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STABILITY ANALYSIS OF A COMPOST-BIOCHAR MIXED CAPPING SOIL ON HYDROPHOBISED CAPILLARY BARRIER IN AN ENGINEERED LANDFILL

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Abstract: : Engineered landfill is a final municipal waste disposal method. A capping system is the final component in the construction of an engineered landfill. In addition to permeability criteria that need to be satisfied, stability is also an important aspect in its design. In this study, the slope stability of the capping layer interfaces and waste interfaces was analyzed. A low permeable soil with or without mixing with biochar and compost can be used as a capping layer. In addition, a hydrophobized sand (using Oleic acid) can under lie the above layer for improved performance. The shear strength parameters between interfaces and of the waste were determined using the direct shear tests. Analyses were carried out for waste – capillary barrier interface and capillary barrier – top soil (with or without biochar and compost mixture) interface, for different side slopes of the capping. Numerical analyses were carried out using SLOPE/W software. A comparative analytical study was also carried out using infinite slope theory. It was found that circular type of slip surface developed within the capping is more critical than the slip surface develop along the interfaces and introducing compost and biochar into the topsoil infact has improved the stability of the slopes of the capping layer.

Keywords: Biochar, Capillary Barrier, Capping, Landfill Stability

1. Introduction

Among several municipal solid waste management methods, landfilling is being used widely as a final municipal waste disposal method. A capping system is the final component in the construction of an engineered landfill. Detrimental effects of disposing municipal solid waste in open dumps can be alleviated by proper use of an engineered landfill. However, instead of using commonly used geosynthetic materials to construct an engineered landfill, locally available materials can be used to be more cost effective and manageable by the local government agencies.

The capping layer of an engineered landfill should be capable of minimising infiltration so as to minimise leachate generation. In addition, it is also essential that the capping allows exchange of gasses emitted within the solid waste during the decomposition process of waste. It is preferable, if methane oxidation can be promoted within the capping with the objective of reducing the emission of green house gases by introducing compost within the capping and also to reduce the volatile organic compounds (VOC) releasing to the atmosphere by introducing biochar. Therefore, a low permeable soil with or without mixing with biochar and compost can be used as a capping layer. In addition, introduction of a hydrophobized sand layer (sand mixed with Oleic acid) beneath the low permeable capping layer can further reduce the infiltration of water into the waste. Although, the capping layer can be so designed considering above factors, its stability when placed on sloping surfaces in a landfill needs to be investigated (Law et al, 2015).

Therefore, the aim of this investigation is to optimize the cover material using locally available materials ensuring its stability in addition to satisfying hydraulic criteria.

2. Literature Review

2.1 Shear strength characteristics of geomembrane - geotextile interfaces

In a study by Belen et. al, (2015), five types of geomembranes and three types of geotextiles were selected which were different to each other from raw materials and manufacturing processes used and type of roughness. This material was combined with one another and eighteen interfaces were analysed. Shear strength parameters have been determined by carrying out direct shear tests under five normal stresses of 25, 50, 100, 300, 450 kPa in wet condition. They observed that the peak interface shear strength had reached at a shear displacement of 4-10 mm and ultimate strength obtained at a shear displacement of about 50 mm. Peak shear strength had increased with increasing normal stress, as shown in Fig. 1.

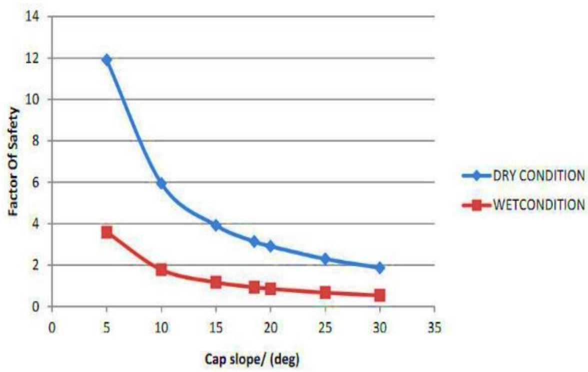

Fig. 1: Variation of shear strength with shear displacement (after, Belen et.al (2015))

2.2 Capping material for an engineered landfill in wet zone of Sri Lanka

Niruthshanan et al, (2015) evaluated interface shear characteristics between waste and biochar-compost mixed capping material using direct shear tests under dry and wet conditions. Infinite slope analysis had been carried out to evaluate the stability of the slope and determine the critical angle of the capping layer.

