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Finite element analysis of sand-tire crumbs filled geotube reinforced embankments subjected to scouring

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Abstract. Geotextile tubes are used worldwide for coastal protection against erosion caused by the action of waves and tides. Very few studies are available on the stability of stacked geotextile tubes subjected to scouring. In this paper, finite element- based numerical analyses were carried out using PLAXIS- 2D to study the stability of stacked geotextile tubes subjected to scouring under various foundation conditions. The different cases of ground modifications considered for stacking the geotextile tubes were: (i) flat ground base foundation; (ii) gravel bedding foundation; (iii) excavated foundation; and (iv) excavated foundation with gravel bedding. Considering rubber's excellent energy absorption capacity and the need to replace conventional materials with sustainable alternatives, analyses were conducted to study the potential utilization of waste rubber tire crumbs as infill material. Analyses were carried out with stacked geotextile tubes filled with pure sand and tubes filled with sand and waste rubber tire crumbs of various proportions. The factor of safety, surface settlement, and horizontal displacement at the embankment toe under different water heights were also studied.

Keywords: *Geotube, Rubber tire crumbs, Sand, Scouring, Factor of safety, Settlement*

1. Introduction

The application of geosynthetics is one of the widely used soil reinforcement methods in the present world. They are used not only to strengthen the soil but also to act as a barrier, help filtration, and separate two materials. Different geotextiles are used to fulfill particular functions, as mentioned above. Depending upon the project's purpose, the type of the geotextile to be adopted is selected. Geotextile tubes are a type of geosynthetic used mainly for shore protection and dewatering. They are permeable fabrics that allow water to drain through them while retaining the fill material. The pressure the tubes are filled with relies on the permeability properties of this filter cake. Usually, these geotubes are hydraulically filled with dredge sand. They are very effective in shock absorption, one of the main factors to be considered while providing shore protection. From the studies done by Sin et al. (2007), it was evident that the crest height and the width of the submerged structure greatly influence the shock absorption characteristics of the tubes.

The infill material also plays a major role in the stability of a structure. This study replaces the usual sand fill with sand rubber mix. Rubber was added as tire crumbs with sand to rubber ratio of 90:10 by weight. Tests were conducted to find out the properties of the mix. The finite element analysis of the model is conducted using PLAXIS 2D software. The analysis is conducted on four foundation conditions : (i) flat ground base foundation; (ii) gravel bedding foundation; (iii) excavated foundation; and (iv) excavated foundation with gravel bedding.

2. Case study considered for the analyses

The data from the field study of geotube reinforced roadway embankment section constructed at the agricultural zone of the Saemangeum Development Project in South Korea reported by Kim et al. (2014) was used for modeling purposes. The embankment is 10.4 m high, and the cross-section of the embankment is shown in Fig.1. The foundation soil is made up of different layers of soil with different depths, as shown in Fig.2. The profile of the foundation soil is as follows: the topmost layer consists of silty sand spread over a depth of 9 m, then sand of depth 7 m, the silt of 7.5 m, gravel of 2 m, clay of 12 m depth, another layer of gravel of 2.3 m depth, weathered soil for 2.2 m and weathered rock of 4 m depth. Three layers of geotextile tubes support the embankment. The bottom and middle layers consist of tubes having a diameter of 4 m and a height of 2.2 m. The top layer is stacked with tubes having a diameter of 2 m and a height of 1.1 m (Fig.3).

Fig. 1. Cross section of the embankment considered in the analysis

3. Numerical model developed

Fig.2 shows the two-dimensional model developed for the analysis. Staged construction was followed. The construction details are given in Kim et al. (2014). Fig.3 gives the the stacked geotextile tube used for embankment protection. The water level was located at 5.2 m. A surcharge of 13 kPa was applied to simulate the traffic loads on the top of the embankment. Five different cases are considered for the analysis of the embankment system. They are listed as follows:

