The 2013 World Congress on
Advances in Structural Engineering and Mechanics (ASEM13)
Jeju, Korea, September 8-12, 2013

Finite Element Analysis of Ground Modification Techniques for Improved Stability of Geotubes Reinforced Reclamation Embankments Subjected to Scouring

Hyeong-Joo Kim[1], *Jay Jamin[2] and Jose Leo Mission[3]

[1], [2] Department of Civil Engineering, Kunsan National University, Kunsan, South Korea
[3] SK Engineering and Construction (SK E&C), Seoul, South Korea
[1] kimhj@kunsan.ac.kr, [2] jaminjc@yahoo.com, [3] joseleo_mission@yahoo.com

ABSTRACT

Geotubes have been gaining popular use in South Korea due to the continuing land expansion activities by reclamation. When properly designed and constructed, Geotubes offer a more economical alternative compared to the conventional use of rock or precast concrete block units for shoreline protection of marine embankments and dikes. However, these Geotube elements are constantly subjected to various static and dynamic forces such as wave load in addition to the lateral and overburden pressures that it supports from weight of embankment fill and superimposed surface loads. A combination of these applied forces and loading may contribute to potential problems such as scouring that may reduce the global stability of the structure. In this study, finite element analysis is performed using Plaxis in order to fully understand the consequences that may arise from these potential problems. Various alternative construction methods are then being studied that includes ground modification techniques such as gravel bedding and recessed base construction, which are shown to help improve the overall and global stability of Geotubes.

KEYWORDS: geotube, Plaxis, embankment, global stability, scouring

1. INTRODUCTION

Currently, rock or precast concrete block units used in the construction of shoreline protection for marine embankments and dikes have increasingly become expensive to construct. The use of geotextile tube technology provides the best alternative to build these structures (Shin, et. al., 2002; Shin and Oh, 2007; Weerakoon et al., 2007). These geotextile tubes has as much strength capabilities as the conventional concrete structures but it is more cost and time efficient. However, like the traditional concrete structures, the geotextile tube structures are also exposed to the constant subjection of

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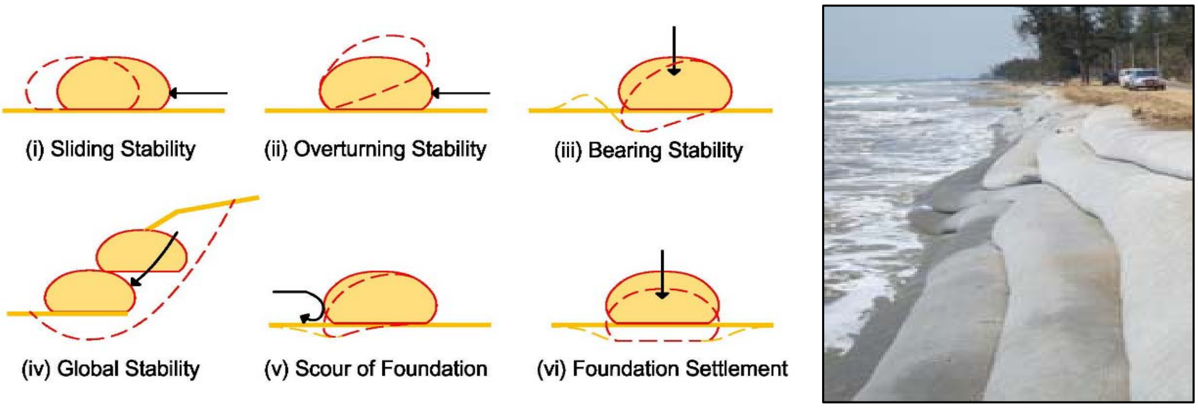
[1] Ph.D., Professor
[2] Graduate Student
[3] Ph.D., Geotechnical Engineer

static and dynamic forces such as wave load in addition to the lateral and overburden pressures that it supports from weight of embankment fill and superimposed surface loads. These combinations of applied forces and loading may contribute to potential problems such as scouring that may reduce the global stability of the structure. The analysis for the stability of geotextile tube is somewhat complicated due to the nature of its shape. By using Plaxis (2008) program, a finite element (FE) analysis was performed to fully understand the consequences that may arise from these potential problems and evaluate the performance of alternative construction and design methods for their mitigation and prevention.



