Use of geogrid as a resistive layer for landfill cover: centrifuge study

Rajesh, S. & Viswanadham, B.V.S.

Department of Civil Engineering, Indian Institute of Technology Bombay, Powai, Mumbai – 400076, India

Keywords: Geogrid, Landfill Cover, Clay Cracking, Centrifuge Modeling, Differential Settlement

ABSTRACT: The objective of this paper is to study the deformation behavior of a landfill cover subjected to differential settlement through centrifuge model studies. The soil barrier present in the landfill cover tends to crack, if the induced tensile strain due to differential settlement exceeds the permissible tensile strain of the barrier material. Strengthening measures in the form of geogrid inclusion within the barrier layer has been studied in the present study. Influence of the overburden pressure on geogrid reinforced soil barrier subjected to differential settlements was studied through centrifuge tests. For the centrifuge study, model soil barrier and the model geogrid was chosen such that it represents the properties of barrier material and the prototype geogrid used in field. A hydraulic trap-door system was used to induce continuous differential settlements to the barrier at a rate of about 0.85 mm/min. Digital image analysis technique was employed to ascertain initiation and propagation of cracking at the onset of differential settlements. An attempt has been made to determine limiting distortion level at which cracks are initiated. Use of geogrid as a resistive layer for landfill cover was observed to enhance deformation behavior of soil barrier and found to sustain high distortion levels without loosing integrity.

1 INTRODUCTION

Waste disposal through engineered landfills is one of the most popular waste disposal systems that are currently in practice in most of the countries. Engineered landfill comprises of various layers of soil and geosynthetics, based on the type of waste, thickness of waste to be contained, desirable period of post-closure monitoring, geological and geotechnical constraints, financial constraints etc. However, every landfill should have an impervious layer in all lining systems (top, bottom and side) intended to control infiltration of water into or from the waste. Clay-rich soils can be considered as an effective and economical barrier material provided it has a coefficient of permeability of 1×10^{-9} m/s or less. However, a soil barrier is susceptible to cracking due to moisture fluctuations (desiccation cracks) and differential settlements (mainly due to readjustments and decomposition of the contained wastes). Excessive differential settlements can lead to cracking of the clay barrier and impair the main function of a soil barrier. The problem due to differential settlements is more pronounced in case of a cover systems than the bottom lining system because the former is subjected to low overburden pressure as well as settlement due to readjustments and ongoing bio-degradation of the wastes that lies underneath. A soil barrier tends to crack, if the induced tensile strain due to differential settlement exceeds the permissible tensile strain of the barrier material. Strengthening measures in the form of geogrid inclusion within the barrier layer has been studied in the present study using centrifuge model testing.

Application of centrifuge modeling technique to the present study is relevant because the loss of integrity of soil barrier is highly influenced by the presence of prototype stress conditions. Centrifuge scaling factors relevant to modeling of soil barriers and geogrid reinforcement has been described elsewhere extensively by Viswanadham & Mahesh (2002) and Viswanadham & Jessberger (2005). The centrifuge tests reported here were performed at 40 gravities. The 4.5 m radius large beam centrifuge at IIT Bombay having centrifuge capacity is 250*g*-ton with a maximum payload of 2.5 t at 100*g* and at the higher acceleration of 200*g* the allowable payload is 0.625 t was used (Viswanadham and Muthukumaran, 2007). A hydraulic trap-door system was used to induce continuous differential settlements to the barrier at a rate of about 0.85 mm/min with a distortion level ranging from 0 to 0.125.

2 EXPERIMENTAL TEST SETUP

A mixture of commercially available kaolin clay and locally available poorly graded sand in proportion of 80:20 (by dry weight) was used to serve as a model soil barrier material. The model soil barrier was found to have a liquid limit of 38%, plasticity index of 16%, maximum dry unit weight and OMC with standard Proctor compaction energies are 15.9 kN/m^3 and 22%. The model soil barrier material was chosen in such a way that it represents the properties of landfill barrier material used in many landfills (Benson et al. 1999). Thickness of the soil barrier used in the present study is 1.2 and 2m. In majority of the landfill sites, thickness of the cover soil placed above the soil barrier in the cover system ranges from 1 to 1.5m which corresponds to an overburden pressure of 25 kPa, hence, used in the present study. Based on the scaling considerations, a model geogrid MG1 representing a bandwidth of properties of commercially available geogrids has been selected and used in the present study. Model geogrid has an ultimate wide-width tensile strength and strain of 12.6 kN/m and 18% respectively in the longitudinal direction. Five centrifuge tests at 40*g* were conducted to study the influence of thickness of the soil barrier and overburden pressure on the deformation behavior of geogrid reinforced soil barrier subjected to differential settlements. Table 1 shows the details of the test program used in the present study. The performance of 0.6m and 1.2m thick unreinforced soil barrier (URSB) has been reported in detail by Viswanadham & Rajesh (2009). The influence of the thickness of geogrid reinforced soil barrier (GRSB) on the deformation barrier has been reported in detail by Viswanadham & Muthukumaran (2007). In the present study, influence of overburden pressure on the geogrid reinforced soil barrier is addressed.