Case 1: Conventional geotextile tube stacking on flat ground base foundation

Case 2: Geotextile tube stacking on gravel bedding foundation

Case 3: Geotextile tube stacking on an excavated foundation

Case 4: Geotextile tube stacking on an excavated foundation with gravel bedding

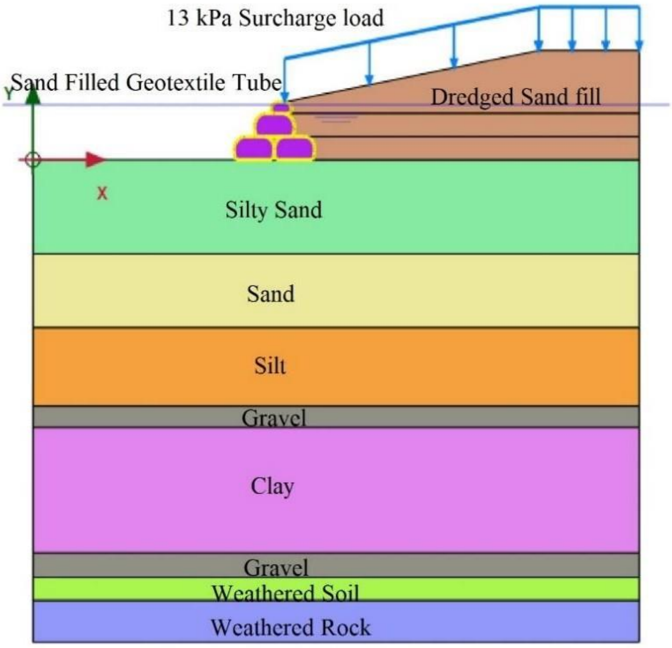


Fig. 2. Two-dimensional model developed for case 1

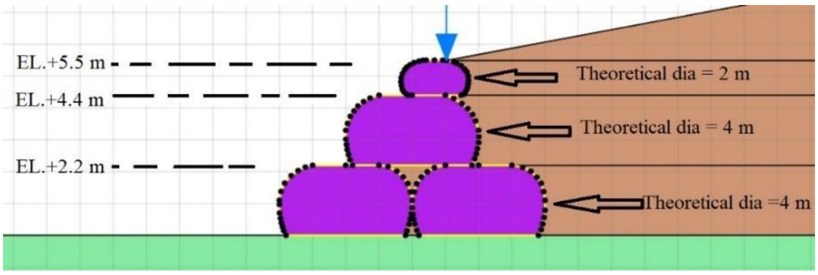


Fig. 3. Stacked geotextile tubes on plane foundation

4. Elements Used for the Analyses

The mesh's coarseness was set by a trial and error process. Both very fine and coarse settings were used for the analysis, from which it was evident that there was not very much difference in the results obtained. From the two, very fine settings were adopted as the global coarseness to conduct the finite element analysis on the embankment system. Fifteen-node triangular elements were used to discretize the geotextile tube fill, embankment fill, and underlying soil layers. Fig.4 shows the mesh generated for the analysis. Interface elements were used to model slippage between soil and geotextiles.

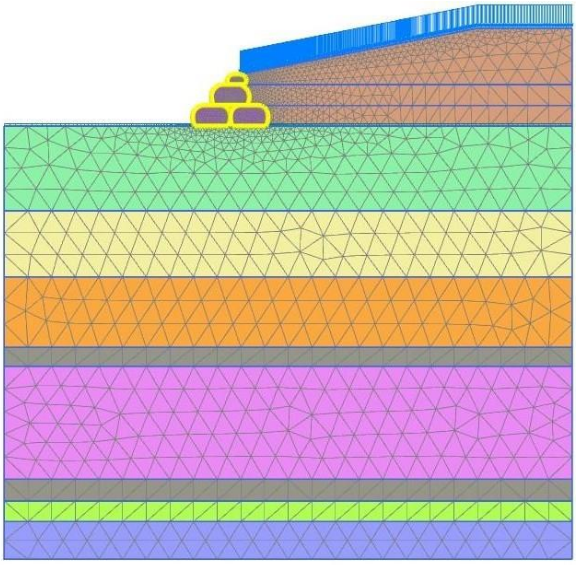


Fig. 4. Meshing adopted in the present work

5. Boundary Conditions and the constitutive model adopted

The model was fixed in horizontal directions on the vertical sides, and full fixity on the base was assumed. The bottom surface was treated as an impermeable boundary. The subsurface soil, embankment, and geotextile tube fill are modeled as linear elastic perfectly plastic materials using the Mohr-Coulomb criterion. The geotubes were modeled as linear elastic. Table 2.1 summarizes the soil properties used in the analyses. The properties of the geotube are given in Table 2. The geotubes have a thickness of 3 mm and a Modulus of Elasticity of $7.0346 \times 10^{\circ}$ kPa.

