Stability analysis of stacked geotextile tubes used in temporary dike construction

Analyse de la stabilité des tubes géotextiles empilés dans la construction des digues temporaires

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ABSTRACT
This study analyzed the behavior of geotextile tube structure which was constructed in Incheon Bridge construction site. In a single tube structure as an internal stability, the displacement and tensile strength of constructed tube indicated that the largest value was occurred at the surface of circumferential direction. The vertical pressure is contributed to the equivalent pressure in the 1st layer, however, when the upper load is increased, the pressure was concentrated on the center of tube structure and then it makes the differential settlement on the ground. The axial strain of geotextile tube is the largest between two geotextile tubes in the 1st layer.

In case of external stability, the tube structure was stable because the magnitude of safe factor indicated more than 1.5. The ground water level was reacted immediately with tidal datum and it was maintained constantly in the level of the 2nd layer height. As a result of seepage analysis, the seepage maintains its steady level in the ground during monitoring period. The structure stacked geotextile tube is safe enough in the phase of the external and internal stabilities.

In this study, it is reaffirmed to show similar behavior through the numerical method for the stacked geotextile tube. Recently, utilization of the geotextile structure is being increased as a structure for protecting beach line and as a structure for the purpose of solving environmental problem as well as temporary dike. Thus, analyzing the behavior of stacked geotextile tube at coastal area through numerically, it would be improved the geotextile tube technology which is regarded as safe construction methodology along the coastal line.

RÉSUMÉ
Dans cette étude, on a analysé le comportement de la structure des tubes géotextiles construits sur le chantier du pont de Incheon. Dans une structure de tube simple en tant que stabilité interne, les forces de déplacement et de résistance des tubes construits ont indiqué que la plus grande valeur apparaissait à la surface de la direction circonférentielle. La pression verticale donnait une pression équivalente à la 1ère strate, cependant, lorsque la charge sur la partie supérieure augmentait, la pression se concentrait vers le centre de la structure du tube, ce qui provoquait un affaissement différent sur le terrain. La tension axiale du tube géotextile est la plus grande entre deux tubes géotextiles de 1ère strate.

Dans le cas de stabilité externe, la structure du tube était stable à cause de l'importance du facteur sécurité qui indiquait plus de 1,5. Et le niveau d'eau dans la terre qui a réagi immédiatement avec les marées de référence a été constamment maintenu. Le résultat de cette analyse d'infiltration, c'est que l'infiltration maintient un niveau stable dans le sol pendant la période de surveillance. La structure des tubes geotextiles empilés est assez sûre dans les phases de stabilité interne et externe.

Dans cette étude, les faits ont confirmé la méthode numérique dans des tubes géotextiles empilés. Depuis peu, l'utilisation de la structure géotextile est en augmentation en tant que structure de protection des plages comme dans le cas de digues temporaires, et en tant que structure pour résoudre des problèmes environnementaux. Ainsi, en analysant le comportement des tubes géotextiles empilés en zone côtière par une méthode numérique, la technique de construction pourrait être améliorée.

Keywords : Stacked geotextile tube, Temporary dike, Numerical analysis, Internal stability, External stability, Tensile strength, Geotextile tube strain, Vertical pressure, Lateral pressure, Field monitoring, Shore

1 INTRODUCTION

Recently, the geotextile tube has been increased in use at marine area as a temporary structure like dike for constructing bridge, for protecting the beach line from the erosion by the sea wave. For the first time in Korea, the geotextile tube was constructed as a 1.8m height tube for protection of coastal line from erosion. It was installed in Youngjin bay, Korea in 2003. Since that time, it was installed in Ilsan Bridge construction site and Incheon Bridge construction site as a temporary construction platform which is constructed by stacked geotextile tube. It does not have much information available about a stacked geotextile tube in Korea by now.

One of these alternatives employs geotextile tube technology in the construction of coastal and shore protection structures, such as embankment, groins, jetties, detached breakwaters and so on. Geotextile tube technology has being changed in construction site as an alternative construction technique instead of crushed stone.

This paper presents the stability analysis of stacked geotextile tube structure for temporary construction platform of Incheon Bridge, Republic of Korea. The Incheon Bridge linking between the Incheon International Airport on Youngjong Island and Songdo New City in Incheon Free Economic Zone(IFEZ). The stacked geotextile tube technology was implemented at the approach bridge of Songdo New City site. In this study, a numerical analysis was carried out based on the field measurements of tube structure. The vertical soil pressure at the bottom of tube, the lateral earth pressure, and the surface strain of geotextile tube during installation are presented. The monitoring was conducted with respect to the stability, the seepage with influence of ground water level by tidal datum after the construction and also, it is compared with the results of numerical analysis.

