IMPACT OF LEACHATE LEVEL ABOVE LINER SYSTEM ON SLOPE STABILITY DURING LANDFILL OPERATION

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ABSTRACT

The ability to predict the slope stability of a sanitary landfill during operation in inclement weather conditions is very important to a landfill manager or operator. This is particularly true for a landfill located in an area that is exposed to seasonal monsoon or tropical rain storm events where the landfill surface cannot provide meaningful runoff to rid off excess liquid from entering into the waste mass. This paper focuses on illustrating the impact of leachate level above the liner system to the landfill operation slope stability. However, the knowledge presented herein also applies to any uncapped landfills, landfill mining, or dump sites. During a typical landfill operation, many steep slopes and relatively pervous surface, if no daily cover material is applied, may result from daily waste placement; especially when there is a rain event causing delay in applying a daily cover soil over an active area. As the waste mass is exposed during landfill operations, infiltration to the waste mass will increase especially during seasonal heavy rainfall event(s) where there is no cap system to control excessive infiltration into the waste mass. The leachate level within the landfill may raise to a level that may trigger a slope instability condition. Because of this concern, a parametric slope stability analysis is presented and discussed in this paper to evaluate the impact of a leachate level within the waste mass on a landfill operation slope.

A model was developed for this parametric case study: the landfill operation slope varies between 1(V):2.5(H) and 1(V):3.5(H); the landfill height varies at 6, 15, 24 to 37 m; and the leachate head varies between 0, 0.7 and 1.5 m, measured above the bottom liner system. The goal of this parametric analysis is to identify any potential instability issues during landfill operation. Results of this landfill operational slope stability analysis are presented in a graphical chart and can be used by a landfill operator to identify any slopes with potential instability. The analytical results presented in a graphic chart indicate that FS above 1.5 are achieved for the all slopes modeled, provided that leachate head levels are less than 0.7 m above the liner. For the 1:2.5 slope with the leachate level above the liner of greater than 0.7 m, the FS values drop below 1.5 when the waste height is less than 24 m. For the 1:3.5 and 1:3 slopes with leachate level grater than 0.7 m, the FS values is less than 1.5 when the waste height is less than 6 m and 15 m, respectively. It is therefore concluded that the graphical chart presented in this paper can be utilized as an important tool for the landfill site manager or operator who may be operating a landfill with steep slopes and a high leachate level above the liner system.

Key Words: landfill operation, landfill slope, leachate level, slope stability, factor of safety

INTRODUCTION

A typical design of a modern sanitary landfill consists of multiple cell phasing and development, partial cell closing, landfill gas capturing system, leachate collection system and/or recirculation, potential landfill mining that may result in steep operational slopes, and reusing of landfill footprint in phases of redevelopement during reclaiming of an old dump. During landfill operation, many steep slopes will result from waste placement and thus its stability would be a concern, particularly if the leachate level builds up as a result of excessive surface infiltration during rainy seasons.

As the waste mass is exposed, infiltration to the waste mass will increase during seasonal heavy rainfall event(s) where there is no cap system to control excessive infiltration into the waste mass. The liquid level within the landfill may raise to a level that may trigger a slope instability condition. In addition, in order to accelerate the waste decomposition, leachate or liquid may be recirculated or bioreactor procedure may be implemented, causing moisture content within the waste mass to reach approximately 40 percent. At this amount of moisture content within the waste, waste shear strength will reduce and the pore water pressure will build up to a point where slope stability of the landfill may become a serious concern.

Designers and regulators often express concern that exposing waste mass during landfill operation (especially when no daily cover material is applied) will introduce surface water or other run-on liquids into the waste mass and ultimately will enhance the degradation of the waste and reduce the stability of the waste mass. Although the introduction of liquids has several potentially destabilizing effects, they can be mitigated through sound design, construction, and operating practices. Because of this concern, in this paper, a parametric slope stability analysis was conducted to evaluate the impact of leachate levels on the slope's factor of safety at typical range of landfill operation slopes. This paper reviews few of the key factors that would affect the landfill operation slope stability. Based on the information presented in this paper, landfill operation slope can be maintained safely for a site and a site-specific slope stability design chart can be developed and used to estimate safe slope angle and waste height during landfill operations.

MATERIALS AND METHODS

When leachate or other liquids are introduced into the waste mass through surface infiltration or liquid recirculation to enhance waste decomposition, it results in increased moisture content. There are two stability-related technical issues that must be considered to address the introduction of liquids: (1) the impact of the presence of leachate or liquids; and (2) the impact of the accelerated degradation of the waste. To understand the impact of the presence of liquids, one must understand the migration of liquids within the landfill. The migration of introduced liquids into relatively non-homogeneous waste is often thought to result in random (and uncontrolled) migration of liquids through preferential flow paths in the waste. Detailed analyses and field observations indicate that this is not the case. Actually, liquids first are absorbed by the waste until the waste reaches its field capacity and then migrate along the path of least resistance, which is predominantly downward through the waste but with a lateral component if lower permeability layers (e.g., daily cover) are present.

