Jour. of the KGS, Vol. 21, No. 2. March 2005, pp. 57~65

Hydraulic Stability and Wave Transmit Property of Stacked Geotextile Tube by Hydraulic Model Test

수리모형시험을 통한 다단식 지오텍스타일 튜브의 안정성 및 파랑 전달특성에 관한 연구

Oh, Young-In[1] 오 영 인
Shin, Eun-Chul[2] 신 은 철

요 지

지오텍스타일은 지난 30여년 동안 모래주머니, 훼브릭 폼, 게비언 등 다양한 형태의 컨테이너(구속체)로 활용되어져 왔다. 다양한 크기의 지오텍스타일 컨테이너(구속체)는 주로 수리학적 제어구조물로 홍수재해 방지 및 복구 구조물로 적용되었으며, 최근 지오텍스타일의 직조기술, 채움기술 등의 발달과 함께 해안침식방지구조물, 방파제, 제방 등 친환경적이며 신개념의 해안구조물로 적용이 확대되고 있다. 본 연구에서는 지오텍스타일 튜브 구조물이 해안구조물로 설치될 경우에 대한 수리모형시험을 통하여 튜브구조물의 수리동역학적 특성(안정성, 파랑제어 및 전달특성)에 대하여 실험적 연구를 수행하였으며, 특히 구조물 단면의 확대와 심해에 설치될 경우를 고려한 다단식 튜브구조물에 대하여 수리모형시험을 실시하였다. 수리모형시험 조건은 해안설치 조건를 고려하여 설치조건과 파랑조건을 요소화하였다. 설치조건은 파랑에 대하여 직각방향과 경사방향으로 설치될 경우를 고려하였으며, 파랑조건은 유의파고 변화를 3.0m~6.0m까지 실험을 실시하였다. 본 연구진의 선행연구결과와 비교할 때, 다단식 튜브구조물이 단일튜브보다 더 안정적이며, 천단고가 없는 경우가 천단고가 0.5H인 경우에 비하여 더 안정적인 것으로 도출되었다. 또한, 파랑 진행에 대하여 경사로 설치된 경우가 천단고 유무에 관계없이 파랑감쇄능력이 우수한 것으로 나타났다.

Abstract

Geotextile have been used for the past 30 years for various types of containers, such as small sandbag, 3-D fabric forms and aggregate filled gabion etc. While they are mainly used for flood and water control, they are also used against beach erosion, for shore protection. Especially, large-sized geotextile tube structures are used in various innovative coastal systems involving breakwaters. This paper presents the hydrodynamic behavior of geotextile tubes based on the results of hydraulic model tests. These tube are generally about 1.0 m to 2.0 m in diameter, though they can be sized for any application. The tubes can be used solely, or stacked to add greater height and usability. Stacked geotextile tubes will be created by adding the height necessary for some breakwaters and embankment, therefore increasing the usability of geotextile tubes. The hydraulic model test was conducted as structural condition and wave conditions. Structural condition is installation direction to the wave (perpendicular and 45°), and wave condition is varied with the significant wave height ranging from 3.0 m to 6.0 m. Compared with previous test result, the stacked geotextile tube is more stable against wave attack than single tube. Also, the case of none-water depth above crest is more stable than 0.5H of water depth above crest. The incline installed stacked tube is more effective for wave adsorption.

Keywords : Geotextile tube, Hydraulic stability, Hydrodynamic properties, Wave transmit, Stacked tube

---

1 Member, Senior Researcher, Agricultural Eng. Research Div., Rural Research Institute, KARICO (yioh2010@incheon.ac.kr)
2 Member, Associate Prof., Dept. of Civil & Environmental System Eng., Univ. of Incheon

1. Introduction

In recent years, traditional forms of river and coastal structures have become very expensive to construct and maintain, because of the shortage of natural rock. Therefore, various structures in hydraulic and coastal engineering use fewer traditional rubble and concrete systems and more cheap material and systems such as gabion, slags, geosynthetics, etc. Moreover, shoreline is eroded by the sea wave attack, and the river and coastal structures are frequently destroyed by the man-induced cause and natural cause such as overwash, and storm. The geosynthetics has been used in civil and environmental application. One of these applications is the use of geotextile tube technology.

Geotextile tubes have been used for many types of big projects, but are mainly used for flood and water control. They are also used for prevention against beach erosion, shore protection, and prevention against contaminated material and pollution. The geotextile sheets are permeable, yet soil-tight, so that any excess water is drained from the geotextile tube. Koerner and Welsh (1980), and Pilarczyk (1990) provide an overview of the many primarily erosion control applications using various types of geotextile containers. Though construction of erosion control structures use dry dredged material filled with geotextile containers in quite straight forward, underwater installation is often required and is thoroughly discussed by Groot et al. (1992). Environmental dredging and backfill technology using geotextile tubes was reported by Fowler et al. (1997), Pilarczyk (1996), and Mori et al. (2002).

