Slope stability of cover systems of hazardous waste landfills

Stabilité des systèmes de couverture de décharges de déchets dangereux en pente

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ABSTRACT

Cover systems of hazardous waste landfills consist of multiple layers of soils and geosynthetics. Steep slopes of covers are desirable to maximize the volume of waste stored in such landfills but low interface shearing strength can limit the inclination of such slopes. In this paper the influence of various parameters such as interface shear angle, slope height, slope inclination, seepage forces, seismic forces and reinforcement on slope stability are examined. The choice of factors of safety for different conditions – static, seismic, seepage as well as seismic with seepage - is discussed. Through a case study it is demonstrated that with proper analysis and design, it is feasible to attain a slope inclination in the range of 2.5 : 1.0 to 3.0 : 1.0 with adequate safety.

RÉSUMÉ

Les systèmes de couverture de décharges de déchets dangereux consistent en couches de terre multiples et de textiles géosynthétiques. Les couvertures en pentes raides sont utiles afin de maximiser le volume de déchets stockés dans de telles décharges mais la faiblesse de l'interface peut limiter l'inclinaison de telles pentes. Dans ce papier l'influence de divers paramètres comme l'angle de rupture de l'interface, la hauteur du plan inclinée, l'inclination incliné, le volume de suintement, les forces sismiques ainsi que le renforcement de la stabilité de la pente sont examinés. Le choix des facteurs de sécurité dans différentes conditions telles que statiques, sismiques, avec suintement ainsi que sismique avec suintement - est discuté. A l'aide d'une étude de cas il est démontré qu'avec un design et une analyse appropriée, il est possible d'atteindre une inclinaison dans la gamme de 2.5:1.0 à 3.0:1.0 avec une sécurité adéquate.

Keywords: landfills, slope stability, interface shear

1 INTRODUCTION

As per the guidelines issued by the regulatory authorities in India (CPCB 2000, CPCB 2002 and MUA 2000), the cover and liner for hazardous waste (HW) landfills, are shown in Fig. 1.

A HW landfill cover system comprises of six basic components: vegetation (VG) on top of a 0.6m thick layer of top soil (TS), underlain by a 0.3m thick drainage layer (DL) below which lies a composite barrier layer comprising of 1.5mm thick HDPE geomembrane (GM) and a 0.6m thick compacted clay liner (CCL) which in turn is underlain by a 0.3m thick gas collection (GC) layer above the waste. In addition to these basic six components, the cover system also includes 3 layers of non-woven geotextiles (NW GTX) as shown in Fig. 2 - one used as a separator between the top soil (TS) and the gravel drainage layer (DL), the second as a protector above the HDPE geomembrane (GM) and the third as a separator between the compacted clay and the sand-gravel gas collection layer (GC).

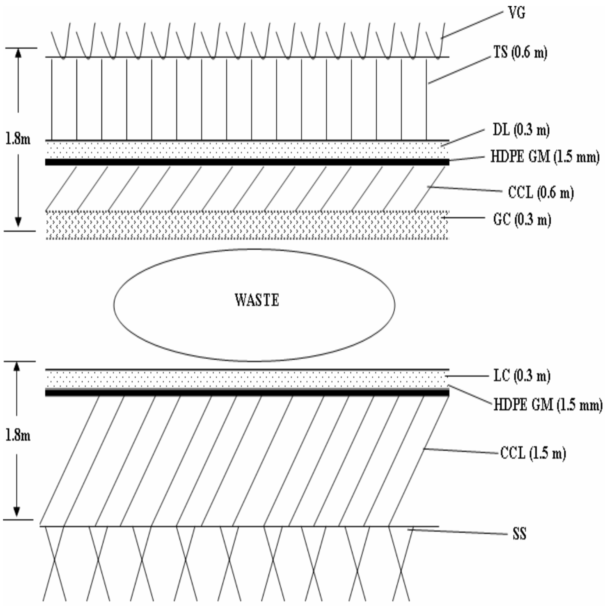

Figure 1. Cover and Liner of HW landfill

2 TYPES OF COVER SYSTEMS

A new above-ground HW landfill is proposed in western India at a site at which the water table is near the ground surface. The site receives high rainfall. The final height of the landfill is estimated at 20m above the ground level. An attempt has been made to arrive at the steepest slope for the cover system with adequate factor of safety so that maximum volume of waste can be accommodated in the landfill (Datta 2006).

