth sample

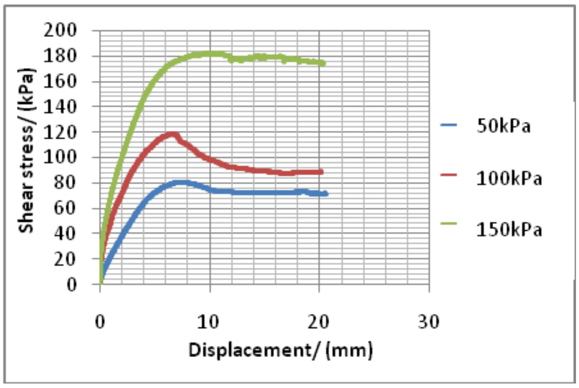


Figure 6: Variation of shear stress with shear displacement for 2.5 m depth sample

Based on the shear stress vs shear displacement curve, shear stress vs normal stress curves were prepared as shown in Fig 7 and the values for cohesion and angle of friction were found based on the graphs.

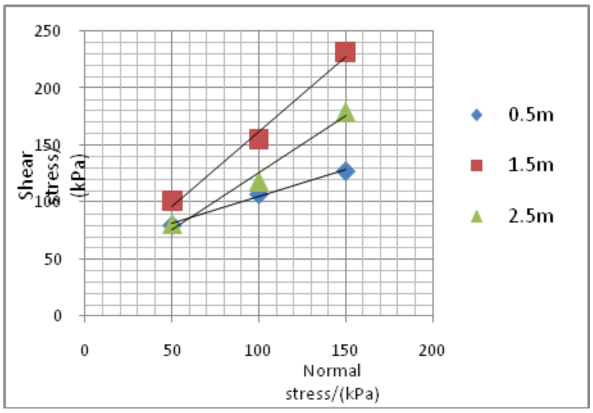


Figure 7: Variation of shear stress with normal stress

The cohesion and angle of friction values obtained for each depth from the direct shear tests are given in Table 2.

Table 2: Results of direct shear test

Depth (m)	c′ (kPa)	ϕ′ (˚)
0.5	57.9	25.1
1.5	30.9	52.8
2.5	26.9	44.7

Figures 8 and 9 show the variation of effective cohesion and the angle of friction with depth. The angle of friction obtained for the 1.5 m depth sample is higher than that of the 2.5 m depth samples. This may be obtained due to the heterogeneity and decomposition with ageing.

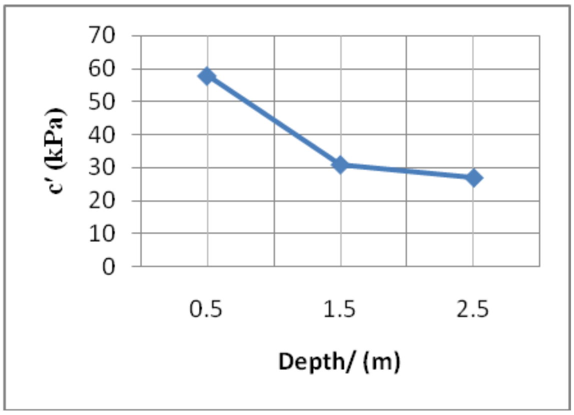


Figure 8: Variation of effective cohesion with depth

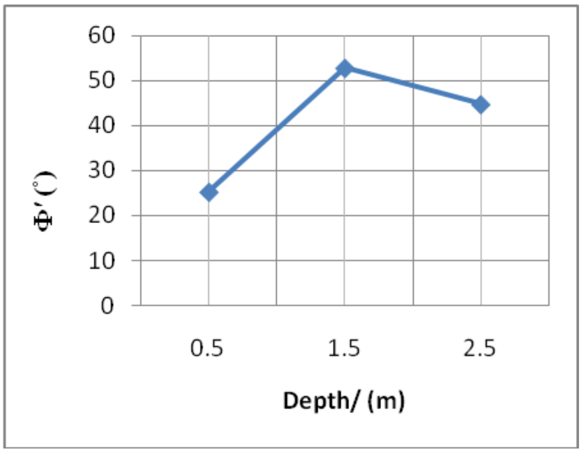
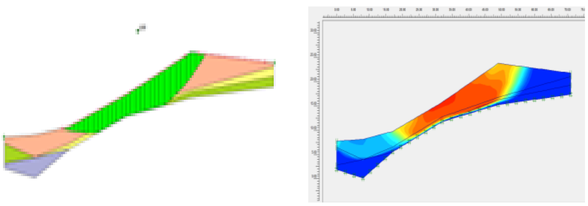


Figure 9: Variation of friction angle with depth

The stability analyses were carried out using Plaxis-2D and Slope/W software. The FOS values obtained from both software are different from each other due to the use of different material models and the results are shown in Table 3. The critical failure surfaces are shown in Figure 10. The watertable is well below the ground surface at the Udapalatha open dump site. Therefore, the stability analyses were carried out without considering the presence of watertable.

Table 3: FOS values obtained from different software (Old site)

Software	Depth (m)		
	0.5	1.5	2.5
Plaxis-2D	2.954	2.799	2.554
Slope/W	2.585	2.924	2.659



(a) (b)

Figure 10: Failure surface obtained using properties at 0.5 m depth (a) Slope/w (b) Plaxis-2D.

However, the possibility of rising of watertable to a reasonable height above the bottom level of the waste layer was also considered in the analysis. Table 4 shows the reduced FOS values obtained from Slope/W software under the above condition.

Table 4: FOS values obtained from Slope/W with watertable

Software	Depth (m)		
	0.5	1.5	2.5
Slope/W	2.384	2.698	2.452

The values of FOS given in Table 3 is compared with those given in Table 5 which gives the FOS values for the site with new waste analysed using the waste properties obtained from three different boreholes. The FOS values reported in Tables 3 and 5 reflect the effect of ageing on the stability of the slopes.

Table 5: FOS values obtained from the new site samples (after, Prathapan R. et al.(2015),[8])

Borehole	Effective Cohesion (kPa)	Effective Friction Angle (°)	FOS	
			SLOPE /W	PLAXIS -2D
PBH1	15.4	31.7	1.184	1.139
BH02	46.7	19.8	1.594	1.382
PBH2	50.2	13.9	1.722	1.428

5. Conclusions

A research study was conducted to evaluate the stability of the slope of an open dump site located in Udapalatha, Sri Lanka. Results revealed that the stability of the slope is in safer range from the obtained results using the two software and the factor of safety values obtained using Slope/W is larger than the values obtained from Plaxis-2D. Presence of ground watertable within the landfill decreases the stability of the slope as expected. Consolidation settlement inside the landfill changes the FOS which is reflected in the Plaxis-2D analysis. Stability of the landfill is increased after the secondary consolidation. Based on the comparison of FOS values of the site with old waste with that of the site with new waste, it can be concluded that the site with old waste is safer which is due to the ageing effect.

Acknowledgement

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