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2 INSTALLATION OF GEOTEXTILE TUBE IN FIELD

The temporary geotextile tube platform is located at the 2nd construction site which station number is STA. No.0+000 ~ STA. No. 1+500 along the Incheon Bridge construction line. The geotextile tube construction site is divided by four sections A, B, C, D. The geotextile tube is installed from D to A. The planned height of embankment is EL +6.2m and total length is about 610m as a temporary construction platform. The geotextile tube site is used as a foundation of main bridge and a place to make the upper plate of bridge. The width of platform pile foundation is constructed is about 33m, and where the tollgate will be located, is about 83m.

The monitoring section for this study is located within Section B where is STA. No.0+600. The first layer and second layer are constructed with 5.0m diameter of geotextile tube. The third layer has 4.0m and the lastly top layer of dike has 3.0m diameter of tube. The characteristics of geotextile tube used in field are summarized in Table 1 and the schematic of geotextile tube installation is shown in Figure 1.

Table 1 Characteristics of geotextile tube

Items	Method	Unit	Standard Value
Composition			Polypropylene
Weight	ASTM D 5261	oz/yd^2	20.0
Wide Width Tensile Strength	ASTM D 4595	lbs/in	Warp 1000 Fill 1000
Wide Width Tensile Elongation	ASTM D 4595	%	Warp 18 Fill 15
Burst Strength	ASTM D 3786	psi	1200
Trapezoid Tear Strength	ASTM D 4533	lbs	Warp 400 Fill 400
Puncture Strength	ASTM D 4833	lbs	350
Factory Seam Strength	ASTM D 4884	lbs/in	600
Water Permittivity	ASTM D 4491	sec	0.10
AOS	ASTM D 4751	U.S. sieve no.	100

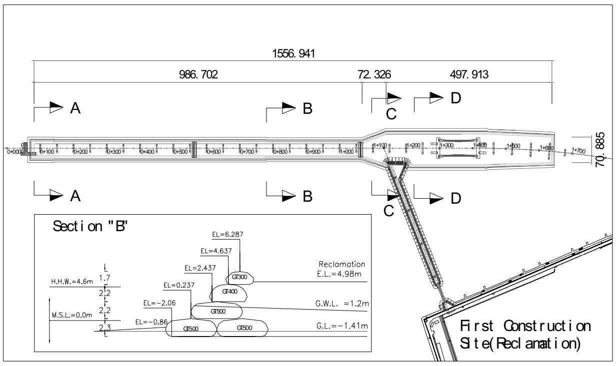

Figure 1 Schematic of geotextile tube installation

3 NUMERICAL MODELING OF GEOTEXTILE TUBE

Based on the monitoring data of stacked geotextile tubes which used in temporary dike construction at the Section B construction site of Incheon bridge, a numerical modeling was designed by an oval shape with geotextile tubes which were constructed up to the 3rd layer, there were traced to 2-dimentional plane strain model with beam element in FLAC.

Cable elements can yield by tension or compression in FLAC. They exist to be anchored at specific points on a grid condition(point-anchored) or grouted condition so that the cable elements were reinforced along its length by a grid's deforms. The geotextile tubes are not anchored at a point on the surface. On the other hand, beam elements attached to sub-grids via interface elements can also simulate the effect of geotextiles. Therefore, beam elements were applied to embody geotextile tubes. Beam elements are two-dimensional element with three degree-of-freedom (x-translation, y-translation, and rotation) at each end node. It can be joined together with one another or the grid. Beam elements are used to represent structural member in which bending resistance and limited bending moments are important. Model is based on plane strain conditions, if the beam has a plane to the other direction such as slab. Elastic modulus has to be divided by using Poisson's ratio, due to plane strain.

The geotextile tube was designed with thin wall tube by beam so that the moment of inertia was reduced. The flexibility of thin-wall tube is modeled with the property of geotextile tube by controlling its elastic modulus. The property of thickness was inputted through a laboratory test and the moment of inertia was inputted by literal data. The property of ground condition and sand material filled in geotextile tube were applied by following the plasticity model. There are typical constitutive equations of the plasticity model like Hyperbolic model, Mohr-Coulomb model, and Cam-clay model. The plasticity model based on elastic theory is corresponded with stress-strain behavior. The failure envelope of boundary conditions for analysis corresponds to the Mohr-Coulomb failure criterion. Mohr-Coulomb model applies an elastic theory until yielding point, and after then that applies a plastic law. There are the behavior law regarding on yielding point like Mohr-Coulomb model and Drucker-Prager model.