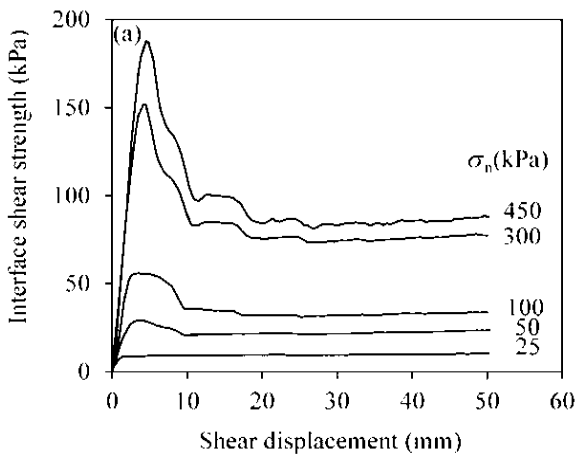

Fig. 2 shows the results obtained from their analyses.

They also obtained the optimum content of oleic acid which introduces water repellent properties of a capillary barrier layer consisting of fine to medium coarse grained sand by measuring the water drop penetration time (WDPT). Based on the results it has been found that an oleic acid content of 3 g/kg would produce low infiltration characteristics for the capillary barrier layer of the selected sand.

The optimum mix proportion of the constituents of biochar-compost capping layer was evaluated by carrying out falling head permeability test. Out of the four samples prepared, the mix ratio that showed the minimum permeability was found to be 82% Top soil, 15% Compost and 3% Biochar giving a coefficient of permeability of 0.58 x 10^{-8} cm/s.

3. Methodology

Direct shear tests were conducted using an automated direct shear apparatus (Fig. 3) to evaluate the shear strength parameters of waste and relevant interfaces. Top soil and capillary barrier interface, biochar composite mixture and capillary barrier interface and capillary barrier and waste interface are three interfaces that were tested and in addition shear strength parameters of waste were evaluated.

Fig. 3. Automated Direct Shear Apparatus

Slope that extends for a relatively long distance and has consistent subsurface profile can be considered as an infinite slope where the critical failure plane is assumed to be parallel to slope surface. The following equations can be formulated to analyse the interface over which either one or two layers of materials exist as illustrated in Fig. 4.

W_1, W_2 = Weight of the prisms

$W = \gamma bH\cos\beta$

N = Normal stress = $W\cos\beta = \gamma bH\cos^2\beta$

T =Resisting shear force= $W\sin\beta = \gamma bH\cos\beta\sin\beta$

$$FOS = \frac{c + N\tan\phi}{T}$$

$$FOS = \frac{c + \gamma_1 H_1 \cos^2\beta.\tan\phi}{\gamma_1 H_1 \cos\beta.\sin\beta} \quad \text{(Interface 1) Eq.1}$$

$$FOS = \frac{c + (\gamma_1 H_1 + \gamma_2 H_2)\cos^2\beta.\tan\phi}{(\gamma_1 H_1 + \gamma_2 H_2)\cos\beta.\sin\beta} \quad \text{(Interface 2) Eq.2}$$

where, β- Side slope, γ- Unit weight, ϕ- Friction angle, c- Cohesion, H_1,H_2- Height of layers.

