Settlement of Landfill Clay Cover Barriers with Geogrid Reinforcement

Akshit Mittal[1[0000-0003-0865-1468]] and Amit Kumar Shrivastava[1[0000-0001-7281-1097]]

[1] Delhi Technological University, Delhi- 110042, India

Abstract. Deformations in landfill clay cover barriers due to settlement in waste pills is a prevalent issue amassing to development of tensile cracks within the barrier, which reduces its usefulness and has a detrimental impact on its performance to reduce waste-water interaction. Geogrids have been widely used for reduction of differential settlement and preserve the utility and integrity of the barrier. However, these geogrids cannot mobilize maximum lateral resistance unless they are placed at optimum locations within the barrier. These locations need to be determined so as to obtain maximum possible benefit from the reinforcement. Hence, in this paper, laboratory scale modeling of the landfill system has been carried out. Different landfill components such as the bottom liner, drainage layer, municipal solid waste pill, foundation layer/ gas collection layer and the cover barrier have been scaled in accordance to the cover barrier height and a uniformly distributed load has been applied using a load frame. Filters, separators and protectors have been provided at suitable interfaces in the form of geotextiles throughout the landfill configuration. Kaolin clay and locally available sand blend in (4:1) proportion is used to simulate the bandwidth of clay cover material properties generally reported in the literature. Municipal waste was collected from different sources and mixed in proportion equivalent to the waste compositions of a typical Indian landfill. The waste was filled in five different horizontal phases, filled every two months and replaced with a new waste pill, which was prepared simultaneously in separate tanks, for different experimental program. Geogrids were applied in cover soil and different parameters such as initial layer spacing, vertical clearance between the reinforcement, effect of mechanical and physical properties of geogrids and the number of reinforcements have been analyzed in this study. The study showed the improvement in load carrying capacity of the landfill cover with application of geogrids, subject to its optimum placement within the landfill cover. The mobilization of maximum tensile force in a geogrid occurred when the geogrid was placed at optimum positions.

Keywords: Geogrids; Deformation; Covers; Settlement; Modeling

1. Introduction

Efficient designing and construction of waste containment systems is critical to ensure that the enclosed waste does not cause deleterious effects on the nearby environment. This requires providing effective barriers at the sides, bottom and the top of the landfill to ensure efficient containment of municipal soil waste. Various types of barriers exist, such as the Compacted Clay Barrier (CCB), Geosynthetic Clay Liners (GCL), different admixtures, geomembranes and the respective combinations of each of the above. The selection of the barrier material depends upon the availability of the material near the site. CCBs are adopted at locations where clay is readily available and hence is economical to be used as the material to design a cover barrier [14, 17]. There are general geotechnical requirements required to be fulfilled to choose the best clay material to be used for the designing of the barrier, the most significant of which is the permeability of the clay. However, municipal solid waste landfills are subjected to differential settlements occurring as a result of waste biodegradation, collapse within the waste cavities or the falling over of the waste containers [8, 36]. Hence, it is inevitable to find solutions to enhance the strength of the soil and to prevent the deleterious outcomes occurrence of cracks might have on the performance of the Cover soil barriers of a landfill. Various researchers have presented methods of reinforcement for bolstering the strength of soil for different civil engineering structures such as embankments, foundations, slope and retaining earth walls [7, 15, 19, 21, 25, 38]. Similar study has been conducted on use of different reinforcement materials for increasing the strength of the clay cover barrier soils. [37] conducted a centrifuge study on utilization of geofibers in the landfill clay covers and proffered that use of geofibers can have beneficial impacts in reducing cracks in the cover soil. They also proved that geofiber reinforced soil barrier sustained higher strains than unreinforced soil barriers at water breakthrough. Utilization of old dump waste for slope stability has also been studied by [22]. In the past few years, geosynthetics have emerged as a low cost method for improving the strength of the soil and has gained wide acceptance as a good reinforcement material. Various studies have been conducted to analyze the performance of geosynthetics in Civil Engineering structures [4, 5, 33, 9, 16, 18, 24, 26–29]. This beneficial reinforcement effects of geosynthetics has also been utilized for reducing differential settlement and occurrence of cracks in landfill cover barrier soil. Material such as geogrid has found wide range of applications in landfill cover barriers. Various researchers have presented studies on use of geosynthetics as a reinforcement material in landfill cover. [30] conducted a large scale ramp study to assess the potential of geogrids in reducing the deformability of the cover soil and for reducing the tensile forces developed in the geomembranes. The study concluded that geogrids successfully reduced tensile forces developed in the geomembranes and simultaneously proffered that the inclusion of geotextiles over geomembranes further reduced deformability of the cover soil. Also, the study suggested that geogrid properties, especially stiffness plays a major role, with deformation lower for stiffer geogrids. [32] carried out centrifuge study to analyze the cracking behavior of the landfill clay cover with and without the application of geogrid at different cover thicknesses. The study concluded that the inclusion of geogrids within the cover soil significantly restrained cracking in the cover soil. [11] investigated the potential benefit of utilizing geomembranes for curbing deformations in the clay cover, by conducting centrifuge model tests. They concluded that geomembranes acts as a hydraulic sealant even at high influx of cracks, thus preventing entry of water into the landfill even while differential settlement has taken place. [3] conducted direct shear tests to analyze to investigate the effect of geotextile and geomembranes interface on the shear strength of cover systems and liners in the landfill. The study concluded that the characteristics of the geomembranes play a substantive role in choosing the best suited type of geotextile for the cover systems. [12] presented a analytical study for computation of factor of safety of a geogrid reinforced landfill cover soil. The study analyzed different slope parameters such as slope angle, slope length, cover soil cohesion, frictional angle and interface friction and proffered that these parameter bear a significant effect on the stability of the slope of a landfill.