(a) (b)

Fig. 1. (a) External limit state modes of the geotube system (Zengerink, 2007), and (b) Example external failure of geotube system (DIRD GROUP, 2013)

2. LITERATURE REVIEW

2.1. Geotextile Tube

Geotubes are made of permeable and soil-tight geotextile material. They are hydraulically filled with dredged marine soil or sand. Essentially a geotube is a single construction unit block containing soil. It is now being used in coastal engineering projects such as shoreline protections and breakwaters. These geotextile tubes also help store and isolate contaminated materials obtained from dredging (Shin, et. al., 2002). Hydration and cementation of the volume after the filling helps these tubes gain stability and resists external loads as a retaining structure in and out of water body (Cho, et. al., 2008).The tube shell, which is made of a woven or a non-woven geotextile, reinforces the structure (Cantre, 2002).

2.2. Causes & Effects of Scouring

Scouring is a significant problem for geotube structures. Significant scouring takes place at the sides of the geotextile tubes facing the shore. This is caused by wave breaking, undertow driven currents and wave overtopping mass flux-driven currents

(Weerakoon, 2003). Typical external limit state modes of geotube systems is shown in Fig. 1(a) and an example external stability failure is shown in Fig. 1(b).

2.3. Plaxis

Plaxis (2008) is a geotechnical software that has been developed specifically for the analysis of deformation and stability in geotechnical engineering projects. The software is based on the finite element method (FEM) and is intended for 2-Dimensional (2D) and 3-Dimensional (3D) geotechnical analysis of deformation and stability of soil structures, as well as ground water and heat flow, in geo-engineering applications such as excavation, foundations, embankments and tunnels. In this study, Plaxis FEM is used to simulate and understand the potential external failures of geotube systems and evaluate the performance of alternative construction and design methods.

