Use of Mulch as Daily and Intermediate Cover for Landfills

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PROJECT TITLE: Use of Mulch as Daily and Intermediate Cover for Landfills

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ABSTRACT: Management of yard waste is a significant challenge in the US, where in 2005 13.1% of the 245 million tons of municipal solid waste was reported to be yard waste. Approximately 61.9% of yard waste is recycled (http://www.epa.gov/garbage/pubs/mswchar05.pdf). Because of its volume and potential use as a soil amendment, the disposal of yard waste in lined landfills is banned in most states. Consequently, yard waste is frequently composted or mulched. Composting involves the aerobic biological degradation of yard waste to a soil-like material, whereas mulching involves size reduction and homogenizing without biological processes. Common uses of compost and mulch are on municipal parks, roadways, and horticultural purposes. Another common use of mulch is as landfill cover to avoid purchase of soil or alternative cover materials. This study investigates the use of mulch as daily and intermediate cover for landfills. Seven mulch samples were collected from different parts of Florida, and direct shear and hydraulic conductivity tests were conducted to evaluate their geotechnical and hydraulic properties. Mulch samples had internal friction angles in the range of 14^0-16^0 and had an interface friction angle with MSW in the range of 12^0-13^0. All mulch samples were cohesive and had some adhesive resistance against MSW. A slope stability analysis was carried out assuming both a linear plane of failure at the interface between the Municipal Solid Waste (MSW) and mulch used as daily and intermediate cover and a circular slip surface where mulch is used as daily and intermediate cover using the program Slope/W. Results for both intermediate and daily covers showed that all seven mulch covers used at a slope of 1:3 and 1:4 had factors of safety above 1.5; indicating a stable slope. All mulch samples had a hydraulic conductivity of 0.1 cm/sec with a porosity ranging from 0.56-0.64. The effects of temperature, moisture content and oxygen concentration on spontaneous ignition of mulch were investigated. Compacted shredded mulch (maximum dimension less than 2.5cm) at various moisture contents and oxygen concentration were placed in a programmable oven and subjected to increasing temperature (3^0C/min) to evaluate the auto-ignition temperature under different moisture contents and oxygen concentrations. The ignition temperature for the dry studied mulch was found to be 230^0.

1. INTRODUCTION

Recently, interest in using yard wastes compost or mulch as biocovers or daily cover for landfills has been increasing because of potential technical and economic benefits. Potential issues with use of vegetative covers include impact on slope stability, fires, and permeability.

Addition of yard waste mulch to soil has been found to be an effective improvement to control soil erosion. Grobe (2006) reported that the department of transportation in California has applied compost to the roadside landscaping and found a remarkable decrease in soil erosion and runoff. Risse et al (2002) conducted a field evaluation of compost and mulch for erosion control. In his study four types of compost layers, hydroseed, silt fence and bare soil were applied in field test plots. The plots were seeded with common Bermuda grass. Different simulated rainfall intensities were applied. The study indicated that a compost blanket tended to produce less runoff and erosion and permit more infiltration.

Reduction of odorous emissions and odor control using compost as a daily cover has been investigated by Hurst et al (2005). In this study odorous gases were passed through test columns filled with municipal waste compost at two different densities (590 kg/m^3 and 740 kg/m^3). Gas samples were taken from the inlet, outlet and varying column depths. Results showed the ability of compost to reduce landfill odors, with 69% odor reduction (OU/m^3) through the column of the lower density of compost and 97% odor reduction for the higher density of compost.

Fires are also a concern with the use of yard waste mulch. Steward et al (2003) studied the ease of ignition of 13 types of landscape mulch. The mulch samples commonly used in landscaping were chosen for evaluation of their ease of ignition under natural field conditions. The mulch materials were subjected to ignition by cigarettes, matches and a propane torch. The study concluded that mulch ignition depends on the mulch material, moisture content and duration of time the mulch was exposed to the ignition source.

Spontaneous fire in yard waste compost and mulch storage piles is considered to be an infrequent but serious problem. Buggeln and Rynk (2002) presented a literature review of self-heating in yard trimmings. In their review, they described how spontaneous combustion occurs in piles of yard trimmings, starting with chemical and physical events that initiate heat-producing reactions via biotic and abiotic processes involving oxygen and moisture. They clarified the various conditions that lead to spontaneous fires and the challenges of detecting and extinguishing the fires.

Potential benefits of the use of vegetative waste as daily and intermediate cover in landfills include reduced expenditure for cover materials and reduction of odor and methane emissions. The goal of this research was to examine the application of vegetative mulch as cover in landfill systems. The specific objectives were to evaluate (1) leachate flow rates, (2) the stability of mulch on landfill slopes, (3) the potential for spontaneous combustion in mulch layers, and (4) the role mulch covers would play in controlling odors and methane emissions. Mulch samples have been collected from central Florida landfills for testing.

2. RESULTS AND DISCUSSION

Seven samples of mulch were gathered from different landfills at various parts of Florida State between March 3rd and March 27th 2008. Table 1 describes the different mulch samples collected. Each sample of mulch was tested to evaluate geotechnical properties, varying moisture content and bulk density (compaction ratio).