Review of existing literature showed that less study has been conducted to analyze the optimum locations of geogrids within the cover barrier. This locations can be significant to mobilize maximum possible tensile resistance within the reinforcements. Hence, in this study, an effort has been made to analyze the optimum locations of the reinforcements within the barrier by varying the top layer spacing of the reinforcements, number of layers of geogrids, types of geogrids and the vertical spacing between two consecutive reinforcements. For this purpose, a laboratory scale model was designed, consisting of the different components of the landfill, significant to design a scientific landfill, which would be useful for the environment.

2. Materials Used

2.1. Cover Soil

The property of the soil play a vital role in choosing the suitable material for the landfill clay cover barrier generally reported in the literature. Clay based landfill barriers are usually designed for a hydraulic conductivity of less than or equal to 10^{-7} cm/sec for MSW type landfills. However, soil properties, such as soil grain size and plasticity index of soil also plays an important role in selection of suitable material for design of landfill clay barriers as they are directly related to the hydraulic conductivity of the soil. [23] proffered a plasticity index$\geq$ 7% to 15% and percentage fines$\geq$ 30% to 50% for a suitable clay cover material, as these parameters directly influence the permeability of the soil. [10] suggested sand-clay mixture as an efficient material for reducing desiccation induced cracking in the landfill covers, which might be caused due to variable moisture content in the soil. Desiccation cracking can also cause expansion and softening of soil on water entry into the soil. Taking into consideration all the proposed characteristics of the landfill clay cover soil, a blend of kaolin and locally available sand (4:1) was chosen to simulate the characteristics of a typical landfill cover barrier. To ensure a permeability less than 10^{-7} cm/sec, the specimen was compacted at OMC+5% as [6] proffered that soils compacted on the wet side of the OMC achieved permeability less than 10^{-7} cm/sec. The properties for the same are represented in Table 1.

Table 1. Properties of CCB soil and MSW

Properties	**Soil Blend**	**MSW**
Specific Gravity	2.63	2.26
Liquid limit (%)	41.2	
Plastic limit (%)	20.44	
Maximum Dry Unit Weight (kN/m^3)	15.41	5.31
Optimum Moisture Content (%)	24.52	63%
Maximum Dry Unit Wight (OMC+5%) (kN/m^3)	14.02	
Coefficient of Permeability(cm/sec)	8.19×10^{-7}	2.34×10^{-4}
Coefficient of Permeability(cm/sec) (OMC +5%)	1.12×10^{-7}	

2.2. Municipal Solid Waste (MSW)

Waste chosen for the testing was such that it reflects the typical characteristics of the MSW waste prevalent in Indian landfills. The waste reaching the landfill in India is typically mixed waste. The waste is found to be having 42.51% biodegradables, 9.63% paper waste, 10.11% plastic/rubber, 0.63% metal waste, 0.96% glass waste and 17% inert waste [20] . The waste has typically high moisture content, pertaining to the presence of high amount of kitchen waste. For preparing waste simulating the characteristics of typical waste in Indian landfill, waste was procured from different places such as hostel mess (kitchen and food waste), recycle plant (paper, cardboard, glass, bottles, cans, metal and plastic waste), lawns and grounds (flowers and leaves) and construction site (debris, dirt and construction and demolition waste). The obtained waste was shredded and waste passing the 10mm sieve was used for modeling of the landfill structure. The shredded waste was then mixed in the respective proportions using hands, and the prepared waste was stored for analysis. The geotechnical properties of the waste obtained after analysis are shown in Table 1. It should be noted that the age of the waste used for analysis was 2-3 weeks and thus some of the organic matter would have decomposed, leading to the small value of specific gravity. The moisture content obtained was typical of the Indian waste.