When performing a slope stability analysis in landfill operation slope environment, three issues must be considered especially when liquid is introduced to the waste: (1) increased weight of the waste compared to the "dry" waste; (2) the possibility of perched leachate, causing a localized pore-water pressure build-up; and (3) liquid migration along an impervious layer and breaking out on the face of the slope. The increase in the pore-water pressure can contribute to instability and increasing the potential for side slope seepage and uncontrolled gas migration. The primary defense against these effects is monitoring of the landfill to confirm that leachate is not building up in the landfill at a level that would cause excessive pore pressures within the waste mass.

Key Factors Affecting Factor of Safety

The key elements of the slope stability analysis, and considerations that should be made specific to landfill operation slope stability are listed as follow:

- Selection of Critical Cross Sections: This involves identifying the sections that have the lowest calculated factor of safety.
- Foundation Conditions: The location and extent of each type of material beneath the ground surface that could affect the stability analysis needs to be identified. In addition, the presence of geosynthetic interfaces must be considered, as geosynthetic interfaces are continuous interfaces that usually are weaker than other soil materials. It is common to perform circular and non-circular analyses along the most critical interface and through the waste mass itself.
- Unit weight and shear Strength: The selected values of unit weight and shear strength of waste and soils are critical to the calculated factor of safety because stabilizing forces are primarily a function of material shear strength.
- Leachate level: Although the shear strength parameters of solid waste may be unchanged by the presence of leachate level, addition of liquids could raise the leachate level or the phreatic surface, which could decrease the effective normal stress and decrease the shear resistance of the waste. Therefore, consideration of the liquid level within the waste is critical, especially when the leachate collection system is not adequate or undersized.
- Operating Conditions: Develop project operating plans to control liquids infiltrating into the waste mass.
- Monitoring: Monitor landfill operation slope performance to confirm that the observed field conditions match those that were assumed in the analysis.

Slope Modeling Methodology

The designer must demonstrate that the landfill operation slope is stable under the permitted operating conditions by performing a comprehensive slope stability analysis. The analysis presented in this paper can be performed using the same analytical tools as those used for typical landfills that are not normally having high liquid levels. The stability analysis typically performed for the waste slope considers the following two potential failure modes: (1) overall global stability of the waste mass, and (2) local and/or deep stability within the waste or along discrete interfaces. The veneer stability of the cover system is not considered in this paper since it would not be installed yet during landfill operation. Limiting equilibrium methods that are common in geotechnical engineering practice are used. Some of the commercially available computer programs can be used to analysis slope stability, e.g., XSTABL, PCSTABL, SLIDE, SLOPE/W, etc.

In this paper, the slope stability was evaluated using PCSTABL, a well-accepted and reliable model used widely in the solid waste industry. This program uses two-dimensional limiting equilibrium methods to calculate a factor of safety (FS) against shear failure for slope sections analyzed. This program utilizes an automatic search routine to generate multiple shear failure surfaces for circular failure mode or block-type failure mode until the surface with the lowest FS-value is found. The analytical methods used for the circular and block-type failure modes in the slope stability analysis are the Modified Bishop and Modified Janbu methods, respectively.

A sensitivity study is performed on the results of FS to evaluate the effect of the various leachate levels at different waste slope configurations. Although this study focuses on the stability investigation of a landfill operation slope, the methodology presented can easily be applied to other general geotechnical stability investigations such as waste excavation slope. For this evaluation, the generally accepted industry standard FS of equal to or greater than 1.5 is considered acceptable for static stability analysis of a landfill interim operation slope.

Parametric Analysis

The goal of this parametric analysis is to identify potential instability issues during landfill operation. The result is presented in a graphical chart which can be used to identify a site's potential instability and serve as a proactive measure used by the landfill manager or landfill operator to minimize the potential for slope instability especially during rainy seasons. A sketch showing a typical interim waste slope profile modeled for this study is presented in Figure 1. The key shear strength assumptions for MSW waste, bottom liner system, and typical soil subgrade materials are provided in Table 1. Slope modeling included both circular and block failure shear surfaces extending through the waste material and along along the weakest soil/liner interface.