The modeling mesh of tube structures was applied a 30m of horizontal size and 10m of vertical size. Total numbers of grid for modeling are 2400 meshes which were consisted of 60 meshes in horizontal direction and 40 meshes in vertical direction. The height of each layer is 2.3 m at the first layer, 2.2 m at the second layer, and the height of top layer is 2.2m, so that the total height of temporary dike structure is 6.7m.

The boundary conditions in x direction and y direction at the bottom of modeling were applied as the fixed condition. It was applied a fixed condition only x direction at the besides of modeling so that it could measure the settlement in the y direction. The tube structure for seepage condition was fully saturated for below the second layer of stacked geotextile tubes because the mean sea level rises up to E.L. 4.6m.

4 THE PROPERTY OF COMPOSIT MATERIAL

Geotextile is made of polypropylene and it is manufactured with woven type geotextile. The result of laboratory test and literal information, a tensile strength of geotextile shows 11kPa in longitudinal direction and 12kPa in circumferential direction when the elastic modulus of 1000 kPa is maintained. Therefore, the geotextile was designed by beam element of which thickness 0.3mm. The characteristics of geotextile tube are shown in Table 2. The sand is hydraulically filled by means of pumping in geotextile tube.

Table 2 Property of geotextile tube

Property	Young's modulus(kPa)	Thickness(m)	Moment of inertia(kPa)
Geotextile tube	1.22×10^{3}	0.3×10^{-3}	1.09×10^{-12}

The final pressure within the geotextile tube exist about 3 kPa by calculating. The unit weight, bulk and shear modulus, cohesion, and friction angles for various soils are tabulated in Table 3.

Table 3 Property of constitutive material

Layer	Soil Type	Unit weight (kPa)	Bulk modulus (kPa)	Shear modulus (kPa)	Cohesion (kPa)	Friction (°)
Bottom layer soil	Clay:medium plasticity	18.0	67	4.0	80	20
Top layer soil	Clay: high plasticity	16.5	40	2.4	100	20
Tube material	Sand: uniform-fine	24.0	30	100	0	35
Embanking material	Gravel:sandy with few fines	21.0	26	160	0	35

The interface of model structure was defined by normal stiffness, shear stiffness and friction angle. The boundary condition between geotextile tube and filled sand was applied by glue type due to unified behavior. Ground - geotextile tube and goetextile tube - geotextile tube were applied by unbonded type. The friction angle of ground-geotextile and the others were estimated through the direct shear test and the interface between sand and geotextile tube was not considered due to bonded type.

Table 4 Interface element of stacked geotextile tube

Item	K_n(kPa)	K_s(kPa)	Friction angle ( )
Sand-geotextile tube	2.0×10^3	1.0×10^3	-
Ground-geotextile tube	1.0×10^1	4.2×10^{-5}	30
Between geotextile tubes	3.3×10^1	2.1×10^{-5}	22

5 RESULT OF NUMERICAL ANALYSIS

5.1 *Analysis of Single Geotextile Tube*

The tensile strength of geotextile tube on surface which is determined by the strength of geotextile and seam strength of itself is the important element to analyze an internal stability interpretation. The tensile strength gives 32 kPa in circumferential direction and 25 kPa in longitudinal direction for 2.2m height of single tube. When the sand mixture with water was injected up to 2.3m height of tube, the maximum pressure indicated 2.6 x 10^{-2} kPa. After consolidation, the final height was reached as 2.2m. Figure 2 shows the shape of geotextile tube through 2-dimensional analysis. The rate of filling was about 44% based on height and the quantity of filling area was about 12.7m^2 which comes under the 64.7% of theoretically estimated area.