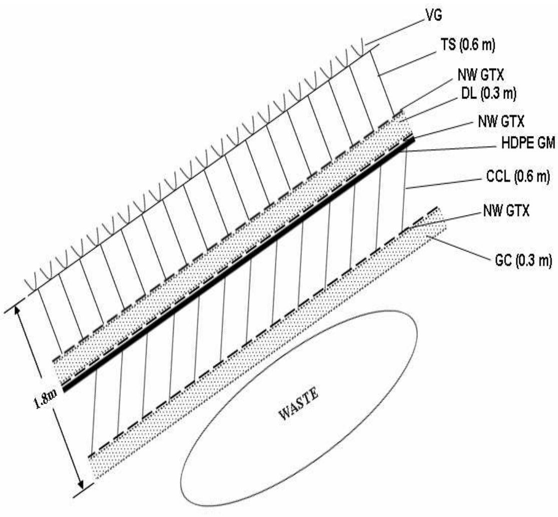

Figure 2. Cover System Components along Slope (Cover A)

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Five types of cover systems have been analyzed:

(a) Cover A: Cover system as per regulatory authorities (Figs.1 and 2);

(b) Cover B: Same as Cover A but with compacted clay layer replaced by a reinforced needle punched geosynthetic clay liner (GCL) (Fig.3);

(c) Cover C: Same as Cover A but with a geogrid reinforcement (anchored at each berm) placed beneath the drainage layer;

(d) Cover D: Same as Cover B but with a geogrid reinforcement (anchored at each berm) placed beneath the drainage layer;

(e) Cover E: Same as Cover D but with drainage layer replaced by a geocomposite drain (GD) (geonet sandwiched between non-woven geotextile on both sides) (Fig.4).

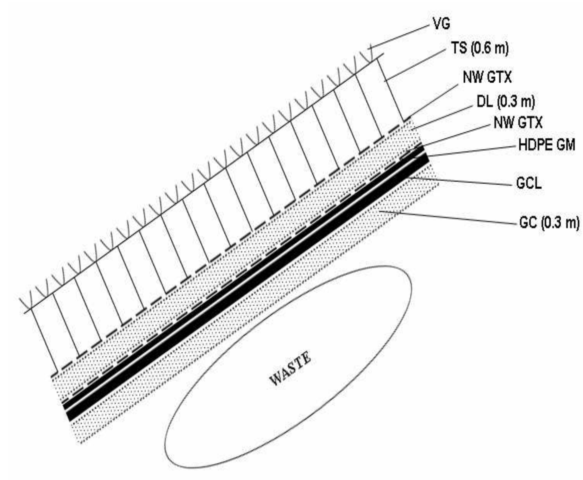

Figure 3. Cover System Components along Slope (Cover B)

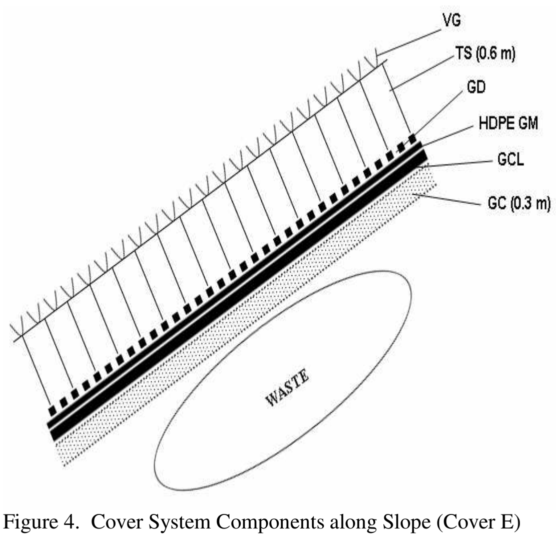

Figure 4. Cover System Components along Slope (Cover E)