Table1. Properties of soil used in the analysis

Soil Type	Parameters							
	γ_{sat} (k N/m³)	γ_{unsat} (kN/m³)	K (m/day)	ν	E (kPa)	c (kPa)	Ψ (degree)	Φ (degree)
Geotextile tube fill	17.5	16.5	0.3456	0.4	18000	5	0	30
Embankment fill	18	16	0.3456	0.4	20000	9	0	30
Silty sand	17.5	15	0.864	0.4	6000	5	0	25
Sand	18	16.5	0.864	0.35	30000	0	0	35
Silt	18	16	0.0432	0.38	15000	30	0	10
Gravel	19	17	2.592	0.35	35000	0	0	38
Clay	18	16	0.0432	0.38	15000	30	0	10
Weathered soil	19	17	0.3456	0.32	60000	22	0	30
Weathered rock	20	19	0.0432	0.30	360000	35	0	32
Gravel bedding	21	19	1	0.35	120000	0	0	38

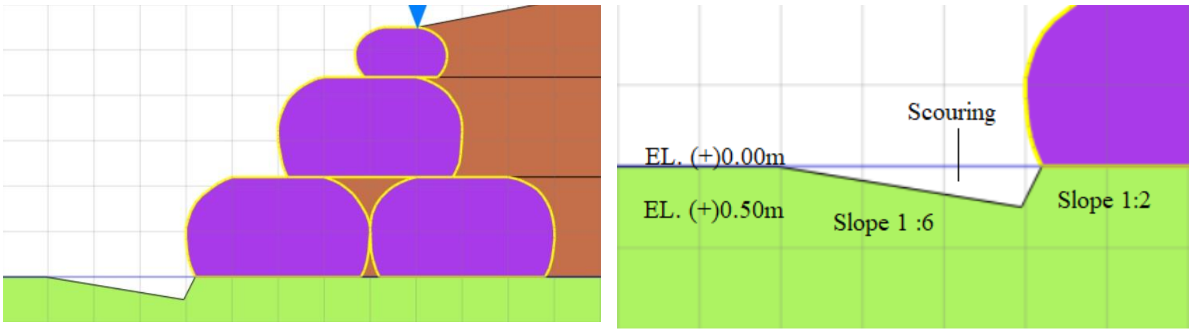
Gold mine tailings	21.15	14.22	0.0406	0.40	15000	33	0	3
Rubber-sand mixture	19.66	13.35	0.976	0.31	36000	0.33	10	40

Table 2. Geotube properties used in the analysis

Tube	Material model	Theoretical diameter (m)	Final tube height (m)	Permeability (cm/s)	Tensile strength (kN/m)	Normal Stiffness (EA) (kN/m)
Tube 1	Linear elastic	4	2.2	1 X 10^{-4}	200	21104
Tube 2	Linear elastic	4	2.2	1 X 10^{-4}	200	21104
Tube 3	Linear elastic	2	1.1	1 X 10^{-4}	200	21104

6. Scouring

Scouring is simulated by removing some soil clusters in the modelled geometry at the base and toe of the geotextile tube embankment. The maximum depth of scouring for all the geotextile tube embankment systems is set to 0.5 m. The image of scoring introduced is given in Fig. 5



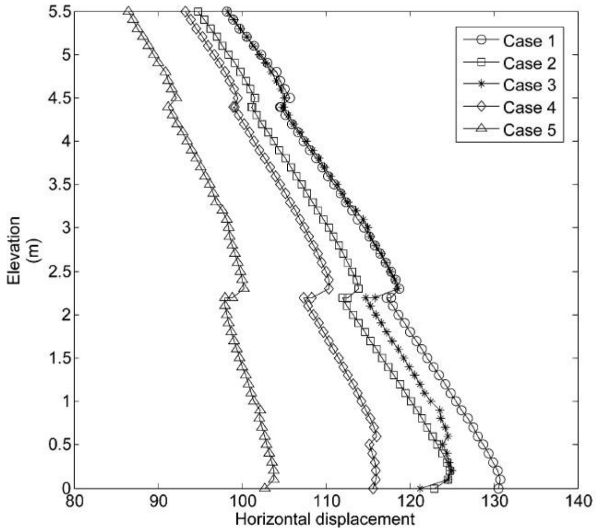
(a) (b)