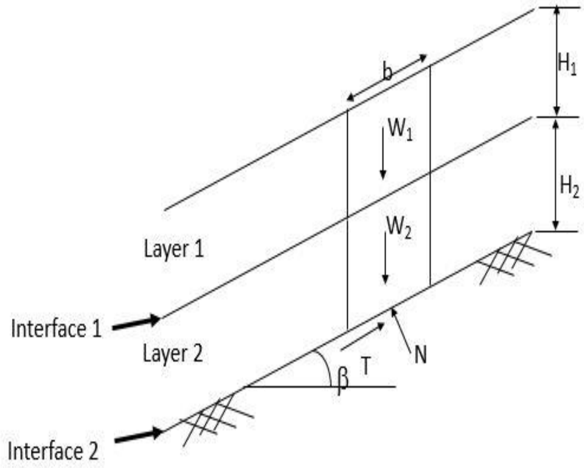

Fig. 4: configuration of the capping layer consisting of two materials and relevant interfaces

Three types of capillary barriers (cb) with oleic acid (Specific gravity = 0.887) content of 2.5 g/kg, 3.0 g/kg and 3.5 g/kg were prepared to be compacted into the bottom half of the direct shear box. The direct shear testing of waste (wt) was carried out by first removing materials like polythene and then by sieving through the 9.5 mm sieve, similar to the procedure followed by Ohata et.al. (2015). All the direct shear tests were carried out under normal pressures of 14 kPa, 27.5 kPa and 57 kPa simulating lightly loaded overburden above the capping.

The shear strength parameters thus obtained were used to carry out the stability analyses considering circular and block failure modes using Geostudio SLOPE/W software. Infinite slope theory was used to arrive at an analytical solution as illustrated in Fig. 4.

4. Results and Discussion

4.1 Laboratory tests for the materials

Based on the particle size distribution (Fig.5) the top soil (ts) was classified as silty sand.

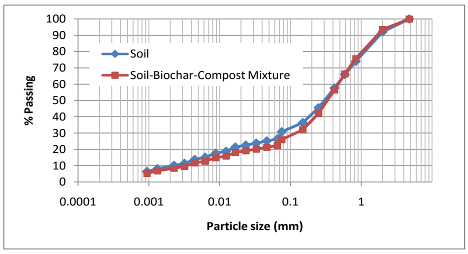

Fig. 5: Particle size distribution of top soil and biochar-compost mixed top soil

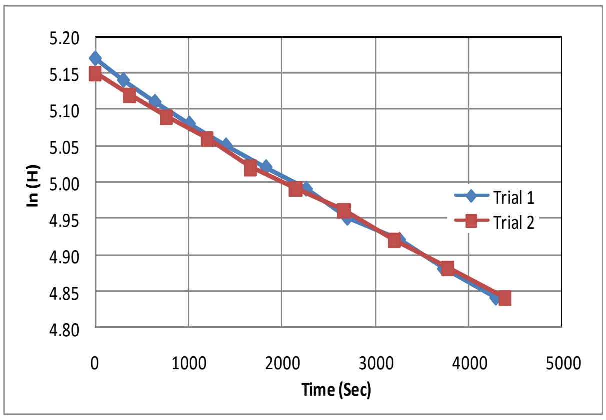

Fig. 6: Results of permeability test (Falling head)

The average coefficient of permeability as determined from the falling head method (Fig.6) was 3.71 x 10^{-6} cm/s.