3 STABILITY ANALYSIS

Stability analysis has been performed for failure parallel to outer slope along the weakest interface in the cover system (Qian et al. 2002, Koerner and Daniel 1997, Daniel et. al. (1998)). The interface shear strength parameters for slope stability analysis were made available by the owner of the project (Table 1). These were determined by performing modified direct shear tests under saturated conditions in a 300 x 300 mm shear box and interpreted in terms of average secant friction angle (adhesion taken as zero) at both peak and large (residual) displacements. There was considerable debate on the choice of parameters - peak or residual - for the purpose of design. Keep in view the fact that movement between various components of the cover could not be ruled out during or after installation, it was decided to adopt residual parameters.

Table 1: Interface shear strength parameters

Base Material	Underlying/ Overlying material	Friction angle δ (deg)	
		Peak	Residual
Smooth HDPE geomembrane	Saturated clay	11	9
Textured HDPE geomembrane	Saturated clay	18	14
Smooth, HDPE Geomembrane	Non woven needle punched geotextile	11	9
Textured HDPE geomembrane	Non woven, needle punched geotextile	22	17
Textured HDPE geomembrane	Saturated sand	34	31
Textured HDPE geomembrane	Needle punched GCL	32	20
Textured HDPE geomembrane	Geocomposite drain: geonet between needle punched geotextile	24	17
Non woven needle punched geotextile	Saturated sand	32	32

Four cases were considered critical for slope stability, namely:

(a) long term case of dry slope under static loading;

(b) short term case, during monsoon, of slope with seepage flow in drainage layer parallel to the outer slope (submergence ratio of 0.5 in the drainage layer);

(c) very short duration case of slope under earthquake loading (pseudo static approach with horizontal seismic coefficient of 0.1 (as per Bureau of Indian Standards));

(d) rare case of slope with seepage flow and earthquake loading occurring simultaneously.

Table 2 lists the minimum acceptable values of factor of safety adopted for the each of these critical cases.

Table 2. Factors of safety

Sl. No.	Condition	Acceptable factor of safety
1	Static case (long term)	1.5
2	Seepage flow during monsoon (short duration)	1.3
3	Earthquake loading (very short duration)	1.1
4	Earthquake loading + Seepage flow (rare)	1.0

Stability analyses were carried out for slope inclinations of 2.0 : 1.0 (hor.: vert.) to 5.0 : 1.0 and for vertical height between berms ranging from 5 m to 10 m.

4 RESULTS

For all cover systems, a textured geomembrane was chosen in preference to a smooth one as the latter exhibited a very low angle of shearing resistance at interfaces. For Cover A, the residual angle of shearing resistance at the interface with clay was 9^0 for a smooth geomembrane as against 14^0 for a textured one (Table1). Even when the latter is used, the factors of safety for Cover A are observed to be well below 1.5 for various slope angles as listed in Table 3(a).

With a view to improve stability, the clay is replaced by a needle-punched GCL in Cover B. This causes the interface shear angle beneath the geomembrane to increase from 14^0 to 20^0 and thus causes the critical interface to change to that between the textured geomembrane and the non-woven geotextile above it with a interface shearing angle of 17^0. It may be noted that a reinforced needle punched GCL with high peel strength (above 30 N/10cm) and thick non-wovens (~300gsm) is chosen to ensure that in-plane failure through hydrated bentonite does not occur. For Cover B, the factor of safety for the static case is marginally higher in comparison to Cover A (Table 3(a)) but is still not high enough as required for acceptable design except for a flat slope of 5.0 : 1.0.

