Application of geosynthetics in low level radioactive waste disposal facilities

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ABSTRACT: The performance of cover soil for low level radioactive waste disposal under differential settlement or subsidence is always crucial. Therefore a number of beam tests were carried out to evaluate the effect of inclusion of geosynthetics like geotextiles and geocell on the flexural strength of cover soil. Size of beams were selected as depth = 100 mm, width = 100 mm and length = 300 mm. Beams were casted at optimum moisture content (O.M.C.) and maximum dry density. Tests were conducted with different placement location of reinforcement of soil beam, so that results can be optimized by comparing the load-deflection curve for unreinforced and reinforced case. The three point loading system for flexural loading system is used for the test. The results were obtained in form of load v/s deflection curve. The results show that the brittleness of soil beam without reinforcement is reduced due to the inclusion of geosynthetics as reinforcement. Improvement in the flexural rigidity is also observed. Finally experimental results were compared (extreme vertical displacement) with the Finite Element Analysis Software PLAXIS V8.

1. INTRODUCTION

The cover system for the low level radio active waste is not under practice in India. The cover soil may fail to fulfill its objectives due to erosion, intrusion (rainfall ingress, human, animal and plant) and differential settlement and subsidence.
The entire above problems may lead to failure of cover system. Previously various attempts had been carried out to determine the long term performance of geosynthetics/geomembrane in the disposal of low level radioactive waste disposal i.e. Badu-Tweneboah et al. 1999, Jeon et al. 2005, and Rowe et al. 2008.
Considerable research has been carried out to assess the flexural strength of soil, clay liners reinforced with different types of geosynthetics materials (Mandal, 1987, Indraratna et al. 1996, Kaniraj and Gayathri, 2006 and Wang 2007). The study on the performance of cover system under differential settlement is also important aspect for the proper function of landfill.
A testing program is carried out to estimate the flexural strength and the effect of inclusion of geotextile and geocell on cover soil. The size of beam was selected as width = 100 mm, depth = 100 mm and length = 300 mm. The test is carried out on the universal tensile strength machine with certain modification.

2 LABORATORY INVESTIGATIONS

The soil samples were collected from the Near Surface Disposal Facility located at Radioactive Waste Storage and Management Site (RSMS); Bhaba Atomic Research Centre Trombay, Mumbai, India. The soil samples were collected from three different locations from a depth of 1 meter from ground surface, and representative sample is made. The properties of local soil are documented in Table 1

Table 1: Properties of local soil collected from waste disposal site from BARC Trombay, Mumbai, India.

Property	Value
Natural Water Content (%)	8.7
Specific Gravity	2.702
Atterburg Limits	
(a) Liquid Limit (%)	48.82
(b) Plastic Limit (%)	38.53
(c) Shrinkage Limit (%)	24.6
(d) Plasticity Index (%)	10.29
Optimum moisture content of soil	20.5
Maximum dry density of soil (g/cc)	1.685
Permeability of soil (cm/sec)	3.79×10^{-5}
Shear strength parameters of soil at O.M.C.	
Undrained cohesion (kPa)	14.5
Angle of internal friction (degree)	20

2.2 Properties of geosynthetics materials

Thermally bonded non woven geotextile and geocell with opening size as 50×50×100 mm were used as reinforcement.

Figure 1 show the geocell (self manufactured) used during beam test.

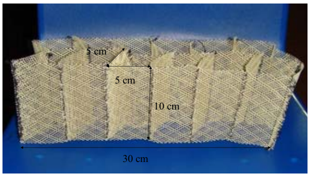


Figure 1: Geocells used in the test having different opening sizes (opening size 50×50×100 mm)

The properties of thermally bonded non woven geotextile and geocell were determined in laboratory as per their technical specifications and are shown in Table 2.

Table 2: Properties of geosynthetics

Types of geotextile	Thickness (mm)	Mass per unit area (gm/m^2)	Tensile strength (kN/m)
Thermally bonded nonwoven	0.13	52.4	5.8
Geocell	0.7	200.8	1.38

3 BEAM TESTING

Initially, soil was oven dried for 24 hours, after the drying, sieved through 4.75 mm sieve. The beams were casted on the optimum moisture content and maximum dry density $\gamma_{d\ (max)}$. Standard proctor compaction method was used for the compaction. The number of blows was calculated as per the energy imparted by the standard proctor test (594 kJ/m^3). As beams were compacted in three layers, so the number of blows for the mould size of (100×100×300 mm) i.e. for the volume of 3000000 mm^3 are obtained as 78 per layer. During the test, three point loading system was used for the flexure loading with strain rate 1 mm/min. The complete arrangement of loading system with the Universal Tensile Strength Machine is shown in Figure 2.