2.1 *Test Procedure*

Figure 1 shows a cross-section of the test set-up used in the present study. Hydraulic trap-door system was custom designed to induce differential settlements to the model soil barrier in enhanced gravity. The model was prepared at normal gravity with the cylinder at its full stoke. Desired settlement rate was achieved by withdrawing the air pressure in the tank in steps and allowed the oil to flow out of the cylinder through a needle flow control valve. On an average, a settlement rate of 0.85 mm/min (in model dimensions) was achieved for all the tests and differential settlements were induced continuously. A miniature potentiometer (P3) was attached to the trap-door plate to monitor the movement of the trap-door plate, which would provide the central settlement values starting from zero to a maximum of 25mm (in model dimensions) during the centrifuge test.

Table 1. Test Program

S.No.	Test Legend	d (m)	σ_o (kN/m^2)	d_g /d	a_{max} (m)
1	RSL9	1.2	25	0.25	1.0
2	+RSL4	2.0	0	0.25	1.0
3	+RSL6	1.2	0	0.25	0.8
4	*BFL6	1.2	12.5	-^{a}	0.9
5	*BFL5	1.2	25	-^{a}	0.95

+ Viswanadham & Muthukumaran (2007); *Viswanadham &Rajesh (2009); -^{a} Not applicable; d_g Location of geogrid from top surface of the compacted soil barrier

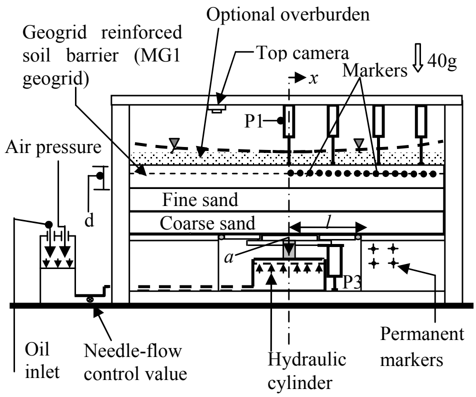


Figure 1. Cross-section view of model test package

2.2 *Model Preparation*

The model preparation involves the placement of non-woven geotextile layer cut into three pieces along the length of the container. A 30 mm thick coarse sand layer followed by 30 mm thick fine sand layer was placed at a relative density of 55 % and it was saturated. These layers were introduced to eliminate any stress concentration, which may arise due to abrupt discontinuity at hinge locations. The kaolin-sand mixture was moist-compacted with OMC+5% and corresponding dry unit weight (14.2 kN/m^3). The chosen model geogrid is placed at a distance of one fourth thickness of the clay barrier (i.e., d_g/d = 0.25) for all geogrid reinforced soil barrier. Discrete markers were glued to the model geogrid, in the case of GRSB, whereas it was placed 5mm below the top surface of the barrier in the URSB. Four numbers of potentiometers were used in all models placed on the right half cross section of the barrier at every 100 mm interval starting from the center line of the barrier (starting from P1, as shown in Fig. 1). One Charge Coupled Device

(CCD) video camera kept on top, one digital camera kept on the front side of the model, to monitor the performance of the soil barrier during the centrifuge test. At various stages of central settlements *a* (refer Fig.1), photographs were taken through an image acquiring software and were later used for image analysis to compute deformation profiles and strain distribution along the top fiber of the soil barrier.