2.3. Geogrids

Two geogrids with different mechanical and physical characteristics were chosen for the purpose of the study. The properties of the same were procured from the manufacturer (H.M.B.S. Textiles Pvt. limited). For the purpose of convenience, first and second type of geogrid has been termed using nomenclature as GG1 and GG2 respectively. The properties of the same are presented in Table 2.

Table 2. Properties of Geogrids

Parameters	GG1		GG2	
	MD	TD	MD	TD
Tensile Strength	7.8	8.2	5	5
Tensile Modulus	550	350	115	115
Aperture Size	30×30		12.5×12.5	

**Notes

[a] Tensile Modulus and Tensile Strength are in KN/m

[b] MD and TD are Machine Direction and Transverse Direction respectively

3. Experimental Testing

3.1. Experimental Testing Model Preparation

The experimental model of the MSW landfill was prepared in a steel tank of dimensions 750mm length, 450mm width and 750mm height respectively. The steel tank modeled for the analysis consisted of uniform thickness steel sheets along the back and side portion of the tank and an acrylic sheet of 8mm thickness along the front portion. The acrylic sheet used provided visual observation for each loading case and hence helped analyze the failure patterns. To prevent the buckling in the acrylic sheet, angles across the cross section of the sheet were used. The effect of friction was minimized using petroleum jelly along the edges of the steel tank. Each of the soil used for the study was first subjected to curing so that they achieve moisture equilibrium. For this purpose, they were stored in air tight bags for two week after adding sufficient moisture. The model preparation was started by first applying the bottom liner. A Geosynthetic Clay Liner (GCL) was chosen to simulate the characteristics of the bottom liner. Bentonite soil, encapsulated in two geotextiles, woven and non-woven respectively was needle punched and applied as a bottom liner. After placing the bottom liner, the drainage layer was designed using uniform gravels. A separator in the form of non-woven geotextile was then placed over the drainage layer to prevent the puncturing of the waste was a result of drainage layer. The MSW was placed in the model in five horizontal phases, with each phase completed in 2 months. Each day, waste was placed in the tank and an intermediate cover was provided and this was repeated until the first phase was not complete. After the completion of one phase, similar procedure was applied on the other phases, until the entire waste was placed at the end of one year. After placing the MSW, a suitable separator was applied and then two layers of sand, one being a coarse sand followed by fine sand of equal thickness were applied. The angle of internal friction obtained for the sands was 45.1^0 and 36.9^0 respectively. After placing the sand layers, the CCB was placed. The CCB was prepared in the form of slope with slope angle corresponding to 45^0. The slope was prepared in four lifts, in form of cubical blocks and the excess soil was removed to form a smooth soil slope. After preparation of a lift, the surface was scarified using a spatula, to promote bonding between the lifts. A spirit level was used at the end of the model creation to ensure the alignment of the structure.

3.2. Testing Program

The tests were carried to find the optimum positions for placement of the geogrid within the cover barrier. For this purpose, the first series of tests was performed to determine the initial layer spacing (u). The u/H ratios were varied as 0.08, 0.16, 0.24, 0.32 and 0.40 respectively for both the geogrids at uniform thickness. After the completion of each test, the MSW was replaced with waste prepared in separate tanks with similar procedure as mentioned before. After determining the optimum top layer spacing, the next series of tests was performed to analyze the effect of increasing the number of layers of geogrids. The tests were carried out by fixing the top layer at the optimum position obtained from the previous test and varying the number of layers as N=1,2,3,4,5 and 6 respectively, placed at 0.16H, 0.32H, 0.48H, 0.64H, 0.80H and 0.96H respectively. After determining the effect of number of layers of reinforcement, the final series of tests was performed to analyze the effect of vertical spacing between the geogrids. The first layer of reinforcement was placed at the optimum location obtained from the first test and the second layer was varied as 0.08, 0.16, 0.24, 0.32 and 0.40 respectively. Fig 1. shows the schematic of the testing model.