The shear strength parameters of waste, and between relevant interfaces were determined using direct shear tests. For this purpose, it was necessary to exactly align the interface between the two materials with the shear plane defined by the direct shear test apparatus. However, if the material placed at the bottom half of the direct shear test box is subjected to consolidation settlement under the applied normal pressure, the shear plane would likely to shift away from the central plane towards the bottom. In this study, the determination of the interface shear strength parameters was along the plane between the capillary barrier (layer 2 in Fig.4) and either the waste or the top soil, both of which would undergo consolidation settlement under the applied normal pressure. Therefore, it was essential that the non-consolidating capillary barrier material of fine to medium coarse sand be placed into the lower half of the direct shear test box to maintain the interface at the desired level. The relationship of shear stress with shear displacement obtained from the direct shear test carried out on the interface between capillary barrier with an Oleic acid content of 3.0 g/kg and, compost and biochar mixed top soil is given in Fig.7 with corresponding variation of peak shear stress with normal stress given in Fig.8. It can be seen that the peak shear stress-normal stress agrees well with the linear Mohr-Coulomb failure surface. The variation of interface cohesion and friction angle with the Oleic acid content of capillary barrier are shown in Fig.9 and Fig.10 respectively, with a summary of results given in Table 1 along with the shear strength properties of waste.

Table 1: Shear strength parameters

Layer*	ϕ (deg)	c (kPa)
2.5cb-bm	33.5	14.9
3.0cb-bm	45.9	2.6
3.5cb-bm	48.8	1.2
2.5cb-ts	41.1	6.1
3.0cb-ts	42.7	9.1
3.5cb-ts	39.8	11.6
2.5cb-wt	43.9	7.0
3.0cb-wt	49.8	5.3
3.5cb-wt	50.9	7.3
wt	56.6	35.3

