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Master's Thesis of Landscape Architecture

# Evaluation of earth pressure reduction mechanism on geofoam- retaining wall systems

옹벽 내 지오폴 적용 시 토압 저감원리에 관한  
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# Abstract

Retaining wall has long been widely used in landscaping, civil engineering and architecture. Since retaining wall is built close to living space such as residential areas and roads, it can cause great damage and loss of life in the event of collapse. Accordingly, there has been a steady discussion on how to enhance the safety of the retaining wall. In particular, one alternative is to improve the safety of retaining walls by reducing the earth pressure of retaining walls by utilizing light weight artificial reinforced soil. The purpose of this study was to investigate the effectiveness of geofoam application for the reduction of earth pressure in retaining walls through finite element (FE) analysis. Furthermore, it was intended to reveal the principle of reducing the earth pressure in the retaining wall by geofoam. In this study, it is tried to reduce the earth pressure on the retaining wall efficiently and economically by examining the various geometric parameters of the geofoam and discovering the optimal shape of the geofoam.

Through this, it was confirmed that the triangular geofoam shape was most optimized for the retaining wall. In addition, the earth pressure in the retaining wall was investigated according to the change in the properties and area of the geofoam and the slope of the backfill. In addition, the results of FE analysis were verified by comparing results with experimental work performed on retaining walls similar to finite element models. In addition, by examining the changes in earth pressure throughout the retaining wall, the principle of reducing earth pressure in the retaining wall due to geofoam was investigated. Through this study, it was confirmed that when the bottom part of the retaining wall was reinforced by using geofoam, it showed a somewhat constant earth pressure reduction regardless of the geofoam shape.

**Keyword** : Earth Pressure, Finite Element Analysis, Geofoam, Retaining Wall

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# **Chapter 1. Introduction**

## **1.1. Background and Purpose**

Since the past, retaining walls have been used to stabilize slopes by preventing collapse. These retaining walls are used in various construction fields, including landscaping, construction, and civil engineering. In particular, the introduction of retaining walls is essential before development, as most of Korea is made up of mountainous areas. Recently, the introduction of retaining walls, which are not just used for engineering purposes to prevent the collapse of the slope, but also for ecological and aesthetic functions such as green wall through planting in the retaining wall and improvement of landscape through design, has been activated. Due to the expansion of the function of these retaining walls, the development of retaining walls and various types of retaining walls using reinforced soil etc. is being carried out (Lee et al. 2006).

However, since retaining walls are continuously subjected to earth pressure from the backfill, there is a possibility of collapse due to accumulated stress (Kim, 2003). In particular, functional expansion of the retaining wall can increase the risk of collapse by increasing stress in the retaining wall. As the frequency of natural disasters such as earthquakes and typhoons has increased in recent years, the risk of collapse of retaining walls has increased. Because retaining wall is installed in space close to living space such as apartments and roadsides, it has a significant influence on human life in the event of collapse. In particular, in the case of Korea, which is mostly made of mountainous regions, large amount of soil can be leaked during the collapse of retaining walls. Therefore, discussions on ways to enhance the safety of retaining walls have continued steadily (Kim et al. 2004). In addition, the safety of retaining walls is closely related to landscaping, as soil runoff caused by the collapse of retaining walls harms the existing landscape.



[Fig 1] Example of damage to landscape by collapse of retaining wall  
("Retaining wall of Changwon apartment, 8m wide retaining wall collapsed",  
2019.08.10, <http://www.ccreview.co.kr/news/articleView.html?idxno=125814>)

## 1.2. Geof foam

In order to enhance the safety of retaining walls, Geof foam was introduced within retaining walls in this study. Geof foam refers to expanded polystyrene (EPS) used in civil engineering, and has been used as a geotechnical material since the 1960s. Geof foam is a lightweight material of 1% of the soil and is less than 10% lighter than other charging substitutes. Thus, the use of geof foam as a reinforcement between the soil and the structure can reduce the load on the structure (Yoo et al. 2003). Since geof foam is easy to handle materials during construction and special equipment is not required to be injected, the use of geof foam can induce shorter construction period and lower construction cost. In addition, since geof foam is easy to cut in various forms, it can be applied according to the situation of the site. Geof foam can be used for various basic roadbeds and grounds because it has various types of specifications as shown in the table below (Table 1)

[Table 1] Property of geofoam

Property	EPS12	EPS15	EPS19	EPS22	EPS29
Density (kg/m <sup>3</sup> )	11.2	14.4	18.4	21.6	28.8
Compression Resistance at 1% (kPa)	15	25	50	50	75
Flexural Strength (kPa)	69	172	207	240	345
Oxygen Index (%)	24	24	24	24	24

Geofoam is applied in various ways to various constructions and is essentially a multi-functional alternative material. In particular, it is advantageous for soft ground, slope stabilization and retaining wall construction. In fact, many countries such as the United States and Japan are using geofoam in constructing process of bridge and road. In addition, the geofoam was used to prevent geologic freezing and swelling in the lower part of the railroad track system and underground storage tank of the building. In addition, the use of geofoam as a backfill for retaining walls reduces the earth pressure received by retaining walls and suppresses horizontal forces that can be deployed in the event of an earthquake. Actually geofoam is used as a backfill for retaining walls (figure 2). The purpose of this study was to study ways to reduce the increase in construction costs and reduce the horizontal earth pressure of retaining walls by using geofoam as reinforcement of retaining wall rather than backing material of retaining wall.

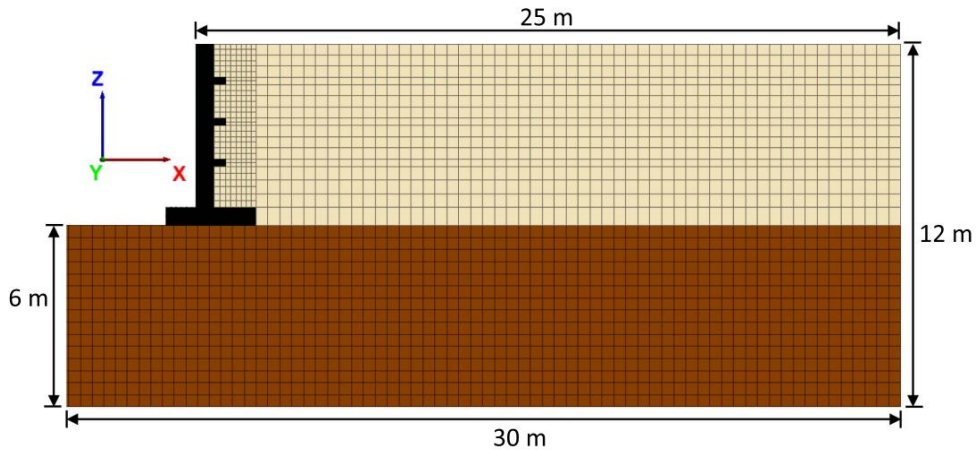


[Fig 2] Example of applying geofabric

### 1.3. Prior Study

The study on the safety of retaining walls can be largely divided into the safety analysis of retaining walls according to the environment of retaining wall installation and the safety analysis of retaining walls due to internal factors of retaining walls. Research on the environment of retaining wall installation as follows. The effects of rigidity on the stress of the retaining wall were examined through finite element analysis to determine the adequacy of the current design basis and to analyze the stability of the retaining wall through the analysis of displacement changes (Yoo and Kim, 2002). In addition, through the case analysis, the cause of the retaining wall collapse during intensive rainfall was analyzed, and it was revealed that the backfill soil may cause the retaining wall to collapse during intensive rainfall (Yoo et al. 2005). Lastly, the safety factor change and the construction cost change according to the depth of penetration of the retaining wall were analyzed and it was confirmed that the depth of penetration did not affect the safety of the entire retaining wall (An and Kang, 2011). The study on the internal factors of retaining walls is as follows. In Korea, the horizontal displacement of the retaining wall according to the land beam area ratio was examined through an indoor model experiment. Through this, ways to enhance the safety of retaining walls were induced by obtaining the optimal area for holding beams (Yoo et al. 2016). In foreign countries, shelves were installed to retaining walls and the amount of soil pressure reduced accordingly was

verified through a three-dimensional Lagrangean analysis method. This confirms that it is possible to reduce the earth pressure by about 20% compared to the case where shelves are not installed (Chauhan and Dasaka, 2018) (Figure 3).



[Fig 3] Study on the reduction of soil pressure through shelves

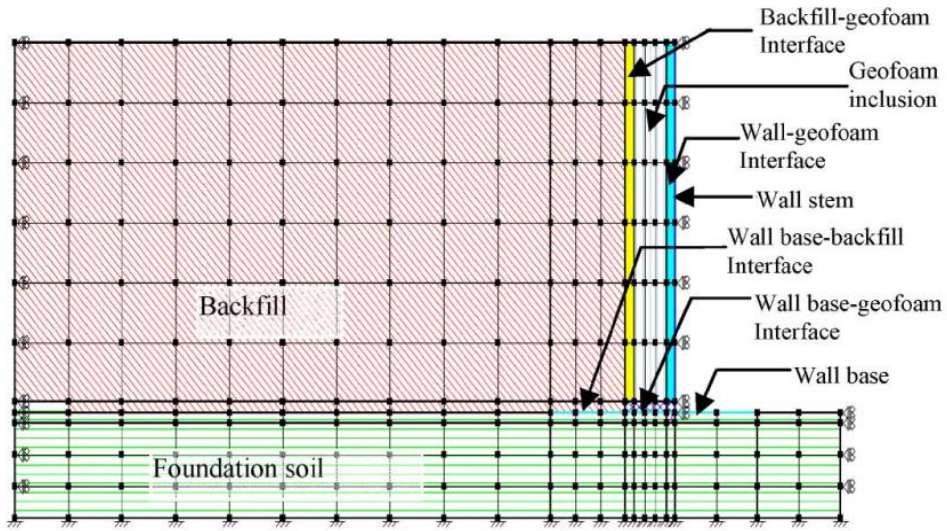
(Chauhan and Dasaka, 2018)

Research on the use of geofoam has been actively carried out in foreign country, but not in Korea. First of all, the research conducted in Korea is as follows. In the case of the concrete structures wrapped by geofoam, changes in earth pressure applied to structures in the event of an earthquake were examined through finite element analysis. At this time, the most efficient physical feature for reducing soil pressure was found by setting the physical properties of the geofoam in various ways (Mabel et al. 2019). It was also confirmed that the use of geofoam as a reinforcement material for bridges reduces the soil pressure received by the bridge, which can enhance the sustainability of the bridge. In addition, various types of geofoam were introduced to bridges to compare the reduction of soil pressure, and thus, an attempt was made to find a geofoam optimized for bridges (Jeong et al. 2018). Furthermore, in case of using geofoam as a reinforcement of retaining walls through indoor experiments and field measurements,

it was confirmed that the effect of reducing horizontal soil pressure was excellent by preventing the resolution crack in retaining walls (Kim et al. 2001).

The following studies are being conducted abroad. In the case of using geofoam in subway tunnels, the stress reduction amount and the damage reduced during an earthquake were analyzed through 3D modeling analysis. At this time, the effects of changes in the physical properties and thickness of the geofoam were investigated together to confirm that there was a difference between the two factors on the impact on the retaining wall (Fei et al. 2008). Also, it was confirmed that the amount of earth pressure received by the buried tube is reduced if it is wrapped with a material with a low elastic coefficient (Kang et al. 2007). This has led to a study that examines the changes in the stress of the pipeline when the pipeline is wrapped with geofoam through finite element analysis (Martin et al. 2019). Empirical experiments conducted on the use of geofoam as reinforcements in bridges, which confirmed that geofoam are resistant to high temperatures (Armin and Dawit, 2012). For the retaining wall, which is the subject of this study, the amount of soil pressure that was reduced when geofoam was used as a reinforcing material was examined. At this time, the difference in the impact was calculated quantitatively for the geofoam having a difference in compression ratio (Dave and Dasaka, 2014). In addition, through the empirical experiment, the reduction of soil pressure reduction when geofoam was tiled on the wall of the retaining wall was confirmed and compared with the simulation results (Ozgur and Aurelian, 2011) (Figure 4).





[Fig 4] Experiment using geofoam in retaining wall as reinforcement

(Ozgur and Aurelian, 2011)

As such, research on the safety of retaining walls and the efficiency of geofoam has been actively carried out at home and abroad. However, not many studies have been conducted on the feasibility of using geofoam in Korea. In particular, in the way to increase the safety of retaining walls, the introduction of geofoam has not been studied compared to other structures. When looking at the previous studies, research is being conducted only on the case where the geofoam is simply tiled on the retaining wall. Therefore, through this study, it is intended to find the optimized form of the application of the retaining wall of the geofoam and consider various properties and installation environments. Through this, it is intended to present guideline for using geofoam as a reinforcement in the retaining wall.

## Chapter 2. Methodology

### 2.1. Mohr-Coulomb Model

The Mohr–Coulomb model is a model used to simulate most of the ground and shows sufficiently reliable results for general ground analysis. According to Mohr's criteria, destruction is expressed in the following equation (Eq. (1)).

$$|\tau| = c - \sigma_n \tan \phi \quad \text{Equation (1)}$$

$\tau$  : Critical Shear Stress

$c$  : Cohesion

$\sigma$  : Normal Stress at Fracture Plane

$\phi$  : Internal Friction Angle

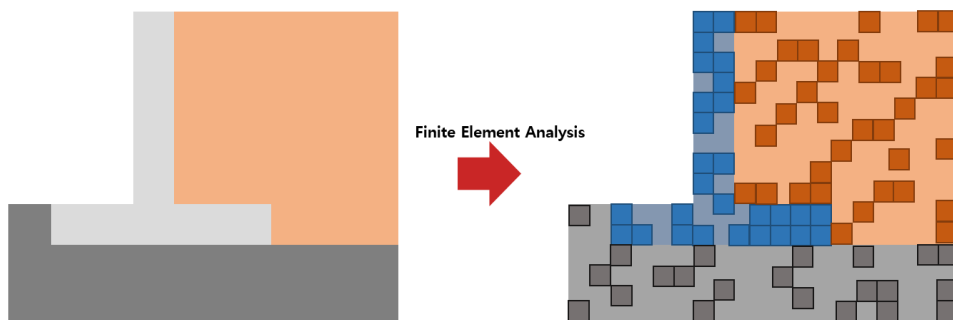
In the above equation, the limit shear stress refers only to the vertical stress on the same plane, which means that the intermediate main stress does not affect the failure condition. The yield function of the Mohr–Coulomb yield plane can be expressed as follows (Equation (2)). The following formula's criteria for destruction are called the Mohr – Coulomb standard, and are widely used to date due to its simple and accurate advantages.

$$f = |\tau| - c + \sigma_n \tan \phi = 0 \quad \text{Equation (2)}$$

This study also introduced a soil model that reflects the Mohr–Coulomb model, thereby enhancing the reliability of this research. Referring to these equations, this study was conducted as a linear study.

## 2.2. Finite Element Analysis

This study was conducted through finite element analysis. Finite element method refers to finding a numerical approximation solution when it is difficult to obtain an accurate theoretical solution. This means that the complex model is divided into finite elements, the characteristics of individual elements are calculated, and then the characteristics of the entire model are combined to approximate the characteristics of the entire model (Figure 5). The finite element method is interpreted by converting the differential equation into an algebraic equation, and the solution is calculated by constructing the matrix equation shown in the table below (Table 2). In the matrix equation of finite element analysis, the characteristic refers to the characteristics of the target structure required by the type of analysis, and the behavior refers to the unknown index, which is the object of calculation to be obtained. Through the analysis of lactic acid elements, it is possible to quantify the physical response of the domain (structure, fluid, etc.) to external conditions (load, temperature, etc.). Finite element analysis is very widely used to analyze the fragility or safety of structures (Kim et al, 2017). In this study, the finite element analysis was used to quantify the horizontal soil pressure received by the retaining wall and to examine the point where it receives the most soil pressure. In addition, it was intended to quantitatively identify the point and horizontal soil pressure change with the greatest impact within the retaining wall when using geofoam as a reinforcement.



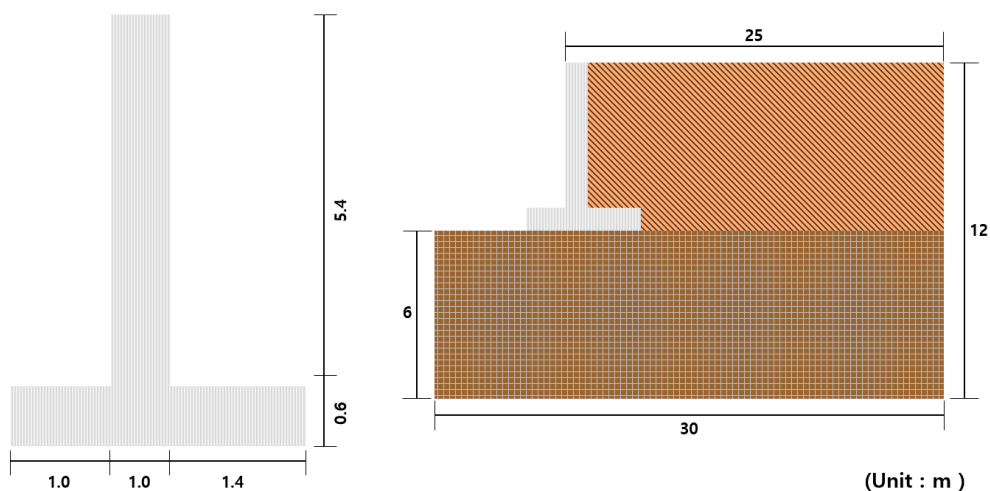
[Fig 5] Schematic design of finite element analysis

[Table 2] Composition of matrix formula in finite element analysis

	[K]	{ $\Delta$ }	{f}
Matrix Equation	Matrix (NxN)	Vector (Nx1)	Vector (Nx1)
	Characteristic (특성)	Behavior (행동)	Action (작용)
Stress Analysis	Stiffness (강성)	Displacement (변위)	Force (힘)
Temperature Analysis	Conduction (열전도)	Temperature (온도)	Heat Flux (열속)

## 2.3. Modeling

In order to proceed with this study, inverted T-type retaining wall was set as shown in the figure below (Figure 6). The retaining wall was set to 6 m in height and 3 m in width, and the backfill soil and ground were previously set by referring to the paper related to the effect of reducing the earth pressure in the retaining wall. In addition, prior research confirmed that the problems of reversal and subsidence of this retaining wall model is safe.



[Fig 6] Schematic diagram of retaining wall

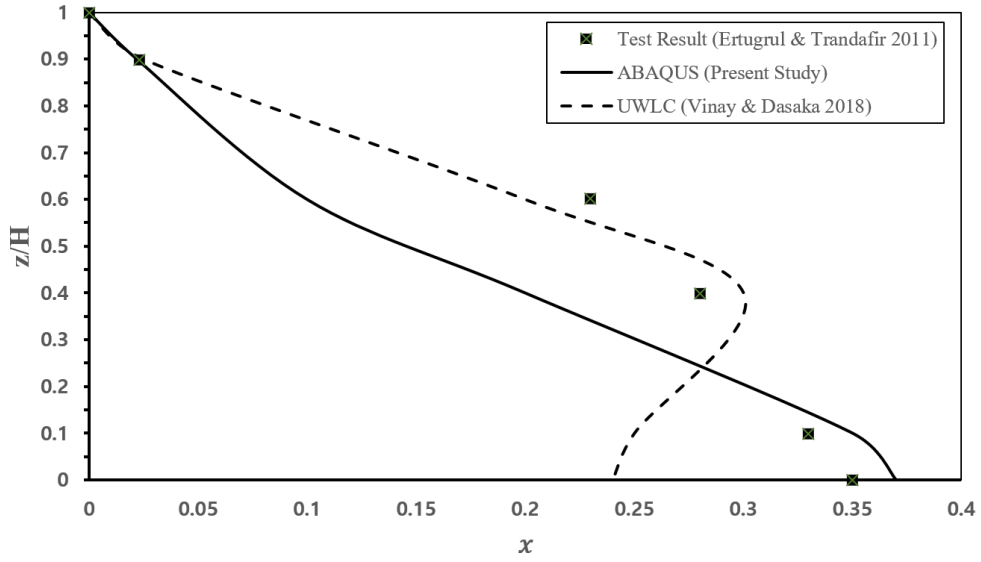
For the finite element analysis, Abaqus, a structural analysis program, was used in this study. Abaqus is a universal structural analysis program and is widely used to analyze the characteristics of materials such as structures such as bridges and concrete structures. To utilize these programs, the properties of each material were set as shown in the table below (Table 3). At this time, the backfill and foundation reflected the Mohr–Coulomb model as previously discussed.