Table 1. Florida landfill mulch sampling

Sample	Details
Osceola Rd. LF (OS1)	Wood chips from pile
Osceola Rd. LF (OS2)	Aged 3-years (Used as intermediate LF cover)
Orange county LF (OR1)	mostly leaves from pile
Orange county LF (OR2)	Wood chips from pile
Brevard Central LF (BR)	Wood chips from pile
Indian River County LF (IRC)	Wood chips from pile
New River Regional LF (NRR)	Wood chips from pile

2.1 SHEAR TESTS

Direct shear tests were conducted on the mulch samples collected from the various landfills in order to obtain their internal friction angle, which in turn was used as input data for the simulations of the Slope/W program that calculated the safety factors for different scenarios of landfill daily and intermediate covers. Shear tests were conducted at the optimum moisture content and maximum compacted unit weight of the mulch samples to simulate actual landfill mulch conditions. The relationship between water content and dry unit weight of soils (compaction curve) was determined by running the modified compaction test (using an auto compaction machine with a 0.05 kN hammer) in accordance with ASTM testing method (ASTM D-1557) from which optimum values of moisture content and dry unit weight were obtained. Mulch samples were mixed with water and placed in three layers in the mold which has a volume of approximately 944 cm^3. Each layer was compacted with 25 blows and the final weight of the mold and the mulch sample was recorded. A sample was taken form the mold and placed in the oven at each trial to calculate the moisture content using equation 1, and then the dry unit weight was calculated using equation 2.

$$\text{Moisture content of the compacted mulch (MC)} = \frac{W_w}{W_s} = \frac{W - W_s}{W_s} \qquad (1)$$

W_s = mass of the dry mulch sample
W_w = mass of water
W = mass of the wet compacted mulch sample

$$\text{The dry unit weight} = \frac{\gamma_t}{1 + MC} \qquad (2)$$

where γ_t = wet unit weight of mulch

$$= \frac{W(g) \times 9.81}{V(cm^3)} \text{ (kN/m}^3\text{)}$$

V = volume of mold

Figures 1 to 7 show the change in dry unit weight with moisture content and the optimum values of moisture content and dry unit weight for the seven samples.