Fig 5 Geotube supported embankment with scouring

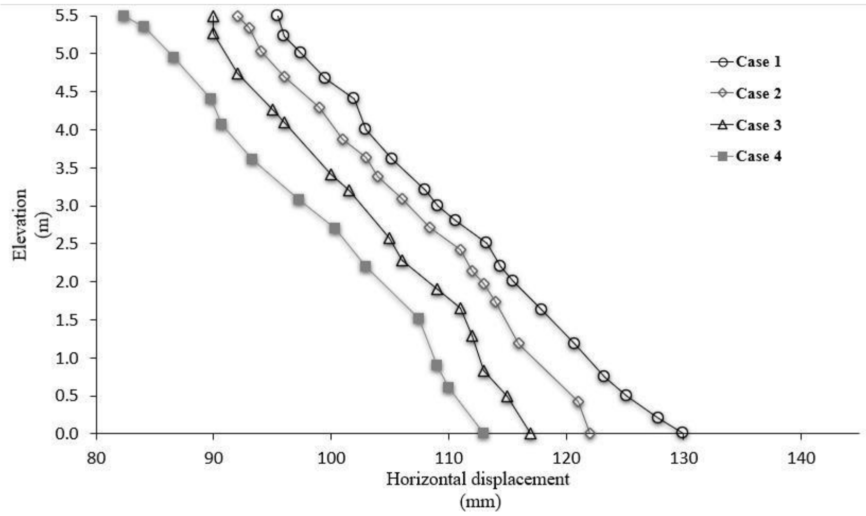
7. Results And Discussions

7.1 Validation

The results obtained from the analysis is compared with those of kim et. al.(2014). The analysed horizontal displacement under normal condition (water level at 5.2m) for all the cases (Fig. 6(b)) shows a comparable value with that of the studies done by Kim et.al.(2014) (Fig. 6(a))



(a)

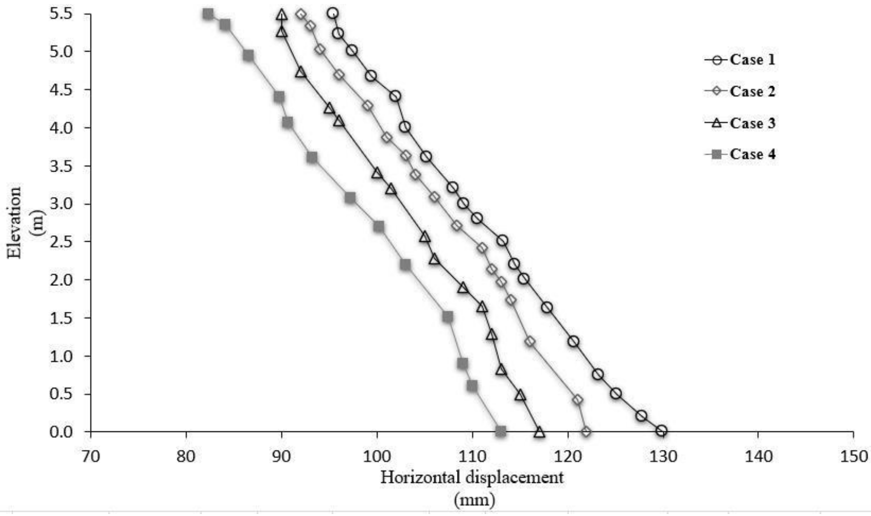


(b)

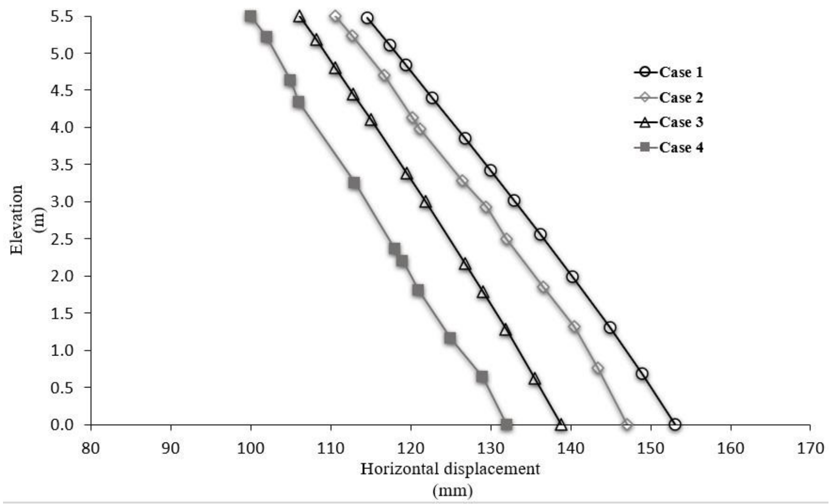
Fig. 6 Horizontal displacement under natural loading conditions without scouring from case 1 (a) Kim et al. (2014) (b) Present work