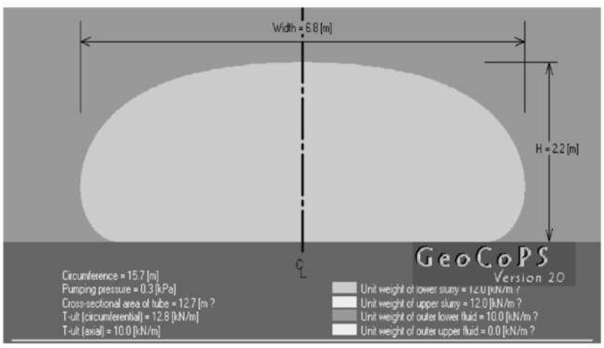

Figure 2 Behavior of single geotextile tube

5.2 *Analysis of Stacked Geotextile Tubes*

5.2.1 *Distribution of Soil Pressure*

The soil pressure of each tube was calculated which it was established at the center of bottom layer. The initial soil pressure by the weight of tube was occurred about 80 kPa at the first layer, and it showed about 70 kPa at the second layer, and about 30 kPa at the top layer. The final soil pressure at the center-bottom of tube for the first layer was moved to central position of structure so that the maximum value by tube weight was occurred about 160 kPa at the center of tube structure. It was increased about 2 times. The soil pressure at the second layer was also moved from center-bottom point to the right-bottom point. It was increased about 40kPa at the right-bottom point. In case of top layer, the value was not changed. Figure 3 shows the distribution of soil pressure through 1000 step iterations.

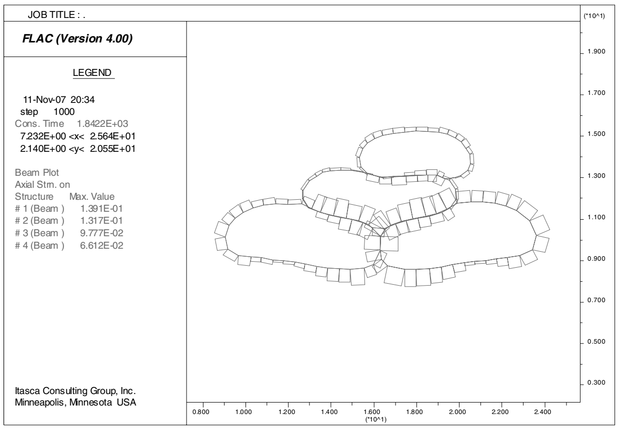

Figure 3 Deformation of stacked geotextile tube

5.2.2 *Circumferential Strain of Geotextile Tube*

The geotextile tube on the stiff ground was stretched down with settlement by the self-weight vertical pressure. When the geotextile tube is constructed on the soft ground, the tensile force is uniformly distributed by stretching. The strain of geotextile increases with the deformation of tube so that tensile force increases along the circumferential direction. Therefore, the maximum strain occurs at the point of maximum deformation. The circumferential strain at the initial time was occurred about 8% at the bottom point of the first layer. It was also occurred about 12% and 5% at the second and third layers, respectively. The maximum (final) strain was occurred 15%, 12%, and 8% at each location. Table 5 describes the results of circumferential strain on tube surface.

Table 5 Transportation of circumferential strain

Installed location		Initial strain (%)		Final strain (%)		Increment (kPa)
		Value	Place	Value	Place	
1st layer	Inside	8	Center-bottom	15	Left-top	7
	Seaside	8	Center-bottom	14	Right-top	6
2nd layer		12	Center-bottom	12	Right-side	0
3rd layer		5	Center-bottom	8	Right-bottom	3

5.2.3 *Vertical Displacement of Geotextile Tube*

The vertical displacement of geotextile tube was concentrated at the center point of tube structure so that the displacement at the first layer was occurred about 1.0 m. The displacement was occurred about 1.8m at the second layer and 1.0m at the third layer. However, the magnitude of increment at each layer was occurred 1.0m on the ground surface, 0.2m at the first layer, 0.6m at the second layer, and 0.0m at the third layer which was measured at the top level of each tube layer. Figure 4 shows the behavior of stacked geotextile tube structure after constructions.