[Table 3] Property used for finite element analysis

	Density (N/m <sup>3</sup> )	Young' s Modulus(kPa)	Poisson' s Ratio	Friction Angle (°)
Backfill	16,500	5,200	0.33	43.5
Foundation	17,500	5,500	0.33	45
Geofoam	110	1,500	0.12	–
Concrete	24,000	31,600,000	0.2	–

## 2.4. Verification of Model

For the test of retaining wall simulation using Abaqus, it is wanted to first verify the reliability of the Abaqus model. To this end, the results of the analysis of earth pressure on retaining walls through model tests were compared with the results through this program. In addition, the reliability of this study was determined by comparing the results of UWLC, a finite element analysis program (article paper). As a result, although the soil pressure ratio was lower than that of the model test at some points as shown in the figure below, it was confirmed that the overall pattern was similar (Figure 7). Therefore, it was possible to confirm that the study of retaining wall model through Abaqus was reliable.

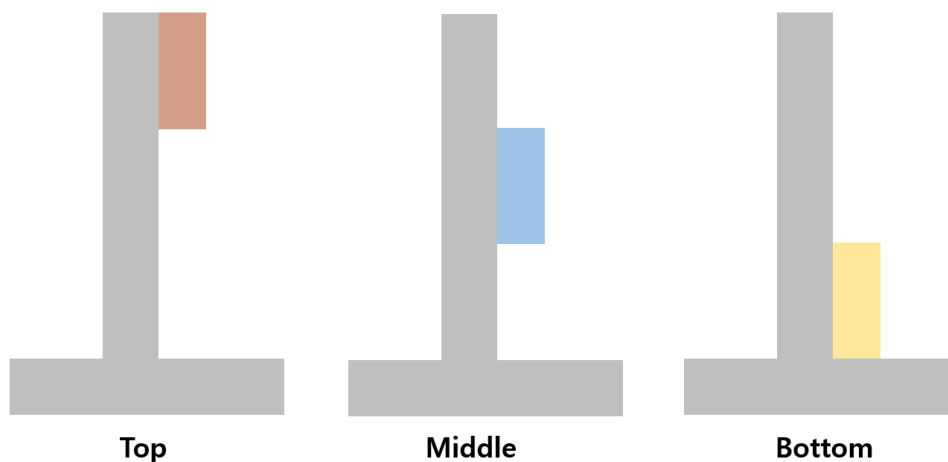


[Fig 7] Comparison with Experiment, UWLC and ABAQUS

( $x$  = Lateral Contact Pressure / Base Contact Pressure,  $z$  = Height (m) ,  $H$  = Overall Height (m) )

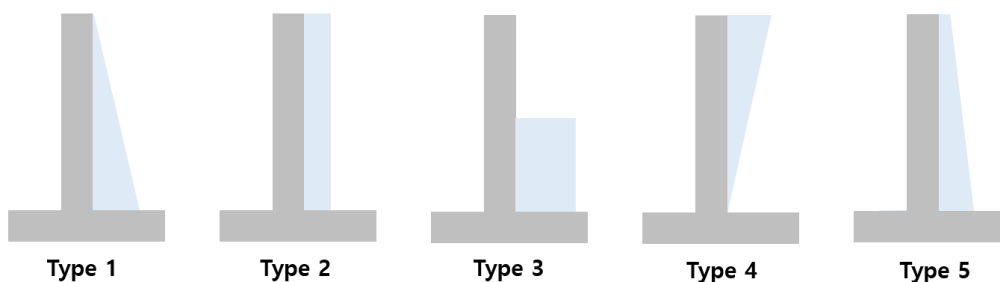
## 2.5. Geometry Optimization of Geofoam

First of all, we tried to find the optimal shape of geofoam for reducing soil pressure in retaining walls. Existing studies were being analyzed only if they were simply tiles attached between the retaining wall and the back fill soil. In order to find the optimal shape, first, to analyze the effect of the geofoam position, the geofoam of the same volume was installed at different heights of the retaining wall (Fig. 8). This was intended to reinforce the existing geofoam experiment, which was only attached in the tile form. At this time, the thickness of the geofoam was about 1m, which allowed it to serve as a reinforcement, not as a substitute.



[Fig 8] Location of geofoam

Next, we have set up five forms of geometry to find the optimal shape (Figure 9). At this time, the area of the geofoam was set to  $2.7\text{ m}^2$ . This is the same value as the area of the geofoam previously tested with respect to its position.



[Fig 9] Shape of geofoam

Various types of geofoam were established to find optimal type for reducing soil pressure in retaining walls, and this will be discussed in detail in the research results. Through the above experiment, it was confirmed that the triangular geofoam shape most effectively reduces the earth pressure in the retaining wall. Based on this, it was intended to examine the changes in the pressure reduction rate in the retaining wall due to changes in the area of the triangle-shaped geofoam. To do this, it was tried to look

at the reduction rate of earth pressure in the retaining wall due to changes in the area of the geometry with changes in the length of the underside of the triangle. At this time, the minimum length of the base was set to 20cm, increasing by 20cm to 300cm. At this time, the maximum length of the base was 300cm, and it was intended to consider that the geofoam was not a substitute for the back fill soil, but rather a reinforcement of the retaining wall.

Next, it was tried to look at the changes in the earth pressure received by retaining walls for the various properties of the geofoam. In this study, three types of geofoam were established: EPS12, EPS15, and EPS19; the properties were set as follows (Table 4). At this time, the purpose was to examine the variation in the strain of the geofoam according to the properties by examining the displacement of the geofoam together, and to identify the safety of the geofoam as a reinforcement at the same time. At this time, the shape of the geofoam was reflected as the result of the previous experiments, as it was found that the triangular shape showed the most efficient reduction of soil pressure.

[Table 4] Property of geofoam

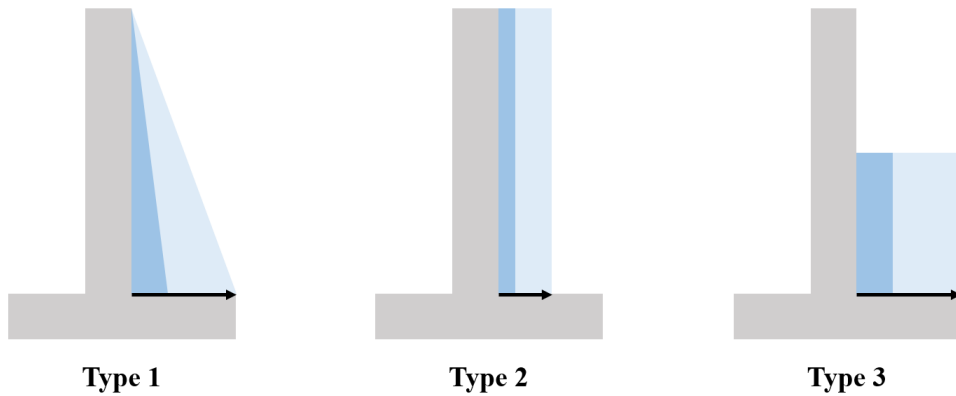
	EPS12	EPS15	EPS19
Density (N/m <sup>3</sup> )	101	141	181
Young' s Modulus (kPa)	1,500	2,500	4,000
Poisson' s Ratio	0.12	0.12	0.12

## 2.6. Reinforcement of the Lower Part of Retaining Wall

Next, we tried to examine the changes in the soil pressure according to the area change of various types of geofoam in addition to the previous tests related to the type of geofoam. According to the previous experiment, it was confirmed that when the geofoam having the same area was installed at the lower end, the soil pressure in the retaining wall could be effectively reduced. By using



this, we tried to see the change in earth pressure in the retaining wall according to the area change of three types of geofoam, Type 1, Type 2, and Type 3 among the five geofoam types previously set. At this time, we tried to examine the change in earth pressure in the retaining wall according to the change in the area of the three types of geofoam. The area of the geofoam was increased by 0.54 m<sup>2</sup> from 0.54 m<sup>2</sup> to an area equal to 5.4 m<sup>2</sup> of the retaining wall (Figure 10). This reflects the fact that the change in earth pressure in the retaining wall due to the change in the area of the geofoam did not show a significant difference after a certain point through previous studies.

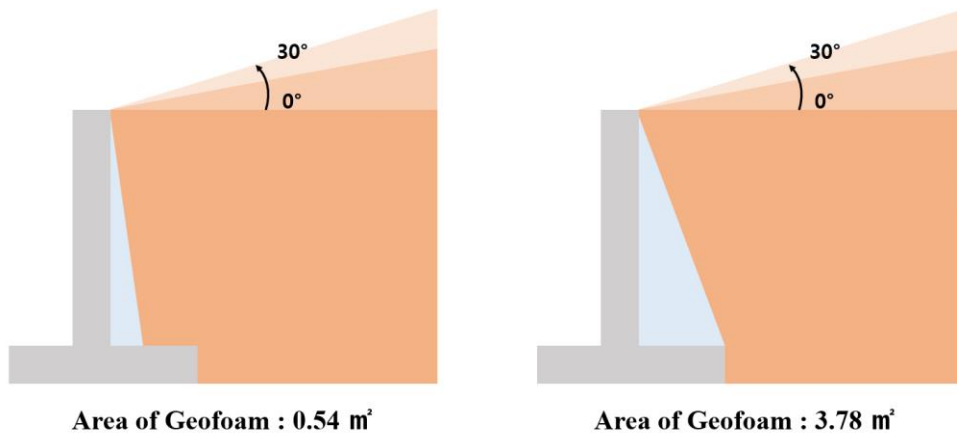


[Fig 10] Area variation according to type

## 2.7. Change the Slope of Backfill

Since most of Korea consists of mountainous regions, retaining walls are often installed in sloped areas. Therefore, further studies were conducted on the applicability of geofoam to the case where backfill soil is inclined. The slope of the backfill soil was set to increase from 0 ° to 30 ° in 5 ° increments, and a total of 7 slopes were set. In addition, within the retaining wall, the geofoam was applied Type 1, the most optimized type of retaining wall, through previous experiments. In addition, the length of the bottom of the triangle was set to two types, 20cm and 140cm (Figure 11). This

takes into account the role of geofoam as an alternative and applies the area of the triangle, which is an inflection point of the minimum geofoam area and the inflection point of the earth pressure change rate derived from the previous experiment, when looking at the earth pressure change rate according to the area of the triangle through the previous study.

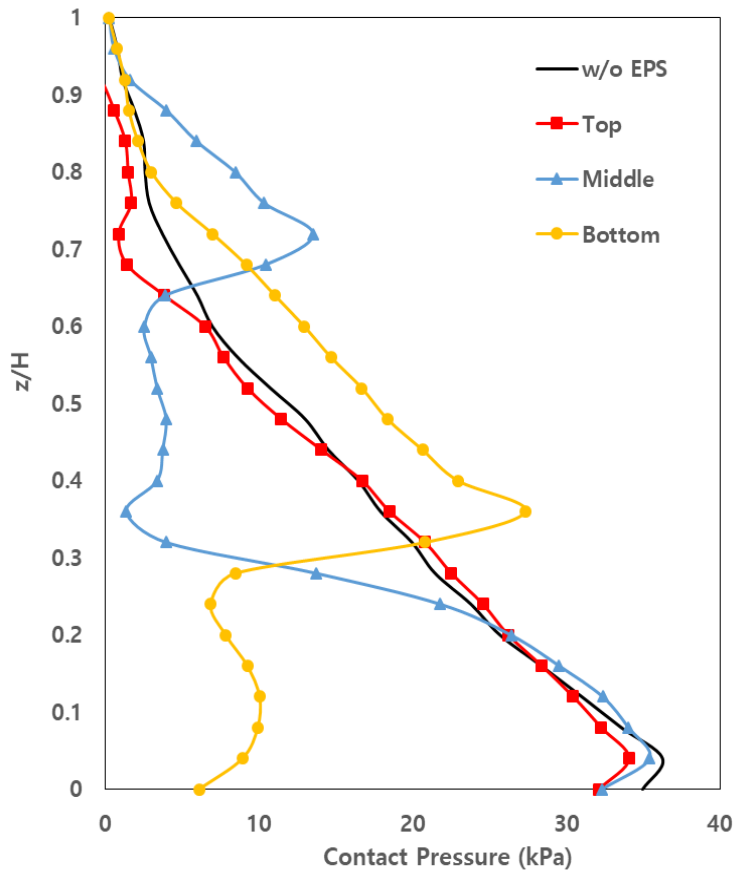


[Fig 11] Change of slope angle of backfill

## **Chapter 3. Results and Discussion**

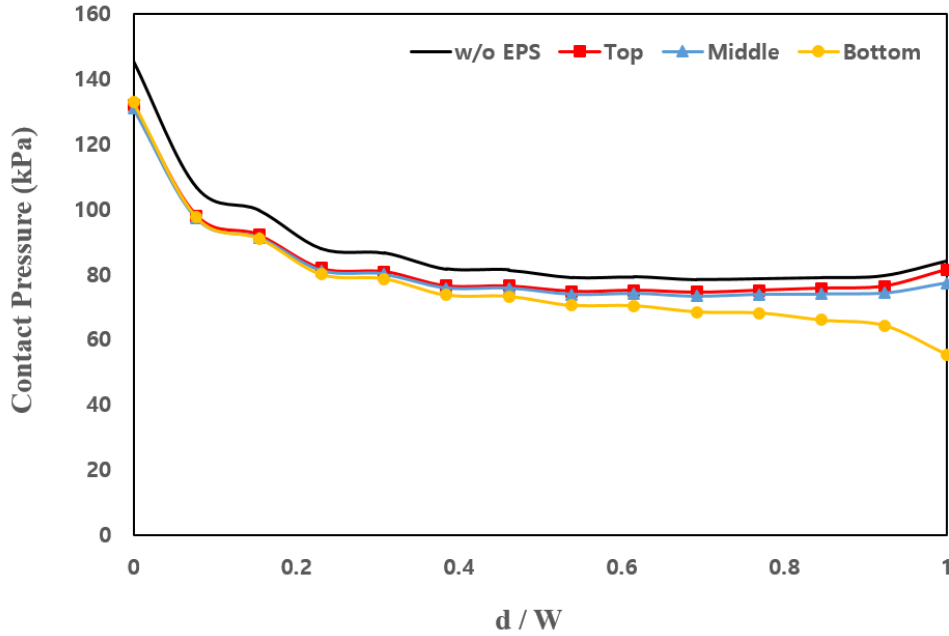
### **3.1. Earth Pressure According to Location of Geofoam**

When examining the change in the lateral earth pressure in the retaining wall according to the location on the geofoam, when the geofoam was installed in the upper part of the retaining wall, the lateral earth pressure showed a similar value to that in the absence of the geofoam. Also, when the geofoam was installed in the middle part, the lateral soil pressure was reduced in the middle layer of the retaining wall. However, the upper part of the retaining wall showed a slight increase in the earth pressure, and the lower part showed a lateral earth pressure similar to that of the one without geofoam. When geofoam was installed at the lower part of the retaining wall, the upper and central parts of the retaining wall showed a higher lateral earth pressure compared to the absence of geofoam, but the lateral earth pressure at the lower part was significantly reduced (Figure 12).



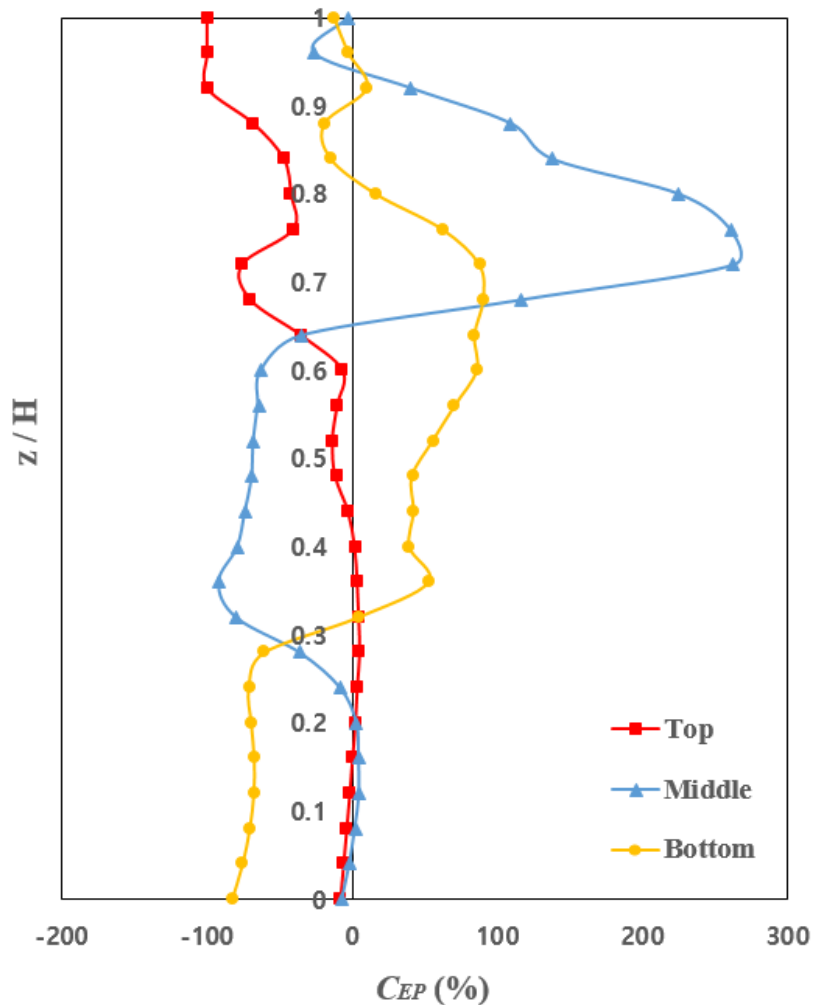
[Fig 12] Lateral earth pressure on wall of retaining wall depending on geofoam position

When looking at the load on the base of the retaining wall, all three types showed similar changes in earth pressure compared to the absence of geofoam. All three types showed an average soil pressure drop of about 10 percent. When installing geofoam at the lower part, the relative largest reduction in earth pressure was shown (Figure 13).



[Fig 13] Earth pressure on base of retaining wall depending on geofoam position

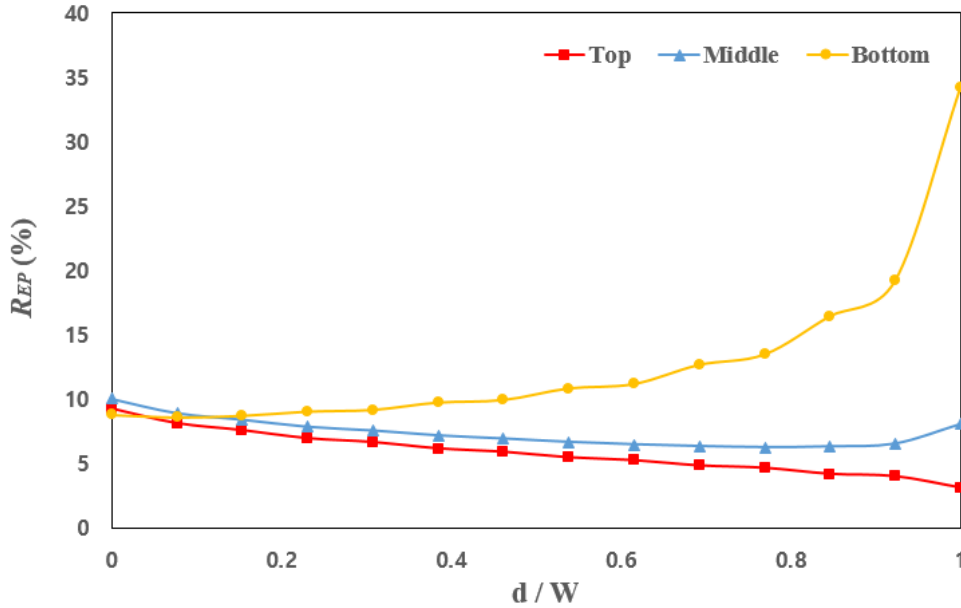
When comparing the rate of change of the earth pressure on the wall of the retaining wall without geofoam, when the geofoam was installed on the upper part of the retaining wall, there was decrease in soil pressure in the upper part, but there was little change in the earth pressure in the middle and lower parts. When the geofoam was installed in the middle of the retaining wall, the upper part of the retaining wall showed a large increase in soil pressure, and the central part showed a decrease in soil pressure. When the geofoam was installed in the lower part, the soil pressure was increased in the central part and the soil pressure was reduced in the lower part. At this time, the decrease rate and the increase rate were similar. In addition, the reduction rate of earth pressure was similar for each part of geofoam installation (Figure 14).