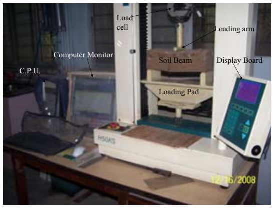
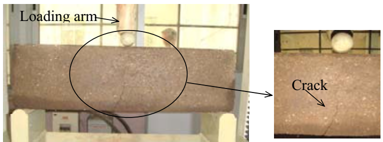


Figure 2: Arrangement of test set up for beam testing

3.1 Soil beam without reinforcement

Three beams were tested without reinforcement at optimum moisture content and maximum dry density. Figure 3 shows before and after test pictures of test of soil beam without reinforcement. The load-deflection response of unreinforced beam is shown in Figure 4.

(a) Soil beam without any reinforcement (before the test)



(b) Soil beam without any reinforcement (after the test)

Figure 3: Beam testing without reinforcement.

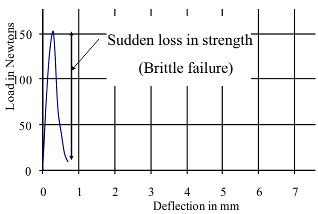


Figure 4: Load deflection response of soil beam without reinforcement.

3.2 Soil reinforced with thermally bonded non woven geotextile

Thermally bonded non woven geotextile was used for reinforcement of soil beam at three different locations i.e. 15 mm, 20 mm and 30 mm from bottom of beam. Figure 5 shows flexural testing of soil beam reinforced with non woven geotextile at a location of 15 mm only from bottom of beam. During the test three beams were casted for each location of reinforcement at maximum dry density as in previous case.

(e) Before the test

(f) Crack pattern after the test

Figure 5: Soil beam testing with thermally bonded non woven geotextile placed at different position

The load-deflection behavior of reinforced beam with geotextile is shown in Figure 6.

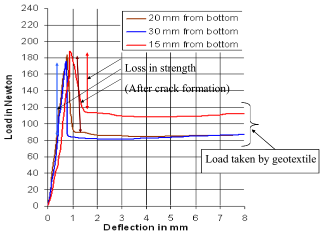


Figure 6 Load v/s deflection curve for soil beam reinforced with non woven thermally bonded geotextile placed different depths from bottom edge.

3.3 Soil reinforced with geocell

Geocells having opening size as 50×50×100 mm and 50×60×100 mm were used for experimental investigation. Initially non woven needle punched geotextile was placed at the bottom of the mould, after that geocells were placed. The soil was filled in cells in three layers. The soil was compacted in alternate cells by giving single blow of hammer. The total numbers of blows was divided into total numbers of cells, by this way the numbers of blows required for per cell were calculated approximately. In this case it was not possible to visualize the crack formation and crack pattern. Figure 7 shows the testing of soil beam reinforced with geocell with opening size 50×50×100 mm only before and after test.

(a) Before the test

(b) After the test

Figure 7 Beam test with geocell having opening size 50x50x100 mm (a) before the test and (b) after the test

Figure 8 shows load-deflection curve of soil beam reinforced with geocells having opening size as 50×50×100 mm and 50×60×100 mm.

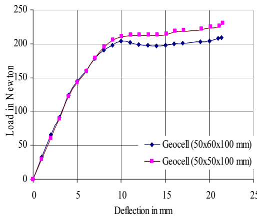


Figure 8 Load v/s deflection curve for soil reinforced with geocell having opening size 50x50x100 mm and 50×60×100 mm.

3.3.1 Test results and discussion

3.3.1.1 Without reinforcement

The load at which the crack initiates was 150.67 N and central deflection was recorded as 0.3 mm as shown in Table 5. Initially load was increased with deflection up to a maximum central deflection 0.3 mm, and after this deflection load value reduced suddenly. Figure 4 shows the brittle failure of soil beam.