Some of the most attractive advantages of geotextile tube technology its use of in-situ filling materials by hydraulic pumping, lower costs and faster construction than other technology. Therefore, the hydrodynamic behavior against wave attack is very important factor of design and analysis of geotextile tube. Most of design and analysis issues are focused on the hydrodynamic stability and the ways of more accurately predicting final tube height during and after construction.

The main problem in this technology, however, is lack of proper design criteria such as stability, structural function, and behavior during and after construction. In the past, the design of these systems was mostly based on rather vague experience than on the general valid calculation methods. More research, especially concerning the large-scale tests and the evaluation of the performance of projects already realized, is still needed. The objective of this paper is to examine several issues associated with the hydrodynamic behavior of tube such as hydraulic stability, wave adsorption capacity, and strain of geotextile during the wave attack. This paper presents the analysis results of hydrodynamic behavior of geotextile tube by hydraulic model test such as hydraulic stability, wave transmit, and adsorption properties.

2. Hydraulic Model Test of Stacked Geotextile Tube

2.1 Overview of Hydraulic Model Test

An advantage of a hydraulic model test is its potential capacity to replicate many features of a complicated flow and in-situ situation. There are many situations for which there is little recourse other than hydraulic modeling to make design or operational decisions involving expensive and complex hydraulic works. Such situation particularly arises when for a variety of reasons, complex flow patterns or intricate transport processes are involved, and reliable answers cannot be obtained by means of analytical solution or computer simulation. A comparatively small investment in a hydraulic model test, especially in the case of expensive construction works, may help allay concerns regarding the viability of a design or a procedure.

The similitude principles that form the basis for hydraulic modeling are fairly straight forward. However, a difficulty incurred with preparation of a manual on hydraulic modeling is determining the extent of background information needed to adequately present the similitude criteria. Generally, the method of similitude has three categories, one is the geometric similarity and the other is kinematically similarity, and the remaining one is dynamic similarity.

Geometric similarity requires that all length ratios between model and prototype be the same. Kinematic similarity is a correspondence of motion; in two kinematically similar systems, particle motion will be similar. Dynamic similarity occurs when the ratios of forces are the same in the two systems. In applying the method of similitude to the design of models for fluid mechanics studies, forces of importance, including the dependent and independent forces, are enumerated by the investigator. These forces are expressed in terms of the problem parameters and variable. Fluid mechanics commonly involves six forces; inertia, pressure, gravity, viscous shear, surface tension, and elastic compression. Correlating groups of these forces express the required similarity of two systems. Two systems having geometric, kinematic, dynamic similarity have complete similitude. The correspondence between a hydraulic model and its prototype is limited because the similitude for one or more forces is usually incomplete. Geometric similarity is independent of motion, but force similarity depends on selection of geometric scale. Scale selection should be made to satisfy the predominant force and to make negligible the remaining forces.

Because most of free surface wave is predominant to the gravity, these types of hydraulic model tests depend on Froude Law. The Froude law represents the condition of dynamic similarity for flow in model and prototype exclusively governed by gravity. Other forces, such as frictional resistance of a various liquid, capillary forces, the forces of volumetric elasticity and cavitation phenomena, either do not affect the flow or their effect may be neglected. With contain limitations, e. g. the choice of model scale, this is permissible especially for free surface flow as it occurs when modeling the movement of larger surface waves and flow in short open channel sections. A practical basis for similitude in models where gravitational forces predominate is the equating of inertia/ gravity force ratios of model and prototype as shown in Equations (1)~(3).

$$\left(\frac{F_i}{F_g}\right)_m = \left(\frac{F_i}{F_g}\right)_p \tag{1}$$

$$\left(\frac{\rho V^2 L^2}{\rho g L^3}\right)_m = \left(\frac{\rho V^2 L^2}{\rho g L^3}\right)_p \tag{2}$$

$$\left(\frac{V^2}{gL}\right)_m = \left(\frac{V^2}{gL}\right)_p \tag{3}$$

where, $\frac{V}{\sqrt{gL}}$ =Froude number, F_i =inertia force = $\rho V^2 L^2$, F_g =gravity force = $\rho g L^3$, ρ is density, L is length, V is velocity, g is local acceleration due to gravity, m is subscript of model system, p is subscript of prototype system.

2.2 Materials

The geotextiles more commonly used to construct geotextile tubes are either woven geotextile or composite geotextile (i.e., an external layer of woven geotextile and an internal layer of non-woven geotextile). For the present study only one woven geotextile type was used. The physical properties of this geotextile are given in Table 1. The tensile and seaming strength test results are shown in Figures 1 and 2.