[Fig 14] Rate of change in earth pressure on wall of retaining wall depending on geofoam position

(( $CEP$  = Rate of Change in Earth Pressure (%))

Comparing the rate of change in the earth pressure on the base of the retaining wall from the absence of geofoam, when it was installed in the upper and middle parts of the retaining wall, there was a constant change in soil pressure at each point. It also showed a decrease in soil pressure. Overall, the geofoam installed in the lower part of the retaining wall showed a greater reduction in earth pressure than the geofoam installed in the upper and middle parts (Figure 15).

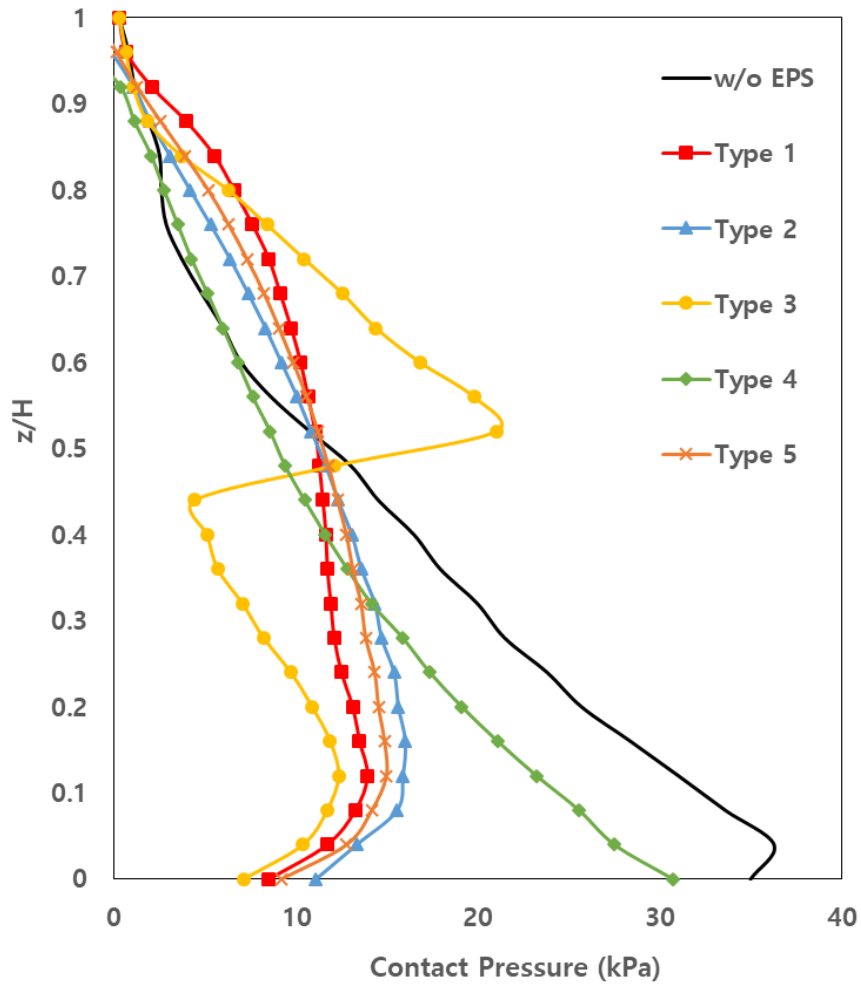


[Fig 15] Reduction ratio of earth pressure on the base of retaining wall depending on Geofoam position

( $REP$  = Reduction Ratio of Earth Pressure (%))

### 3.2. Earth Pressure According to Shape of Geofoam

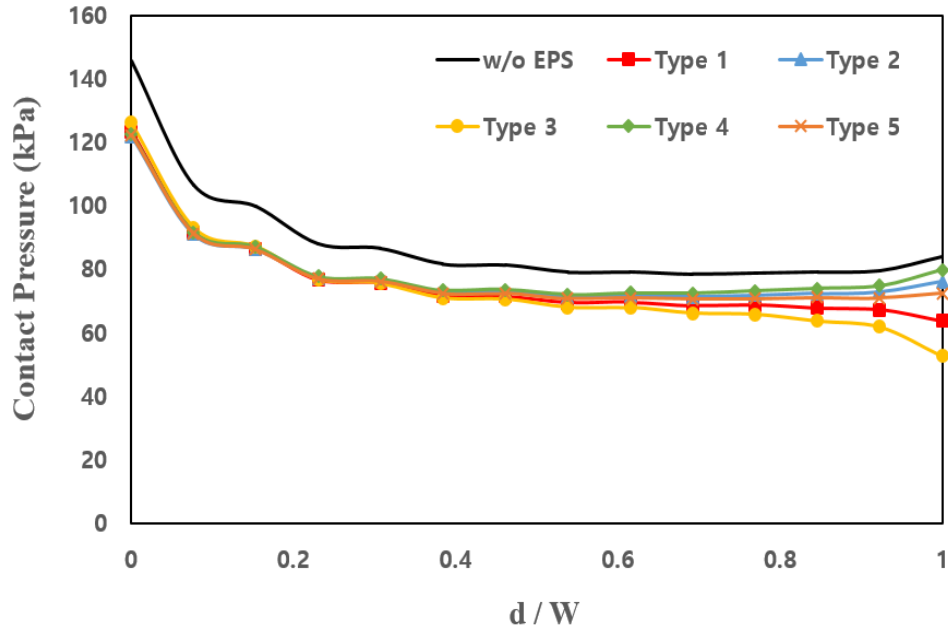
When looking at the changes in the soil pressure according to the shape of the geofoam, it was found that, on average, the lateral earth pressure decreased when there were geofoam for all the shapes. The geofoam of type 3 reduced the maximum lateral earth pressure the most, and the shape of the inverted triangle had the lowest reduction rate of the maximum horizontal soil pressure. Geofoam in the type 1, type 2, and type 5 showed similar changes in horizontal soil pressure reduction. In all geometries except type 3, the maximum lateral earth pressure was reduced by more than 50%. In addition, it was confirmed that for all types of geofoam, the lateral earth pressure was increased at the top of the retaining wall compared to the absence of the geofoam (Figure 16).



[Fig 16] Lateral earth pressure on wall of retaining wall depending on geofoam shape

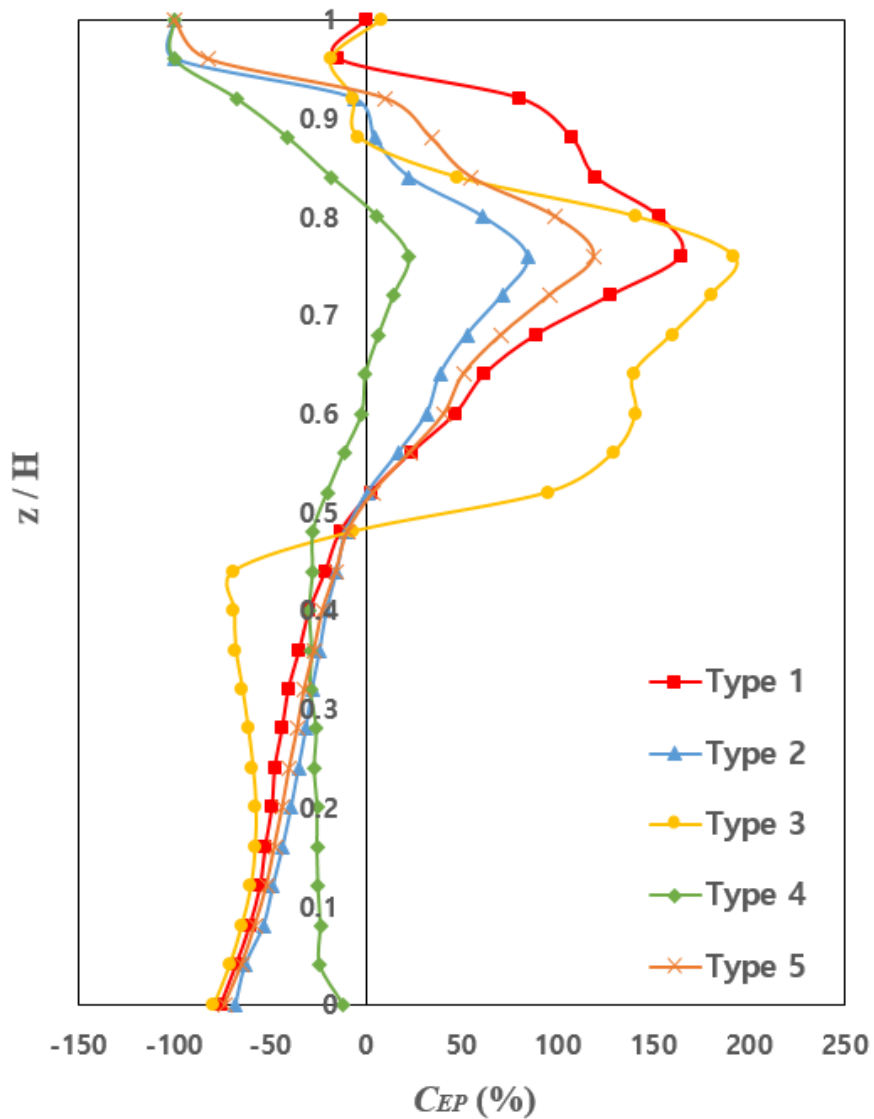
Looking at the changes in the earth pressure of the base of the retaining wall, similar changes in the reduction of the earth pressure were made for all types of geometry. In the case of Type 3, the most reduced earth pressure, and the maximum earth pressure was reduced by about 20%. For all types of models, an average earth pressure reduction of about 10% was shown (Figure 17).





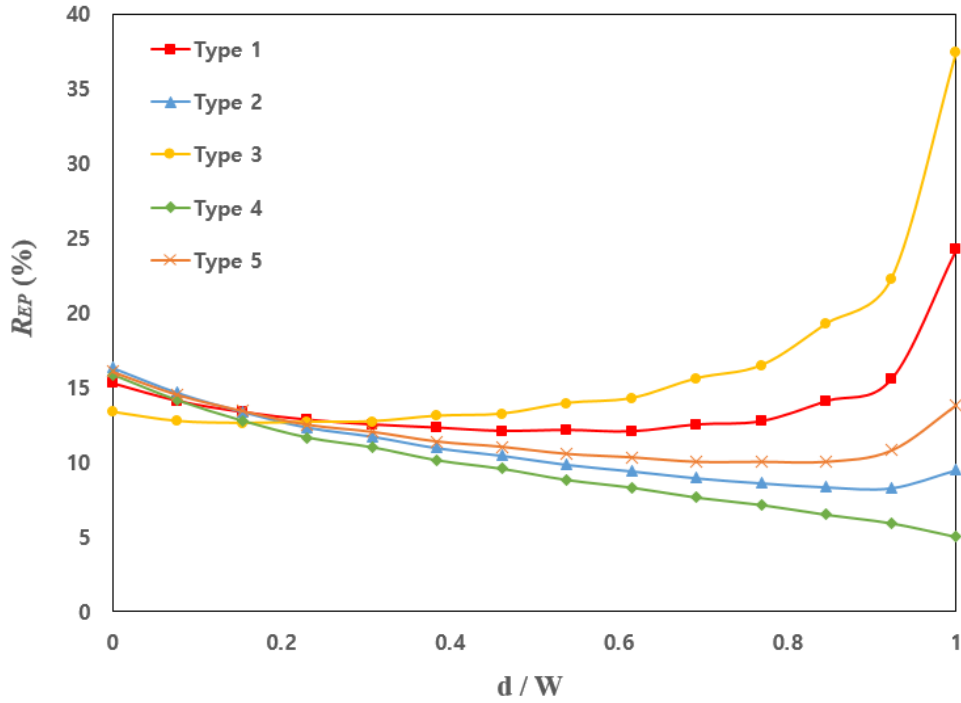
[Fig 17] Earth pressure on the base of retaining wall depending on geofoam shape

When examining the rate of change of the earth pressure on the wall of the retaining wall compared to the case without geofoam, the case of type 1 showed a slightly greater increase in earth pressure at the upper part of the retaining wall compared to the type 2 and type 5. In addition, in the case of type 3, the difference between the maximum increase rate of the earth pressure and the maximum decrease rate was the largest (Figure 18).



[Fig 18] Rate of change in lateral earth pressure on wall of retaining wall depending on geofoam shape

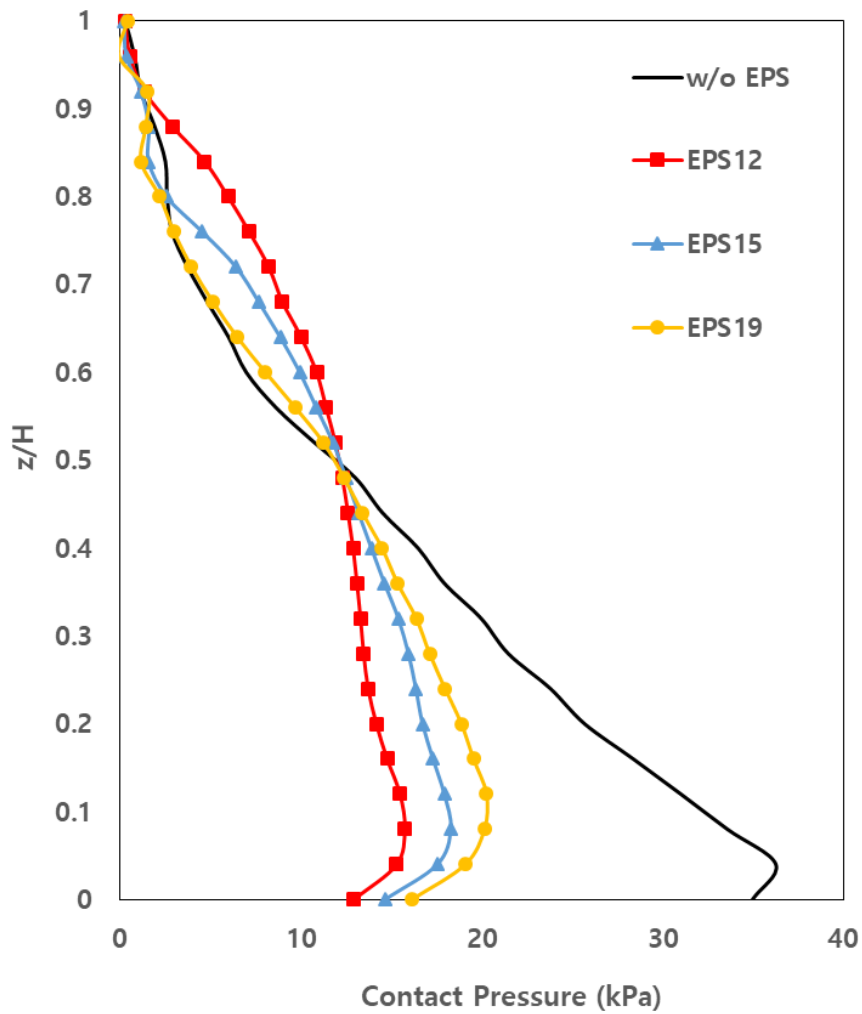
When comparing the earth pressure change rate of the base of the retaining wall from the absence of geofoam, the earth pressure reduction rate was mostly about 10% in the rest of the form except for the case of type 3. In the case of type 3, the earth pressure reduction rate was about 15%. In addition, except the case of type 3, the case of type 1 showed the highest reduction in soil pressure overall (Figure 19).



[Fig 19] Reduction ratio of earth pressure on the base of retaining wall depending on geofoam shape

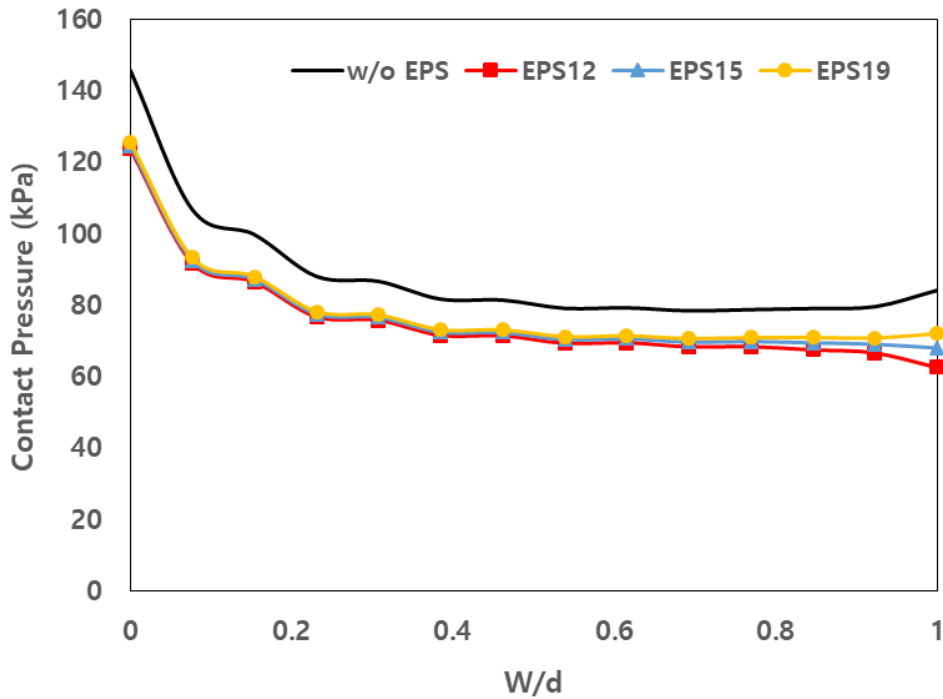
### 3.3. Earth Pressure According to Property of Geofoam

When examining the change in lateral earth pressure according to the properties of geofoam, the effect of reducing the lateral earth pressure by EPS19 was the highest at the upper part of the retaining wall, and the effect of reducing the earth pressure by EPS12 was the largest by the bottom of the retaining wall (Figure 20). In addition, all three geofoam showed similar lateral earth pressure in the middle of the retaining wall.



[Fig 20] Lateral earth pressure on wall of retaining wall depending on geofoam property

The earth pressure on the base of the retaining wall showed a largely similar earth pressure regardless of the properties of the geofoam and a similar earth pressure distribution pattern as in the absence of the geofoam (Figure 21).



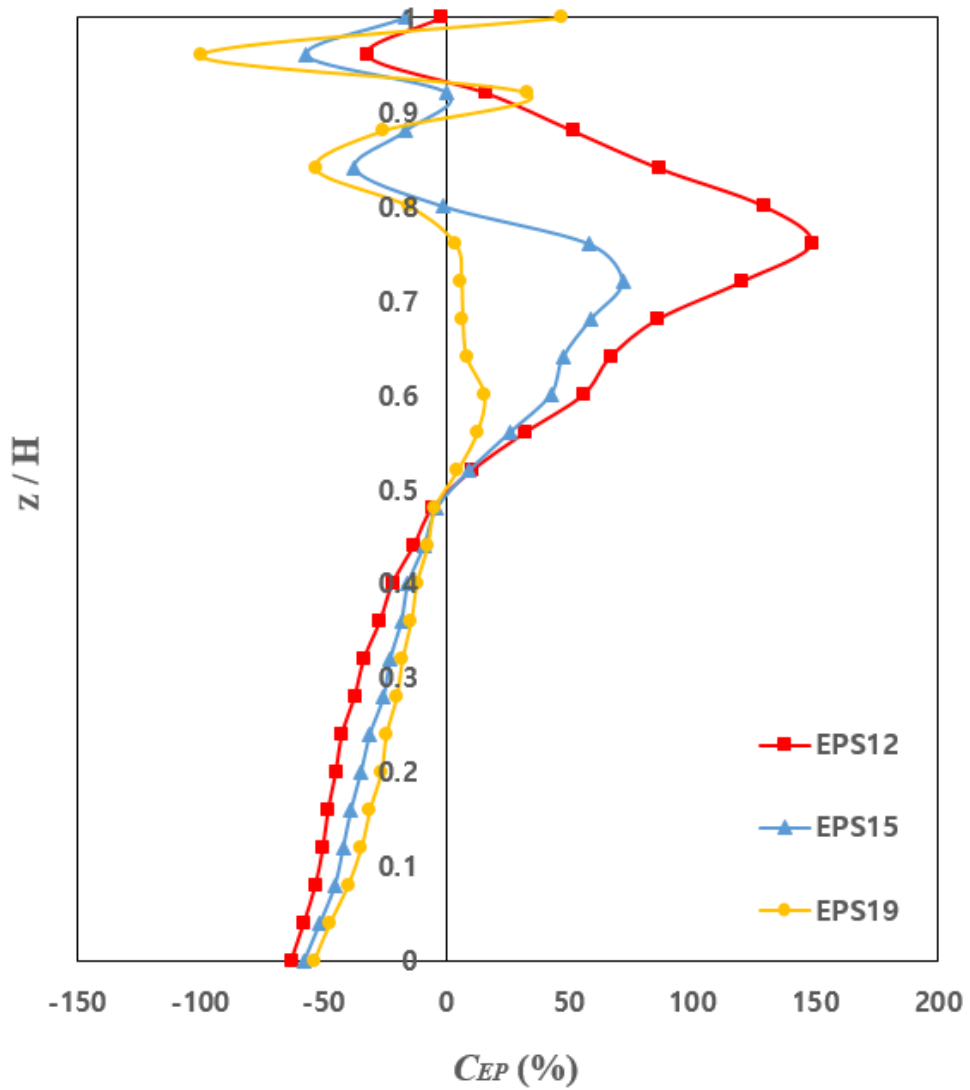
[Fig 21] Earth pressure on the base of retaining wall depending on geofoam property

When examining the displacement of the geofoam according to the properties of the geofoam, the maximum tensile and compressive rates were as shown in the table below (Table 5). The difference between the maximum tensile modulus was rather large depending on the properties of the geofoam, but the difference in compressibility was not large. In addition, it was confirmed that the overall deformation rate of the geofoam was less than 1%. In addition, in the case of EPS 19, the maximum compression rate was higher than the maximum tensile rate.