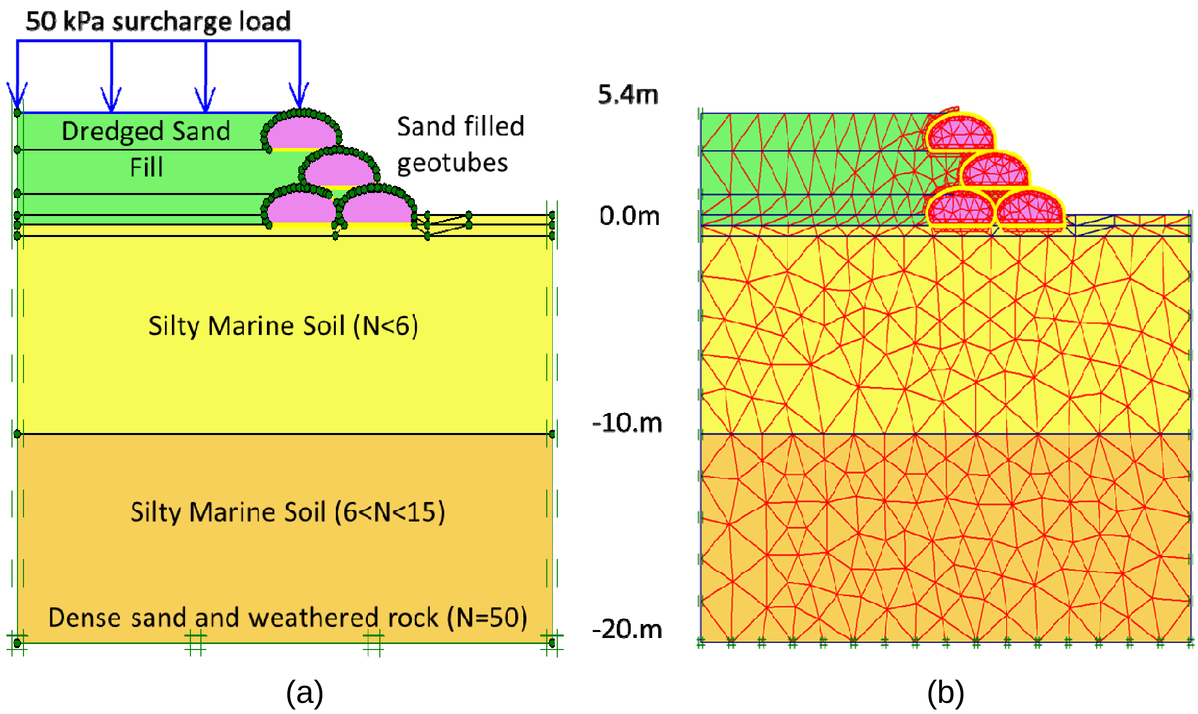


Fig. 2. (a) Embankment cross-section, (b) Plaxis finite element mesh

3. SIMULATION STUDY

3.1. Embankment Section

In this study, an embankment structure shown in Fig. 2(a) was used in the analysis. The embankment is 5.4m high, supported by 3 layers of stacked geotextile tubes. All tubes have a theoretical diameter of 3.0m. The studied soil profile under the reclamation embankment is an example of typical marine subsurface soil profile at

Incheon, South Korea (Cho et al., 2008). The approximate highest water level is 3.0m. A typical finite element mesh in Plaxis is shown in Fig. 2(b). A 50kPa surcharge loading is applied to simulate superimposed loads due to heavy traffic on a rigid pavement surface.

3.2. Material Properties

The material properties assigned to each soil layer is shown Table 1. The geotube textile thickness is 3mm (Cho et al., 2008) and has a modulus of elasticity (E) of 7.0346×10^9 Pa (Seay, 1998).

Table 1. Soil Properties

PROPERTIES	Dredged Sand Fill (Embankment)	Geotubes Sand Fill	Silty Marine Soil (N<6)	Silty Marine Soil (N>6)
Saturated unit weight, $\gamma_{(sat)}$ (kN/m^3)	18	18	18	20
Unsaturated unit weight, $\gamma_{(unsat)}$ (kN/m^3)	16	17	16	18
Soil modulus, E (kN/m^2)	1×10^4	1.5×10^4	1×10^4	1×10^4
Poisson ratio, v	0.3	0.3	0.35	0.33
Cohesion, c (kN/m^2)	1	2	5	4
Friction angle, φ (°)	30	30	25	25

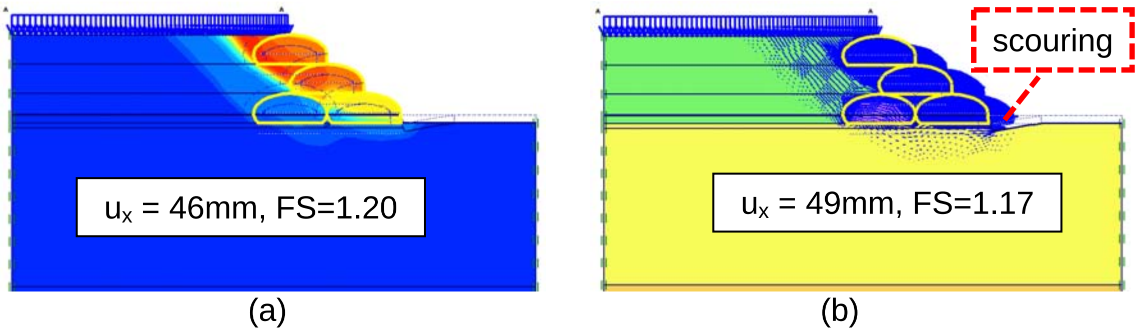


Fig. 3. Case 1: Extreme horizontal displacement (u_x), factor of safety (FS), and total incremental displacement: (a) without scouring (shadings), (b) with scouring (arrows)