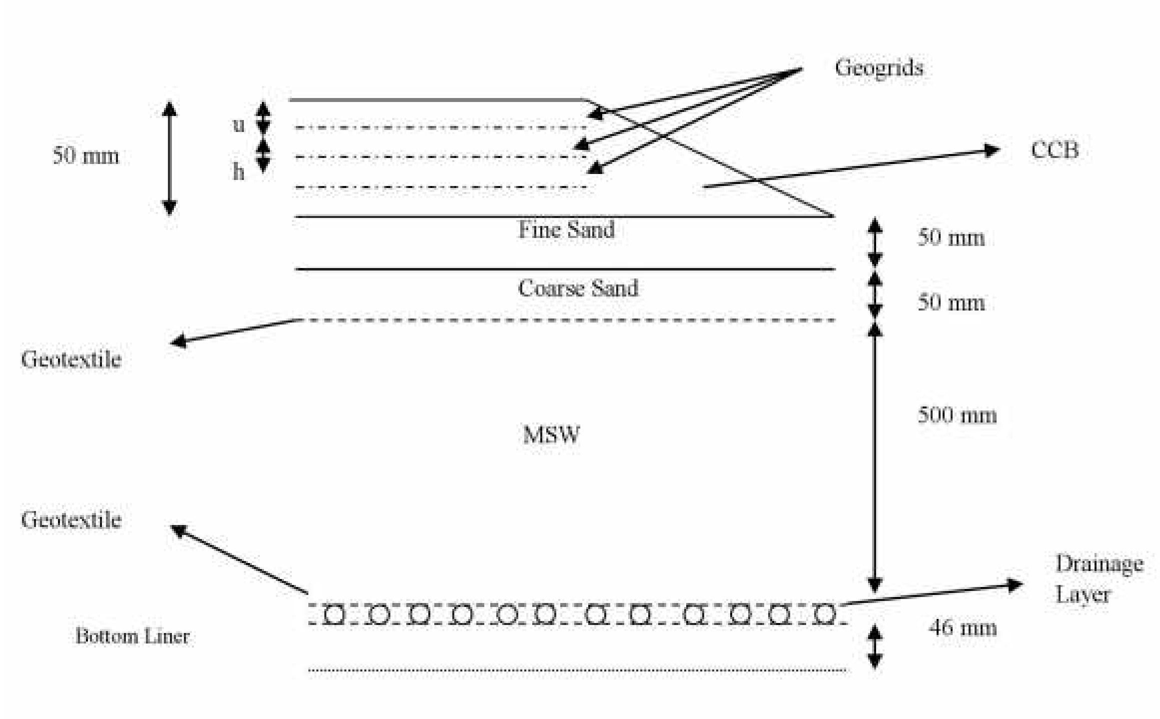


Fig 1. Schematic of the testing model

3.3. Testing Procedure

The tests to analyze the load-settlement characteristics of the landfill model were carried out in a Compression Testing Machine of overall capacity of 30 KN with geogrids placed at varying positions in the CCB. Two dial gauges were used for measurement of settlement with the increase in the load, each with an accuracy of 0.001%. The average of the dial gauge readings were used for computation of settlement. Two data logger, one for measurement of the load applied using the compression frame and other for the measurement of settlement using a LVDT. Each of the test was performed in accordance to ASTM D 1196-93 [2], according to which the load was increased until the rate of settlement achieved was lower than 0.03 mm/min for three minutes consecutively. Two tests were repeated to analyze the variations in the results, if any. The average of the two values were reported.