[Table 5] Maximum tensile and compressive rate according to the property of the geofoam

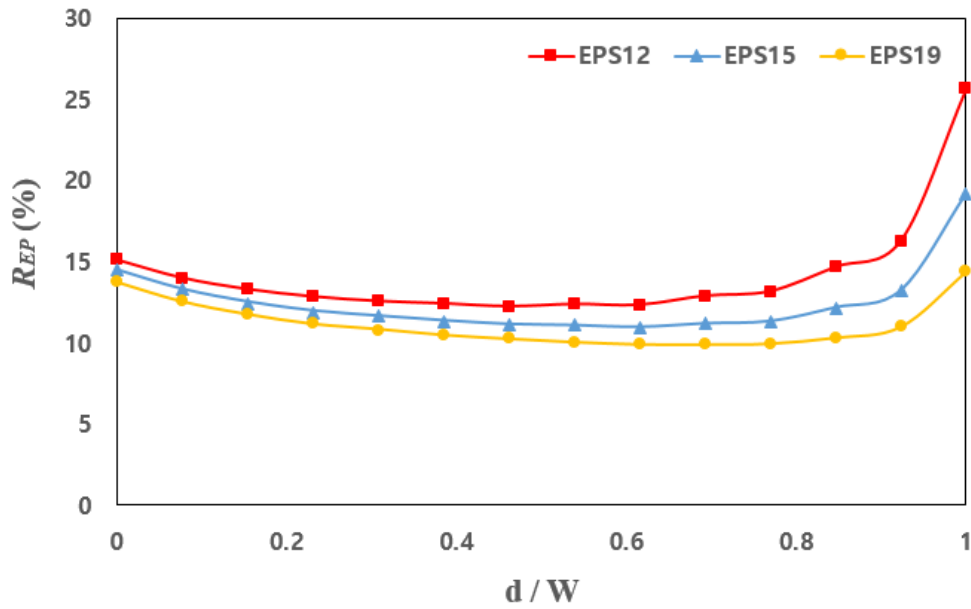
	EPS12	EPS15	EPS19
Maximum Tensile Rate (%)	0.798	0.436	0.118
Maximum Compressive Rate (%)	0.494	0.387	0.265

When the rate of change in the earth pressure on the wall of the retaining wall according to the change in physical properties of the geofoam was examined in detail, it was confirmed that in the case of EPS12, the rate of increase in earth pressure over 50% from the top of the retaining wall. Particularly, at some upper points, the rate of increase in soil pressure was over 100%. Also, when the relative height was greater than 0.9, the soil pressure was decreased regardless of the properties of the geofoam. EPS15 and EPS19 showed a decrease in soil pressure from 0.8 to 0.9, but EPS12 showed an increase in soil pressure (Figure 22).



[Fig 22] Rate of change in lateral earth pressure on wall of retaining wall depending on geofoam property

When looking at the reduction rate of earth pressure on the base of the retaining wall according to the properties of geofoam, similar patterns were shown regardless of the properties. In addition, EPS12 with the lowest density showed the highest reduction rate (Figure 23).

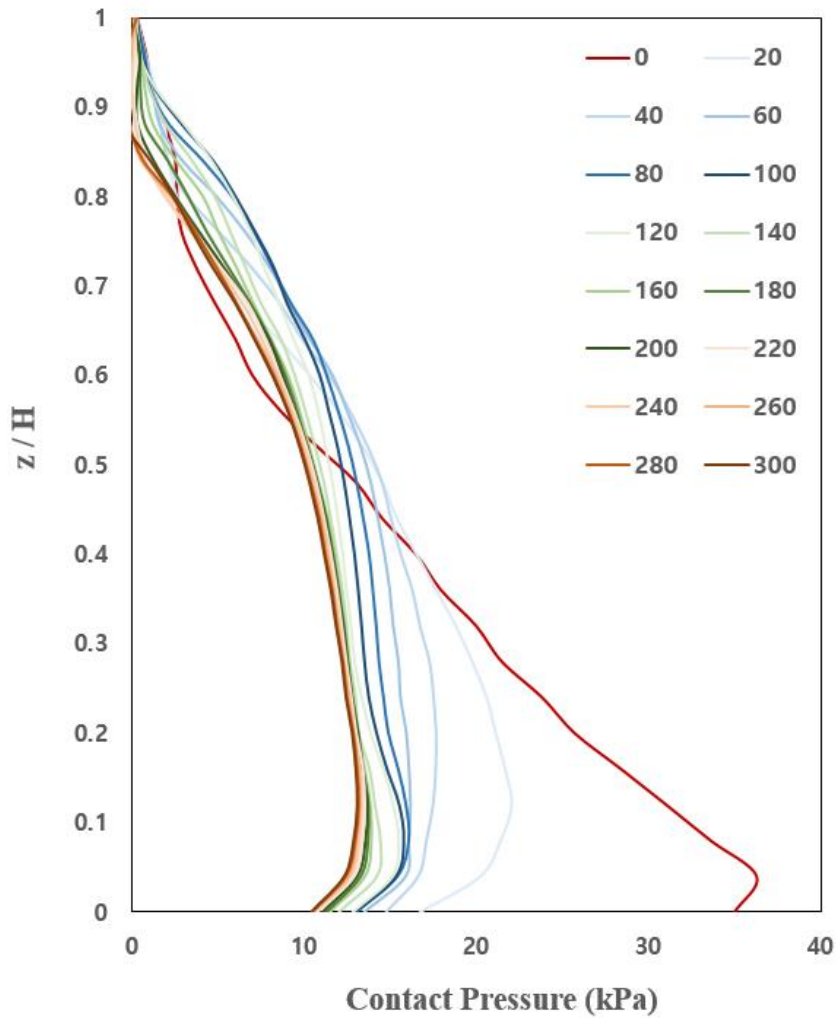


[Fig 23] Reduction ratio of lateral earth pressure on the base of retaining wall depending on geofoam property

### 3.4. Earth Pressure According to Area of Geofoam

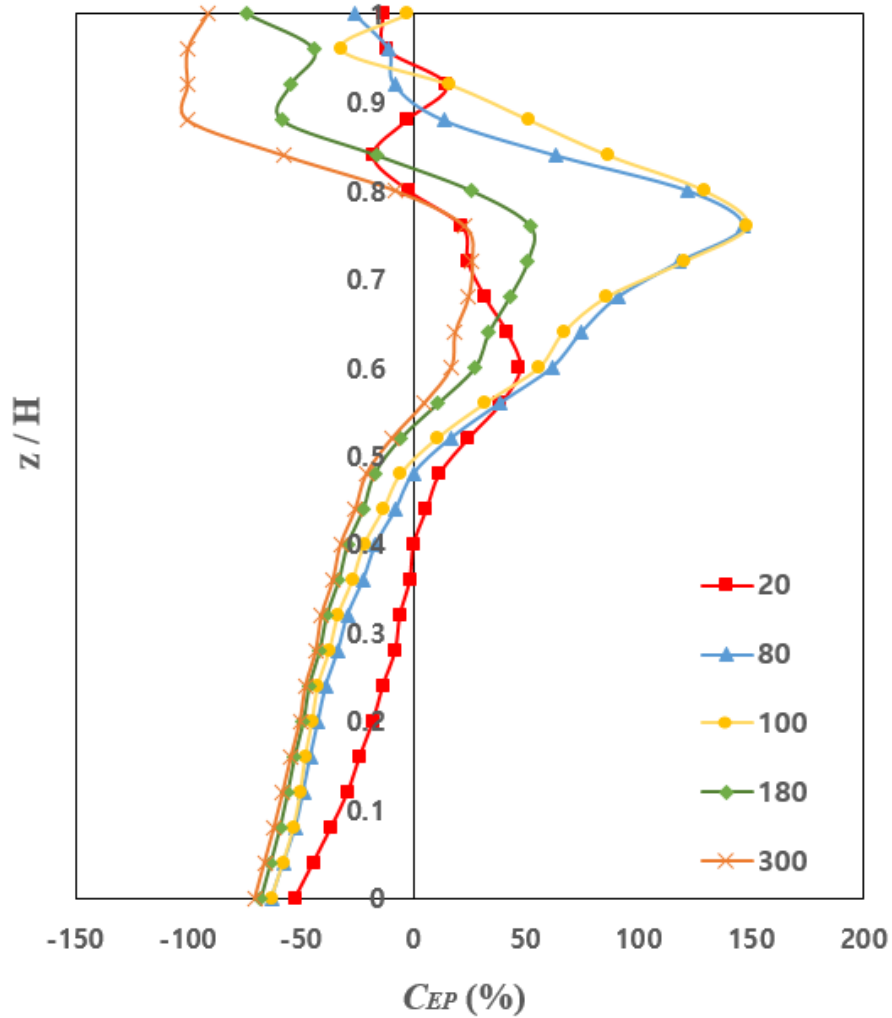
When the length of the base of the triangular shape was increased, as shown in the figure below, it was confirmed that the lateral earth pressure decreased as the length of the base increased. In addition, it was confirmed that the amount of reduction in lateral earth pressure decreased as the length of the base side increased (Figure 24).





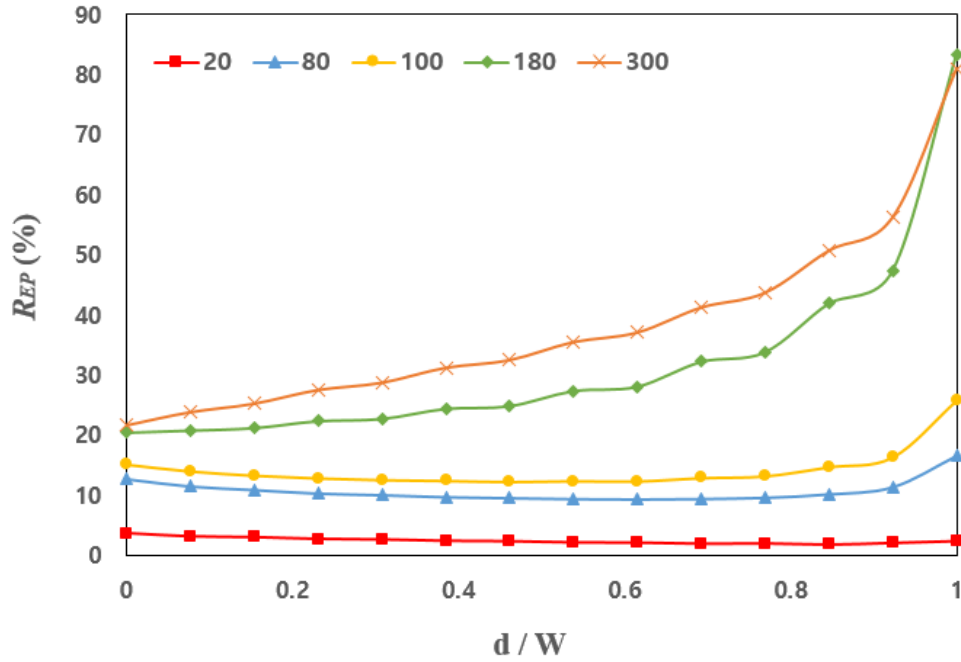
[Fig 24] Lateral earth pressure on wall of retaining wall depending on the length of base side in triangular shape

Looking at the rate of change in the earth pressure of the wall of retaining wall by section for some triangular shapes, it was found that the reduction rate of lateral earth pressure from below the middle part of the retaining wall was similar to about 50%. In addition, in the case of 80cm and 100cm with the base length greater than 20cm, the lateral earth pressure growth rate at the upper part of the retaining wall was high. However, if the length of the underside of the triangle is greater than 180 cm, the soil pressure growth rate at the top of the retaining wall is reduced again (Figure 25).



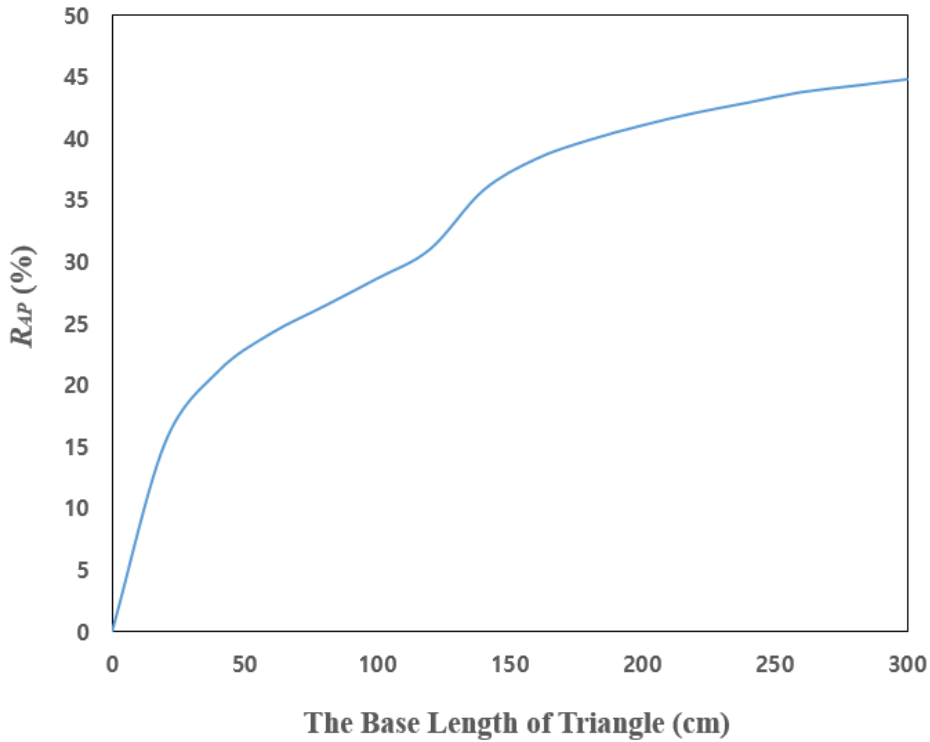
[Fig 25] Rate of change in lateral earth pressure on wall of retaining wall depending on length of base in triangular shape

When looking at the rate of reduction in earth pressure on the base of the retaining wall, the rate of soil pressure decreases until the length of the triangle base is 100cm. However, it was confirmed that at 180cm or more, the rate of reduction in soil pressure increased significantly. When the length of the triangle base is 80 cm and 100cm, the average earth pressure reduction rate of the retaining wall bottom is about 10%. In addition, when the length of the triangle base is 180cm and 300cm, the reduction of soil pressure at the bottom of the retaining wall of 20% or more was shown (Figure 26).



[Fig 26] Reduction ratio of lateral earth pressure on the base of retaining wall depending on length of base in triangular shape

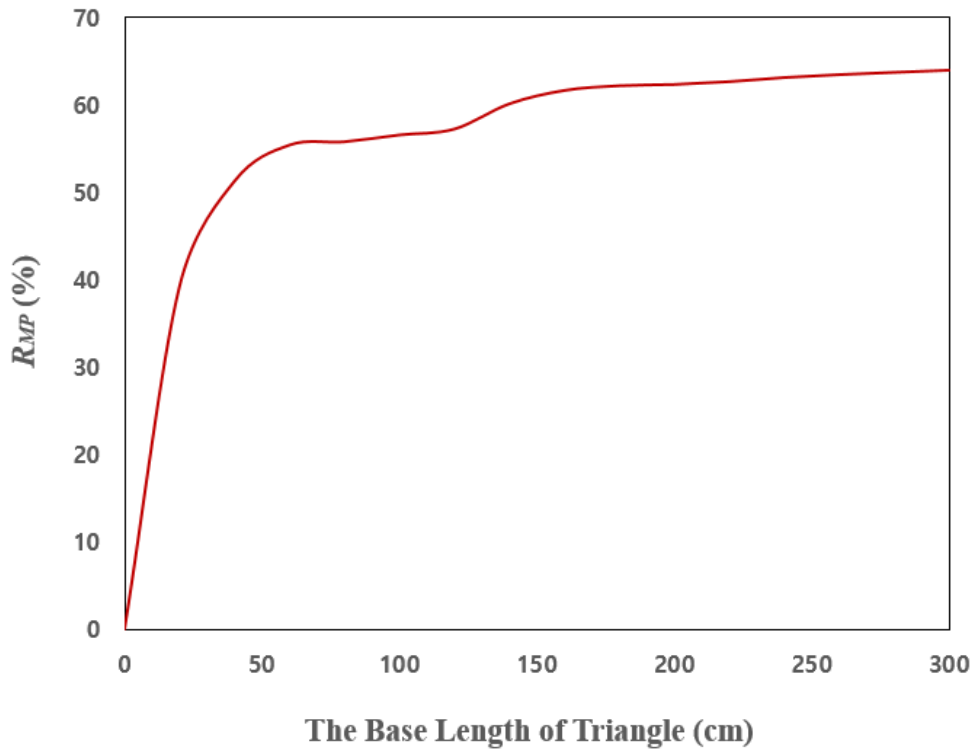
The average rate of lateral earth pressure reduction on the wall of the retaining wall according to the change in the length of the base of the triangle was shown below. When the length of the base side increased from 20 cm to about 120 cm, it was found that the average lateral earth pressure reduction rate increased somewhat constantly from about 20%. When the length of the base increased more than 120cm, the rate of decrease in lateral earth pressure increased significantly to about 40% and then showed a constant increase (Figure 27).



[Fig 27] Reduction ratio of average lateral earth pressure on wall of retaining wall depending on length of base in triangular shape

( $R_{AP}$  = Reduction Ratio of Average Earth Pressure)

The maximum lateral earth pressure reduction rate of the retaining wall was shown below due to changes in the length of the base of the triangle. If the length of the base was more than 60 cm, the maximum lateral earth pressure reduction rate was about 55%. In addition, if the base length is greater than 140 cm, the maximum soil pressure reduction rate was approximately 60 % (Figure 28). It was also confirmed that the decrease and decrease rates were not significant compared to the average decrease in lateral earth pressure on the retaining wall as previously discussed.