To improve the factor of safety further, a geogrid with long term tensile strength of 30 kN/m is introduced in Covers C and D. Table 3(b) shows that the factor of safety increases in both cases and is observed to be dependant on the height between berms. For Cover D a slope of 3.0 : 1.0 is observed to be stable in the static case for a height of 5m between berms.

Table 3(a). Factors of safety for covers A and B (static case)

Slope angle	Height between berms (m)	Factor of safety	
		Cover A	Cover B
3:1	10	0.75	0.92
	5	0.75	0.92
4:1	10	1.00	1.22
	5	1.00	1.22
5:1	10	1.25	1.53
	5	1.25	1.53

Table 3(b). Factors of safety for covers C and D (static case)

Slope angle	Height between berms (m)	Factor of safety (with reinforcement)	
		Cover C	Cover D
		(T= 30 kN/m)	(T = 30 kN/m)
3:1	10	0.86	1.18
	5	0.98	1.65
4:1	10	1.11	1.57
	5	1.23	2.20
5:1	10	1.36	2.18
	5	1.48	3.62

Table 4(a) and Table 4(b) show how the factor of safety of Cover D varies for conditions of seepage as well as earthquake forces. It is important to note from the first row in Table 4(a) that even though the factor of safety is adequate for the static case, it falls below acceptable value in the earthquake + seepage case. To satisfy all conditions of safety, a reinforcement of long–term tensile strength of 40 kN/m is observed to be satisfactory when the height between berms is 5.0m and the slope inclination is is 3.0 : 1.0 as brought out by the results in the first row of Table 4(b).

To be able to achieve steeper slope or greater distance between berms, the replacement of 300mm thick drainage layer of gravel by a 5mm thick geocomposite drain is found effective because the weight of the soil overlying the geomembrane is reduced.

This is brought out in Table 5(a) and Table 5(b), where the results of stability analysis are presented for Cover E. One notes from these tables that the factors of safety are higher in comparison to those reported for cover D in Tables 4(a) and (b) for the same slope inclinations. A slope of inclination 2.5 : 1.0 with height between berms of 7.5m is observed to be feasible with a reinforcement having a long term tensile strength of 40 kN/m (Table 5(b)).

Table 4(a): Results of stability analysis at interface of GM (textured) – geotextiles ($\delta = 17^o$) for cover D with geogrid reinforcement

Slope (H:V)	Height between berms (m)	FOS (with reinforcement) Long term tensile strength T=30kN/m			
		Static	Seepage	E.Q	E.Q + Seepage
3:1	5.00	1.65	1.45	1.04	0.95
	7.50	1.30	1.15	0.88	0.81
	10.00	1.18	1.04	0.82	0.75
3.5 : 1	5.00	1.93	1.69	1.15	1.06
	7.50	1.52	1.34	0.99	0.91
	10.00	1.38	1.22	0.92	0.85
4:1	5.00	2.20	1.93	1.25	1.15
	10.00	1.57	1.39	1.01	0.93

Table 4(b): Results of stability analysis at interface of GM (textured) – geotextile ($\delta = 17^o$) for Cover D with geogrid reinforcement

Slope (H:V)	Height between berms (m)	FOS (with reinforcement) Long term tensile strength T=40kN/m			
		Static	Seepage	E.Q	E.Q + Seepage
3:1	5.00	2.25	1.95	1.25	1.15
	7.50	1.52	1.33	0.98	0.90
	10.00	1.30	1.15	0.88	0.81
3.5 : 1	5.00	2.63	2.27	1.37	1.27
	7.50	1.77	1.56	1.09	1.00
	10.00	1.52	1.34	0.99	0.91
4:1	5.00	3.00	2.60	1.48	1.37
	10.00	1.74	1.54	1.08	1.00