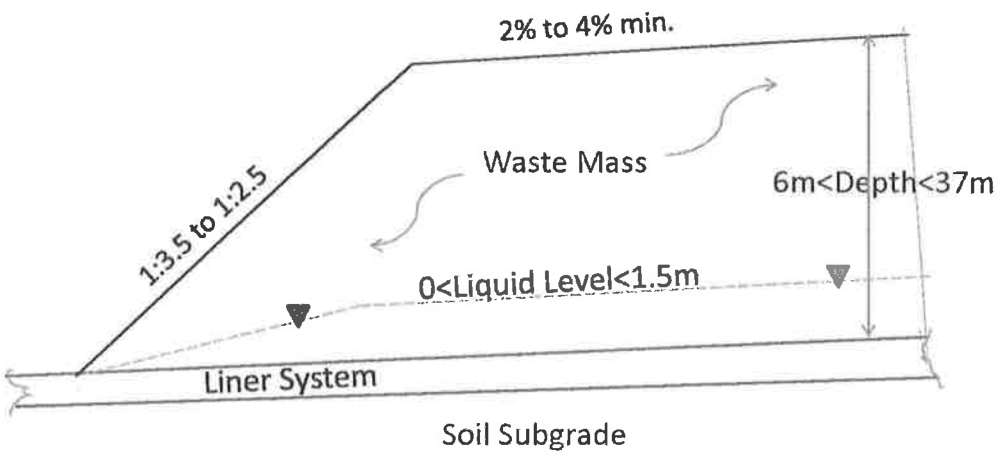

Figure 1. Typical Waste Interim Slope Profile

Assumptions on Material Properties

The slope stability analysis was performed using the following assumed values (as shown in Table 1):

- Foundation Material and Bottom Liner System: Internal shear strength of the foundation soil layer is assumed to be 96 KN/m^2 cohesion and zero degrees friction angle. Total unit weight was assumed to be 18.85 KN/m^3. Interface shear strength of the bottom liner system is assumed to have 21 degrees friction angle and zero adhesion.
- Waste: Internal shear strength of the waste material is assumed to have zero cohesion and that the shear strength is derived entirely from a friction angle of 33 degrees. In place total unit weight is assumed to be 8.64 KN/m^3.
- Waste heights (vertical distance from bottom liner to top of operating slope) evaluated at 6, 15, 24, and 37 m.
- Interim waste slope angles evaluated are at 1:3.5 (15.9 degrees), 1:3 (18.4 degrees), and 1:2.5 (21.8 degrees).
- The leachate levels above the bottom liner were analyzed for the 0.0 m, ,0.7 m and 1.5 m scenarios. The baseline analysis assumed zero leachate head above the liner.
- Any impact to the slope stability due to presence of landfill gas pressure is not considered in this paper.

Table 1. Material Properties

Layer	In-Situ Density (KN/m^3)	Shear Strength Parameters	
		Friction Angle (deg.)	Cohesion (KN/m^2)
Waste	8.64	33	0
Bottom Liner System	18.85	21	0
Soil Foundation	18.85	0	96

RESULTS AND DISCUSSION

The factor of safety values for landfill operation interim slope stability analyses (under static loading conditions) for the above-mentioned slope section configurations are listed in Table 2; these results are depicted graphically on Figure 2. Figure 2 represents all slope conditions on a single chart. These figures indicate that FS values decrease more significantly when leachate heads increase, compared with the scenario of a greater waste height. It is an indication that the leachate head has more of an influence of the critical surface than for the higher waste heights. For the head on liner is zero, the relationship is reversed, as would be expected.

Table 2. Results of Landfill Operation Slope Stability Analysis

Leachate Head on Liner (m)	Waste Height (m)	Factor of Safety (FS)		
		1:3.5 Slope	1:3.0 Slope	1:2.5 Slope
0	6	1.99	1.77	1.56
	15	2.09	1.85	1.60
	24	2.13	1.89	1.64
	37	2.22	1.94	1.66
0.7	6	1.70	1.52	**1.31**
	15	1.99	1.74	1.51
	24	2.04	1.83	1.59
	37	2.17	1.91	1.63
1.5	6	**1.27**	**1.15**[1]	**1.03**[1]
	15	1.78	1.52	**1.36**
	24	1.90	1.73	1.52
	37	2.09	1.83	1.58

1. Critical failure surfaces analyzed are located within the waste itself, all in circular modes except for two scenarios as indicated above as in block-type failure modes. FS is calculated using assumed waste shear strength with a friction angle of 33 degrees and 0 cohesion (conservative). The unit weight of the waste is assumed to equal to 8.64 KN/m^3. Liner system: friction angle = 21 degrees and 0 cohesion. Soil Subgrade: cohesion only = 96 KN/m^2 and unit weight = 18.85 KN/m^3.