*cb-capillary barrier, bm-biochar/compost mixed top soil, ts-top soil, wt-waste

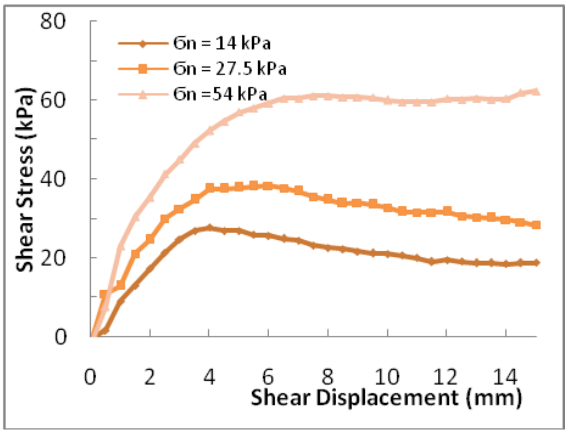

Fig. 7: Variation of shear stress with shear displacement

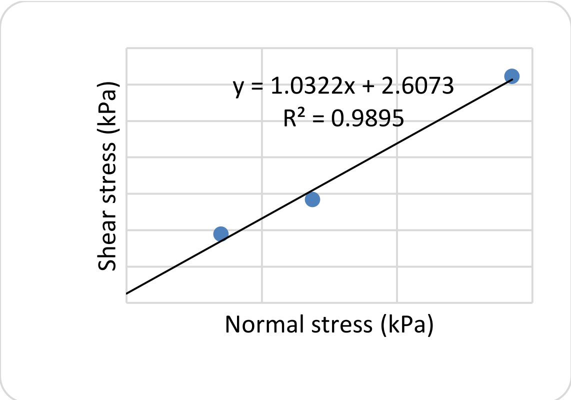

Fig. 8: Variation of peak shear stress with normal stress

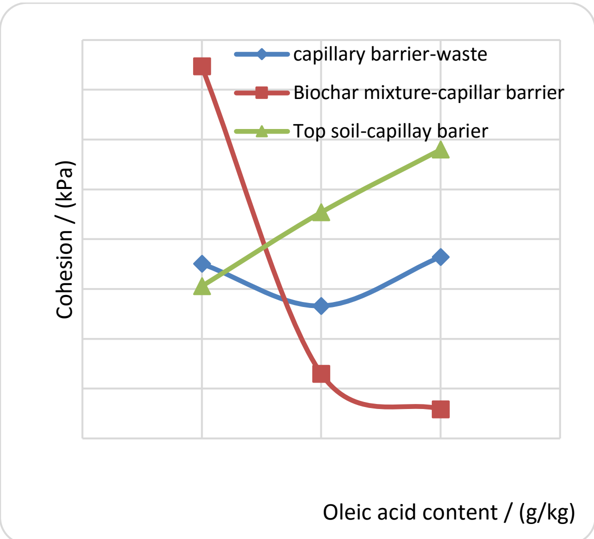

Fig. 9: Variation of cohesion with oleic acid content of capillary barrier

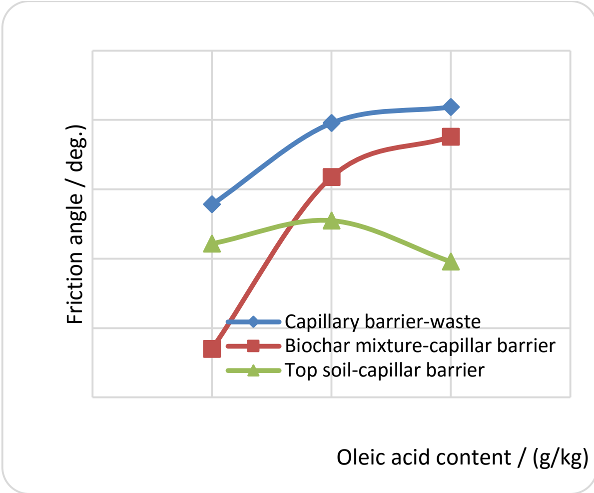

Fig. 10: Variation of friction angle with oleic acid content of capillary barrier (cb)

4.2 Numerical and Analytical Solutions

Numerical analyses were carried out using Slope/W software. Two types of stability analysis using circular and block failure modes were carried out for the capping. Fig.11 shows a typical configuration of the sloping side of the landfill used for the numerical analyses for a particular side slope. Material properties of layers 1 and 2 were assigned with those corresponding with the interface shear strength. The critical failure surfaces corresponding to circular and block failure modes are given in Fig.12 and Fig.13 respectively.