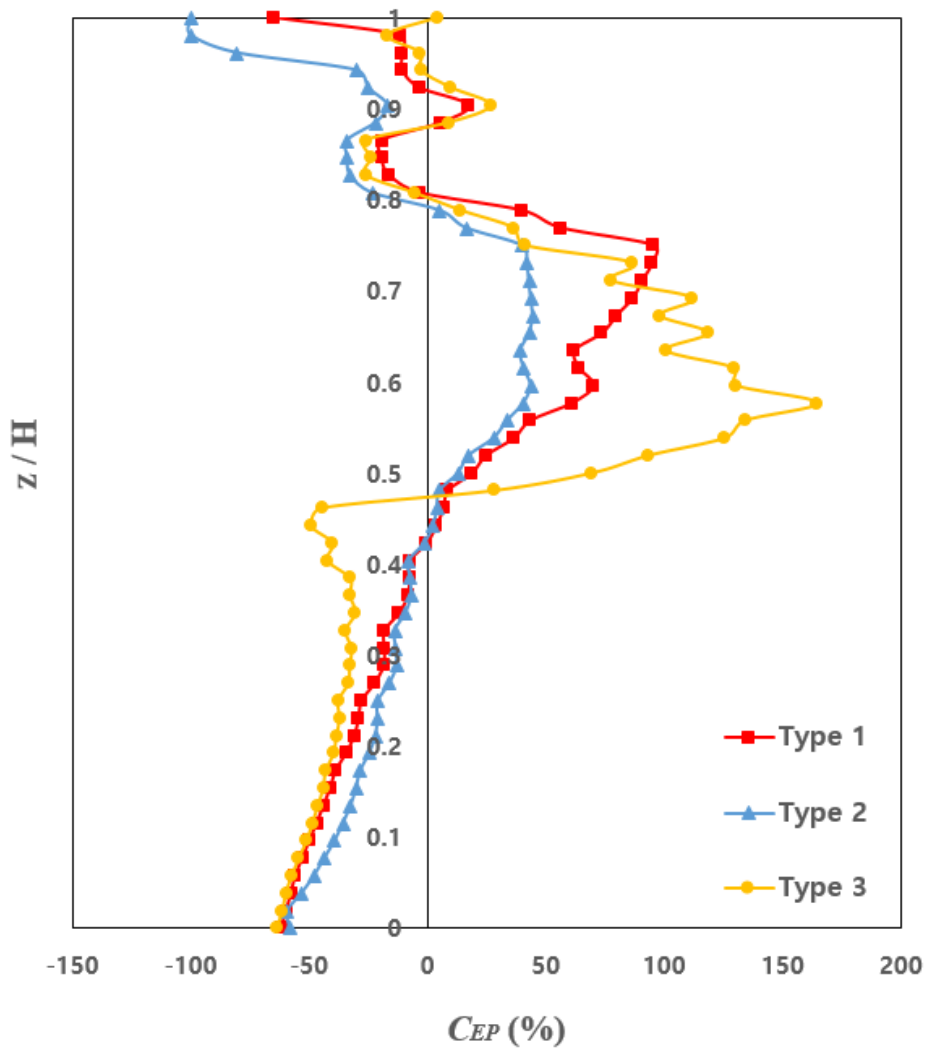
[Fig 28] Reduction ratio of maximum lateral earth pressure on wall of retaining wall depending on length of base in triangular shape

( $R_{MP}$  = Reduction Ratio of Maximum Earth Pressure)

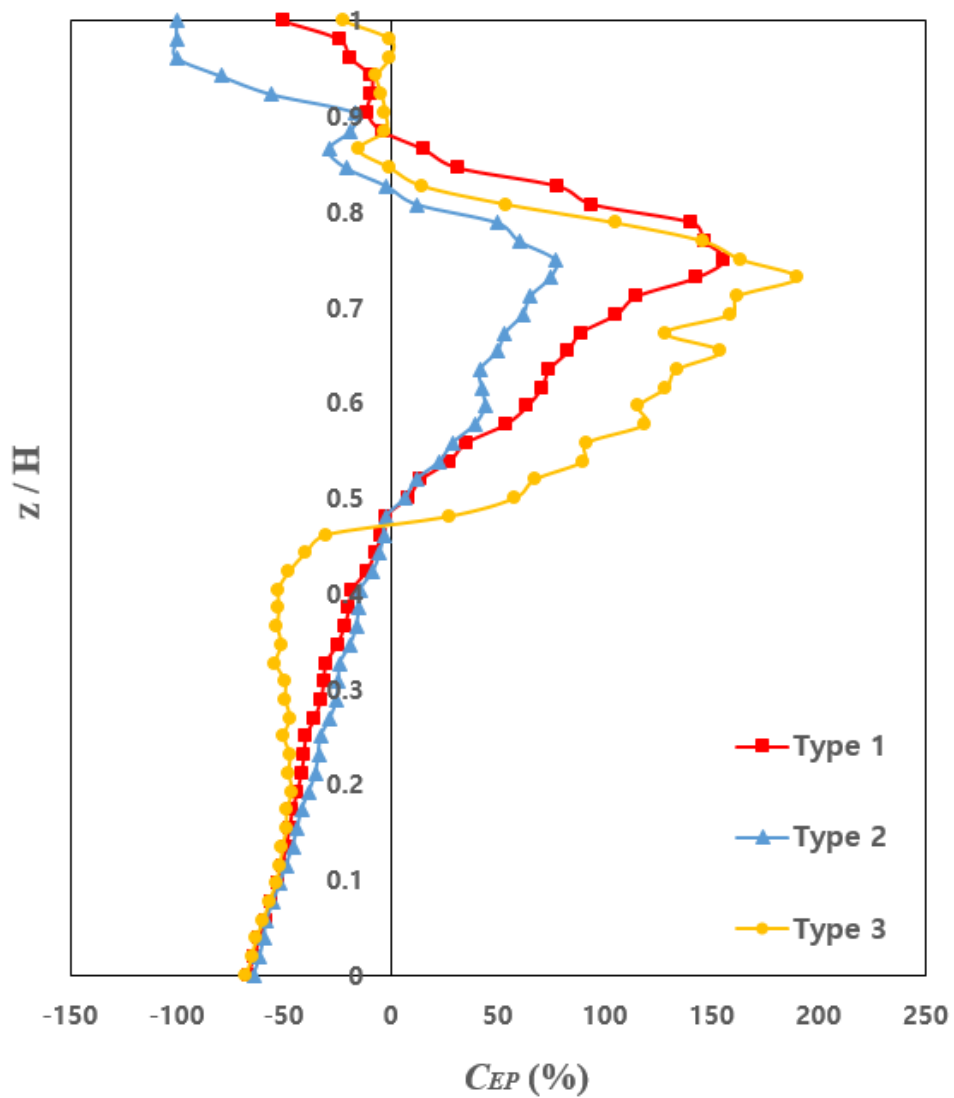
### 3.5. Earth Pressure According to Type

As the area of the geofoam increases, the rate of soil pressure change at the lower part of the retaining wall is almost identical in three types. When the area of the geofoam was equal to  $5.4\text{m}^2$  of the area of the retaining wall, it was confirmed that the reduction rate of lateral earth pressure at the lower part of the retaining wall was very similar. In addition, in the case of Type 3, it was shown that the soil pressure growth at the top was increasing as the area of the geometry increased. In addition, Type 1 showed a high decrease in soil pressure at the top up to a certain area of geofoam, but a low increase in lateral earth pressure thereafter. In addition, Type 2 showed relatively low earth pressure growth at the top of the retaining wall compared to other types. In the case of Type 3, it

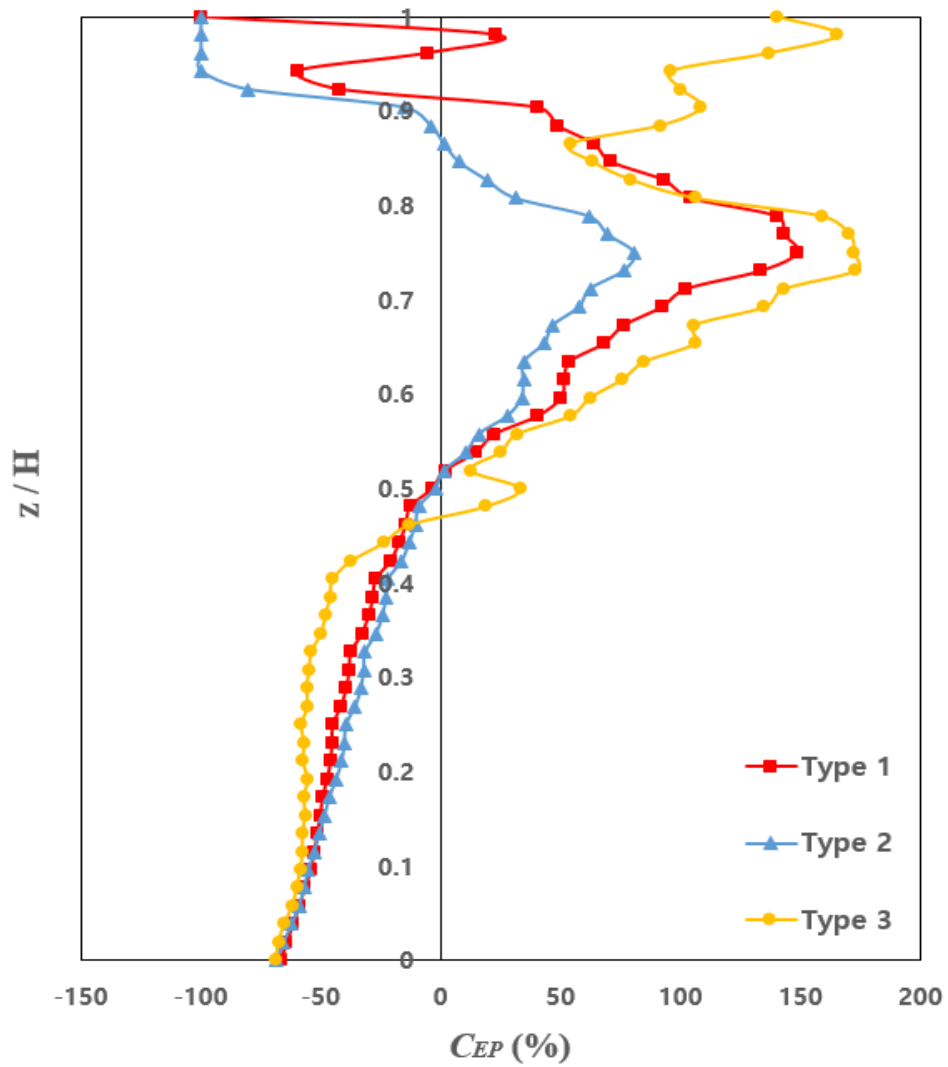
was possible to see a large increase in lateral earth pressure at a relative height of 0.9 or higher of the retaining wall, as the area of the geofoam was larger than 3.24m<sup>2</sup> (Figure 29–33).



[Fig 29] Rate of change in lateral earth pressure on wall of retaining wall when the area of geofoam is 1.08m<sup>2</sup>

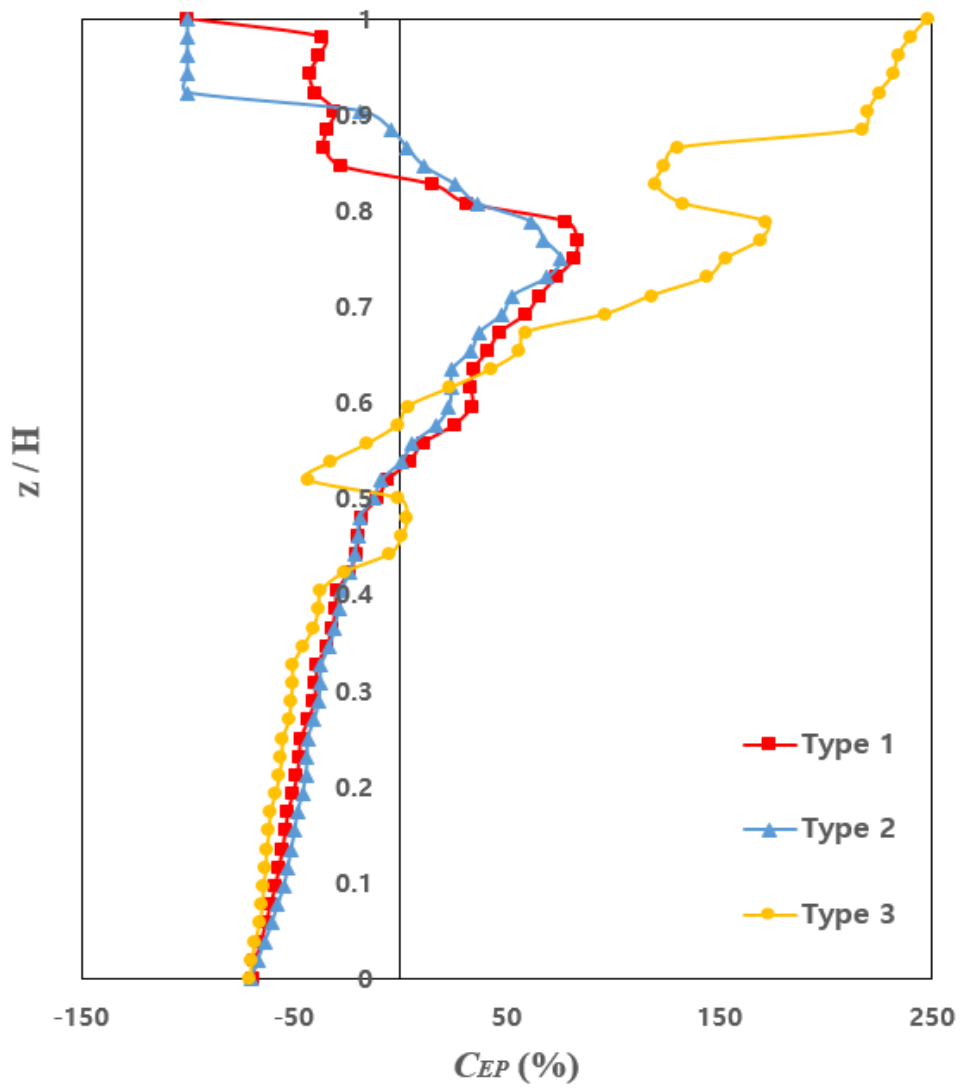


[Fig 30] Rate of change in lateral earth pressure on wall of retaining wall when the area of geofoam is 2.16m<sup>2</sup>

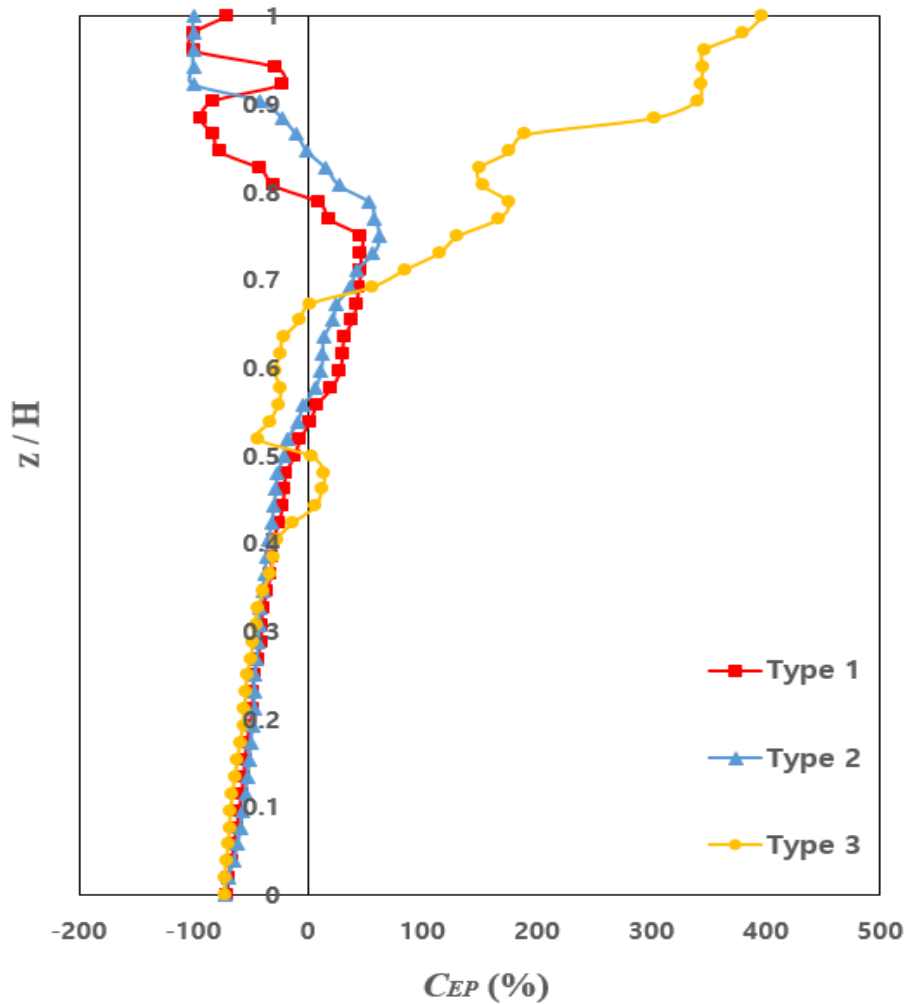


[Fig 31] Rate of change in lateral earth pressure on wall of retaining wall when the area of geofoam is 3.24m<sup>2</sup>



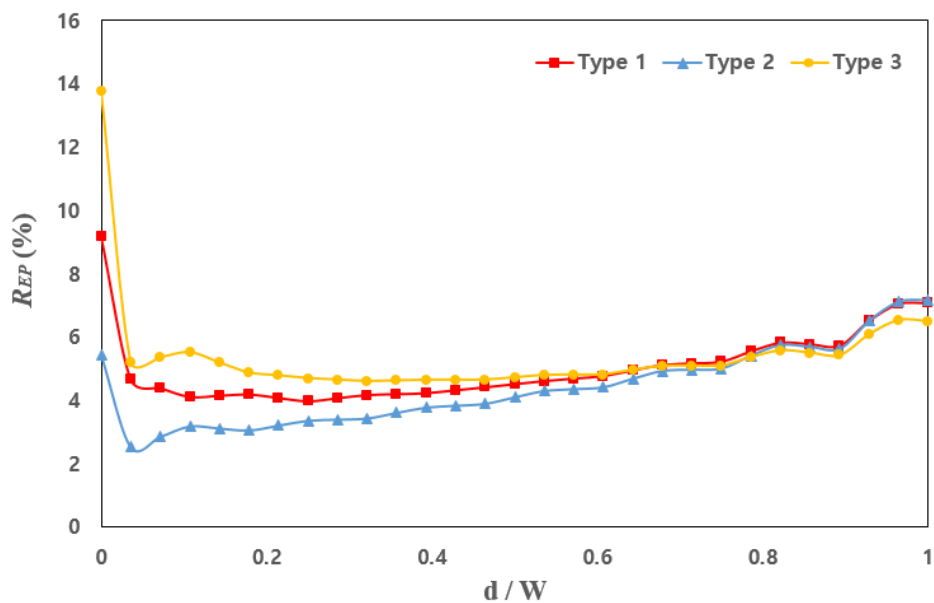


[Fig 32] Rate of change in lateral earth pressure on wall of retaining wall when the area of geofoam is 4.32m<sup>2</sup>

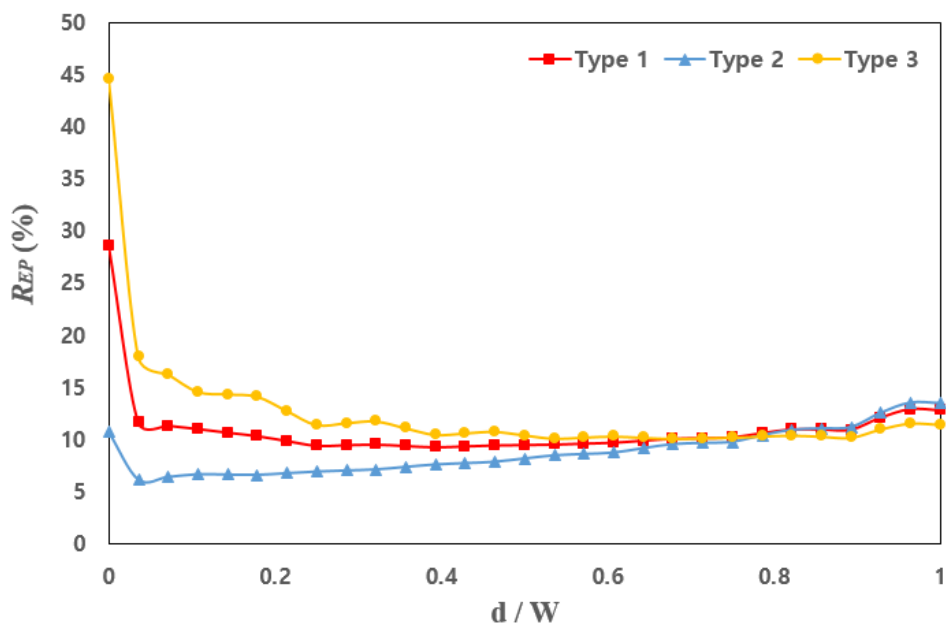


[Fig 33] Rate of change in lateral earth pressure on wall of retaining wall when the area of geofabric is 5.4m<sup>2</sup>

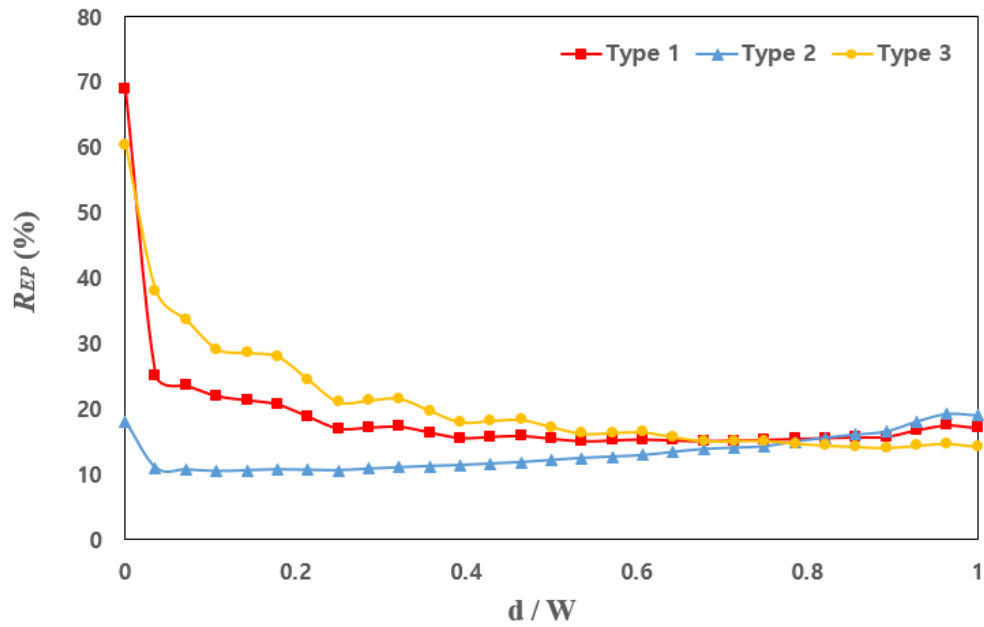
When the earth pressure reduction ratio of the base of the retaining wall by type was observed according to the area of the geofabric, similar patterns of the earth pressure reduction rate were shown for all types of geofabric until the area of the geofabric was 2.16m<sup>2</sup>. The cases of Type 1 and Type 3 showed similar earth pressure reduction ratio regardless of the geofabric area. In the case of Type 2, regardless of the area of the geofabric, similar pattern of earth pressure reduction rate was shown. In the case of Type 1 and Type 3, large reduction in earth pressure was observed at some points from the area of geofabric more than 4.32m<sup>2</sup> (Figure 34–38).