7.2 Horizontal displacement

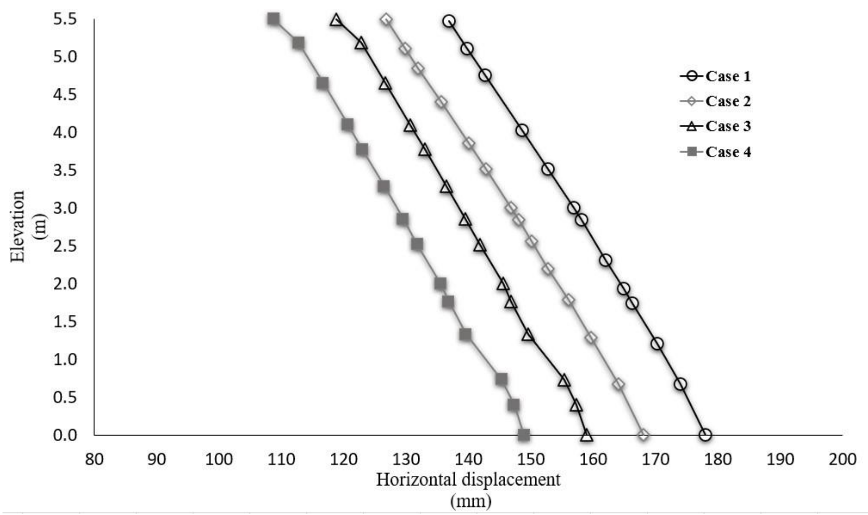
PLAXIS -2D software was used to determine the horizontal displacement of a geotube-supported embankment system with scouring. The water level is decreased from 5.2m (maximum water level) to 0m (foundation level). The effect of water on the horizontal displacement is studied by observing the displacement values at water levels of 5.2 m, 4 m, 3 m, 2 m, 1 m, and 0 m depth. Fig. 7 gives the displacement values when the infill material is sand and Fig.8 when the infill is sand-rubber mix.


5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Elevation (m)
70
80
90
100
110
120
130
140
150
Horizontal displacement (mm)
Case 1
Case 2
Case 3
Case 4

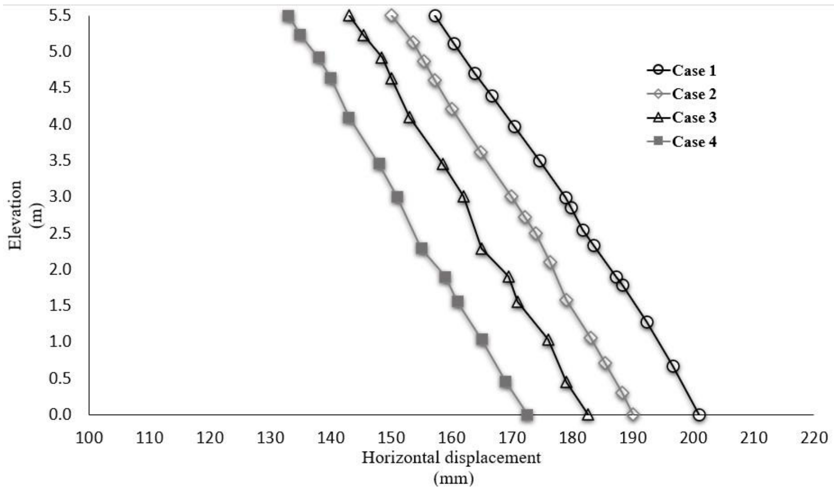
(a)


5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Elevation (m)
80
90
100
110
120
130
140
150
160
170
Horizontal displacement (mm)
Case 1
Case 2
Case 3
Case 4

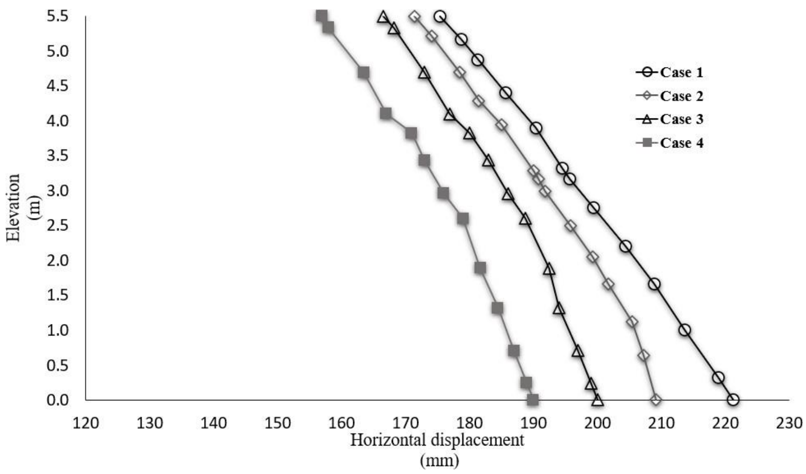
(b)


5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Elevation (m)
80
90
100
110
120
130
140
150
160
170
180
190
200
Horizontal displacement (mm)
Case 1
Case 2
Case 3
Case 4