3.3. Plaxis FEM case simulation studies, analyses, and results

There were 4 cases of FE analysis considered in this study. Cases 2 to 4 presents a ground modification approach to improve the stability of the geotube structure. In each case, the extreme horizontal displacement and global factor of safety for the embankment profiles with scouring and without scouring is presented. The extreme horizontal displacement (u_x) is obtained from the plastic analysis results and the global factor of safety for stability (FS) is obtained from phi-c reduction analysis results.

3.3.1. Case 1: Global stability of the studied geotube embankment profile with and without scouring (without applied ground base modification methods)

Scouring is modeled by physical removal of some soil cluster in the Plaxis geometry at the base and toe of geotube embankment as indicated in Fig. 3(b).

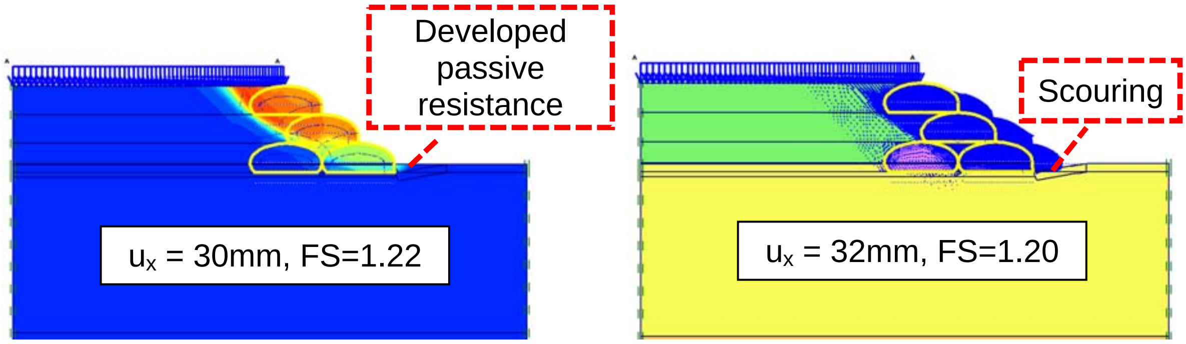
3.3.2. Global stability analysis and results with applied ground base modification methods

(a) Case 2: Method using recessed base construction

The basic concept is to provide future allowance for effects of scouring while additional passive resistance would be provided at the toe when scouring does not exist as shown in Fig. 4.

(a) (b)

Fig. 4. Recessed base construction: (a) small dredging pre-excavation (0.3~0.5m depth), and (b) geotube placement and filling

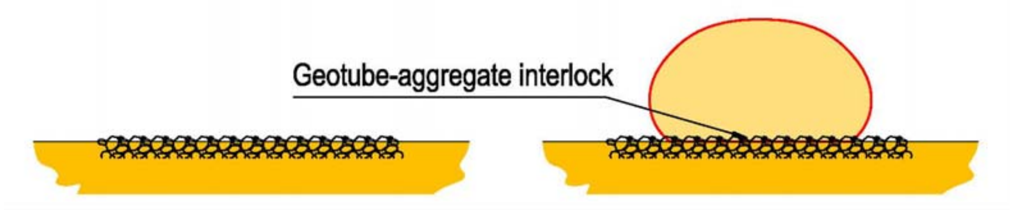


(a) (b)

Fig. 5. Case 2: Extreme horizontal displacement (u_x), factor of safety (FS), and total incremental displacement: (a) without scouring (shadings), (b) with scouring (arrows)