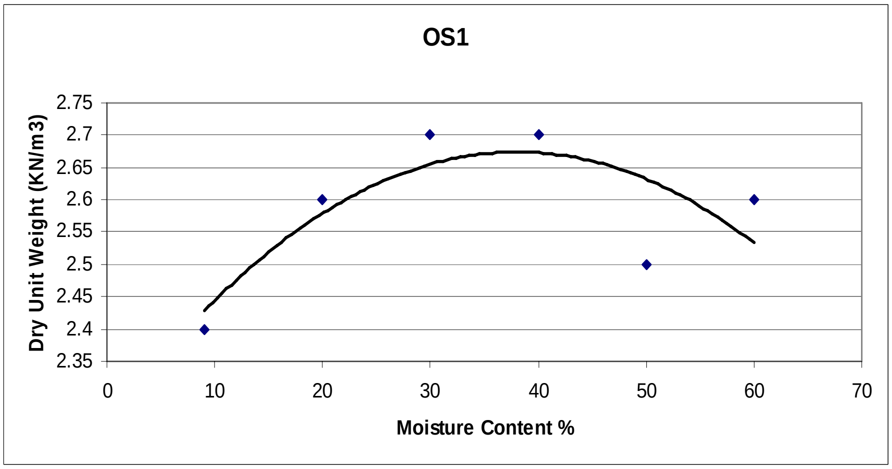

Figure 1: Optimum moisture content and dry unit weight for the OS1 mulch sample

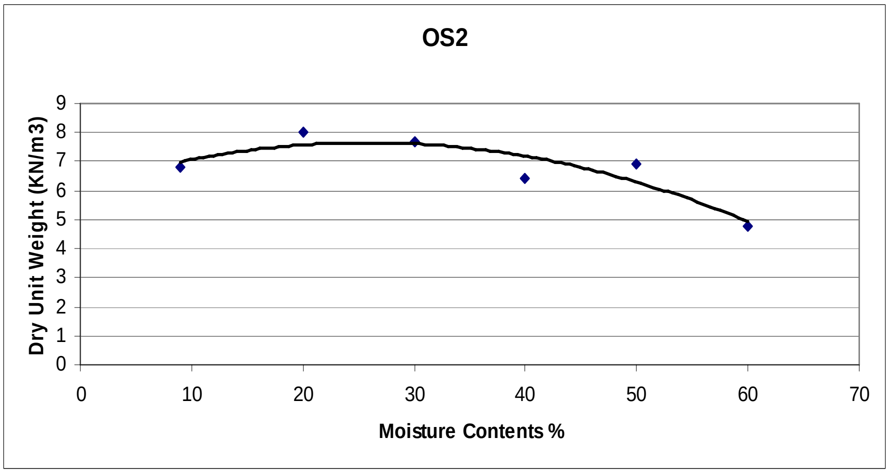

Figure 2: Optimum moisture content and dry unit weight for the OS2 mulch sample

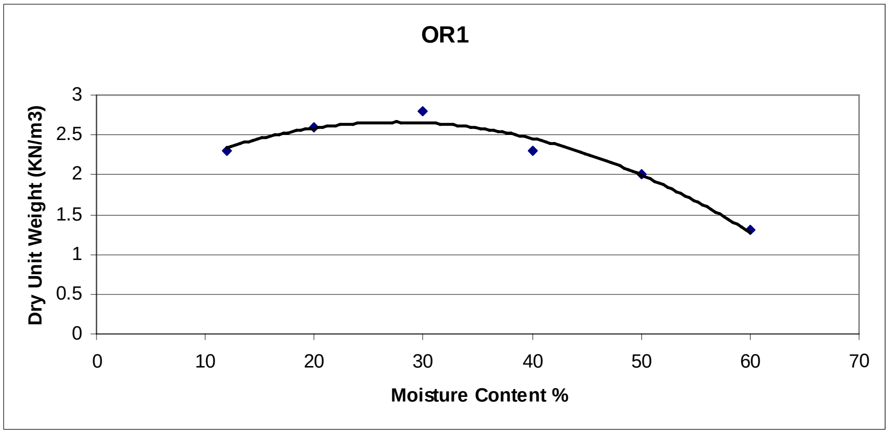

Figure 3: Optimum moisture content and dry unit weight for the OR1 mulch sample

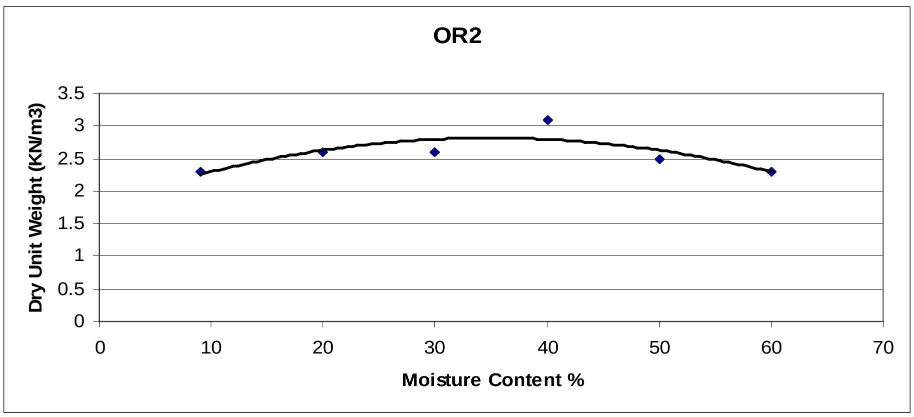

Figure 4: Optimum moisture content and dry unit weight for the OR2 mulch sample

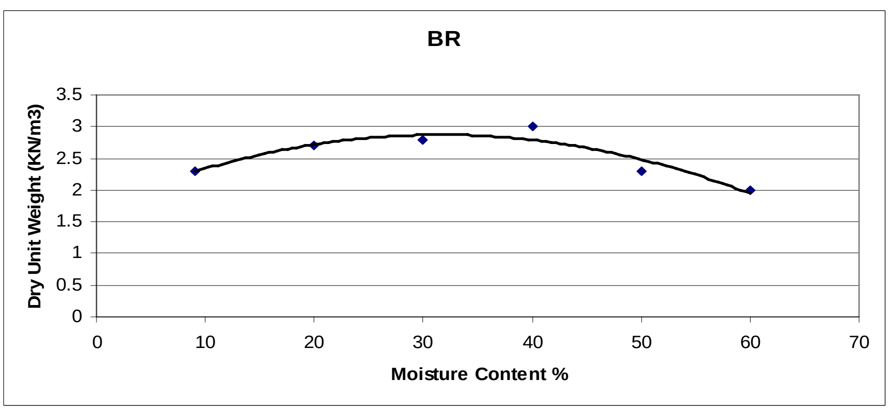

Figure 5: Optimum moisture content and dry unit weight for the BR mulch sample

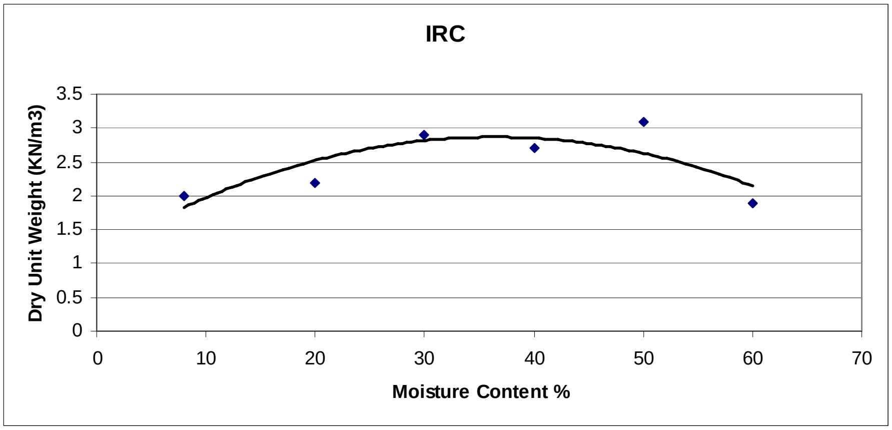

Figure 6: Optimum moisture content and dry unit weight for the IRC mulch sample

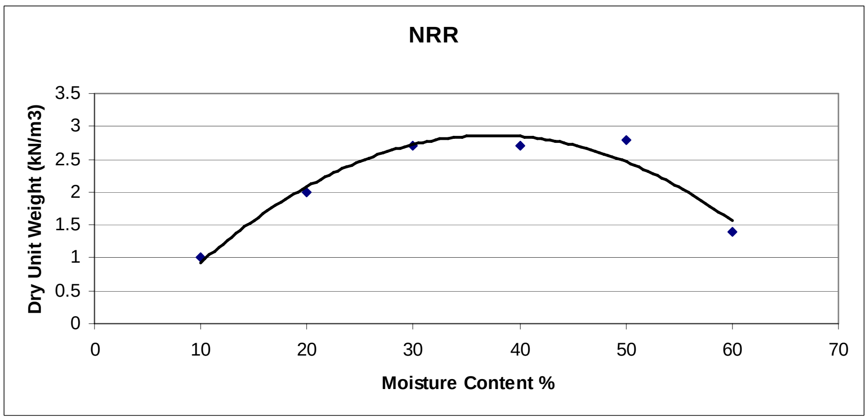

Figure 7: Optimum moisture content and dry unit weight for the NRR mulch sample

Mulch samples were shredded to around 1 inch. A large size direct shear mold previously designed and built at UCF for shear tests on solid waste samples was used for this study. The large size direct shear mold could accept a sample size of 14 x 14 x 11 cm. This mold was designed to fit the testing apparatus which allowed for a maximum horizontal deflection of 1.9 cm which was the limit for the horizontal shear displacement. This horizontal deformation corresponds to a strain of 12.7%. During direct shear testing a low strain rate was estimated and drained conditions were assumed to prevail. Therefore, strength parameters estimated from these tests were apparent effective shear strength parameters. The testing procedures followed the specifications outlined in ASTM D-3080 for direct shear tests of soil under consolidated and drained conditions. The horizontal deformation was noted from the horizontal dial gauge and the shear force applied was noted from the proving ring dial gauge. Table 2 summarizes the shear test results.

Table 2. Shear test results for mulch samples

Sample	Optimum Moisture content % By weight	Unit weight KN/m^3	Friction angle tan (friction angle)	Friction angle Degrees	Cohesion KN/m^2
OS1 1	35	2.7	0.28	16	0.6
OS2 1	28	8	0.28	16	0.2
OR1 1	30	2.7	0.29	16	1.0
OR2 1	37	2.7	0.25	14	1.2
BR 1	33	2.7	0.29	16	0.9
IRC1	38	2.7	0.28	16	1.0
NRR1	38	2.7	0.28	16	1.2

Bulk unit weights indicated the amount of compaction that can be achieved for the mulch samples. All the samples had the same bulk density except for the OS2 mulch sample which had a much greater compaction capacity due to the finer size and homogeneous shape of its particles. The OS2 mulch sample had been used as an intermediate landfill cover for three years and had already degraded to a soil-like texture. Friction angles were almost the same for all the mulch samples with