4. Results and Discussion

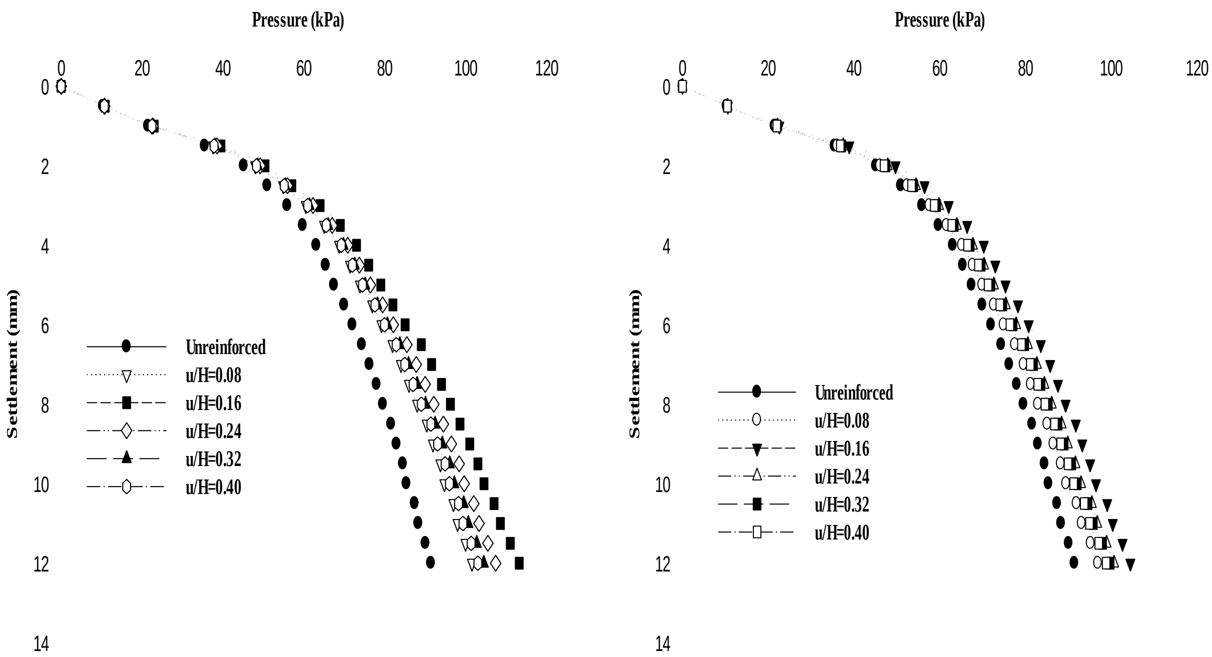
4.1. Optimum Single layer spacing

The first series of tests was performed to analyze the effect of top layer spacing (u) of the geogrid on the performance of geogrid reinforced CCB. To analyze the improvement in the load carrying capacity of the CCB, a factor called Improvement Factor (IF) was used. This factor was analyzed at different s/H ratios, where s is the settlement in mm, induced due to the application of the overburden pressure. Improvement Factor can be defined as the ratio of the load carried by the Geogrid Reinforced CCB to the load carried by the unreinforced CCB at different s/H ratios. I.F. can be mathematically represented as

$$IF = \frac{q_r}{q}, \text{ for } s/H = 2\%, 4\%, 8\%, 12\% \text{ and } 16\% \quad (1)$$

where, q_r is the load carried by geogrid reinforced CCB and q is the load carried by unreinforced CCB.

The optimum top layer spacing was analyzed by varying the u/H ratio at five different points as discussed in the testing program. Fig 2(a-b). shows the Pressure-Settlement graphs for GG1 and GG2 respectively. As can be observed from the graphs, application of a single layer reinforcement for each of the geogrid improves the stress carrying capacity of the landfill and also decreases the settlement under loading, for each of the u/H ratios. Fig 3(a-b) shows the improvement factor versus u/H curves for both the geogrids. As can be observed from the figure, the maximum possible benefit is obtained at u/H= 0.16, thus suggesting that the maximum mobilization in the reinforcement occurs at this ratio. It thus signifies the necessity of providing a suitable cover to the reinforcement, so as to obtain the maximum possible benefit from it. Similar results have been obtained for each of the geogrid. As can be observed, at u/H=0.08, the improvement obtained is lower than that obtained at u/H=0.16, thus signifying that at u/H<0.16, the depth available for mobilizing sufficient tensile resistance in the reinforcement is not available, as a result of which maximum plausible benefits from the reinforcements cannot be obtained. In other words, the cushion of soil is not sufficient over the geogrids, as a result of which maximum lateral resistance cannot be obtained. It can thus be proffered that sufficient embedment of the geogrid should be ensured, so as to obtain maximum lateral resistance from the geogrids. Similar findings have also been reported by other researchers for geosynthetic reinforced structures. [35] reported a top layer spacing corresponding to 0.4 times the footing width (B) for geogrid reinforced foundation constructed over clay soil foundations. Similar observations were also reported by [9] reported a top layer depth of 0.33B for both geogrid and geotextile reinforced clay foundations.