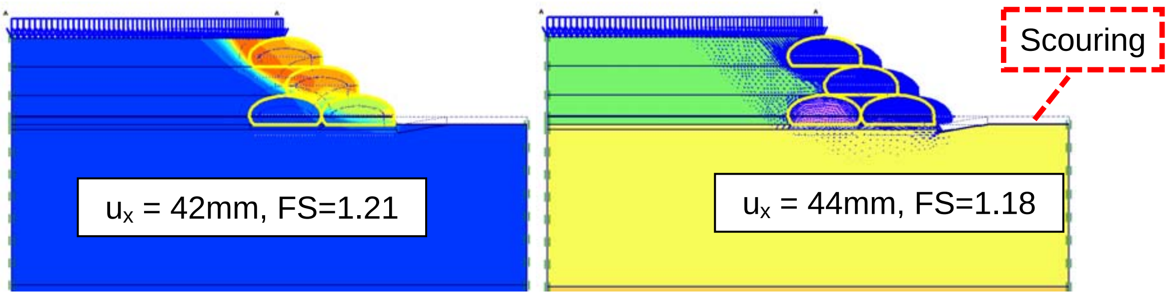
(b) Case 3: Method using gravel improved ground base

The basic concept is to produce a firmer base with higher sliding friction resistance due to the aggregate interlocking mechanism at the bottom. The modified base is modeled in Plaxis by an increase in friction angle and increase of soil interface interaction reduction factor (R_{inter}=0.9~1.0) of the soil-gravel composite as shown in Fig. 6.



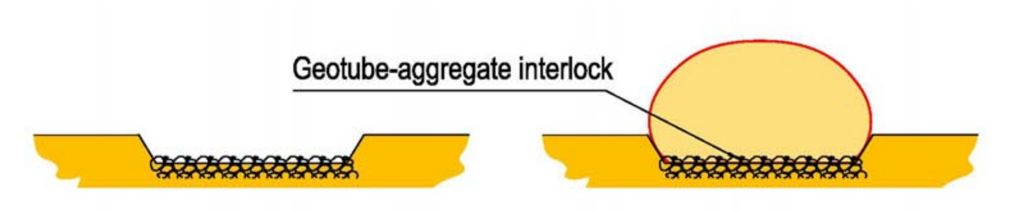
(a) (b)

Fig. 6. Ground base modification with gravel bedding: (a) gravel bedding (0.10~0.20m thick), and (b) geotube placement and filling



(a) (b)

Fig. 7. Case 3: Extreme horizontal displacement (u_x), factor of safety (FS), and total incremental displacement: (a) without scouring (shadings), (b) with scouring (arrows)



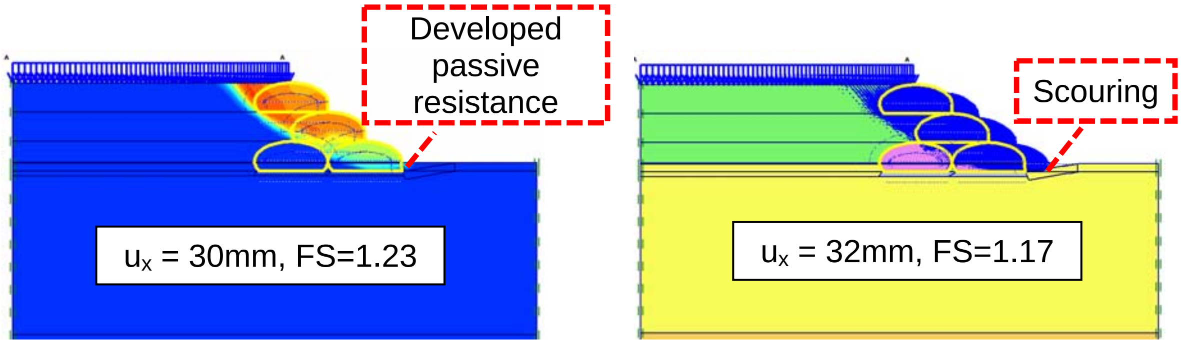
(a) (b)

Fig. 8. Recessed base construction with ground modification by gravel bedding: (a) pre-dredging excavation (0.3~0.5m depth) and gravel bedding (0.10~0.20m thick), and (b) geotube placement and filling

Comparing the results shown in Fig. 7 and Fig. 3, it can be seen that gravel base modification method decreases the extreme horizontal displacement of the geotube system while only a slight improvement of the overall stability and factor of safety is observed.