varying cohesion values; once again the OS2 sample had a very low cohesion value due to the lack of interlocking of fine particles while all the other mulch samples were composed of wooden pieces of about 2.5 cm. The general trend was that mulch had lower friction angles than that of soil which is usually in the range of 30^0 to 35^0, and higher cohesion than soil that usually has near zero cohesion (Taylor 1965). The effect of mulch layers on slope stability can only be determined through modeling and static calculations.

2.1.1 Slope stability calculations for mulch covers (assuming a linear failure plane)

The potential failure surface for veneer cover soils is usually linear with cover soil sliding with respect to the lowest interface friction layer in the underlying cross-section (Koerner et al. 2005). Safety factor calculations for the intermediate and daily mulch cover were based on the stability analysis done by Koerner and Soong (2005) for a finite length slope with uniformly thick soil cover placed over a geomembrane liner. The interface friction angle between MSW and mulch was used and the soil friction angle and unit weight were replaced by those of mulch samples. The potential failure plane being linear allows for a straightforward stability calculation without the need for trial center locations and different radii, as with soil stability problems analyzed by rotational failure surfaces. Figure 8 shows the linear anticipated surface of failure along with the forces acting on the passive and active wedges. After balancing the vertical forces for the active wedge and the horizontal forces for the passive wedge, and equating the two interwedge forces acting on the active and passive wedges, the factor of safety against mulch cover sliding over the MSW is given by equation 3.

$$\mathrm{FS} = \frac{-b + \sqrt{b^2 - 4ac}}{2a} \qquad (3)$$

Where,
$a = (W_A - N_A \cos\beta)\cos\beta$
$b = -[(W_A - N_A \cos\beta)\sin\beta\tan\Phi$
$\quad + (N_A \tan\delta + C_a)\sin\beta\cos\beta$
$\quad + \sin\beta\,(C + W_P \tan\Phi)]$
$c = (N_A \tan\delta + C_a)\sin^2\beta\tan\Phi$

W_A (Weight of the active wedge) $= \gamma h^2\,[(L/h) - (1/\sin\beta) - (\tan\beta / 2)]$
N_A (Effective force normal to the failure plane of the active wedge) $= W_A \cos\beta$
C_a (Adhesive force between mulch of the active wedge and MSW) $= c_a\,(L - h/\sin\beta)$
W_P (Weight of the passive wedge) $= \gamma h^2 / \sin 2\beta$
C (Cohesive force along the failure plane of the passive wedge) $= c\, h / \sin\beta$
β = Angle of the slope
c = Cohesion of mulch
Φ = Friction angle of mulch
c_a = Adhesion between mulch and MSW
δ = Interface friction angle between mulch and MSW
L = Length of the slope
h = Thickness of cover