(a) (b)

Fig 2. Pressure-Settlement curves for (a) GG1 and (b) GG2

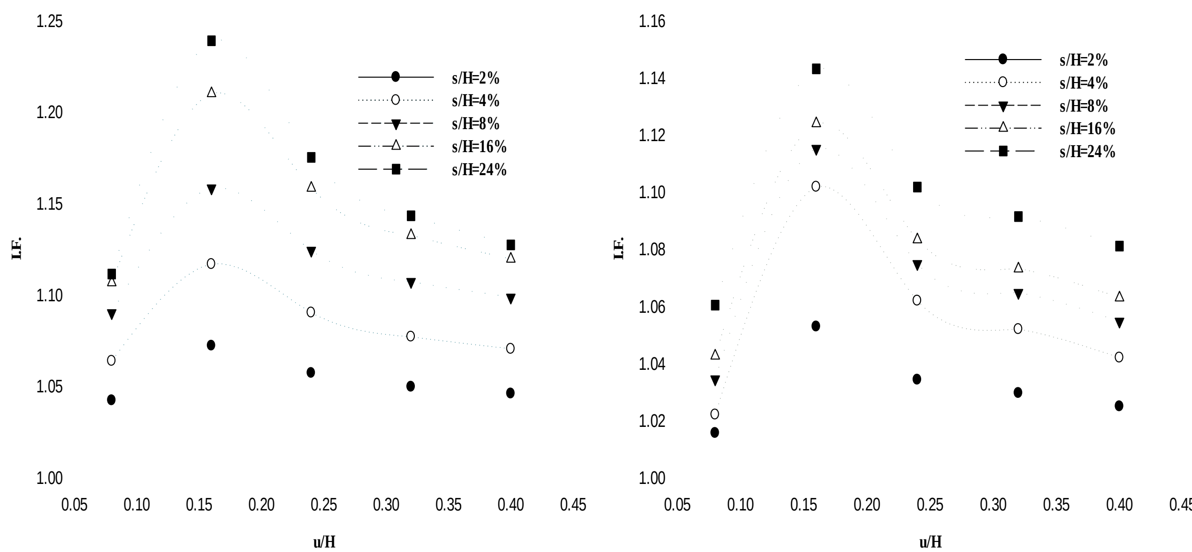
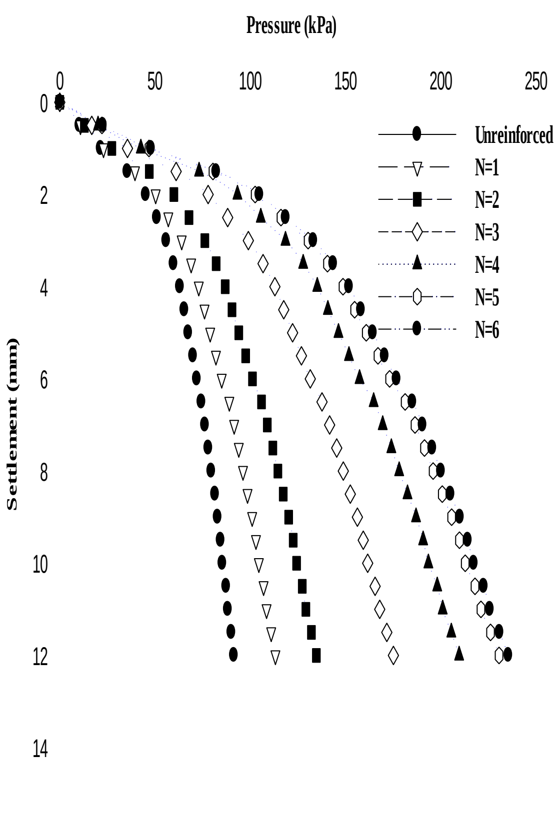