One of the best filling material is dredged material near the construction site, which has the advantage of continuous filling process and being more economical. In most cases, the coarse grained material will dewater much faster than that of the fine grained material such as silty clay, hence the sandy soil is useful for geotextile tube construction. In this project, the filling material used dredged sand obtained from west coast of Korea. The physical properties of dredged filling materials are given

Table 1. Properties of geotextile material

Property	Test Method (ASTM)	Unit	Geotextile
			K-1
Mass per unit area	D-5261	g/m^2	600
Tensile strength	D-4595	KN/m	196
Elongation	D-4595	%	10~25
Coefficient of Permeability	D-4991	cm/sec	1.3×10^{-2}
Effective opening size (U.S. sieve)	D-4751	No.	100
Material	–	–	PET (Polyester)

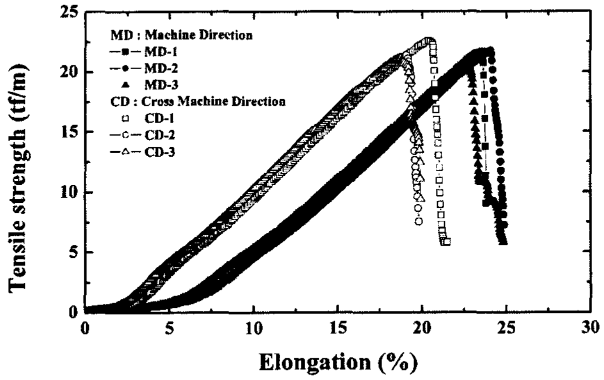


Fig. 1. Tensile strength test results

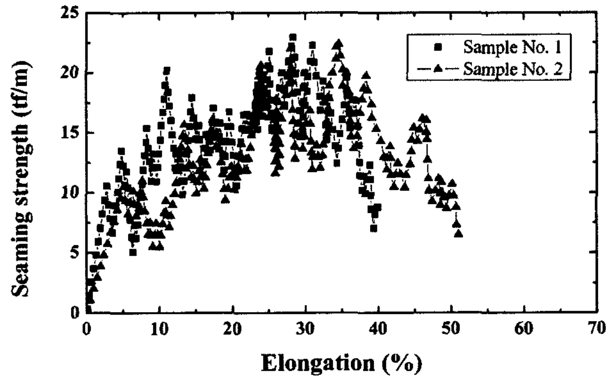


Fig. 2. Seaming strength test results

Table 2. Physical properties of filling material

Item	Quantity
Specific gravity, G_s	2.64
Effective size, D_{10} (mm)	0.50
Uniformity coefficient, C_u	1.90
Coefficient of gradation, C_c	0.84
Interface friction angle(Saturated) (°)	32.0
USCS	SP

in Table 2. The interface friction angle of dredged sand and geotextile was determined by a large scale direct shear tests (ASTM D-5321). The size of the geotextile used for interface friction test was 0.3 m×0.3 m, the normal stress varying up to 100 kN/m^2.

The interface friction angle is an important parameter in determining the stability of geotextile tube when there is sloping ground for shore protection projects such as the construction of breakwater and groin. Test results of large scale direct shear test are shown in Figures 3 and 4.

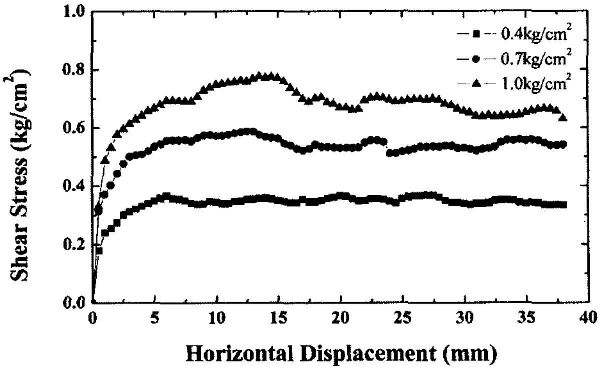


Fig. 3. Large scale direct shear test results (horizontal displacement vs. shear stress)

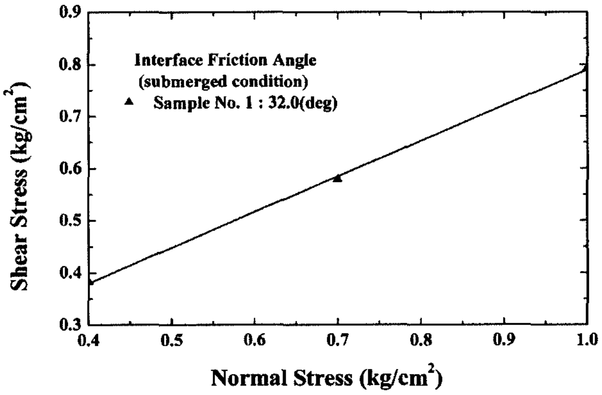


Fig. 4. Large scale direct shear test results (normal stress vs. shear stress)

2.2 Test Equipments

Hydraulic model test was conducted in Kunsan Ocean and Hydraulic Research Center at the Kunsan National University. The free surface channel had a width of 7.0 m, 30.0 m in length, and maximum water depth of 1.0 m. Also, the main control is operated by active wave absorber control system. The schematic diagram of laboratory equipment and model is shown in Figures 5 and 6, also the specification of hydraulic model test device is tabulated in Table 3.