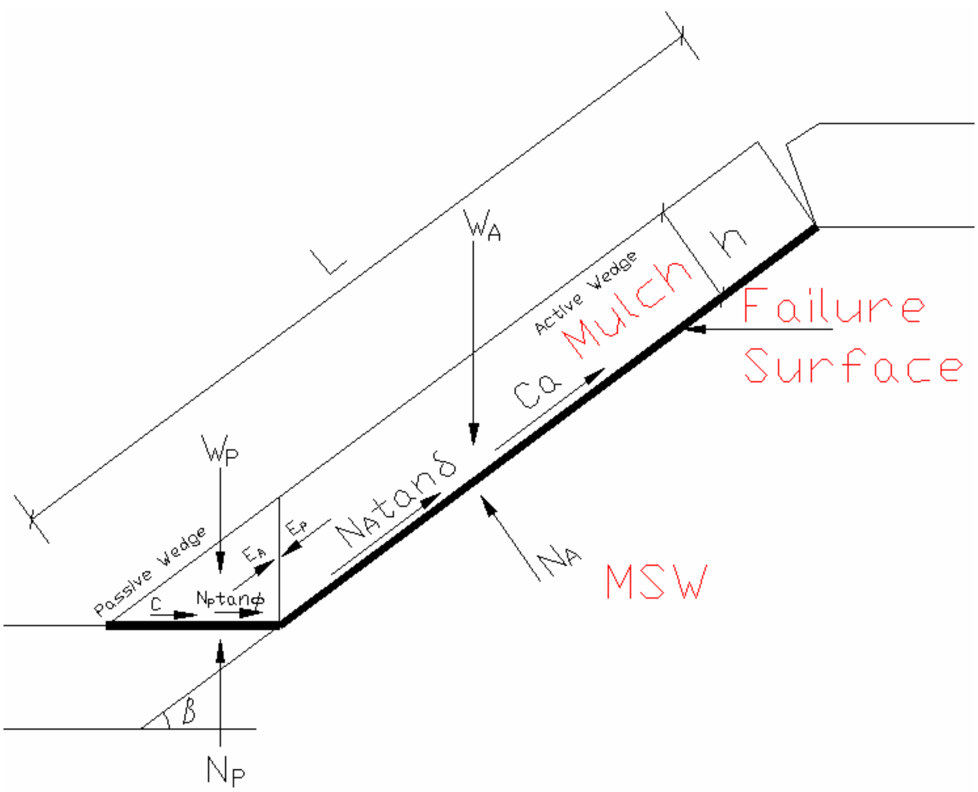

Figure 8: The linear surface of failure at the interface between mulch and MSW

The input data needed for the calculations of the factor of safety were unit weight, cohesion, an internal friction angle for mulch samples, and adhesion and interface friction angle between mulch samples and MSW. The interface friction angle and adhesion between each type of mulch and MSW were obtained by conducting the direct shear tests according to ASTM D5321. The lower half of the shear box was filled with MSW and the upper half with mulch. MSW samples were prepared based on the waste composition published in the Florida Solid Waste Management Report (FDEP). The composition of the waste prepared in the laboratory is shown in Table 3.

Table 3. Composition of synthetic MSW prepared for geotechnical testing

Material	Percentage By Weight
Paper	46
Metal	19
Glass	5
Organic	9
Wood Mulch	8
Plastic	13

The MSW sample was tested at moisture content of 25% by weight, which best simulates the actual case of moisture of solid waste arriving at a landfill (Vesilind 2002). Slope length was assumed to be 30m and 3m, and thickness was assumed to be 30cm and 15cm for intermediate and daily cover, respectively. Table 4 shows the interfacial friction angles between different types of mulch and MSW, and Table 5 provides the calculated factors of safety for 1:3 and 1:4 slopes. It can be seen that all mulch samples had almost the same interface friction angle and adhesion with MSW. Interface friction angles and adhesion of all the mulch samples with MSW were less than their corresponding internal friction angles and their internal cohesion except for the OS2 sample. This sample had a higher adhesion with MSW than its internal cohesion due to the rougher nature of the interface between MSW and OS2 mulch.

Table 4. Interface friction angles and adhesion between mulch types and MSW

Sample number	Interface Friction angle with MSW (Degrees)	Adhesion KN/m^2
OS1 1	12	0.6
OS2 1	12	0.4
OR1 1	12	0.4
OR2 1	13	0.4
BR 1	13	0.6
IRC1	12	0.6
NRR1	12	0.5

Table 5. Factors of safety of linear failure for different types of mulch

Sample	Factor of Safety			
	Intermediate		Daily	
	1:3	1:4	1:3	1:4
OS1	2.8	3.7	5.9	8.1
OS2	1.3	1.7	2.1	2.9
OR1	2.2	2.9	5.1	7.3
OR2	2.5	3.3	5.9	8.6
BR	3.3	4.3	7.1	10.0
IRC	3.0	3.9	6.7	9.5
NRR	2.6	3.5	6.3	9.1

Results show that all mulch samples had a factor of safety above 1.5 when placed as both intermediate and daily cover with a slope of 1:3 and 1:4, with exception of the OS2 mulch that had a 1.3 factor of safety when used as intermediate cover at 1:3 slope. Results also show that the slope is more stable with milder slopes, thinner covers, and shorter slopes. The BR mulch sample was the safest mulch sample to be used because of its high adhesion and cohesion, and OS2 mulch had the lowest factor of safety because of its high unit weight and lower adhesion and cohesion. Safety factors of the daily cover were dramatically higher than those for intermediate, the values of safety factors for daily covers almost doubled as the thickness was reduced by half.