Table 5(a): Results of stability analysis at interface of GM (textured) – geotextile (δ = 17°) with geogrid reinforcement for Cover E (after replacing drainage layer by geocomposite drain (5mm))

Slope (H:V)	Height between berm (m)	FOS with reinforcement Long term tensile strength T= 30kN/m			
		Dry	Seepage	E.Q	E.Q + Seepage
2:1	5.0	2.24	1.63	1.23	1.01
	7.5	1.19	0.93	0.81	0.68
	10.0	0.96	0.77	0.69	0.58
2.5 : 1	5.0	2.80	2.04	1.40	1.17
	7.5	1.48	1.17	0.96	0.81
	10.0	1.20	0.96	0.83	0.70
3:1	5.0	3.36	2.45	1.55	1.31
	7.5	1.78	1.40	1.09	0.93
	10.0	1.44	1.15	0.95	0.81
3.5:1	5.0	3.92	2.86	1.67	1.43
	7.5	2.08	1.63	1.20	1.03
	10.0	1.68	1.34	1.05	0.91
4:1	5.0	4.47	3.26	1.77	1.54
	7.5	2.37	1.86	1.30	1.13
	10.0	1.92	1.54	1.15	1.00

Table 5(b): Results of stability analysis at interface of GM (textured) – geotextile (δ = 17°) with geogrid reinforcement for Cover E (after replacing drainage layer by geocomposite drain (5mm))

Slope (H:V)	Height between berm (m)	FOS with reinforcement Long term tensile strength T= 40kN/m			
		Dry	Seepage	E.Q	E.Q + Seepage
2:1	5.0	19.64	6.53	2.51	1.98
	7.5	1.73	1.31	1.05	0.87
	10.0	1.19	0.93	0.81	0.68
2.5 : 1	5.0	24.47	8.15	2.61	2.13
	7.5	2.16	1.63	1.21	1.02
	10.0	1.48	1.17	0.96	0.81
3:1	5.0	29.55	9.80	2.68	2.25
	7.5	2.59	1.96	1.36	1.15
	10.0	1.78	1.40	1.09	0.93
3.5:1	5.0	34.56	11.45	2.73	2.34
	7.5	3.02	2.29	1.48	1.27
	10.0	2.08	1.63	1.20	1.03
4:1	5.0	39.11	13.03	2.76	2.41
	7.5	3.45	2.61	1.58	1.37
	10.0	2.37	1.86	1.30	1.13

5 CONCLUDING REMARKS

In the present study a geosynthetic clay liner has been used to replace a clay layer. It is important to note that in-plane stability of GCL under hydrated bentonite condition can be critical if peel strength of the GCL is low. Hence use of reinforced (needle punched or stitch bonded) GCLs with high peel strength is desirable. Further, if bentonite extrudes out of the GCL under hydration it can cause reduction in interface shear angle between the GCL and the geomembrane, thereby affecting the overall cover stability. Use of thick non-wovens on either side of the sandwiched bentonite is reported to reduce or eliminate extrusion and is recommended for use.

The present study leads to the following conclusions regarding the stability of side slopes of cover systems of hazardous waste landfills:

(a) In a cover system, the presence of a geomembrane influences the stability of the cover along side slopes. The interfaces between the geomembrane and the clay beneath it or the geotextile above/below it are the weak locations at which slippage are likely to occur.

(b) Seepage forces parallel to the geomembrane during monsoon as well as horizontal seismic loading during earthquakes also cause the factor of safety to reduce significantly.

(c) Provision of veneer reinforcement in the soil above the geomembrane, and use of textured geomembrane, improves the stability of slope.

(d) Provision of berms at intervals of low heights also helps in increasing the stability of the cover system.

(e) Reducing the thickness of the soil above the geomembrane by replacing the gravel drainage layer by a thin geocomposite drain improves the stability of covers which have veneer reinforcement. In such covers, a slope of 2.5 : 1.0 to 3.0 : 1.0 can be adopted with adequate safety.

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