Table 3. Specification of hydraulic model test device

Item	Specification
Channel size	7.0 m×30.0 m×1.5 m
Wave plate size	width 7.0 m, height 1.4 m
Max. water depth	1.0 m
Max. wave height	0.3 m
Period	0.5-5.0 sec
Wave type	Regular and irregular

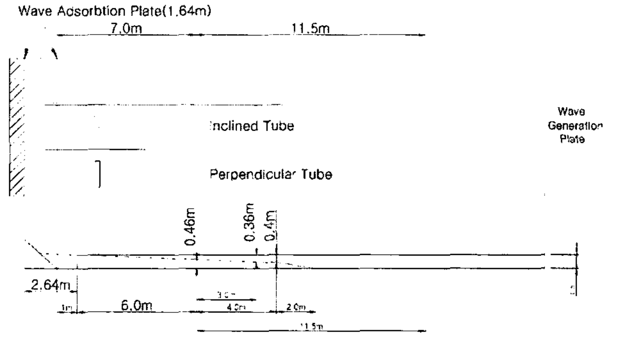


Fig. 5. Schematic diagram of hydraulic model test

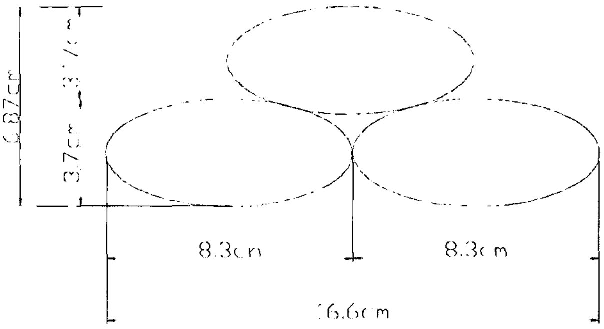


Fig. 6. Cross-section of stacked tube

2.3 Similarity and Test Conditions

The laboratory hydraulic model tests were performed to estimate the hydrodynamic behavior of stacked geotextile tube with the variation of water depth above crest, significant wave height, and install direction to the wave. The geometrical geotextile tube condition of prototype is 1.8 m of effective height, 50.0 m of total length. Also the filling ratio of geotextile tube is fixed by 85% and the significant wave height is varied from 3.0 m to 6.0 m. The geometrical similarity is 1/50 and wave condition of hydraulic model test by similarity is described in Table 4. Hydraulic model tests simultaneously applied two types of stacked geotextile tube perpendicular and inclined tube. It can apply the same wave attack to the geotextile tube with various significant wave height. Also, the applied wave spectrum was of the Brestschneider- Mitsuyasu type. Figure 7 shows the hydraulic model test channels and the measuring of transmit wave height is shown in Figure 8.

3. Results of Hydraulic Model Test

3.1 Stability

Stability analysis of costal and hydraulic structure by hydraulic model test was performed measuring the displacement against the wave attack. The significant wave

Table 4. Wave condition of hydraulic model test by similarity

Prototype wave condition		Model wave condition	
Significant wave height (m)	Period (sec)	Significant wave height (cm)	Period (sec)
3	6.69	6	0.95
4	7.72	8	1.09
5	8.63	10	1.22
6	9.46	12	1.34

