A MASTER'S THESIS

A STUDY ON THE EROSION CONTROL OF THE COASTAL BEACH WITH AN ARTIFICIAL REEF

CHEJU NATIONAL UNIVERSITY GRADUATE SCHOOL

Department of Civil & Ocean Engineering

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February 2008

人工리프에 의한 海濱의 侵蝕解析 에 관한 研究

指導敎授 金 南 亨

文 智 嫄

이 論文을 工學 碩士學位 論文으로 提出함

2008年 2月

文智嫄의 工學 碩士學位 論文을 認准함

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濟州大學校 大學院

2008年 2月

A STUDY ON THE EROSION CONTROL OF THE COASTAL BEACH WITH AN ARTIFICIAL REEF

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A thesis submitted in partial fulfillment of the requirement for the degree of Master of Engineering

2008. 2

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February. 2008

Department of Civil & Ocean Engineering

GRADUATE SCHOOL
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Summary

Recently, the erosion problem in our coast zone becomes more and more serious because of several artificial activities due to the expansion of city function, industrial complex and harbor facility and so on. To make matter worse, the erosion problem becomes serious more and more because of picking of sea sand that is used to aggregate resources in construction sites, which is major factor of income and outgo of sea sand. Also, environmental and economical importance of the coastal beach zone grows bigger and bigger.

Coastal beach zone is eroded constantly by the waves accompanied with the rising of the water lever by storm surge and high tide. For this reasons, the concern for the coastal beach protection increases more and more. Therefore, it is necessary to study on the erosion control of the coastal beach.

When it comes to the models of the coastal beach erosion, Vellinga (1982, 1983, 1986) calculated the coastal beach change by the time. But Vellinga(1982, 1983, 1986) model for the numerical simulation of the coastal beach erosion has restrictions, which is that it will not timely be able to track the coastal beach change to reappear the sandbar and predicted time is restricted. Also, Krebel Model can calculate the change of the coastal beach and sandbar, but can not express the sandbar, timely. So considering the drawbacks of the incident waves of the Vellinga model, SBEACH model proposed by Larson and Kraus (1989) is applied to calculation of the formation and the erosion behavior of the coastal beach topography in this study, for SBEACH model proposed by Larson and Kraus (1989) is more suitable to this numerical computation.

The calculative order of the two-dimensional SBEACH model is the same with other normal coastal beach models and can be written as follows:

(1) Dally (1980), Dally et al. (1985)'s equation is used to calculation of the wave transformation in this paper.

(2) About the calculation of the cross-shore sediment transport rate in this study, the cross-shore sediment transport rate is basically calculated by energy dissipation per unit day in broken wave zone. And based on the division of the profile applied in near-shore wave dynamics and the physical characteristic of cross-shore sediment transport under

various flow conditions, four different zones of transport were introduced as four sections. These zones are pre-breaking zone, breaker transition zone, broken wave zone and swash zone.

(3) The profile change calculation of the coastal beach by continuity equation of sediment is based on sediment transport rate of time level of two.

In this study, an artificial reef is applied to exposed non-erodible bottom, and this study is composed of three sub models. The formation of the coastal cliff and erosion behavior of the coastal beach has been carried out using SBEACH model proposed by Larson and Kraus (1989).

First, the numerical analysis of the coastal beach with and without an artificial reef is carried out in order to investigate erosion control effect by an artificial reef. Form the numerical results, it is shown that the result is more effective for the case with an artificial reef than without an artificial reef in controlling the coastal beach erosion.

From the results of the coastal beach erosion analysis due to the offshore distance of the artificial reef, it is shown that as the offshore distance of the artificial reef is closer to the shoreline, the erosion control ability of the artificial reef is more effective in controlling the coastal beach erosion.

When it comes to the coastal beach erosion analysis due to the height of the artificial reef, it is shown that the higher the height of the artificial reef is, the smaller the coastal beach erosion occurs. And, it is also shown that the scouring phenomenon is occurred at the outside of the artificial reef and sandbar is formed. It is considered because higher the height of the artificial reef is, the weaker the wave force becomes.

From the results of the coastal beach erosion analysis due to the width of the artificial reef, it is shown that the narrower the width of the artificial reef is, the bigger the scouring depth and scouring area by the wave is. This reason is considered because the broader the width of the artificial reef is, the weaker the wave force becomes.

As the optimum conditions of the artificial reef in controlling the coastal beach erosion, it is shown that as the offshore distance of the artificial reef is close to the shoreline, the erosion control of the coastal beach is more effective. And, it is shown that as the height of the artificial reef is high, the erosion control of the coastal beach is more effective. Also, it is shown that as the width of the artificial reef is wide, the erosion control of the coastal beach is more effective than any other condition of the artificial reef. But, the conditions of the height and the width of the artificial reef are not more effective than the condition of offshore distance of the artificial reef in controlling the coastal beach erosion.

On the results of the erosion behavior of the coastal beach due to berm location of the artificial reef, an artificial reef with a left-hand side berm is more effective than any other condition in controlling the coastal beach erosion. And the scoring area in artificial reef with a left-hand side berm is greater than other two cases, but the scouring depth is the most small.

From the numerical results of the erosion behavior of the coastal beach due to the incident wave angle, when the incident wave comes into as 0°, the coastal beach erosion was the greatest. And, it is shown that the smaller (bigger) the incident wave angle is, the larger (smaller) the coastal beach erosion occurs. Also, it is shown that the coastal beach erosion is not seriously affected when the incident wave angle comes into as 45° and 60°.