2.1.2 Slope stability modeling for mulch covers (assuming a circular failure plane)

The software Slope/W was also used to model and examine the slope stability of the different kinds of mulch used as both daily and intermediate covers at different slopes. The slope/W developed by GEO-SLOPE International Ltd. was designed for soils. Similar soil-based slope stability analysis program have been found to be suited for modeling idealized landfills slopes as the waste is assumed to act like a cohesive soil (Shafer et al. (2003)). The software uses the theory of limit equilibrium of forces and moments to compute the factor of safety against failure. The General Limit Equilibrium (GLE) theory is used as the context for relating the factors of safety for all commonly used methods of slices. A slope length of 30 and 9 meters with a thickness of 30 and 15 cm were used as intermediate and daily cover, respectively. Figures 9 through 12 show the Slope/W factor of safety results of the slope stability analysis for both daily and intermediate covers with slopes of 1:3 and 1:4 (along with the failure surface that passes through the interface between MSW and mulch cover) for OS1 mulch. Table 6 provides the Slope/W factor of safety for daily and intermediate cover of all mulch samples.

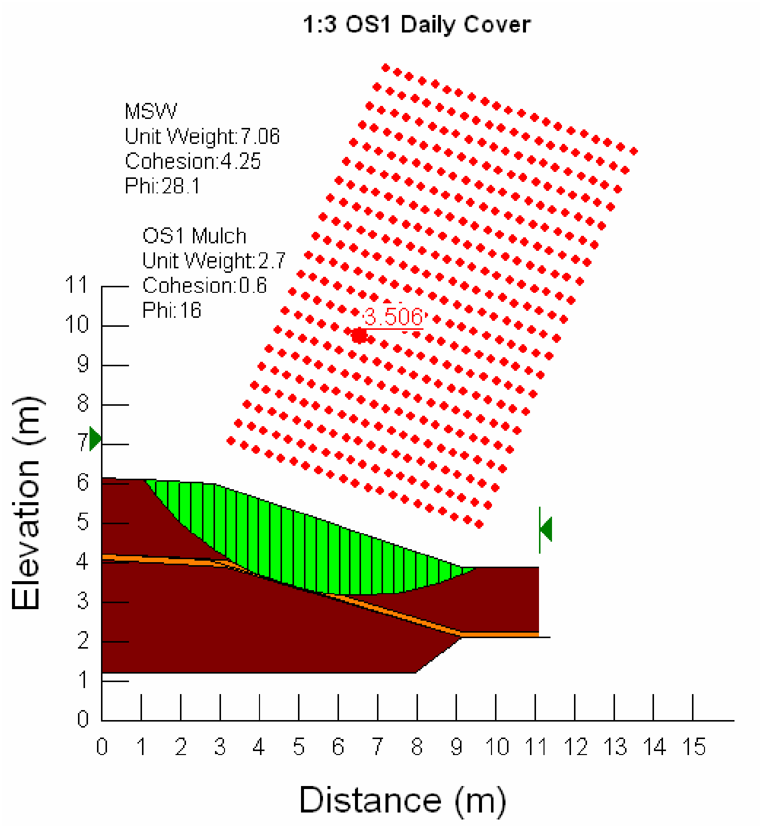

Figure 9: Stability analysis for OS1 as daily cover with a 1:3 slope using Slope/W

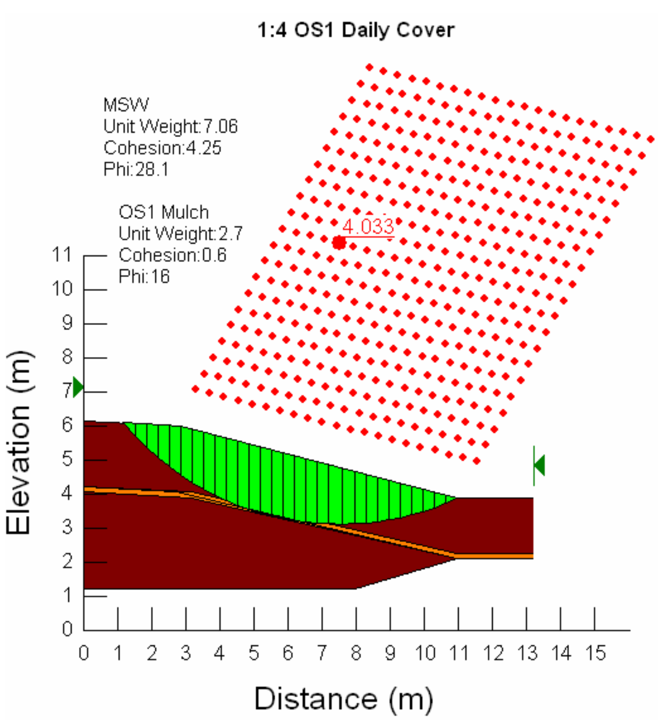

Figure 10: Stability analysis for OS1 as daily cover with a 1:4 slope using Slope/W