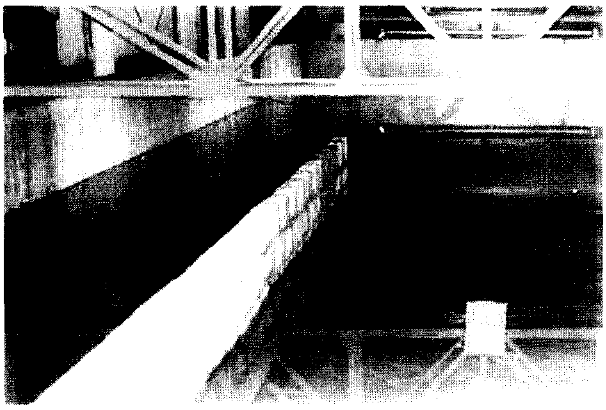


Fig. 7. Hydraulic model test device and flow channel

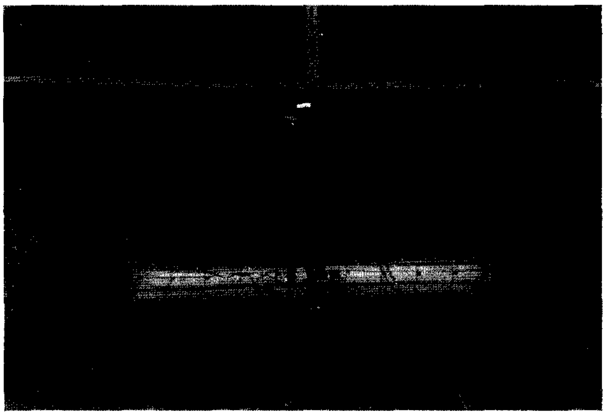


Fig. 8. Measuring of transmit wave height

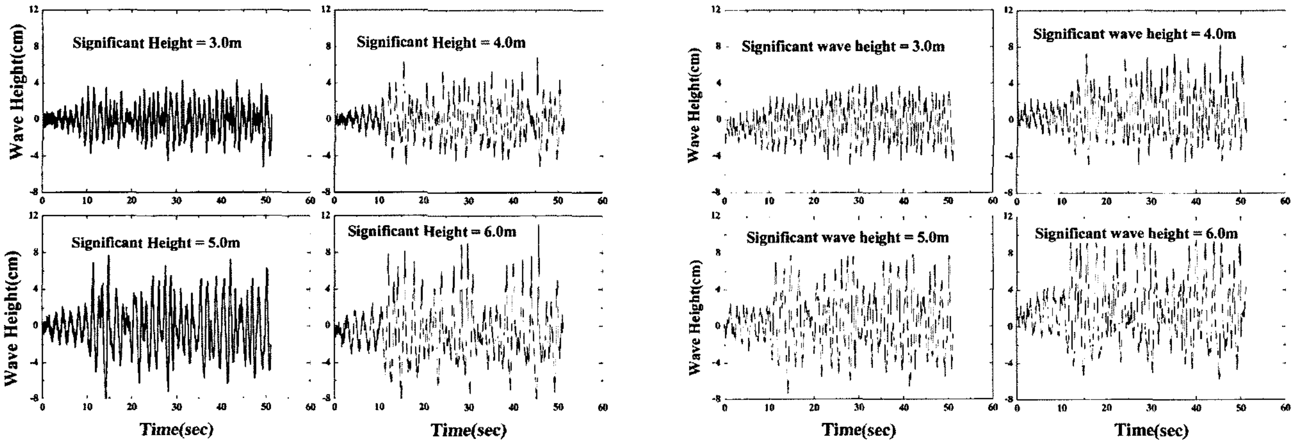
Table 5. Result of stability test (N.D. : No Displacement)

	None water depth above crest				0.5H water depth above crest			
Significant wave height	3.0 m	4.0 m	5.0 m	6.0 m	3.0 m	4.0 m	5.0 m	6.0 m
Inclined tube	N.D.	N.D.	0.73 cm	0.75 cm	N.D.	0.55 cm	0.77 cm	0.85 cm
Perpendicular tube	N.D.	N.D	N.D.	10.84 cm	N.D.	0.72 cm	1.01 cm	12.76 cm

height increased in steps until the geotextile tube structure collapsed or until the highest obtainable significant wave height had been reached. The results of the hydraulic model test for stability is tabulated in Table 5. Based on the test results, inclined tube had the minor displacement until significant wave height of 6.0 m. However, the perpendicular tube collapsed at 6.0 m of significant wave height, also the case of 0.5H water depth above crest was damaged by lower wave height. The minor displacement is sliding of top tube and the major collapsed failure type is sliding of bottom tube and overturning the top tube. These results can be summarized that the incline installed tube and the case of none water depth above crest are more stable than perpendicular tube installed in 0.5H water depth above crest against wave attack.

3.2 Wave Transmit Properties

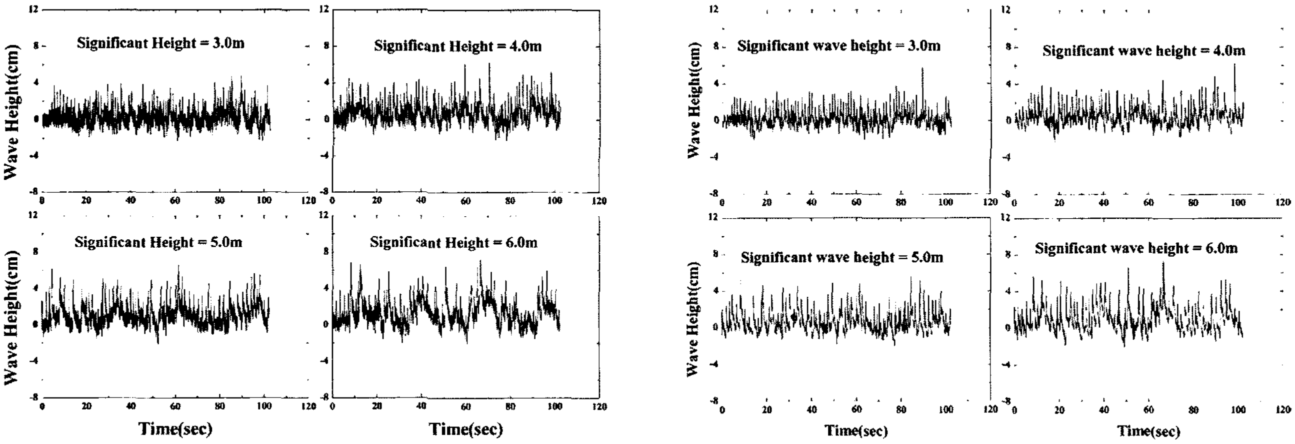
To evaluate the wave transmit properties of geotextile tube,