3 ANALYSIS AND INTERPRETATION

Strain distribution along the clay barrier surface was analyzed optically by measuring the integral displacements of the discrete markers embedded in the soil (Fig. 1). The images were captured with the help of an image capturing software during centrifuge tests. Pictures captured at various settlement stages were digitized by using map edit module of GRAM++ package. Position of permanent markers relative to each other was pre-measured and was used to scale and control the images captured. In the next step, tracking the location and analyzing the displacement of markers at each settlement stage was carried-out. The measured co-ordinates of a row of markers fixed in the soil in all settlement stages are approximated with an exponential equation of the normal distribution to get the deformation at various stages of the soil barrier. Figure 2 shows the deformation profiles of the geogrid under various stages of central settlement, for the model RSL9.

The computation of the strain along the top fibre of the soil barrier can be arrived using combined bending and elongation method (Lee & Shen, 1969) and the detailed methodology adopted for computing strains are described in detail by Viswanadham & Rajesh (2009). Figure 3 shows the variation of total strain for various stages of central settlement, for the model RSL9. It can be observed that as the central settlement increases, the strain levels also increases and the maximum strain were observed to be occurred near the location of hinges.

3.1 *Influence of geogrid reinforcement.*

Variation of maximum geogrid strain occurred at the zone of maximum curvature with the central settlement and distortion level for all GRSB models were plotted as shown in Fig. 4. Distortion level is the ratio of central settlement *a* at ant particular stage of centrifuge testing to the horizontal distance (*l*) [see Fig.1]. From Fig. 4, it can be observed that values of maximum geogrid strain at the various distortions are on higher side for a thicker barrier [Model RSL4, 2m thick] when compared to thin barrier [Model RSL6 and RSL9, 1.2m thick]. With an increase in the overburden pressure, a slight increase in strain values of the geogrid can be observed.

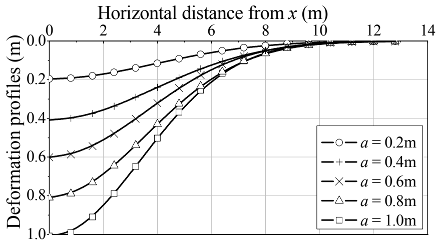


Figure 2. Deformation profile of model geogrid under various stage of central settlement [Model RSL9]

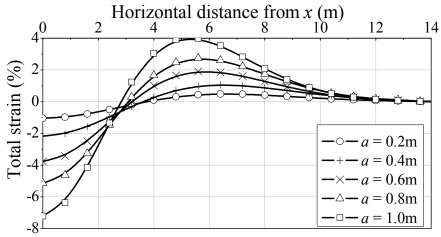


Figure 3. Total strain distribution of model geogrid under various stage of central settlement [Model RSL9]

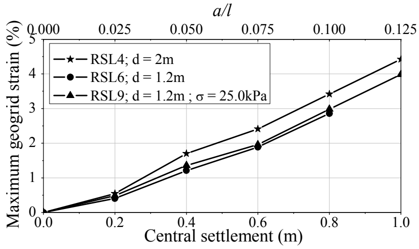


Figure 4. Variation of maximum total strain for various distortion levels.

Variation of radius at the zone of maximum curvature with the corresponding strains for all the centrifuge model tests are shown in Fig.5. From this figure, it can be noticed that an almost identical variation in total strain with respect to radius at the zone of maximum curvature, for all 1.2m thick URSB and GRSB; however, a slight shift for a 2m thick GRSB is noticed. Figure 6 shows the observed cracking patterns for a 1.2m thick model soil barrier with and without geogrid reinforcement at the end of the centrifuge tests. It can be observed that URSB tends to experience multiple cracking patterns with the crack depths extending to full depth of the barrier whereas for the GRSB, it was found to have only hair-line cracks extending up to the location of the geogrid (d_g). Similarly, Fig.7 shows the cracking pattern for a 1.2m thick URSB and GRSB with 25kPa overburden pressure at the end of the centrifuge tests. It can be noticed from Fig.7 that URSB fails completely forming singe narrow deep crack near the zone of maximum curvature. However, GRSB was observed to retain its integrity even after inducing distortion of 0.125. Influence of geogrid reinforcement on the cracking pattern of soil barrier can be clearly seen from Figs. 6 and 7.