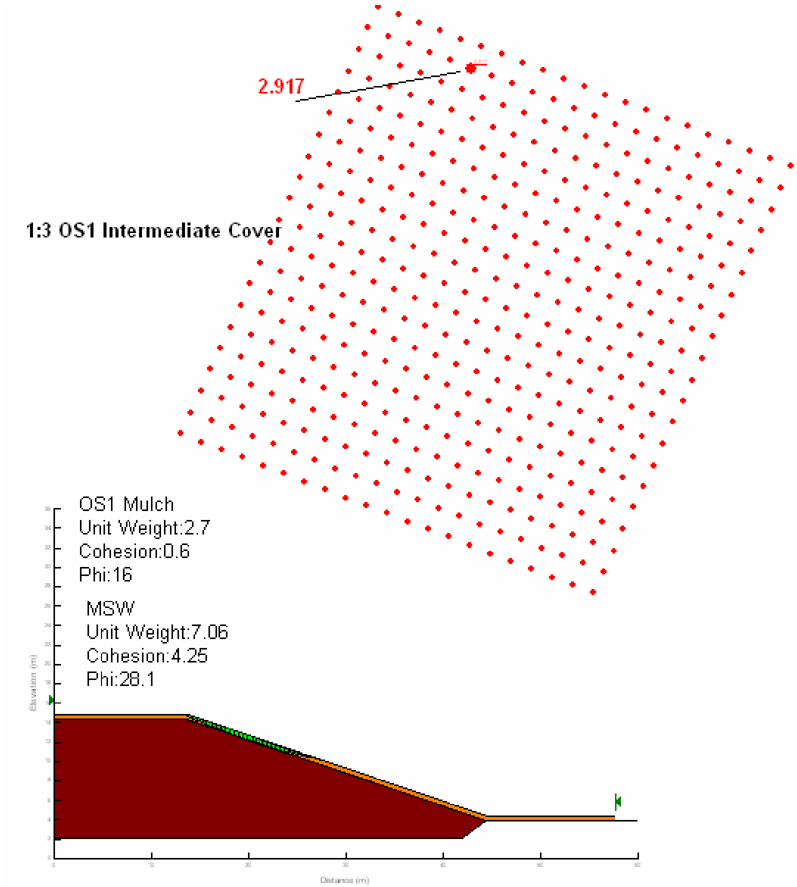

Figure 11: Stability analysis for OS1 as intermediate cover with a 1:3 slope using Slope/W

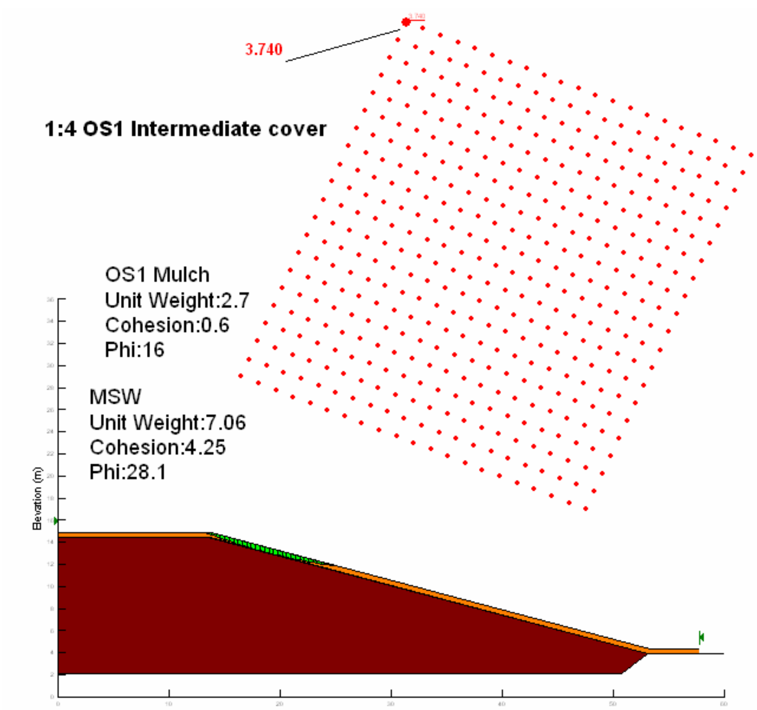

Figure 12: Stability analysis for OS1 as intermediate cover with a 1:4 slope using Slope/W

Table 6. Slope/W factors of safety's results for different types of mulch

Sample	Factor of Safety			
	intermediate		daily	
	1:3	1:4	1:3	1:4
OS1	2.92	3.74	3.51	4.03
OS2	1.10	1.41	3.40	3.92
OR1	4.22	5.37	3.56	4.10
OR2	4.90	6.23	3.53	4.05
BR	3.98	5.06	3.55	4.08
IRC	4.32	5.50	3.57	4.10
NRR	5.02	6.38	3.60	4.13

Results showed that except for OS2 mulch sample when used as an intermediate cover, all other samples had a factor of safety greater than 1.5 when used as daily and intermediate cover. Stability decreased with increasing slope and with placing the MSW weight on top of the cover (as in the daily cover situation) except for the OS1 and OS2 samples where placing MSW weight on it made it more stable. Factors of safety for daily cover of all the different mulch samples were in the close range of 3.4 and 4.1. This similar behavior under MSW weight is mainly due to the close values of internal friction angle of the mulch samples. However, factors of safety of the intermediate cover (under no normal stress) show a wide range of values. This might be due to the wide range of cohesion values for the different mulch samples. OS2 mulch sample had the lowest cohesion of 0.21 kN/m^2 among the other samples and that was apparent in the low factor of safety when used as intermediate cover, while it didn't have much effect on the factor of safety when used as daily cover.