Fig 3. Improvement Factor versus u/H curves for (a) GG1 and (b) GG2

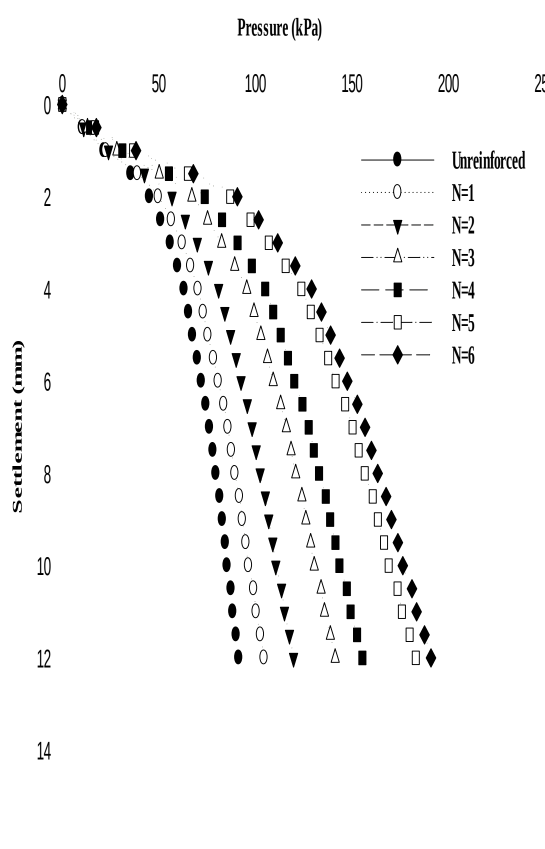
4.2. Effect of number and types of geogrids

Number of layers of geogrids within the cover barriers would play a significant role during the construction of reinforced barriers. Hence, the next set of analysis was performed to determine the effects of increasing the number of layers of geogrids within the landfill CCB. Fig 4(a-b). shows the pressure settlement curves for GG1 and GG2 respectively. As can be observed, the inclusion of multiple layers of geosynthetics significantly improves the stress carrying capacity. This increase in the load carrying capacity of the reinforced CCB with the increase in the number of layers of reinforcements can be attributed to the increase in the interface friction between the geogrids and the CCB, which increases with the increase in the number of layers of geogrids. Also, the increment in the number of layers of geogrids enhances the interlocking between the soil blend and the geogrid, as a result of which the lateral resistance provided by the geogrid increases and hence better improvement in load carrying capacity is observed. The stiffness of the CCB increases with the addition of multiple layers of geogrids. Similar observations were reported by researchers such as [1]and [34] for geosynthetic reinforced foundations. Fig 5(a-b) shows the Improvement Factor versus Settlement curve for GG1 and GG2 respectively. As can be observed, the stress carried by the CCB increases upto N=5, beyond which any further increase in the number of reinforcement layers does not increase the load carrying capacity substantially. In other words, addition of further reinforcement layers beyond N=5 in the CCB would be insignificant for the landfill design. Such an observation can be attributed to the stress envelope, which has its influence only upto a particular depth. Moving deeper than this point would not help in improving the load carrying capacity of the reinforced CCB.

Comparing the performance of GG1 and GG2 shows that under similar conditions, both the geogrids perform differently, thus signifying that the properties of the geogrids plays an important role in the reinforced CCB [31]. GG1 with higher stiffness provides better improvements at all the s/H ratios. Significantly, CCB is subjected to low overburden pressure (around 25 kPa) in typical field conditions. Performance of the geogrids at low over burden pressures thus becomes significant. GG1 would be the recommended geogrid for field operations, because it provides higher improvement at all the s/H ratios and significantly at lower overburden pressures.



(a)



(b)

Fig 4. Pressure Settlement curves for (a) GG1 and (b) GG2 for different number of layers of reinforcements