(a) perpendicular tube

(b) inclined tube

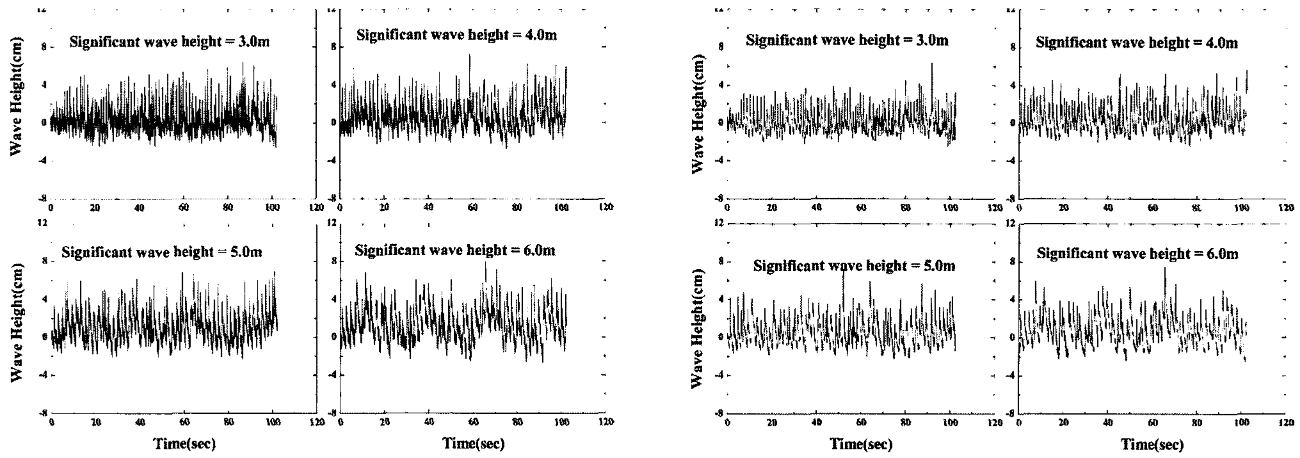
Fig. 9. Input wave profiles



(a) perpendicular tube

(b) inclined tube

Fig. 10. Transmit wave profiles (None water depth above crest)



(a) perpendicular tube

(b) inclined tube

Fig. 11. Transmit wave profiles (0.5H water depth above crest)

Table 6. Transmit wave height and ratio

Significant Wave Height (m)	Input Wave Height (cm)	Transmit Wave Height (Ratio)	
		None water depth above crest	0.5H water depth above crest
3.0	6.0 (stacked inclined)	3.41 (56.83%)	4.35 (72.50%)
	6.0 (stacked perpendicular)	3.71 (61.83%)	4.64 (77.33%)
4.0	8.0 (stacked inclined)	3.81 (47.63%)	4.95 (61.88%)
	8.0 (stacked perpendicular)	3.94 (49.25%)	4.90 (61.25%)
5.0	10.0 (stacked inclined)	4.25 (42.50%)	5.57 (55.70%)
	10.0 (stacked perpendicular)	4.41 (44.41%)	5.48 (54.50%)
6.0	12.0 (stacked inclined)	5.38 (44.83%)	6.88 (57.33%)
	12.0 (stacked perpendicular)	5.55 (46.25%)	6.50 (54.17%)