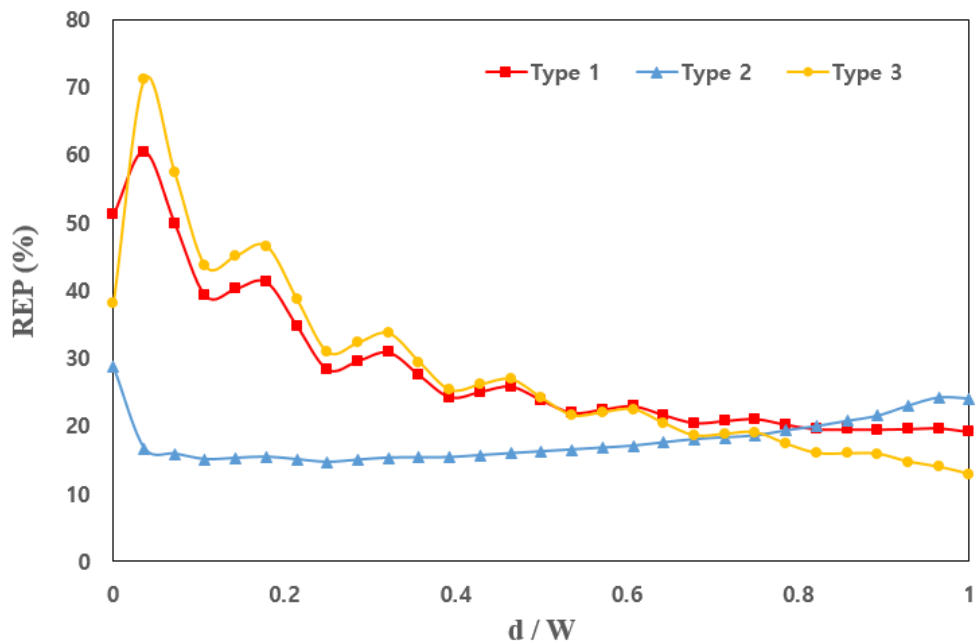
[Fig 34] Reduction ratio of earth pressure on the base of retaining wall when the area of geofoam is 1.08m<sup>2</sup>



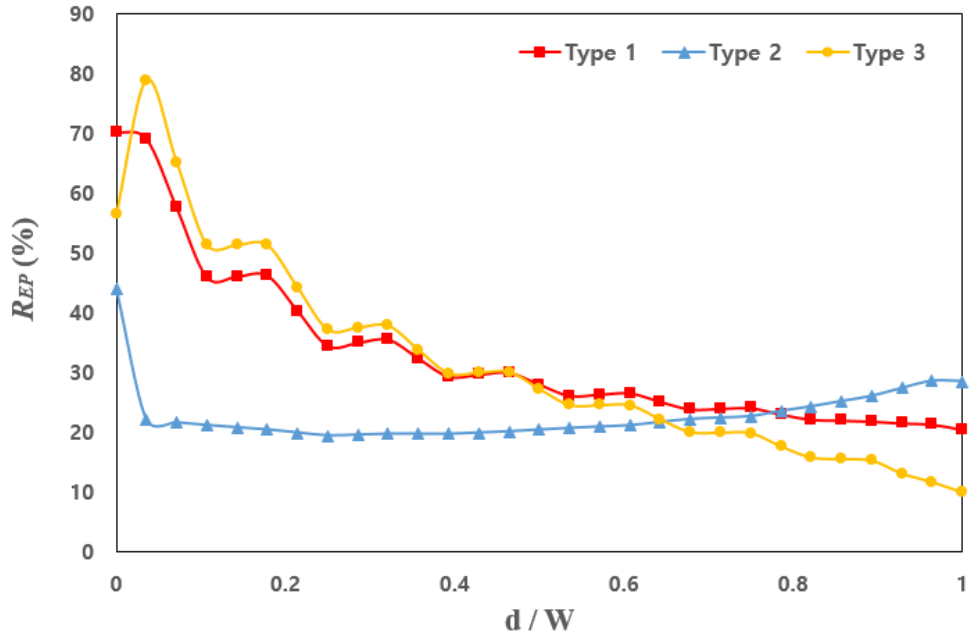
[Fig 35] Reduction ratio of earth pressure on the base of retaining wall when the area of geofoam is 2.16m<sup>2</sup>



[Fig 36] Reduction ratio of earth pressure on the base of retaining wall when the area of geofoam is 3.24m²

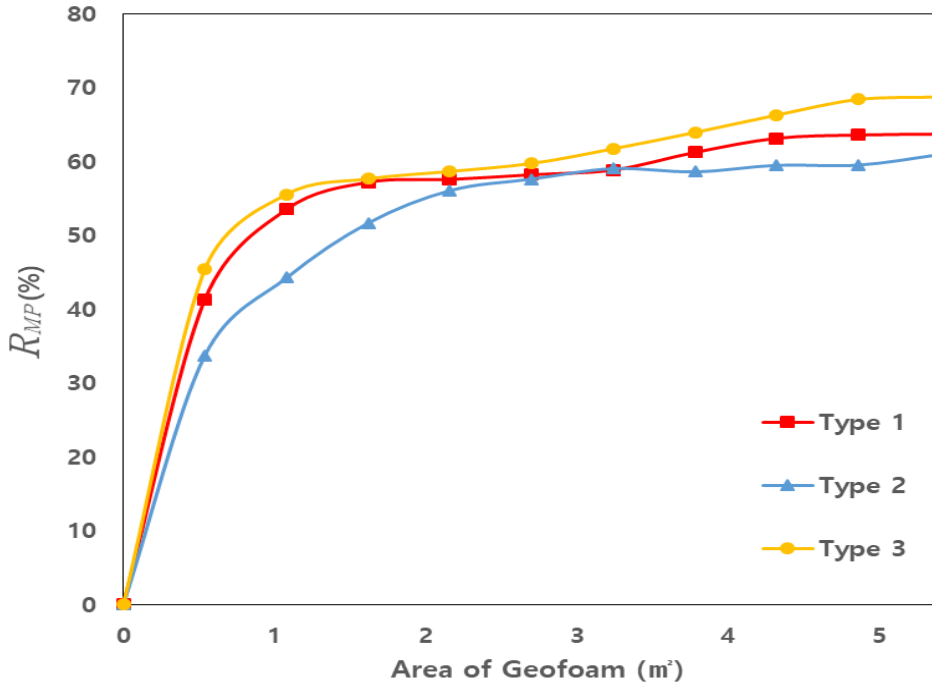


[Fig 37] Reduction ratio of earth pressure on the base of retaining wall when the area of geofoam is 4.32m²



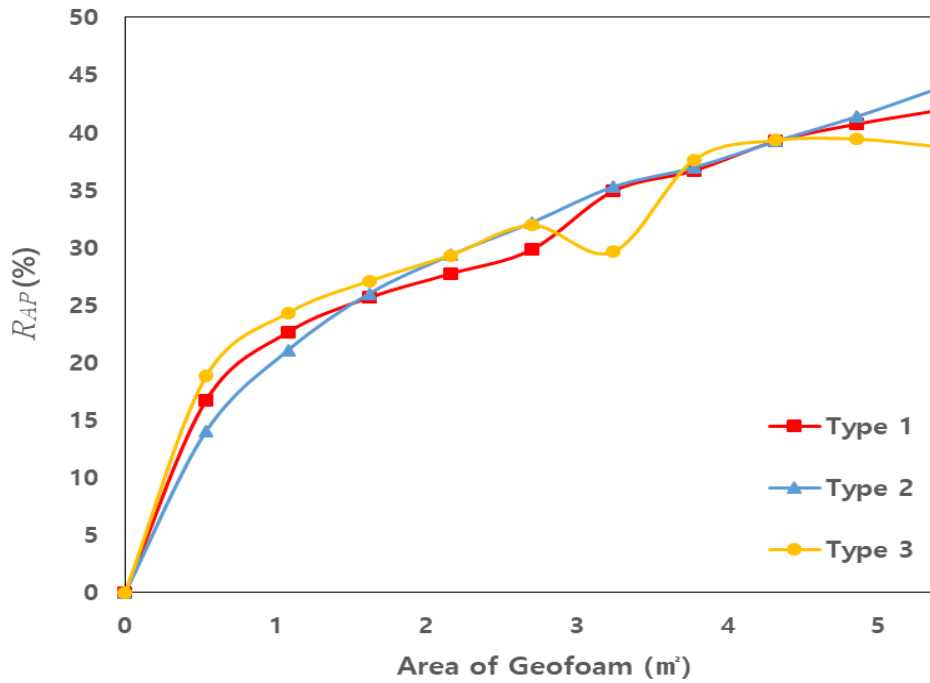
[Fig 38] Reduction ratio of earth pressure on the base of retaining wall when the area of geofoam is 5.4m<sup>2</sup>

When the maximum lateral earth pressure reduction rate of the retaining wall according to the geofoam area was examined, the maximum lateral earth pressure reduction rate of about 60% was observed in Type 1 and Type 3 when the area of the geofoam was more than 1m<sup>2</sup>. In addition, when the area of the geofoam is about 2 m<sup>2</sup> or more, similar maximum soil pressure reduction rates were observed in all types. In the case of Type 2, when the area of the geofoam was about 2m<sup>2</sup> or more, there was little change in the maximum lateral earth pressure reduction rate as the area increased (Figure 38).



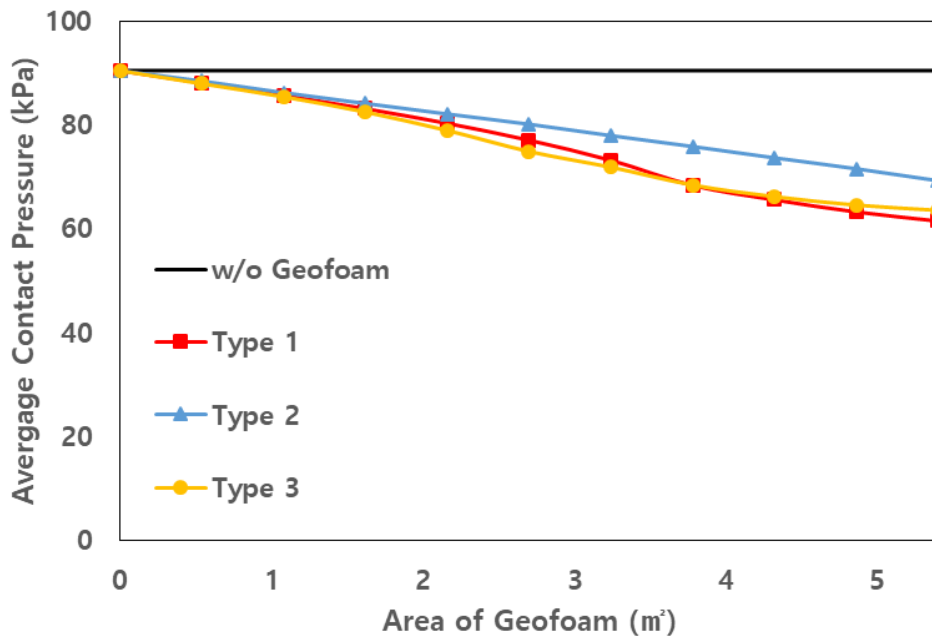
[Fig 39] Reduction ratio of maximum lateral earth pressure on wall of retaining wall depending on area of geofoam

When examining the average lateral earth pressure reduction rate of the retaining wall according to the geofoam area, it can be seen that the change rate of the reduction rate is larger than the maximum soil pressure reduction rate. In addition, the average lateral earth pressure reduction rate was similar for all types. When the area of the geofoam was  $1 m^2$  or more, the average soil pressure reduction rate was 20% or more (Figure 39).



[Fig 40] Reduction ratio of average lateral earth pressure on wall of retaining wall depending on area of geofoam

When looking at the average earth pressure of the retaining wall floor according to the geofoam area, it was confirmed that the earth pressure of the retaining wall floor decreased as the geofoam area increased regardless of the type. Also, regardless of the type, the soil pressure at the bottom showed similar values. In addition, in the case of Type 2, the average increase in earth pressure on the retaining wall floor was the smallest (Figure 39).

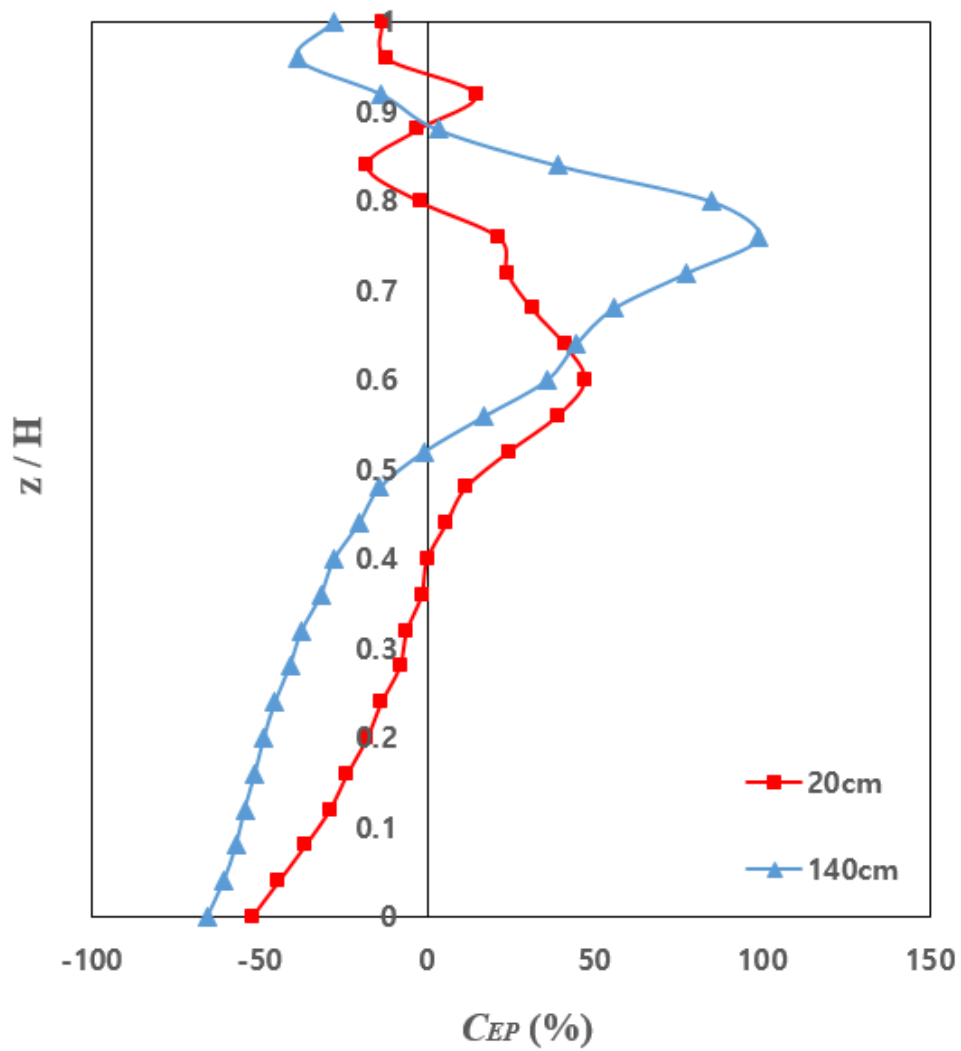


[Fig 41] Average earth pressure on base of retaining wall depending on area of geofoam