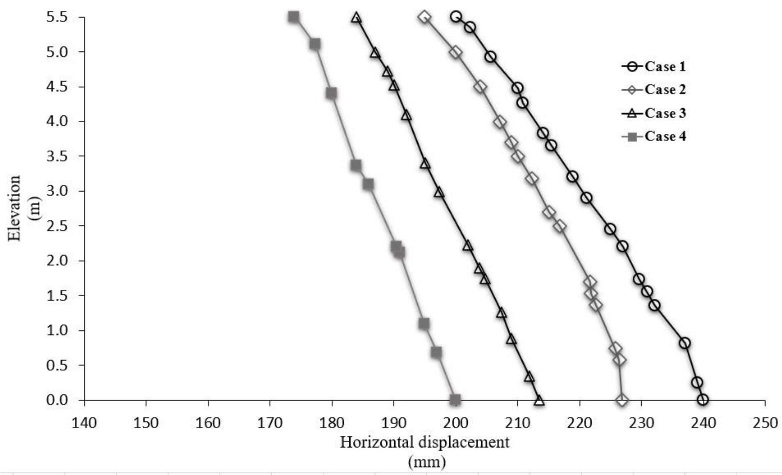
(c)



(d)

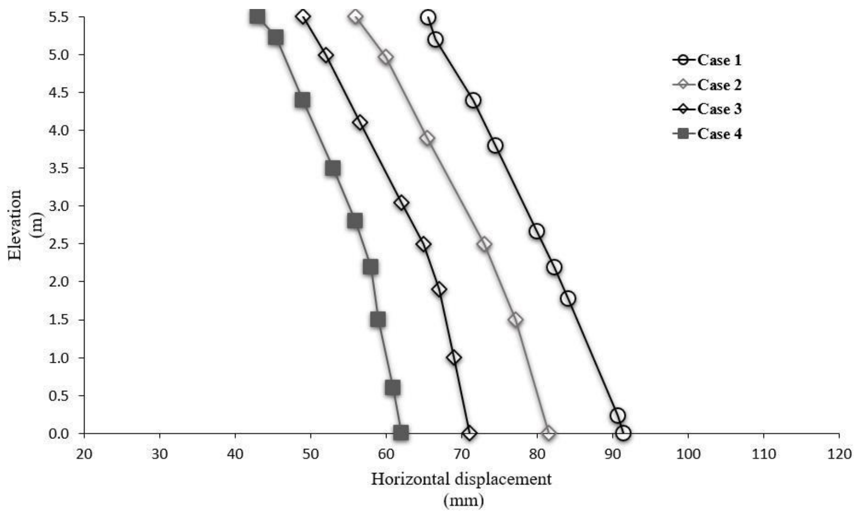


(e)



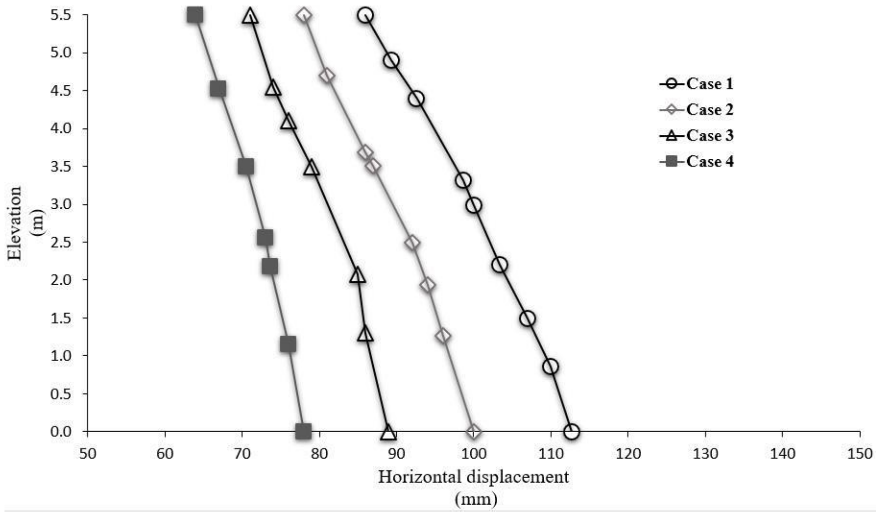
(f)

Fig.7 Horizontal displacement of different cases under static water conditions with water levels at (a)5.2 m-maximum water level (b)4 m (c)3 m (d)2 m (e)1 m and (f)0 m-ground level