Factor of safety values calculated assuming a circular surface and linear surface of failure showed differences that ranged from minor, *i.e.,* OS1 mulch sample used as intermediate cover, to more than double the value, *i.e*., IRC mulch sample as daily cover.

2.2 HYDRAULIC CONDUCTIVITY AND SPECIFIC GRAVITY

The saturated hydraulic conductivities of mulch samples were tested using a permeameter following the ASTM D5101-99. Mulch samples (screened to < 2.5 cm) were placed in the permeameter on top of a mulch support made of porous stone. The permeameter was backfilled through the outflow section at a very slow rate to expel air inside of the mulch sample and the permeameter without disturbing the test material. Flow was started by pumping water into the inflow port. The level of inflow was adjusted to obtain several differences in head across the mulch layer. Flow was allowed to continue for 10 minutes to saturate the specimen. The flow rate from the system was measured by taking outflow volume measurements every 30 seconds.

Specific gravity of each mulch sample was obtained using a water pycnometer following ASTM D854. The definition of specific gravity is the ratio of the weight in air of a given volume of a material at the same temperature to the weight in air of an equal volume of distilled water at the same temperature. Dry mulch samples of known weight were placed in the pycnometer and water was added to completely cover the mulch sample. After air bubbles were extracted through gentle heating, water was added to a volume of 500ml and the pycnometer was weighed. The pycnometer was then filled with 500ml of distilled water only and weighed. Specific gravity was calculated using equation 4. Porosity was calculated using the specific gravity and the bulk density values obtained earlier using equation 5. Table 7 shows the results of the hydraulic conductivity for the mulch samples as well as specific gravity measurements.

$$G_s = [W_{\text{Dry mulch sample}}] / [W_{\text{Dry mulch sample}} + (W_{\text{500ml water}} - W_{\text{500ml water + mulch}})] \quad (4)$$

Where,
G_s = Specific gravity of mulch sample
$W_{\text{Dry mulch sample}}$ = Oven dry weight of mulch sample
$W_{\text{500ml water}}$ = Weight of 500 ml of distilled water
$W_{\text{500ml water + mulch}}$ = Weight of mulch sample and distilled water in the 500ml pycnometer

$$\text{Porosity} = 1 - [\text{Bulk density} / \text{Mulch density}] \quad (5)$$

Table 7. Mulch Hydraulic Conductivity Constants, Specific Gravities, and porosities

Sample	Hydraulic Conductivity (cm/sec)	Specific Gravity	Porosity
OS1	0.11	0.74	0.64
OS2	0.07	1.9	0.58
OR1	0.11	0.61	0.56
OR2	0.11	0.73	0.63
BR	0.11	0.73	0.63
IRC	0.11	0.73	0.63
NRR	0.11	0.73	0.63

All the mulch samples had approximately the same hydraulic conductivity. The values are higher than that of MSW which has been reported to be in the range of 1×10^{-8} to 1×10^{-4} (Hughes et al. 1971; Fungaroli and Steiner 1979; Korfiatis et al. 1984; Oweis et al. 1990; Bleiker et al. 1993.; Jain et al. 2006). This makes it easy for water (leachate) to infiltrate through the mulch cover. However, vertical flow may be impaired by the less permeable MSW layer under the cover. Lateral percolation might also take place and water can be transported outside the landfill boundaries. Porosity results showed that all mulch samples had almost a 60% porosity (with OS2 and OR1 having the lowest porosities) making them a good candidate for moisture accumulation and exerting positive pore pressure on the slope interface between mulch and MSW which may lower the factor of safety.

3. TAG MEETINGS

The first Technical Advisory Board Meeting was held on Monday February 18 and attended by nine people and a second TAG meeting was held August 11th and was attended by seven people.

4. WEB PAGE

A project web site is provided at http://people.cecs.ucf.edu/reinhart/main%20page.htm.

5. NEXT STEPS

5.1 FURTHER MODELLING

In order for the slope stability study to be comprehensive, the effect of ponding and pore water pressure will be studied and analyzed through the use of the Slope/W program. Hydraulic conductivity results obtained earlier along with retention curve data collected from literature will be used in modeling the infiltration of leachate through the mulch covers using the UNSAT-H program.

Summer samples will be collected during the month of August, and geotechnical and hydraulic properties will be tested once again. Slope stability and infiltration will also be modeled for the summer samples and sieve analysis test will be conducted to evaluate the particle size distribution of mulch samples.

5.2 FIELD WORK

Plots will be built at the Osceola Rd. Landfill where the original cover will be removed and both mulch and soil will be used as intermediate cover to monitor the efficiency of the material in controlling gas emissions, conduct a water balance to evaluate cover's infiltration rate, and to measure the erosion of material cover.

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