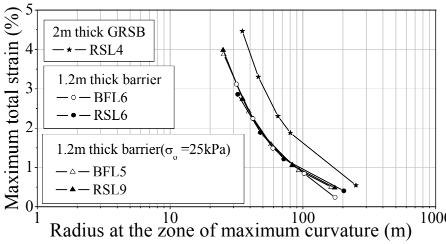
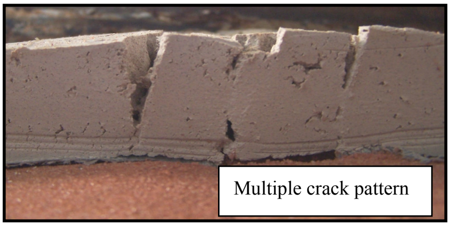
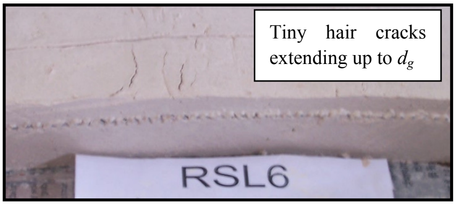


Figure 5. Variation of maximum total strain with the radius at the zone of maximum curvature.



a) Model BFL6

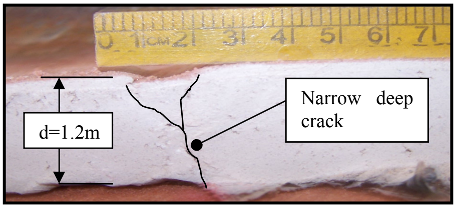


b) Model RSL6

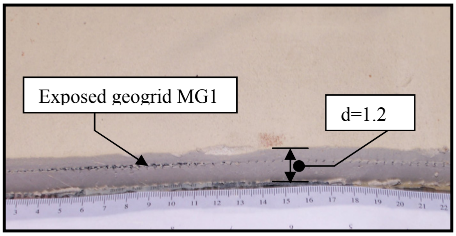
Figure 6. Status of 1.2m thick URSB and GRSB at the end of the centrifuge tests

3.2 *Discussion*

In the case of URSB without any overburden, the soil barrier is subjected to induced bending stress, σ_b due to differential settlement and once σ_b crosses the allowable strength of barrier material, initiation of tension cracks can occur, and propagates further with an increase in the curvature radius. On the other hand, the increased stresses generated within the soil barrier as a result of overburden, σ_o (i.e., $\sigma_b + \sigma_o$) allows the soil barrier to fail at greater distortion. In the case of GRSB, in addition to the soil strength, the influence of soil-geogrid interaction in the form of bond strength and frictional resistance makes GRSB better than URSB, as shown in Figs. 6 and 7. The reason behind the formation of tiny hair-line cracks extending up to d_g for GRSB [Model RCSL6] could be due to inadequate mobilisation of the required tensile strength. With the provision of 25kPa overburden pressure, 1.2m thick GRSB found to retain its integrity even after inducing distortion of 0.125, which implies that overburden pressure has assisted in increasing the mobilisation of tensile strength.



a) Model BFL5



b) Model RSL9

Figure 7. Status of 1.2m thick URSB and GRSB at the end of the centrifuge tests having 25 kPa overburden pressure

4 CONCLUSIONS

Results of centrifuge study, clearly demonstrates that presence of overburden pressure in the form of confining stress equivalent to that of cover system along with inclusion of suitable geogrid within the soil barrier, can retain the integrity of GRSB even after inducing distortion of 0.125.

References:

Benson, C. H., Daniel, D. E. & Boutwell, G. P. 1999. Field performance of compacted clay liners. *Journal of Geotechnical and Geoenvironmental Engineering*, ASCE, Vol. 125(5), pp. 391-403.

Lee, K.L.& Shen, C.K. 1969. Horizontal movements related to subsidence. *Journal of Soil Mechanics and Foundation division*, ASCE, Vol. 94 (6), pp. 139-166.

Viswanadham, B.V.S.& Jessberger, H.L. 2005. Centrifuge modelling of geosynthetic reinforced clay liner of landfills, *Journal of Geotechnical and Geoenvironmental Engineering*, ASCE, Vol. 131(5), pp. 564-574.

Viswanadham, B.V.S. & Mahesh, K.V. 2002. Modelling deformation behaviour of clay liners in a small centrifuge. *Canadian Geotechnical Journal,* Vol. 39 (6), pp. 1406-1418.

Viswanadham, B.V.S. & Muthukumaran, A.E. 2007. Influence of geogrid layer on the integrity of compacted clay liners of landfills. *Soils and Foundations,* Vol. 47 (3), pp. 519-534.

Viswanadham, B.V.S. & Rajesh, S. 2009. Centrifuge model test on clay based engineered barriers subjected to differential settlement. *Applied Clay Science*, Vol. 42 (3-4), pp. 460-472.