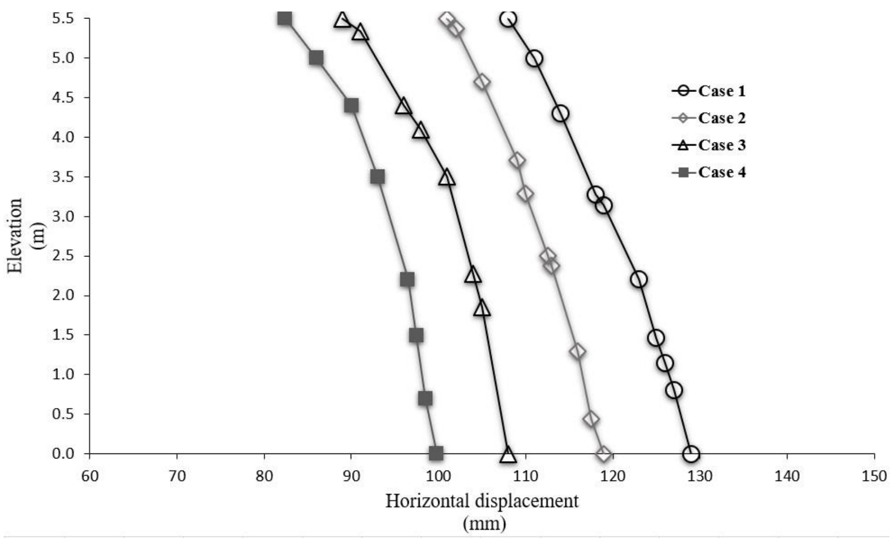
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Elevation
(m)
20
30
40
50
60
70
80
90
100
110
120
Horizontal displacement
(mm)
Case 1
Case 2
Case 3
Case 4

(a)



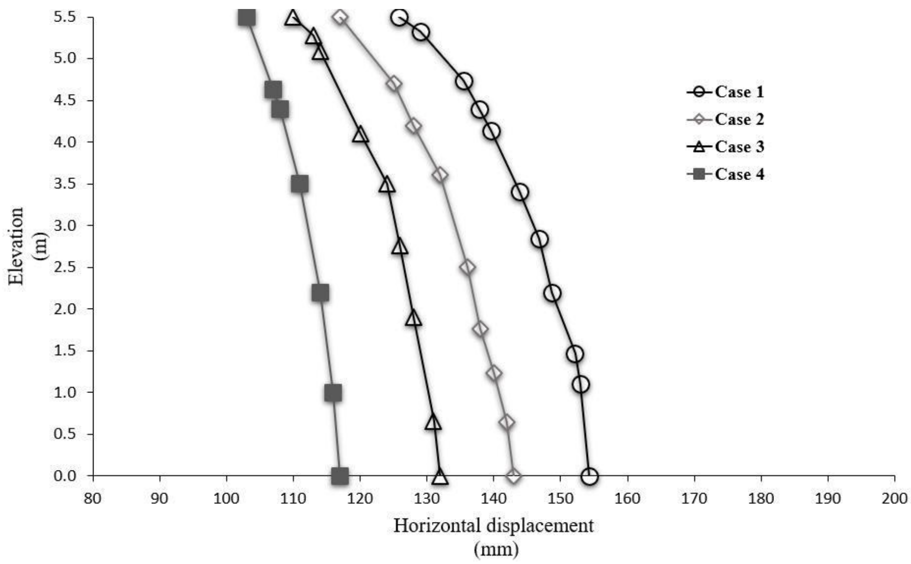
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Elevation
(m)
50
60
70
80
90
100
110
120
130
140
150
Horizontal displacement
(mm)
Case 1
Case 2
Case 3
Case 4

(b)

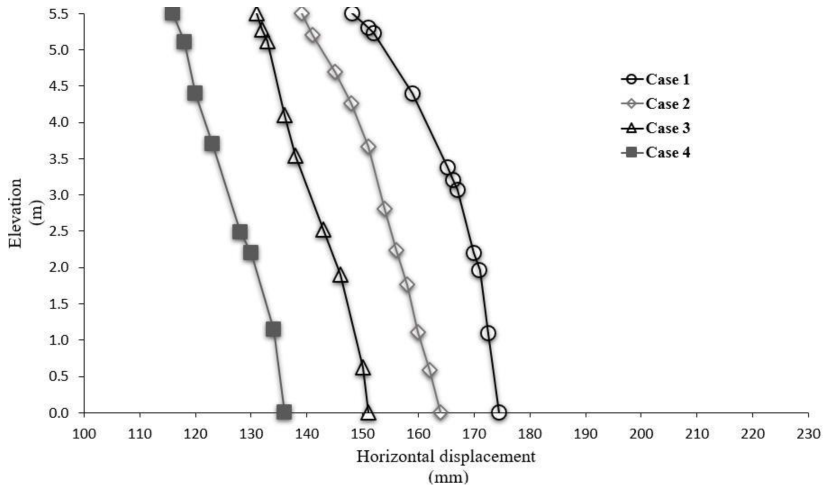


5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Elevation
(m)
60
70
80
90
100
110
120
130
140
150
Horizontal displacement
(mm)
Case 1
Case 2
Case 3
Case 4