(c) Case 4: Method using combined recessed base construction with gravel improved ground

A combination of methods described in Case 2 and 3, as shown in Fig. 8.



(a) (b)

Fig. 9. Case 4: Extreme horizontal displacement (u_x), factor of safety (FS), and total incremental displacement: (a) without scouring (shadings), (b) with scouring (arrows)

3.4. Summary of analyses results

Table 2. Comparison of extreme horizontal displacement and global factor of safety: Geotube Embankment System without Scouring

	Case 1: Without ground base modification	With ground base modification methods		
		Case 2: Recessed Base Construction	Case 3: With gravel bedding base improvement	Case 4: Combination of recessed base with gravel bedding
Extreme horizontal displacement, u_x (mm)	46	30	42	30
Global factor of safety for stability, FS	1.20	1.22	1.21	1.23

Table 3. Comparison of extreme horizontal displacement and global factor of safety: Geotube Embankment System with Scouring

	Case 1: Without ground base modification	With ground base modification methods		
		Case 2: Recessed Base Construction	Case 3: With gravel bedding base improvement	Case 4: Combination of recessed base with gravel bedding
Extreme horizontal displacement, u_x (mm)	49	32	44	32
Global factor of safety for stability, FS	1.17	1.20	1.18	1.18

Table 4. Percentage variation of extreme horizontal displacement and global factor of safety relative to Case 1 without ground base modification: Geotube Embankment System without Scouring

	Case 1: Without ground base modification	With ground base modification methods		
		Case 2: Recessed Base Construction	Case 3: With gravel bedding base improvement	Case 4: Combination of recessed base with gravel bedding
% decrease in Extreme horizontal displacement, u_x (mm)	0.0 %	34.8 %	8.7 %	34.8 %
% increase in Global factor of safety for stability, FS	0.0 %	1.7 %	0.8 %	2.5 %

Table 5. Percentage variation of extreme horizontal displacement and global factor of safety relative to Case 1 without ground base modification: Geotube Embankment System with Scouring

	Case 1: Without ground base modification	With ground base modification methods		
		Case 2: Recessed Base Construction	Case 3: With gravel bedding base improvement	Case 4: Combination of recessed base with gravel bedding
% decrease in Extreme horizontal displacement, u_x (mm)	0.0 %	37.7 %	10.2 %	34.7 %
% increase in Global factor of safety for stability, FS	0.0 %	2.6 %	0.8 %	0.9 %

5. CONCLUSION

This study performs finite element analysis using Plaxis in order to simulate and understand the potential external failures of geotube systems and evaluate the performance of various mitigation and prevention measures such alternative construction and design methods. Applied ground modification methods such as recessed base construction and gravel bedding of the base are shown to improve the overall performance and stability of sand-filled geotube supported embankments to a slight degree. With applied ground base modification techniques, extreme horizontal displacements are generally smaller, while there is an insignificant improvement in overall global factor of safety compared to the conventional geotube design and construction method. In addition, combination methods are shown not to contribute altogether in the improvement of the overall geotube system performance, while only adding up the cost and schedule, in which the recessed base construction is shown to provide the better overall improvement in terms of the decrease in extreme horizontal displacement and increase in global factor of safety. In conclusion, when deciding whether base modification techniques have to be applied, associated issues in terms of additional costs and extended construction schedule will typically govern, in comparison with the increase in achieved performance of the geotube embankment system.

ACKNOWLEDGMENTS

This research was supported by a grant (code: 12TRPI-C064124-01) from R&D policy infrastructure Program funded by Ministry of Land, Transport and Maritime Affairs of Korean government.

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