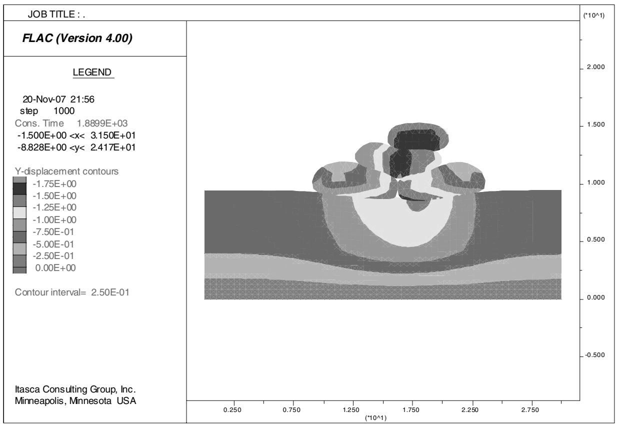

Figure 4 Vertical displacement of geotextile tube structure

5.2.4 *Slope Stability of Temporary Dike Structure*

To confirm the slope stability of the temporary dike, the safety factor was calculated on the circular sliding condition using limit equilibrium method by Slope/w Ver. 5.0 which is able to analysis on soil slope stability or combined slope stability. The periodic function was occurred by the tidal wave at the 12 hours interval with sine curve. The amplitude of sine curve was 4.63m which is the approximately highest high water (approx. H.H.W.) at Incheon coastal area. The input data of each layer was used the soil property on design library of software, soil boring data and the results of laboratory test. The safety factor from the slope stability analysis was turned out to be 1.3 so that is safe. Figure 5 shows the analysis of slope stability.

Seepage analysis of geotextile tube was considered the sectional change which follows the construction segment of the geotextile tube. The elapsed time for flow type was set up 16 days with considering seepage condition and water level. An input data used in Seep/w program is permeability on steady flow, hydraulic function, and soil property. The seepage line in the water front with stacked geotextile tube construction was changed very much with the tidal wave. The permeability of embankment was estimated as $0.2\text{x}10^{-3}$ cm.

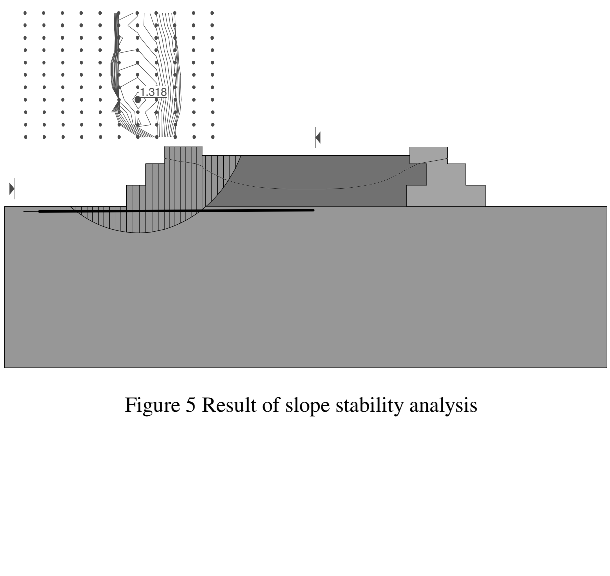

Figure 5 Result of slope stability analysis

6 CONCLUSION

In this study, the numerical analysis was carried out for the deformation of geotextile tube structure, the vertical soil pressure at the bottom of tube, the surface strain of geotextile tube during installation and stability of geotextile tube structure. The analysis was conducted with respect to the slope stability, the seepage influence with ground water level by tidal datum after the construction of temporary dike structure. In case of single geotextile tube, GeoCoPS Ver. 2.0 was used and FLAC Ver. 4.0 was used for the stacked geotextile tube. Slope/W Ver. 5.0 and Seep/W Ver. 5.0 programs were used for the slope stability and seepage analysis.

The deformation and tensile strength of constructed stacked geotextile tube indicates that the largest value was occurred on the surface of circumferential direction. The vertical pressure is contributed to equivalent pressure in the first layer. However, when the upper load is increased, the pressure was concentrated on the center of tube structure and then it makes a differential settlement on the ground. As a result of analyzing, the stacked geotextile tube structure is safe in terms of the external and internal stabilities. As a result of seepage analysis, it maintains its steady level at the ground during monitoring. Therefore, when the temporary dike structure with filling material is constructed, it should be not only considered stability as a structure, but also considered reduction of height caused by settlement such as filling sand with low pressure, scouring of the ground with velocity of tidal level, losing of fine material by flow of water from the geotextile tubes.

In this study, it is reaffirmed to show similar behavior through the numerical method for the stacked geotextile tube. Recently, utilization of the geotextile structure is being increased as a structure for protecting beach line and as a structure for the purpose of solving environmental problem as well as temporary dike. Thus, analyzing the behavior of stacked geotextile tube at coastal area through numerically, it would be improved the geotextile tube technology which is regarded as safe construction methodology along the coastal line.

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