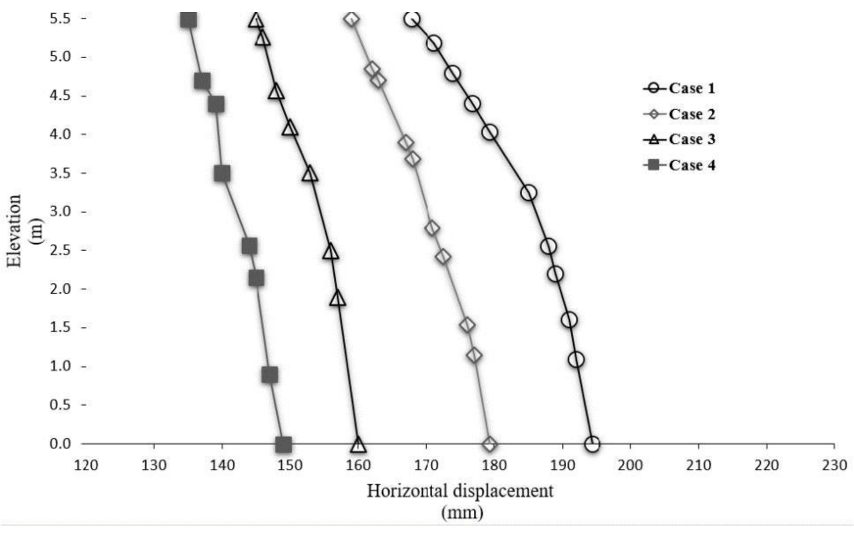
(c)



(d)



(e)



(f) **Fig.8** Horizontal displacement of different cases with the sand-rubber mixture as infill with water levels at (a)5.2 m-maximum water level (b)4 m (c)3 m (d)2 m, (e)1 m, and (f)0 m

7.3 Settlement

Settlement is the vertical movement of soil under the effect of stress. Due to the effect of water, the geotube supporting the embankment will be subjected to settlement. The value of settlement at the base toe of the stacked geotubes is given in the tables below (Table 3 and Table 4)

Table 3 Settlement with respect to varying water levels for sand-infill

Water level (m)	Settlement (mm)			
	Case 1	Case 2	Case 3	Case 4
0	60.48	50	34.14	28.435
1	40.022	40.6	25	20.022
2	35.722	28.6	15.76	10.13
3	25.369	18.73	6.54	4.53
4	12.72	9.96	5.6	3.1
5.2	8.875	3	2.5	1.5

Table 4 Settlement with respect to varying water levels for sand-rubber infill

Water level (m)	Settlement (mm)			
	Case 1	Case 2	Case 3	Case 4
0	48.02	40.26	27.9	22.88
1	39.21	33.95	18.36	16.53
2	33.52	22.58	12.04	7.83
3	23.82	13.6	4.54	3.48
4	11.23	7.1	4.13	2.3
5.2	8.36	1.95	1.72	0.98

7.4 Factor Of Safety

In the analysis conducted, the global safety factor for the geotextile tube-supported embankment is found. Table 5 shows the value of the global safety factor for different cases when the geotube infill is sand slurry and sand-rubber mix. The lowest value of the global safety factor is observed for Case 1 when the water level is at ground level. Due to the sudden drawdown created by the effect of waves, the stability of the embankment system decreases. Therefore, the most critical condition to be considered is when the embankment is fully saturated, and the water level is at the foundation.

Table 5 Factor of safety with different water levels

Case	Factor of Safety											
	Sand Infill						Sand-Rubber Mix					
	0 m	1 m	2 m	3 m	4 m	5.2 m	0 m	1 m	2 m	3 m	4 m	5.2 m
Case1	1.04	1.1	1.11	1.18	1.37	1.56	1.38	1.41	1.43	1.46	1.65	1.66
Case2	1.06	1.11	1.12	1.18	1.4	1.57	1.39	1.42	1.44	1.47	1.66	1.68

Case3	1.08	1.14	1.15	1.22	1.42	1.59	1.42	1.44	1.46	1.5	1.68	1.73
Case4	1.1	1.16	1.17	1.25	1.45	1.78	1.45	1.47	1.49	1.53	1.71	1.85

8. Conclusion

Finite element analysis was conducted on geotube reinforced embankment while changing the infill material. From the analysis conducted, the following conclusions were arrived at:

- Applied foundation improvements increased the performance of the geotextile tube system compared to conventional geotextile tube supported embankment.
- The water level and the type of infill are major factors affecting the stability of the geotube supported embankment system.
- As the water level decreased, the displacement and settlement increased and the factor of safety decreased. The sudden drawdown induced negative pore water pressures, which in turn caused instability of the structure.
- With the introduction of the sand-rubber mix as the infill material for geotubes, the factor of safety increased compared to that of the ordinary sand infill.

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