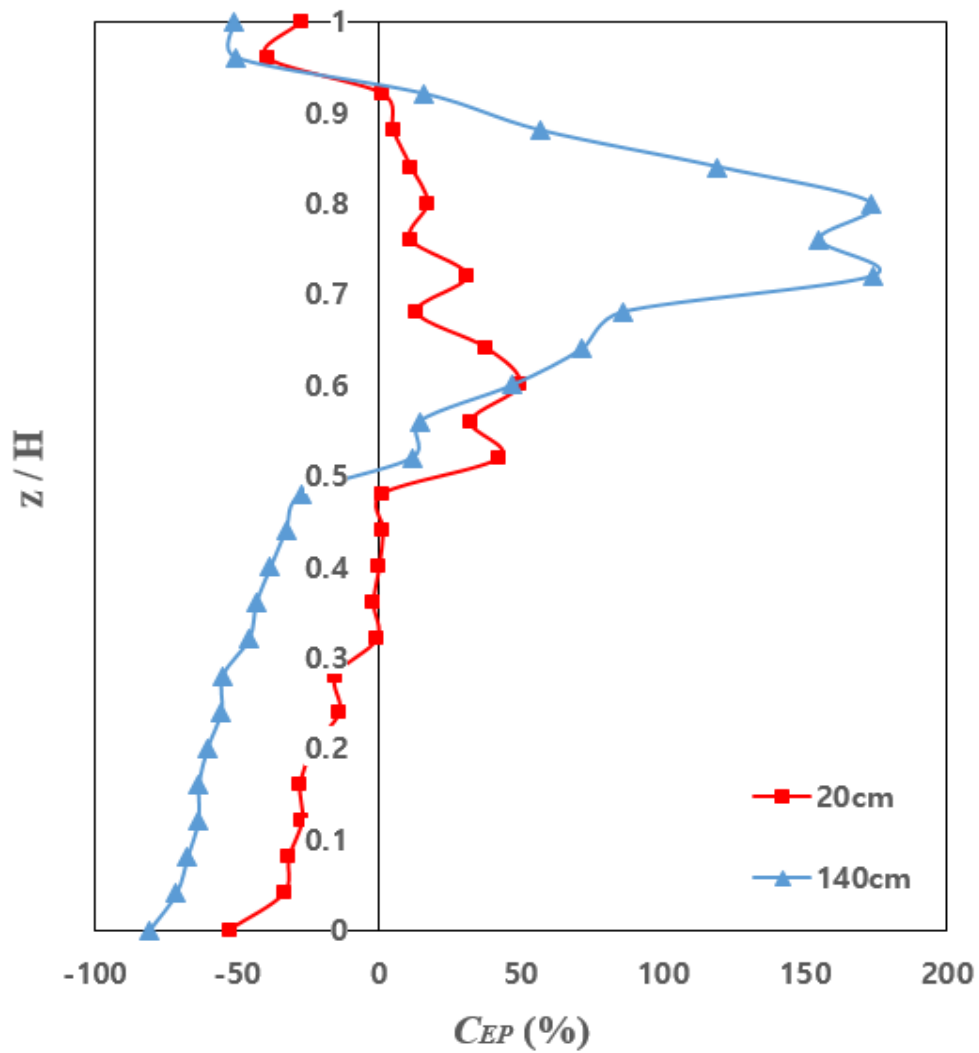


### **3.6. Earth Pressure According to Slope of Backfill**

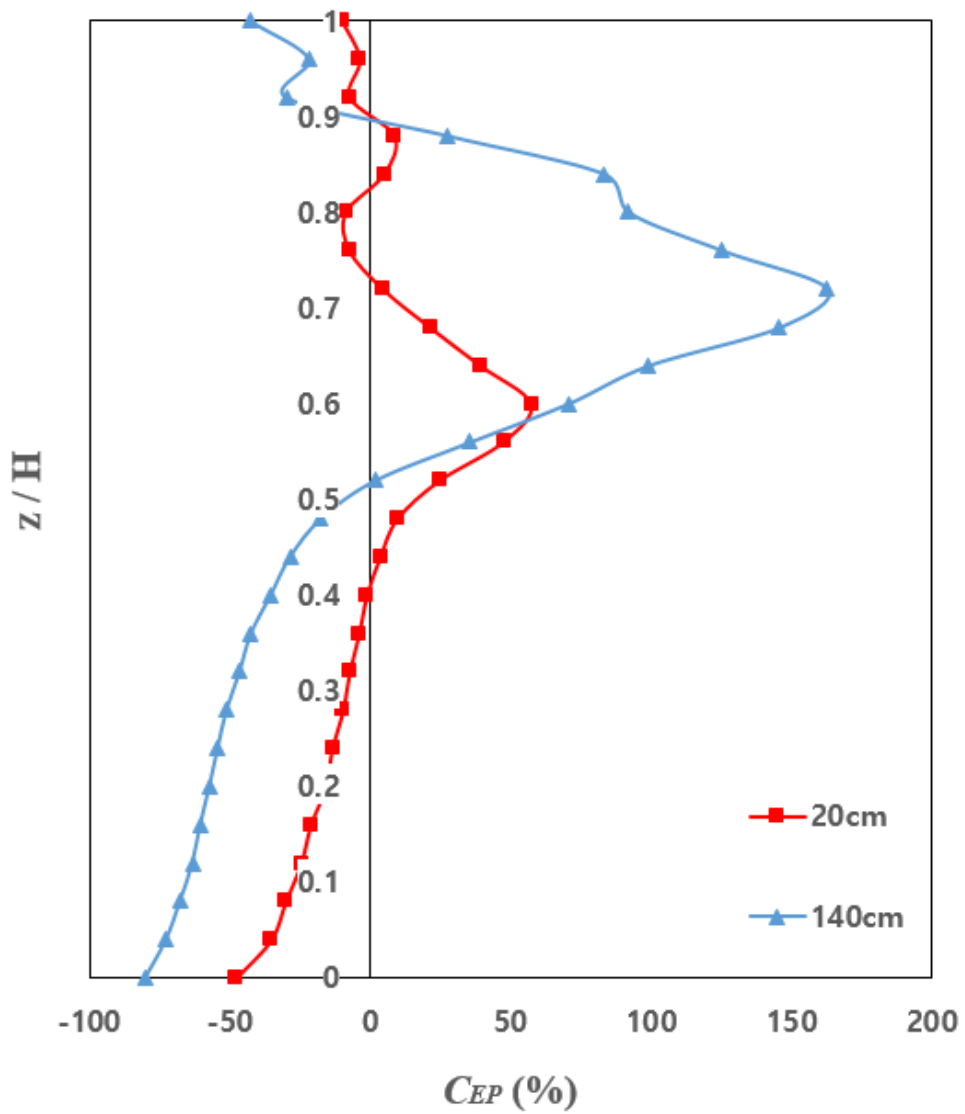
The rate of contact pressure change according to the slope of the backfill was as follows (Figure 40–46). When the length of the base of the triangular geofom is 140 cm, the rate of increase in soil pressure at the top of the wall of the retaining wall increases as the slope of the backfilling soil increases. On the other hand, when the length of the base was 20cm, the earth pressure increase rate at the top of the retaining wall was somewhat similar regardless of the slope of the backfill soil. In addition, it was confirmed that regardless of the length of the base of the triangular geofom, the reduction rate of soil pressure at the bottom of the retaining wall was not significantly affected by the slope of the backfill soil. Through this, it was confirmed that even when there is a slope of the backfill, it is possible to reduce the earth pressure in the retaining wall through the geofom.



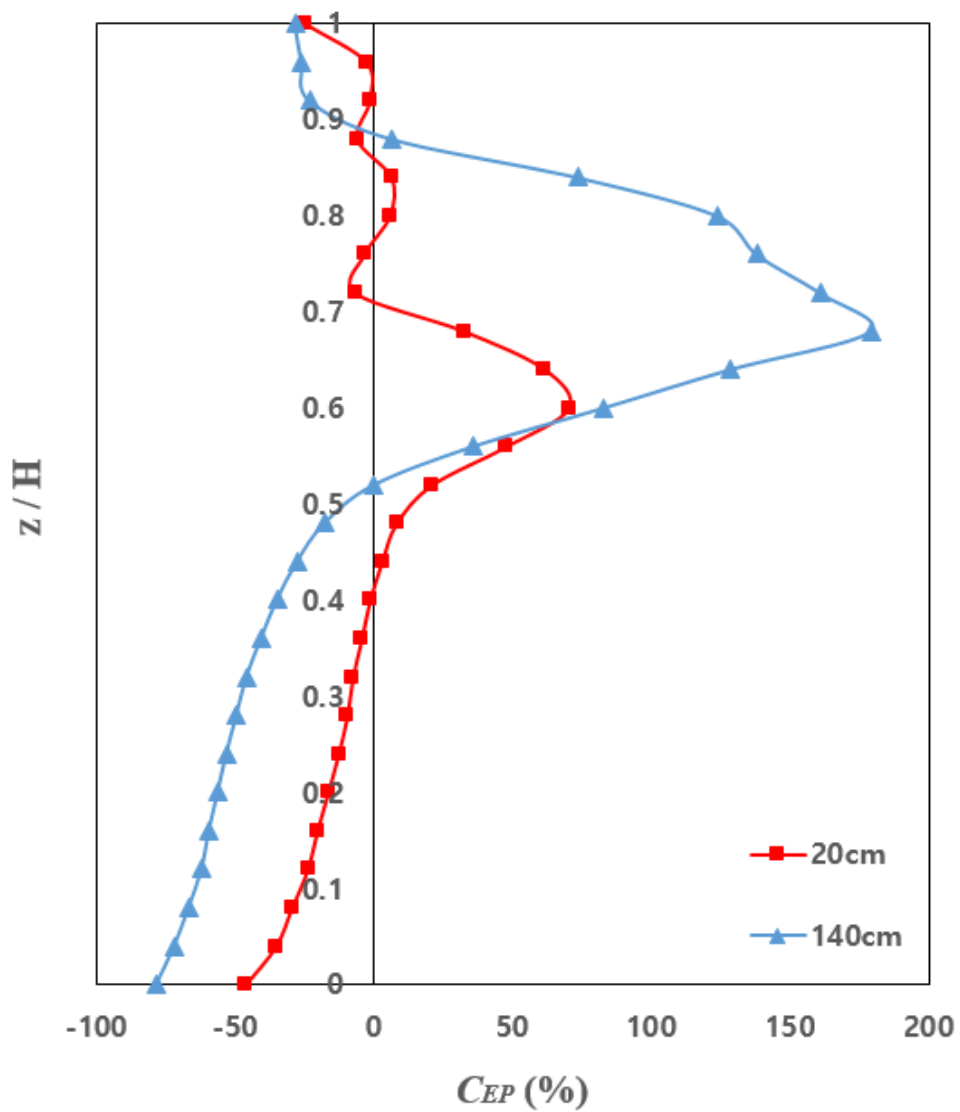
[Fig 42] Rate of change in lateral earth pressure on wall of retaining wall depending on base length of geofabric when slope of backfill is  $0^\circ$



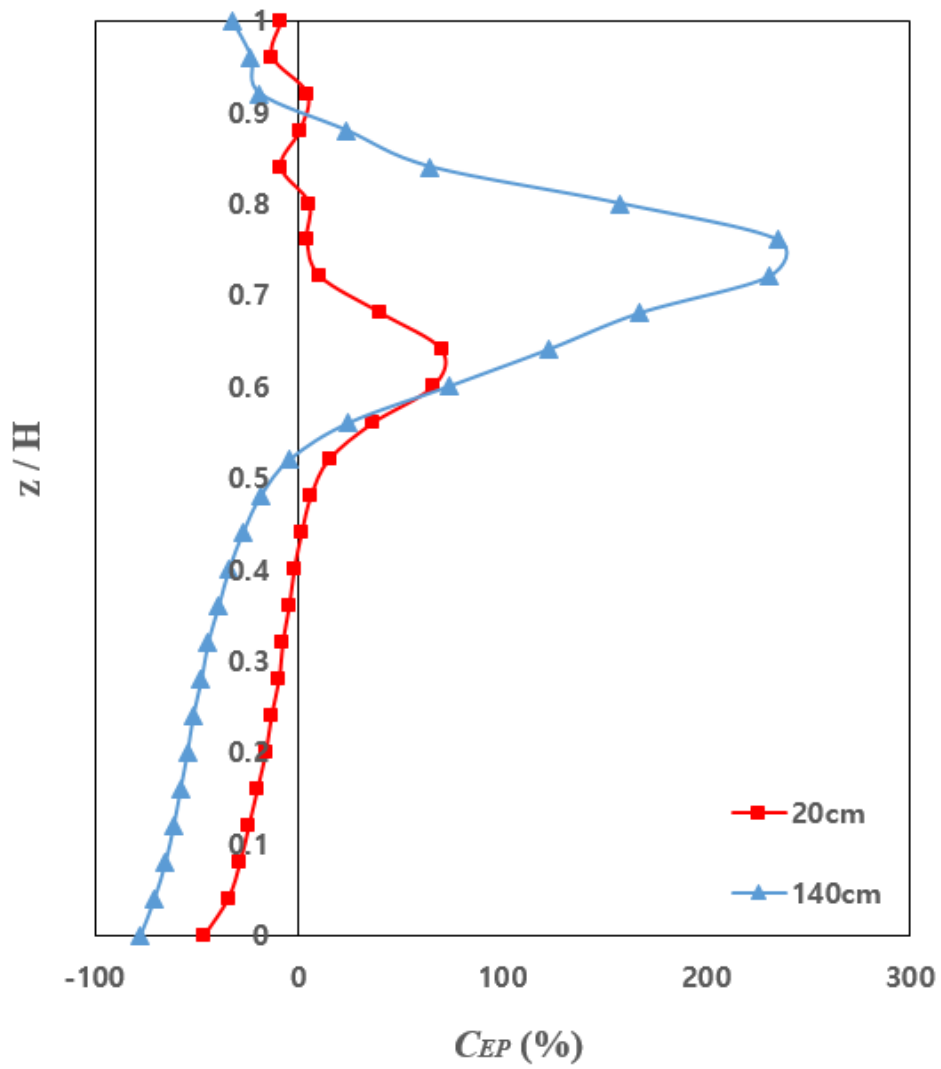
[Fig 43] Rate of change in lateral earth pressure on wall of retaining wall depending on base length of geofoam when slope of backfill is  $5^\circ$



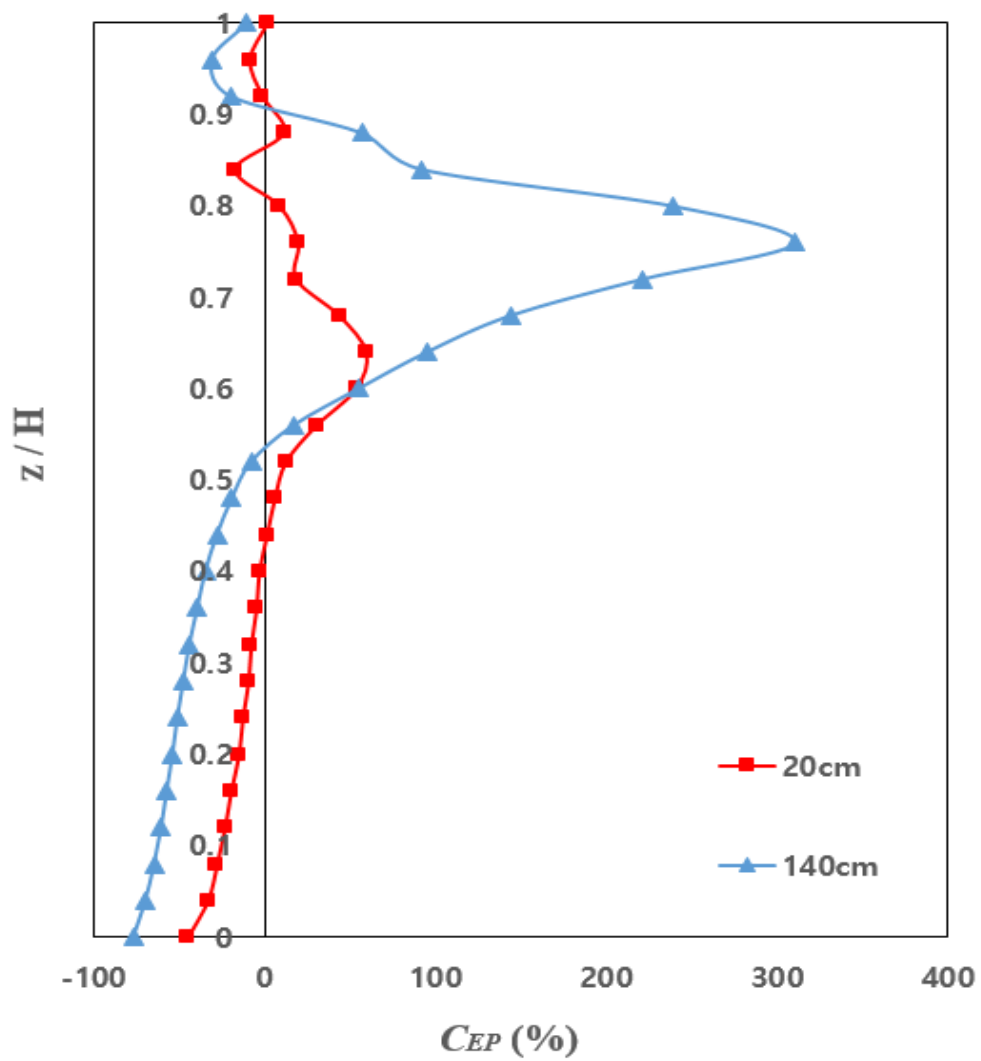
[Fig 44] Rate of change in lateral earth pressure on wall of retaining wall depending on base length of geofoam when slope of backfill is  $10^\circ$



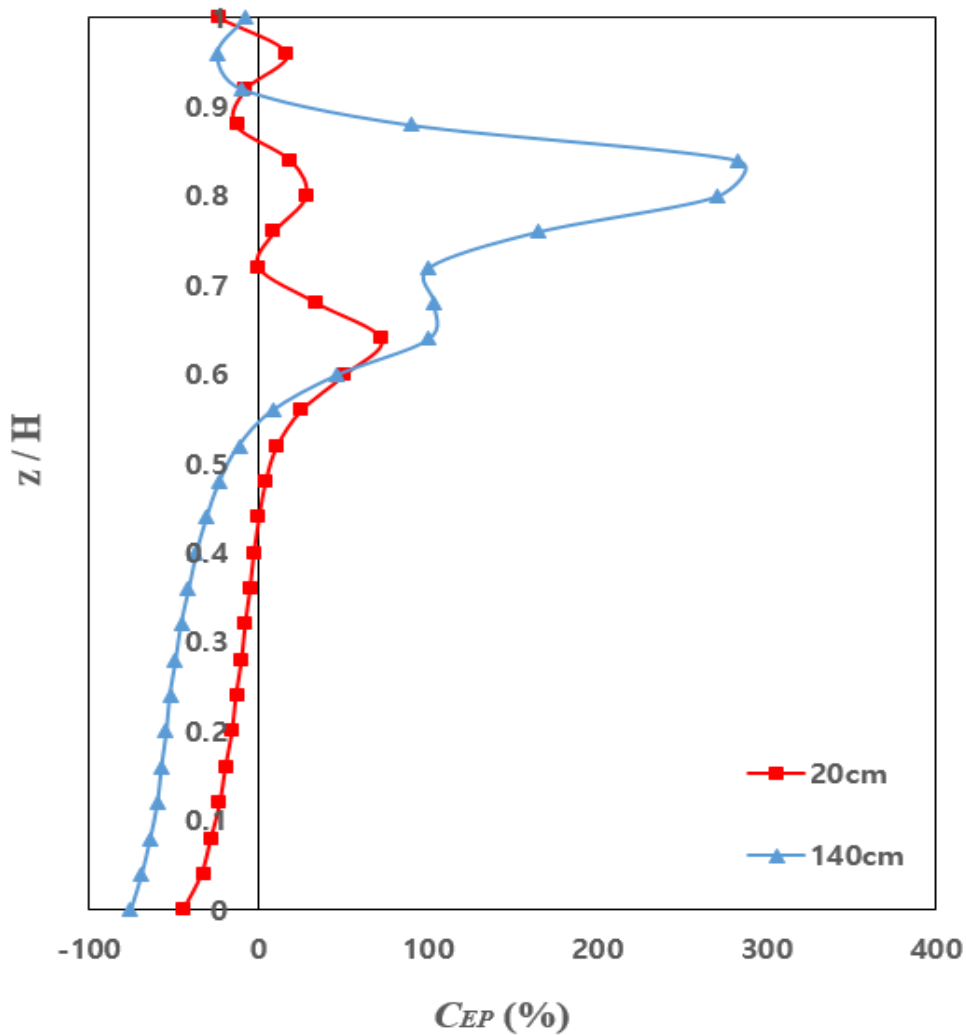
[Fig 45] Rate of change in lateral earth pressure on wall of retaining wall depending on base length of geofoam when slope of backfill is  $15^\circ$



[Fig 46] Rate of change in lateral earth pressure on wall of retaining wall depending on base length of geofoam when slope of backfill is  $20^\circ$



[Fig 47] Rate of change in lateral earth pressure on wall of retaining wall depending on base length of geofabric when slope of backfill is  $25^\circ$

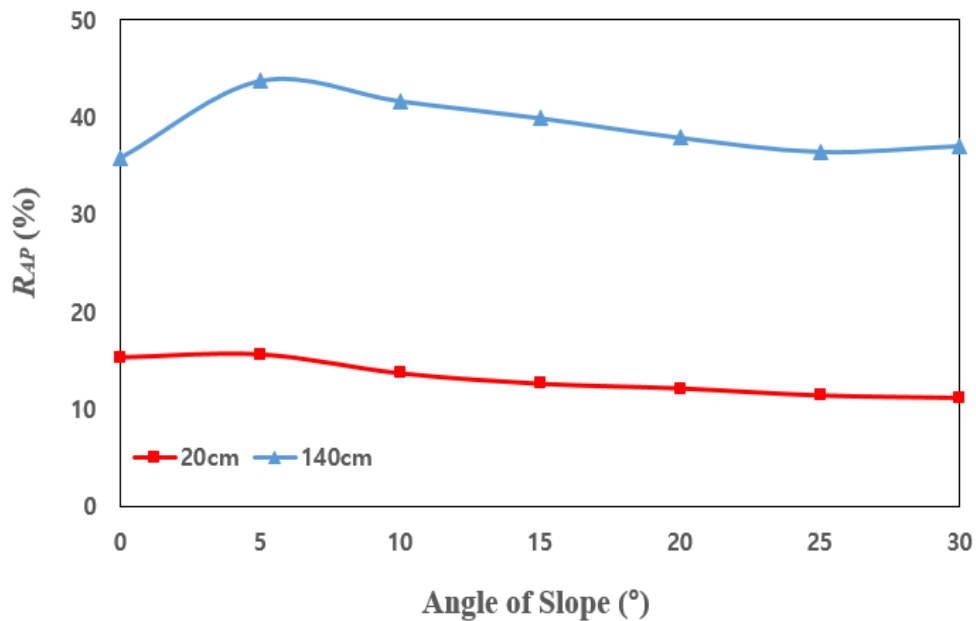


[Fig 48] Rate of change in lateral earth pressure on wall of retaining wall depending on base length of geofoam when slope of backfill is 30°

When examining the change in the average lateral earth pressure on the wall of the retaining wall when applying geofoam to the retaining wall with the slope of the backfill soil, when the length of the base of the triangular geofoam is 20 cm, it is confirmed that average lateral earth pressure reduction rate is about 10% regardless of the inclination. In addition, it was confirmed that as the slope increased, the effect of reducing the average lateral earth pressure by the geofoam decreased. When the length of the base of



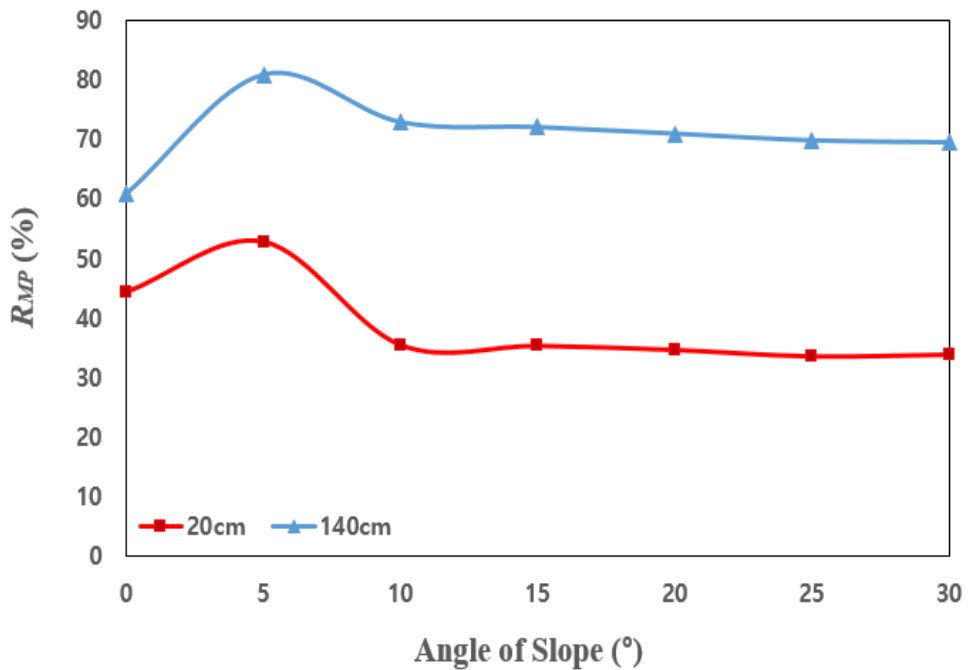
the triangular geofoam is 140 cm, the average lateral earth pressure reduction rate is about 45% when the slope is 5 degrees, but the rate of decrease gradually decreases as the slope increases. When the inclination angle was 30 degrees, the average earth pressure reduction rate was about 35%. In addition, the reduction rate of the average soil pressure according to the increase in slope was larger when the width of the base of the triangular geofoam was 140 cm than when the length of the base was 20 cm (Figure 47).