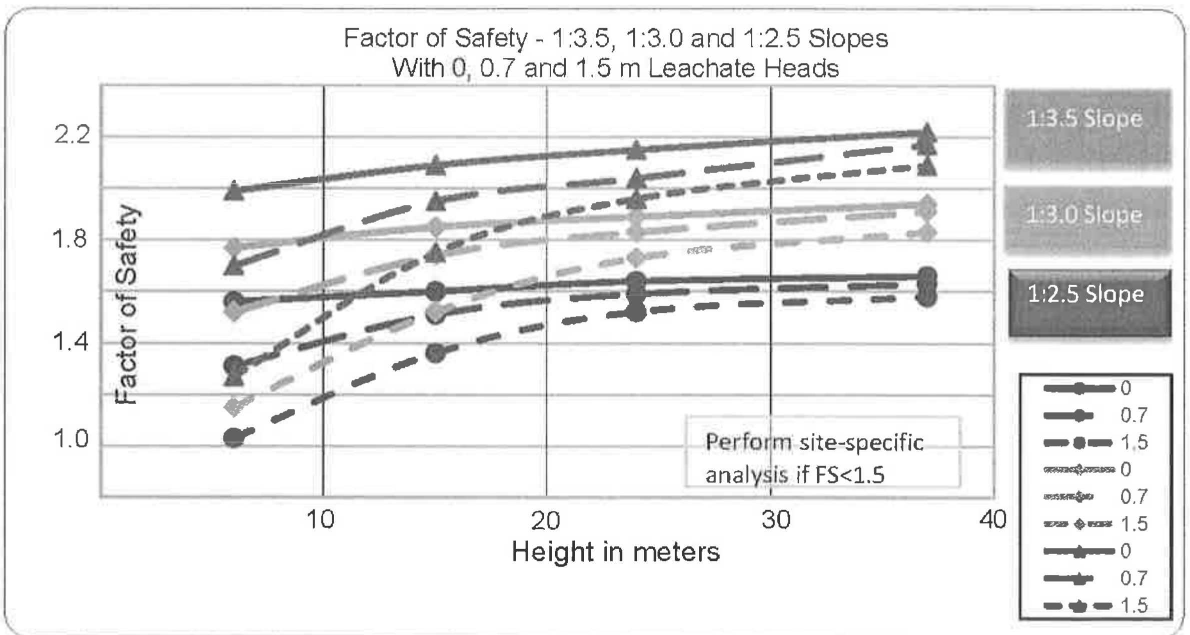

Figure 2. Landfill Operation Slope Stability Chart

It is notable that all failure surfaces are located within the waste itself and/or along the soil/liner interface. The potential for failure surfaces intersecting the bottom liner increases as the strength of the bottom liner decreases. The analytical results presented indicate that FS above 1.5 will be achieved for the all slopes modeled provided leachate head levels are less than 0.7 m or zero head above the liner. For the 1:2.5 slope when the leachate level above the liner is greater than 0.7 m, the FS values drop below 1.5 when the waste height is less than 24 m. For the 1:3.5 and 1:3 slopes, the FS values is less than 1.5 when the waste height is less than 6 m and 15 m, respectively. This study also concludes that a circular failure mode is more critical than the block-type failure mode in all scenarios.

The results of this study can be used for the purpose of evaluating in a simple and rapid manner if interim landfill operating slopes and heights are likely to maintain a slope stability factor of safety above 1.5, under various liquid levels that are either measured in the field or by obsesrvation of seep locations. These models and the results discussed herein do not represent an actual site or specific site conditions. More refined, site-specific modeling, taking into account actual slopes, material properties, liquid levels and other factors should be performed if FS values are less than 1.5, or if conditions are materially different from what was modeling in this study. Factor of Safety values will be lower than indicated in Figure 2 chart if shear properties of the materials are less than indicated or if leachate levels are higher than the 1.5 m level modeled.

CONCLUSION

The graphical presentation in this paper can be utilized as an important guide for a landfill site manager who may be operating landfill at a steeper slope or with exposed waste slope that allow excessive surface infiltration during rainy seasons. However, this graphical chart should be developed for site-specific use and based on its landfill design criteria and site conditions.

Landfill operation slopes may have a greater impact on slope stability than a closed landfill site, so additional performance and site monitoring is recommended, using the current state of the practice for monitoring, to verify that operations are not having an adverse impact on slope stability. The landfill operator should monitor the performance of the landfill slopes to confirm that the conditions assumed in the stability analyses are present in the site, including leachate level measurements or leachate seep locations in relation with the bottom of the landfill. It is also valuable to monitor the changes of these parameters over time, as they may serve as early indicators of potential problems. Most important, however, is the development and implementation of a site monitoring plan that can detect lateral seepage from the side slopes and odor problems. Collection and documentation of this information requires a commitment to regular, systematic, and programmatic inspections by the landfill manager or landfill operator.