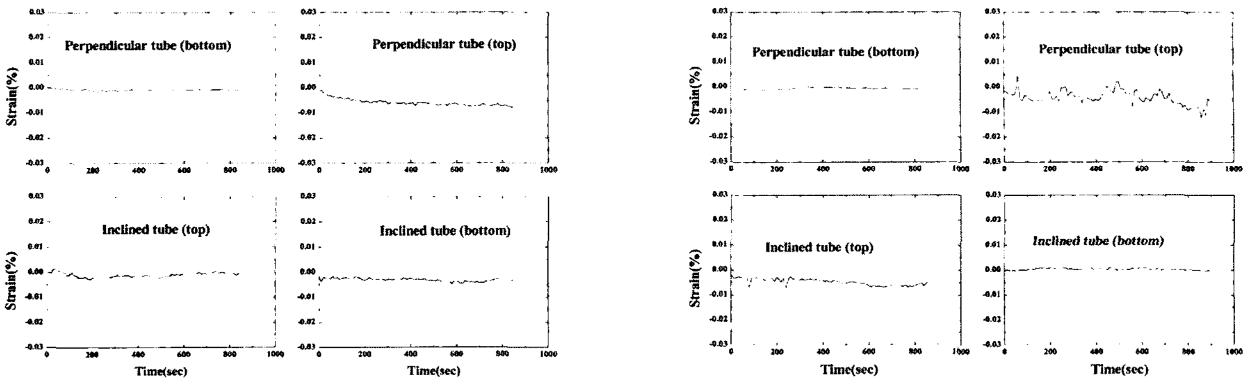
transmit wave height was measured and transmit wave spectrum was analyzed. A total of 1024 transmit wave height data ware collected every 0.05 second. The input and transmit wave profiles are shown in Figures 9~11 (same scale) and the transmit ratio is tabulated in Table 6.

As the significant wave height increased, the transmit wave height decreased. Also, the incline installed stacked tube is more effective for wave adsorption. Therefore the wave adsorption capacity of geotextile tube is dependent not only on the later projection area but also on other influence factors such as geometrical shape of ellipse, characteristics of wave, and contact width toward the wave propagation direction.

3.3 Strain of Geotextile

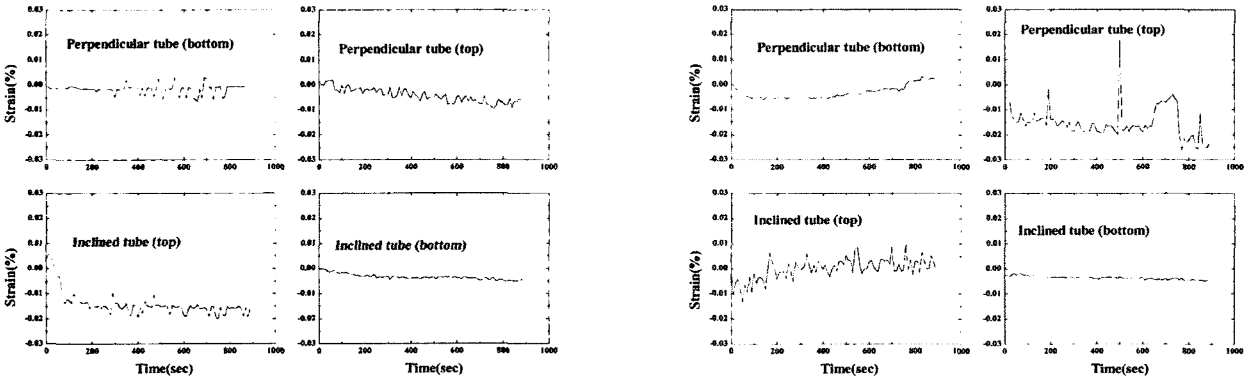
The strain of geotextile was measured by strain gauge for vertical and horizontal directions. The strain gauge is plastic gauge YFLA-5 for geosynthetics and the strain data was collected every 10 second. Figures 12 and 13 present the variation of strain with significant wave height and direction for none water depth above crest by same scale.

Vertical strain of top tube is higher than bottom tube, on the other hand, horizontal strain of bottom tube is higher than top tube. Also, the strain of none water depth above crest is higher than the case of 0.5H water depth above crest and the strain of front tube is much higher than the back side of tube. It represents the flow velocity in front of the geotextile tube structure increased with significant wave height until the structure collapsed.