[Fig 49] Reduction ratio of average earth pressure of wall of retaining wall depending on slope of backfill

The maximum lateral earth pressure reduction rate increased when the slope of the backfill soil increases from 0 to 5 degrees regardless of the length of the base of the triangular geofoam when examining the change in the maximum lateral earth pressure of the retaining wall when applying geofoam to the retaining wall with the slope of the backfill soil. Also, when the slope of the soil increased from 5 degrees to 10 degrees, the maximum lateral earth pressure reduction rate decreased, and the maximum lateral earth pressure

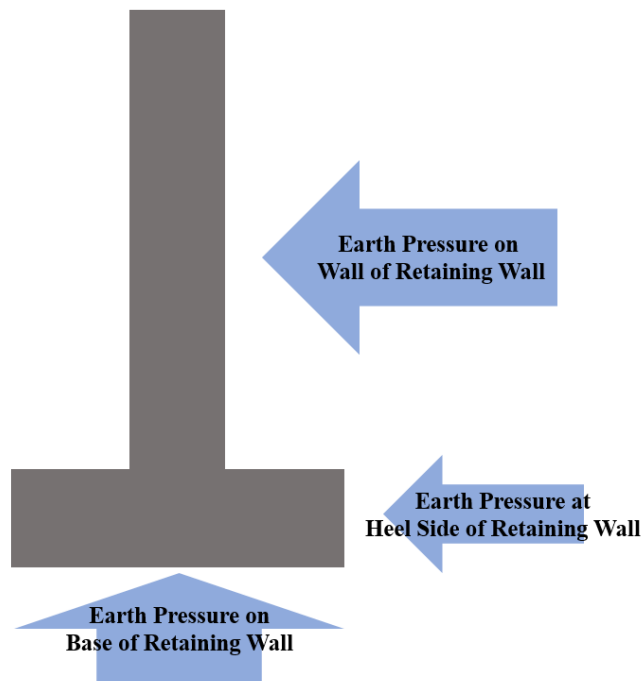
reduction rate after the slope increase was almost constant. When the length of the base of the triangular geofoam is 20cm and the slope of the backfill soil is 5 degrees, the maximum soil pressure reduction rate is about 50%, and when the slope is 5 degrees or more, the maximum soil pressure reduction rate is about 30%. When the length of the base of the triangular geofoam was 140 cm and the slope of the backfill soil was 5 degrees, the maximum soil pressure reduction rate was about 80%, and when the slope was 5 degrees or more, the maximum soil pressure reduction rate was about 70% (Figure). When examining the changes in the maximum lateral earth pressure reduction rate and the average lateral earth pressure reduction rate on the wall of the retaining wall, it was found that the soil pressure reduction effect of the geofoam was less affected by the slope of the backfill soil (Figure 48).



[Fig 50] Reduction ratio of maximum earth pressure of wall of retaining wall depending on slope of backfill

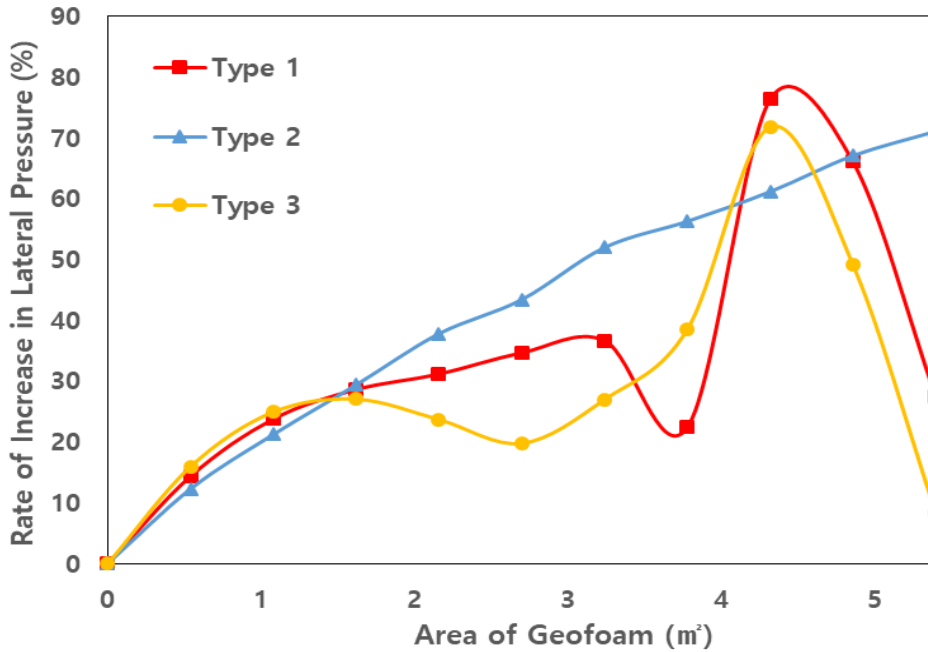
### 3.7. Variation of the Earth Pressure Ratio of Retaining Wall

Through previous experiments, it was possible to confirm the reduction of earth pressure on the wall of the retaining wall. In this experiment, the earth pressure received by the retaining wall was largely three. It can be divided into the earth pressure applied to the retaining wall first, the earth pressure received from the wall of the retaining wall, second earth pressure received from the base of the retaining wall, and the earth pressure at the heel side of the retaining wall (Figure 51). In this study, the reduction of earth pressure on the walls and floor of the retaining wall was mainly examined. In the case of retaining walls, there are many studies mainly examining changes in pressure of wall of the retaining wall, so this study also attempted to analyze safety by observing changes in wall pressure and base pressure. As a result, the reduction of the retaining wall and base soil pressure was confirmed. This study intends to examine the change in the earth pressure at the heel side of the retaining wall.



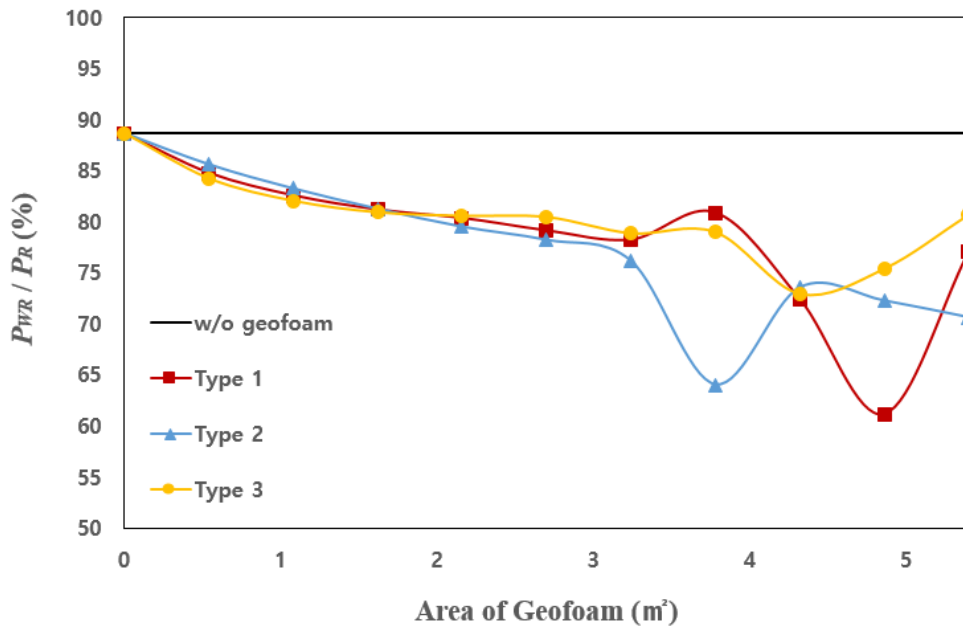
[Fig 51] Schematic diagram of earth pressure of retaining wall

First, when examining the change in the average earth pressure at the heel side of the retaining wall according to the geofoam area by type, when the area of the geofoam became larger than  $1\text{ m}^2$ , it showed an increase in earth pressure of 20% or more. In the case of Type 1, when the area of the geofoam increased from  $1\text{ m}^2$  to  $3\text{ m}^2$ , it showed a constant average increase in earth pressure of about 30%. However, if the area of the geofoam is more than  $3\text{ m}^2$ , the average increase in earth pressure decreased to 20%, and when the area became larger than  $4\text{ m}^2$ , it showed an average increase in earth pressure over 60%. However, when the area becomes larger than  $5\text{ m}^2$ , the increase in earth pressure was found to be about 20%, which could be inferred that geofoam acted as a substitute for backfill, not as a reinforcement for retaining walls. In the case of Type 2, it was confirmed that the rate of increase in the earth pressure at the bottom of the retaining wall was relatively constant. When the area increased by about  $1\text{ m}^2$ , the rate of increase in earth pressure increased by about 15%. In the case of Type 3, the average earth pressure increase rate pattern similar to Type 1 was shown, and when the area increased from about  $1.5\text{ m}^2$  to  $3\text{ m}^2$ , the earth pressure increase rate decreased. In addition, when the area exceeded  $5\text{ m}^2$ , the rate of increase in earth pressure decreased to 10% (Figure 52).



[Fig 52] Rate of increase in lateral earth pressure at heel side of retaining wall depending on area of geofoam

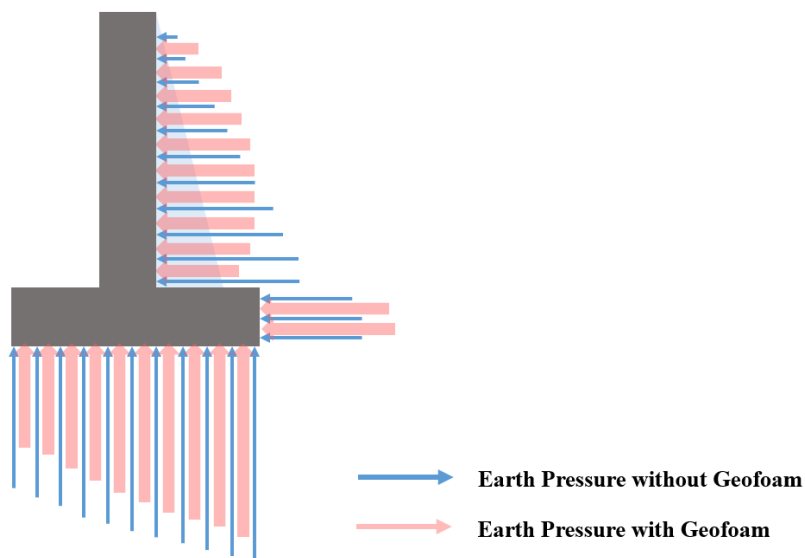
Next, the sum of the earth pressure received by the wall of the retaining wall and the earth pressure received by the heel side of the retaining wall was considered as the retaining wall earth pressure, and the ratio of retaining wall earth pressure and earth pressure received by the wall of the retaining wall was examined. First of all, if there is no geofoam, the earth pressure on the wall of the retaining wall was about 90%. On the other hand, with geofoam, the earth pressure ratio of 80% of the wall of retaining wall was shown up to about 3m² regardless of type. This is a decrease of about 10% compared to the absence of geofoam, and considering that the average earth pressure growth rate of the heel side of the retaining wall according to geofoam is about 20% or more, it was confirmed that the decrease in the earth pressure of the wall of the retaining wall is significantly affecting the earth pressure of the retaining wall (Figure 53).



[Fig 53] Ratio of earth pressure to the wall of retaining wall according to area of geofoam

( $P_R$  = Pressure on wall of retaining wall + Pressure at heel side of retaining wall,  $P_{WR}$  = Pressure on wall of retaining wall)

Through this study, change in the earth pressure of the entire retaining wall through the geofoam was examined, and the effect and principle of reducing the earth pressure through the geofoam were generally understood.



[Fig 54] Schematic diagram of change of earth pressure in retaining wall

## **Chapter 4. Conclusions**

The purpose of this study was to investigate the effect of reducing soil pressure as a reinforcement in the retaining wall of the geofoam, and to find the optimized geofoam shape. Furthermore, it was intended to examine the principle of reducing earth pressure as a reinforcement of geofoam. Experiments have confirmed that geofoam can be used as reinforcements between the retaining wall and backfill, not as substitutes for the backfill. In particular, it was confirmed that the maximum soil pressure reduction effect of the geofoam was excellent when reinforcing the geofoam at the bottom of the retaining wall, and that the distribution of the earth pressure within the retaining wall was even. In addition, there was a decrease in the earth pressure on the walls and floors of the retaining wall when the geofoam was introduced within the retaining wall, but there was an increase in the earth pressure at the bottom of the retaining wall. This allowed to predict the movement of soil when using geofoam in retaining walls as reinforcements. Through this study, the results of the study were derived as follows.

First, in the application of geofoam in the retaining wall, the triangular geofoam is the most optimized shape for the retaining wall. Through the previous experiments, it was confirmed that reinforcing the lower part showed the greatest effect of reducing the maximum earth pressure when applying the same area of geofoam. Based on this, as a result of applying various types of geofoam to the retaining wall, it was confirmed that the shape of the triangle, which was reinforced not only by the simply lower part but also by the upper part to some extent, can most effectively reduce the soil pressure. When reinforcing a retaining wall through a triangular shaped geofoam, even if an additional load is generated on the upper part of the backfill soil, it is expected that the deformation of the geofoam itself is small compared to the existing tile-shaped retaining wall reinforcement. In addition, when looking

at the reduction of the earth pressure of the wall of the retaining wall as the length of the base side of the triangular geofom increased, it was found that the maximum reduction rate of the wall of the earth wall increases as the length of the base side increases. However, the maximum earth pressure reduction rate of the retaining wall did not show a significant difference when the length of the base was 50cm or more, and the average soil pressure reduction rate did not show a significant difference when the length of the base was 150cm or more. Therefore, through this study, it is expected that the role of the geofom as a reinforcing material to lower the earth pressure of the retaining wall surface can be expected if the length of the base is applied only to about 10% or more of the height of the retaining wall.

Second, the geofom with relatively low density has a greater effect of reducing the maximum earth pressure of the retaining wall. As a result of applying the geofom of various physical properties to the retaining wall in a triangular shape with the same area, it was confirmed that the maximum earth pressure reduction effect is greater as the geofom density decreases. Therefore, in this experiment, it was confirmed that EPS12 is the most efficient property. In addition, when considering the deformation of the geofom itself for various properties, it was confirmed that the strain is very low. From this, it seems that if geofom is used as a reinforcement for retaining walls, not as a substitute for backfill soil, there will be no problem in construction safety even if geofom with low density is used. In addition, even if geofom having a density lower than that of EPS12 used in this study is used, it is expected that there will be no problem of geofom deformation.

Third, it was confirmed that if a certain reinforcement was made under the wall of the retaining wall by geofom, there would be a constant decrease in soil pressure under the wall of the retaining wall regardless of the type of geofom. The study of the earth pressure change on the area change of three types of geodes reinforced with geofom at the lower part of the wall of the retaining wall showed the average lateral earth pressure reduction



effect of at least 15% and maximum lateral earth pressure reduction effect of at least 30% in the wall of the retaining wall. In addition, if a certain area of geofoam is reinforced at the lower part, the average lateral earth pressure reduction effect was about 30% and the maximum lateral earth pressure reduction effect was 50% in the wall of the retaining wall. However, as the reinforcement of the lower part of the wall increases, the rate of increase in soil pressure at the upper part of the wall of the retaining wall also increases, so this part should be considered as well. It is expected that the safety of retaining walls will be improved efficiently if applied appropriately for construction considering the rate of earth pressure change at the upper and lower ends of retaining walls derived from this experiment.

Fourth, when reinforcing the retaining wall through geofoam, the earth pressure at the heel side of the retaining wall increases due to the movement of soil. In this study, not only the earth pressure of the wall of the retaining wall but also the earth pressure of the heel side and floor of the retaining wall were observed, and as a result, it was confirmed that the change in the earth pressure at the heel side of the retaining wall was not significantly affected by the properties and shape of the geofoam. The increase in earth pressure at the heel side of the retaining wall by geofoam could be observed, but considering the rate of reduction of the earth pressure in the retaining wall, it is not expected to significantly affect the safety of the retaining wall. However, it is expected that construction will not only take into account the reduction of the earth pressure on the walls and base of retaining walls, but also take into account the increase of the earth pressure at the heel side.

In this study, no studies have been conducted on the safety of earthquakes or the groundwater level when reinforcing retaining walls through geofoam. However, through this study, it was possible to confirm the possibility of various application of geofoam in the retaining wall. In addition, it was possible to quantitatively calculate the effect of geofoam in actual construction by examining the changes in the earth pressure of the retaining wall, such as the wall

surface and the floor, according to the change in the area of the retaining wall. The results of this study may be an indicator of the actual effectiveness of geofoam. Furthermore, through the results of this study, it was confirmed that it is possible to reduce the cost and resources by reducing the area of the retaining wall or reducing the weight during construction using actual geofoam. It was confirmed that geofoam can provide additional landscaping space and reduce landscaping costs. If more experiments with retaining wall models are made in the future, it is thought that it will be possible to provide practical guidelines for the application of geofoam in retaining walls.

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## Abstract (Korean)

# 옹벽 내 지오포름 적용 시 토압 저감원리에 관한 연구

정연옥

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옹벽은 조경 및 토목, 건축 분야에서 널리 사용되어 왔다. 옹벽은 주택가, 도로 등 생활공간에 밀접한 곳에 건설되기 때문에 붕괴 시 큰 피해와 인명 손실이 발생할 수 있다. 이에 따라, 옹벽의 안전성을 높이는 방법에 대해서는 꾸준한 논의가 이어져 왔다. 특히 옹벽의 토압을 줄임으로 옹벽의 안전을 향상시키는 방법이 하나의 대안으로 연구되고 있다. 본 연구의 목적은 유한 요소(FE) 해석을 통해 옹벽의 토압 감소에 대한 지오포름 적용의 효율성을 조사하는 것이었다. 나아가 지오포름 활용 시의 옹벽 내 토압 저감 원리를 밝히고자 하였다. 본 연구에서는 지오포름의 다양한 기하학적 매개변수를 검토하여 지오포름의 최적 형상을 발견함으로써 옹벽에 대한 토압을 효율적이며 경제적으로 감소시키고자 하였다. 이를 통해 삼각형의 지오포름 형태가 옹벽에 가장 최적화되어 있음을 확인하였다. 또한, 지오포름의 물성 및 면적 변화, 뒷채움의 흙의 경사에 따른 옹벽 내 토압을 조사하였다. 아울러 유한요소 해석 결과는 유사한 옹벽에서 수행된 실험과의 결과비교를 통해 검증되었다. 또한 옹벽 전체의 토압 변화를 살펴봄으로 지오포름으로 인한 옹벽 내 토압 저감 원리를 규명하였다. 본 연구를 통해 지오포름을 이용해 옹벽하단부를 보강하는 경우, 지오포름의 형태에 관계없이 다소 일정한 토압감소를 보임을 확인할 수 있었다.

**주요어 :** 유한요소해석, 지오포름, 옹벽, 아바쿠스

**학번 :** 2019-27874