3.3.1.2 With geotextile

From the test data (P_{crack} = 174.3 N and δ_{crack} = 0.76 mm (reinforcement location 30mm), P_{crack} = 183.5 N and δ_{crack} = 0.80 mm (reinforcement location 20mm) and P_{crack} = 186.8 N and δ_{crack} = 0.92 (reinforcement location 15mm), inclusion of reinforcement (thermally bonded non woven GT) in soil (see table 5), the load-deflection curve of soil improves. Initially the load increases with deflection (in all the three location of placement), after getting a particular value (i.e. P_{crack}) the crack formation is takes place, and after the crack formation the load value is reduces suddenly, which shows some short of brittle failure of beam. During this reduction in load value the crack propagates and the load now transfers to reinforcement. Now at this load the crack formation stopped for some time and the elongation of geotextiles took place. As now the load is taken by the reinforcement the load value get constant. The location of reinforcement nearer to bottom edge (i.e. 15 mm) gives us the optimum test results.

3.3.1.3 With geocell

In the initial stage of test load increases with deflection up to 4.8 mm, this shows the elastic behavior of beam, after that load-deflection behavior get shifted from elastic to plastic gradually. So the behavior of beam reinforced with geocell can be considered as elasto-plastic. The failure load at which the beam fails was observed as 214.8 N and the maximum deflection was as high as 11.2 mm. In this case the radius of curvature was 1.01 m $^{-1}$ and the modulus of rigidity was 1.95 × 10^3 kN/m^2 as shown in Table 3. So it can be conclude that the geocell provide not only reinforcement effect but also the confinement effect to soil and provides a significant increase in flexural strength and enables beam to sustain much longer deflection (up to 25 % of the depth of beam).

4 FINITE ELEMENT ANALYSIS OF SOIL BEAM

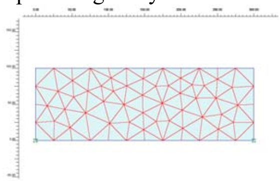
Geometry model is created in PLAXIS-V8 for flexure test of soil beam without reinforcement. The same model was used during the test in laboratory. The two supports of beam were modeled by total fixity. The local soil is modeled using linear elastic model. The model involves two basic parameters, namely Young's modulus, *E*; Poisson's ratio, *υ*. Table 4 shows the material properties.

Table 4 Material properties (local soil)

Properties of Soil	Value
Unsaturated unit weight (N/mm^3)	1.653E-05
Saturated unit weight (N/mm^3)	1.780E-05
Material type	Drained
Permeability of soil (mm/day)	32.8
Cohesion (kPa)	14.5
Angle of internal friction	20
Young's modulus (N/mm^2) (E_{ref})	8.2
Poisson's ratio	0.32

4.1 Soil beam without reinforcement

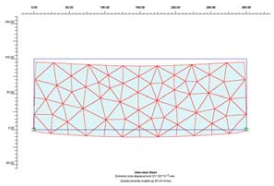
Soil beam without reinforcement is modeled in software Plaxis V8. Figure 9 shows mesh and deform mesh shape during analysis.



(a) Mesh

Table 3: Summary of beam test (experimental study)

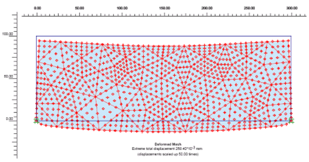
Description of soil beam	Max. central deflection δ^{max} (mm)	Load at which crack forms P_c (N)	Radius of curvature R (m^{-1})	Moment of resistance M (kN-m)	Modulus of rigidity E (kN/m^2)
Soil beam without any reinforcement	0.3	150.67	37.5	0.0113	5.08 × 10^4
Soil beam +GT (TB*)					
30 mm	0.76	174.3	14.8	0.013	2.3 × 10^4
20 mm	0.80	183.5	14.06	0.0137	2.32 × 10^4
15 mm	0.92	186.8	12.228	0.0147	2.05 × 10^4
Soil beam with geocell made up by PVC geonet					
Opening size (50×50×100)	11.2	214.8	1.01	0.0161	1.95 × 10^3
Opening size (50×60×100)	10.1	204.8	1.04	0.0153	1.90 × 10^3



(b) Deformed mesh

Figure 9 Generation of mesh in Finite Element Analysis (FEM) and deformed mesh for soil beam without reinforcement.

The vertical displacement of soil due to flexure loading is shown in Figure 10. The extreme vertical displacement is obtained as 0.258 mm.



(a) Vertical displacement (0.258 mm)

Figure 10 Extreme vertical displacement of soil beam without any reinforcement

4.2 Soil beam reinforced with geotextile

Geometric simulation of geotextile in software Plaxis V8 is done by geogrid chain line. The properties assign for simulation is shown in Table 5.