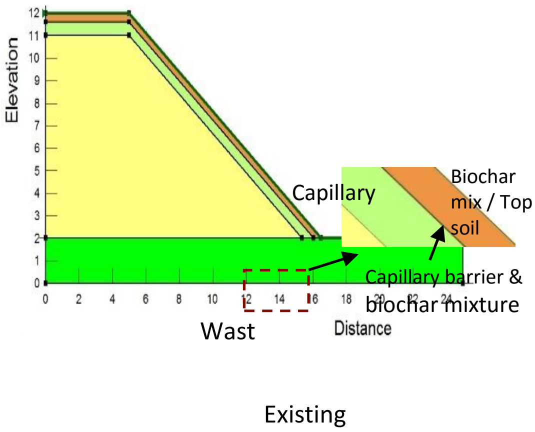

Fig.11. Configuration of the landfill used in Slope/W

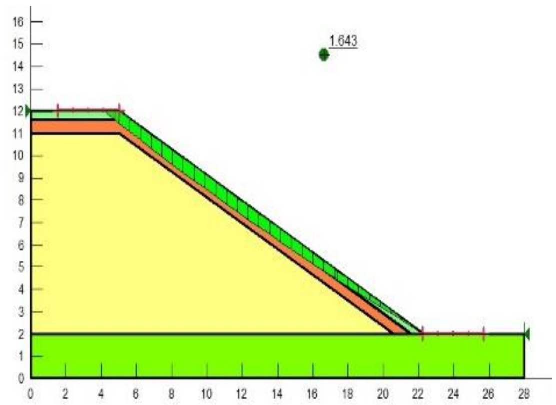

Fig. 12. Critical failure surface corresponding to circular slip surface

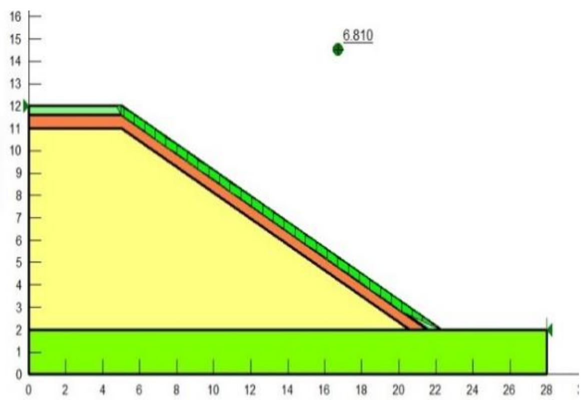

Fig. 13: Critical Block failure surface analysis

A comparative analytical study was also carried out using the infinite slope theory for sliding along the two interfaces as shown in Fig.4, using Eq.1 and Eq.2. Fig. 14 and Fig. 15 shows the variation of Factor of safety (FOS) with slope angle for infinite slope and circular modes of failure respectively.

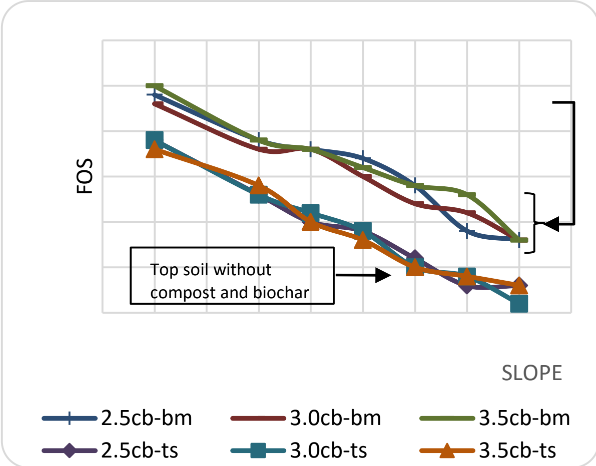

Fig. 14: Variation of FOS with slope angle obtained numerically and analytically for block and infinite failure modes respectively

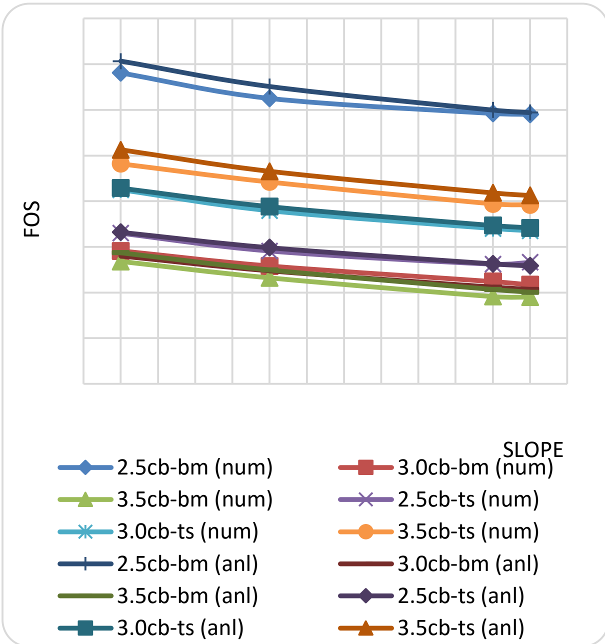

Fig. 15: Variation of FOS with slope angle obtained numerically for circular failure modes

It can be seen from Fig.14 that numerical analyses and analytical solutions corresponding to a particular case, are closely matching qualitatively as well as quantitatively. Further, the introduction of compost and biochar into top soil to enhance methane oxidation and removal of volatile organic compounds has incidentally increased the stability of the slope as well, which is compatible with the shear strength properties listed in Table 1. Comparison of Fig.14 and Fig.15 shows that the circular failure mode is critical than the failure along the interfaces.

5. Conclusions

Based on the numerical and analytical studies carried out on the stability of capping materials it can be concluded that the circular failure mode is more critical than the failure along interfaces. The introduction of compost and biochar into the top soil enhances the stability of the capping.

Acknowledgement

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