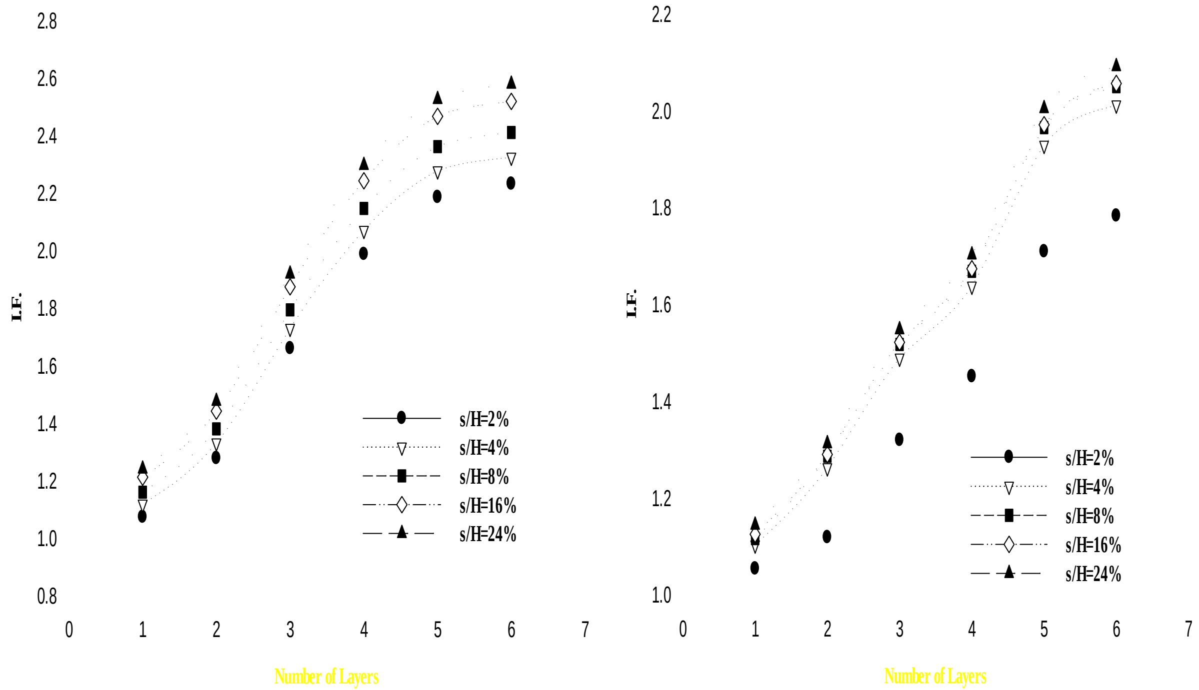


Fig 5. Improvement Factors versus Number of Layers curves for (a) GG1 and (b) GG2

4.3. Effect of spacing between geogrids

The vertical spacing between the reinforcements plays an important role in designing reinforced structures, as it determines the cost of the project [13]. The effect of vertical spacing (h) was analyzed by fixing the top layer of the geogrid at u/H=0.24 and varying the spacing of the second layer of reinforcement. As can be observed from Fig 6, when the second layer of GG1 was placed at h/H=0.24, maximum improvement in the load carrying capacity of the CCB was obtained, thus signifying that the maximum mobilization of the second layer was obtained at this depth.

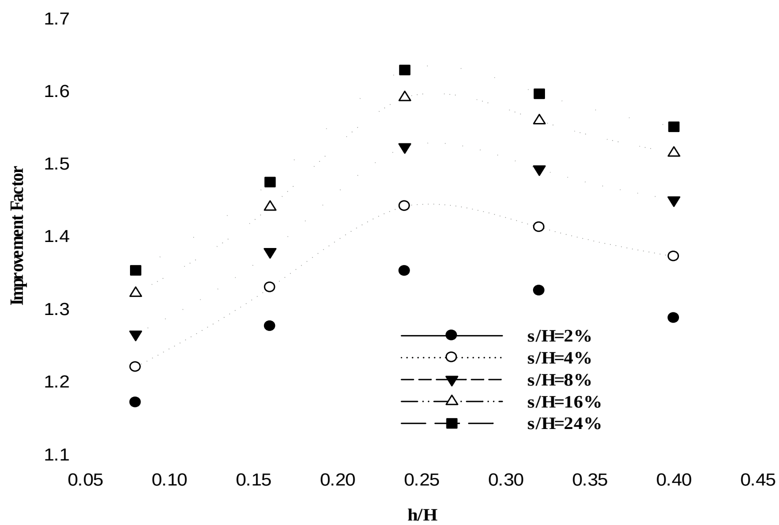


Fig 6. Improvement Factors versus h/H curves for GG1

Conclusions

Inclusions of geogrids within the CCB significantly improves its load carrying capacity, however, the maximum benefit is obtained when the geogrids are placed at optimum locations. Some of the key findings obtained from the study are:

1. Inclusion of even a single layer of geogrid significantly improves the stress carrying capacity of the CCB.
2. Maximum improvement in case of a single layer reinforcement was obtained when GG1 and GG2 were placed at u/H=0.16 respectively, thus suggesting that a suitable cover has to be provided to the reinforcement to mobilize significant lateral resistance within itself.
3. The effect of increasing the number of layers of reinforcement becomes redundant after placing the sixth layer of the geogrids, thus signifying that beyond N>5, the inclusion of geogrids would not be beneficial for the design of the CCB.
4. Properties of the geogrid plays an important role in choosing the right material to be applied in the CCB.
5. GG1 with higher tensile modulus performed much better than GG2 at every confining pressure and settlement ratio.
6. The maximum improvement, when varying the vertical spacing between the two layers of GG1 was obtained at h/H=0.24.

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