(a) significant wave height 3.0 m

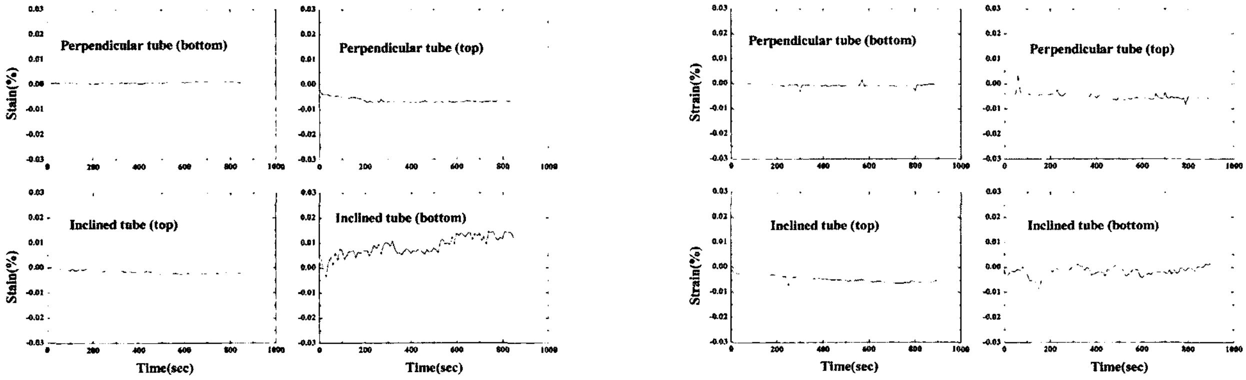
(b) significant wave height 4.0 m



(c) significant wave height 5.0 m

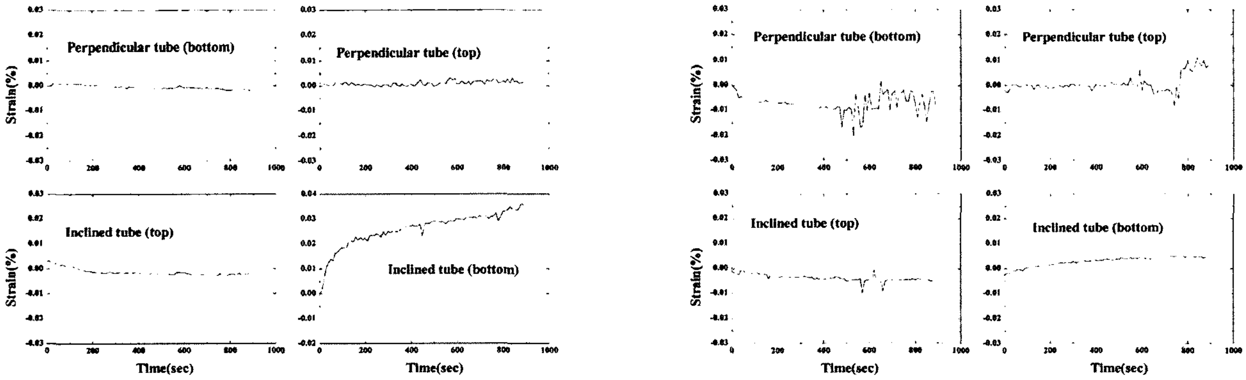
(d) significant wave height 6.0

Fig. 12. Vertical strain of geotextile (None water depth above crest)



(a) significant wave height 3.0 m

(b) significant wave height 4.0 m



(c) significant wave height 5.0 m

(d) significant wave height 6.0

Fig. 13. Horizontal strain of geotextile (None water depth above crest)

4. Conclusions

This paper presents the hydrodynamic behavior of stacked geotextile tube by hydraulic model test. Based on the hydraulic model tests, the following conclusions can be drawn;

(1) The incline installed tube and the case of none water depth above crest are more stable than perpendicular installed and 0.5H water depth above crest against wave attack.
(2) The wave adsorption capacity of geotextile tube is dependent not only on the later projection area but also on other influence factors such as geometrical shape of ellipse, characteristics of wave, and contact width toward the wave propagation direction.
(3) The strain of none water depth above crest is higher than the case of 0.5H water depth above crest and the strain of front tube is much higher than the back side of tube.

Acknowledgements

This study was supported by 2002 University of Incheon Academic Research Fund. The financial support is gratefully acknowledged.

References

1. Fowler, J, and McLella. (1997), "Geotextile Tube Development and Filling Technique", *Proc. of the National Workshop on Geotextile Tube Applications*, WRP Technical Report, U.S. Army Corps Engineers, WRP-RE, 17, pp.1-8.
2. Groot, de, MB, Bakker, KJ, and Verheij, HJ (1992), "Design of Geometrically Open Filters in Hydraulic Structure", *Geo-filter '92*, Int. Conf. on filters and filtration phenomena in geotechnical eng., Karlsruhe, Balkema, 1993, Rotterdam.
3. Koerner, RM and Welch, JP (1980), "*Construction and Geotechnical Engineering Using Synthetic Fabrics*", Wiley, New York, pp.160-229.
4. Mori, H, Miki, H, and Tsuneoka, N (2002), "The Use of Geo-tube Method to Retard the Migration of Contaminants in Dredged Soil", *Proc. of 7 ICG-NICE, France*, Vol.3, pp.1017-1020.
5. Pilarczyk, KW (1990), "*Coastal Protection*", A.A. Balkema Publ., Rotterdam.
6. Pilarczyk, KW (1996), "Geosystems in Hydraulic and Coastal Engineering--An Overview", *Proc. Euro-Geo1*, Maastricht, The Netherlands.

(received on Jan. 17, 2005, accepted on Mar. 24, 2005)