Table **4** Material properties (local soil)

Properties	TBNW GT	Geocell
Material type	Elastic	Elastic
Tensile strength of GT (kN/m)	5.8	1.38
Interaction coefficient R_{inter}	0.35	0.42

Figure 11 shows the geometric modeling of soil beam reinforced with thermally bonded non woven geotextile placed at 15 mm from bottom of the beam.

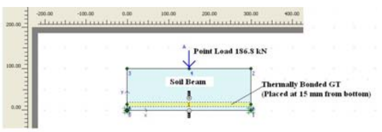
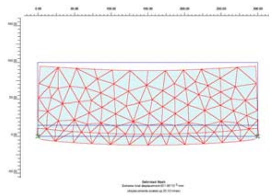


Figure 11 Geometric model of soil beam reinforced with thermally bonded non woven geotextile placed at 15 mm from bottom of the beam.

The mesh generated in FEM analysis is shown as Figure 12 (for reinforcement location 15 mm from bottom edge and the deformed mesh is shown in Figure 12.



(b) Deform mesh

Figure 12 Deform mesh shape for soil beam reinforced with TB NW GT placed at 15 mm.

The vertical displacement of soil reinforced with thermally bonded non woven GT due to flexure loading is shown in Figure 13 for 15 mm location of reinforcement.

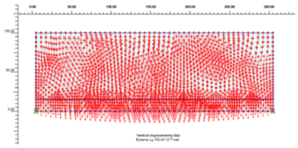


Figure 13 Vertical displacement (extreme U_y 0.753 mm) (location of reinforcement 15 mm from bottom)

4.3 Soil beam reinforced with geocell

Geocell is modeled by geogrid. The geogrid was selected as elastic material type. Figure 14 shows the geometric modeling of soil beam reinforced with both PVC geocell.

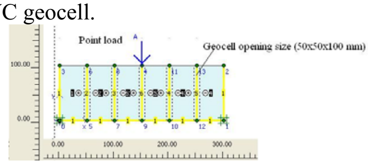


Figure 14 Geometric model of geocell reinforced soil beam opening size 50×50×100 mm.

Figure 15 shows the deform mesh in finite element analysis of soil beam reinforced with geocell having opening size as 50×50×100 mm (PVC geocell).

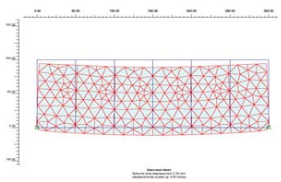


Figure 15 Deform mesh shape for soil beam reinforced with PVC geocell (Opening size 50×50×100 mm)

The vertical displacement of soil reinforced with geocell (both types) due to flexure loading is shown in Figure 16 for all three location of reinforcement.

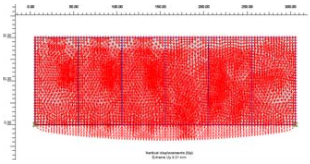


Figure 16 Vertical displacement (Extreme U_y 9.31 mm) (PVC geocell opening size 50×50×100 mm)

5 CONCLUSION

The failure load and load at which crack initiated, clearly indicate about brittle failure of soil beam without reinforcement. Inclusion of thermally bonded non woven geotextile in soil, load-deflection curve of soil improves. Initially the load increases with deflection in all the three location of placement, after getting a particular value (i.e. P_{crack}), crack formation is initiated, and after the crack formation the load value is reduces suddenly, which shows some short of brittle failure of beam followed by elongation of geotextile. The location of reinforcement nearer to bottom edge (i.e. 15 mm) gives the optimum test results (as expected earlier). The behavior of beam reinforced with geocell can be considered as elasto-plastic. Geocell enables soil beam to sustain much longer deflection (up to 25% of the depth of beam). The experimental and FEM study show good agreement in terms of maximum vertical displacement.

Table 6: Comparison of experimental results with finite element method output

Description of Test	Applied central load (N)	Extreme vertical displacement in experiment study (mm)	Extreme vertical displacement in FEM analysis (mm)	Percentage error (%)
Soil Beam without any reinforcement	150.67	0.30	0.258	(+) 14.0
Soil beam reinforced with thermally bonded non woven geotextile				
GT location 15 mm	186.8	0.92	0.753	(+) 18.15
GT location 20 mm	183.5	0.80	0.715	(+) 10.625
GT location 30 mm	174.3	0.76	0.634	(+) 16.45
Soil beam reinforced with geocell (PVC geonet)				
Opening size (50x50x100 mm)	214.8	11.2	9.31	(+) 16.8
Opening size (50x60x100 mm)	204.8	10.1	9.91	(+) 1.88

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