This numerical analysis can be applied to real coastal beach through numerical simulation model of the coastal beach erosion, including non-erodible and exposed non-erodible bottom. But this study should be improved in the future. The numerical simulation of the coastal beach erosion behavior, including erodible bottom, non-erodible bottom and exposed non-erodible bottom, has carried out in this study. But, it is necessary to study in order to raise accuracy of the numerical analysis.

The compacted effect of sand dune surface, the covering effect by landing treatment, the recovering of erodible area by wind-blown sand, the flow effect by the storm waves or tsunami and the formative factor are should be considered in the future as well as erodible bottom, non-erodible bottom, exposed non-erodible bottom. Also, the difference of the coastal beach erosion behavior by porous and non-porous of the artificial reef should be considered. And, the improvement of the numerical simulation by field surveying is necessary in the future.

Therefore, this numerical method will be broadly used to prevent erosion and protect eco-system in the coastal beach zone in the future. And the results obtained by this erosion analysis will usefully be used to control the erosion process.

CHAPTER 1: INTRODUCTON

1.1 Background

Recently, the erosion problem in our coast zone becomes seriously more and more because of several artificial activities due to the expansion of city function, industrial complex and harbor facility and so on. To make matters worse, the erosion problem becomes seriously more and more because of picking of sea sand that is sued to aggregate resources in construction sites, which is major factor of income and outgo of sea sand. Also, the environmental and economical importance of the coastal beach zone grows bigger and bigger.

The configuration of the shoreline is very different according to the time and zone, and the shoreline changes variously. The coastal beach zone has many primary roles as the boundary between land and sea. This coastal beach zone protects land from the erosion caused by wave motion. Also, this coastal beach zone controls both wind-blown and wind-blown salt. And, the coastal beach zone has many functions as a source of supply of bottom material sediment when the coastal beach is eroded by storm, a shock-absorbing zone due to the sea level rising and the global warming, a hydrophilic space including a campground, water-sport space and so on.

Like this, coastal beach zone is constantly eroded by the waves accompanied with the rising of the water level by storm surge and high tide. Therefore, this erosion motion accelerates the regression of the coastal cliff as a result of the regression of the dune or the shoreline. In addition, the regression loses real estate in the hinterland as well as ruins the shock-absorbing zone between land and sea. So the destruction of the dune may lead to a loss of the habitat of egg-laying grounds of living creatures. Also, the erosion motion of the coastal beach zone takes away life sites of inhabitants who live in coastal beach zone, and the erosion problem has influence on local economy because of decreasing in visitors.

There is a sea cliff in the shore, Horikawa and Sunamura (1967, 1968, 1969, 1970, 1972) clarified the behavior of sea cliff erosion by air photos and experiments. And, Ven de Graff (1977) defined the erosion section, based on the data obtained by storm surge in the field. Vellinga (1982, 1983, 1986) defined the equilibrium profile of the beach formed by the storm surge, based on experimental results, and performed the computation of the erosion section using a computer. In addition, the erosion model of sand dune by time was developed by Kriebel and Dean (1984, 1985), Kriebel (1990) and Larson and Kraus (1989, 1990).

Furthermore, Gonzalez and Medina (2000) compared natural beach with an artificial beach and computed changes of the coastal beach profile in the coastal beach erosion behavior. Hanson and Kraus (2000) studied about the representation of tombolos and sediment transport by tidal currents using the GENESIS model. Moreover, Larson, Erickson and Hanson (2004) carried out an analytical model to predict dune erosion due to wave impact. On top of that, Kim and Kang (2003) computed a numerical simulation of erosion behavior for the beach cliff with and without a seawall. Donnelly and Larson (2005) studied about numerical modeling of the beach profile changes caused by over-wash. Also, Kim and Mun (2007) carried out numerical simulation of the erosion behavior of the coastal beach by an artificial reef.

Therefore, it is necessary to study on the erosion control and erosion process of the coastal beach.

1.2 Objectives

Erosion of the coastal beach around the world is serious and complex problem. And, this erosion of the coastal beach is occurred by waves accompanied with the rising of the water level by storm surge, high tide, storm, over-wash, hurricanes and winter-storms impact in the shore.

Recently and globally, Numerical simulation for the erosion behavior and erosion process in the coastal beach zone including erosion of the coastal beach, sand dune, coastal cliff, shoreline, cross-shore transport and long-shore transport has been actively studied.

Like this, it is necessary to study for the erosion of the coastal beach to control and predict the erosion of the coastal beach. The main objectives of this study are to control and predict the coastal beach erosion and cross-shore sediment transport rate and to investigate the optimum conditions of the artificial reef in controlling the coastal beach. Accordingly, erosion control and erosion predict of the coastal beach are very important problems in coastal and ocean engineering, technologically, these problems related in the erosion control of the coastal beach by an artificial reef has been carried out through numerical simulation around the world.

1.3 Study Contents

Unlike groin and offshore breakwater, if the coastal beach is controlled by an artificial reef which not spoils the beauty of coastal beach, artificial reef will used semi-permanently as well as good for the beauty of coastal beach. Therefore, to investigate the optimum conditions of the artificial reef in controlling the coastal beach erosion, the numerical analysis of the coastal beach due to the location of the berm is carried out. And, the numerical analysis due to the offshore distance of the artificial reef is carried out. Also, the numerical analysis due to the height of the artificial reef is carried out. And, the numerical analysis due to the width of the artificial reef is carried out. Moreover, erosion analysis of the coastal beach due to the incident wave angle is carried out in this study.

1.4 Scope and Organization

First, introduction and development process for the basic equation of the coastal beach erosion model and the cross-shore sediment transport rate is described in this study. And, SBEACH model by Larson and Kraus (1989) is used in formation of the coastal cliff and the calculation of the erosion behavior.

Calculative order of 2-dimensional SBEACH model is the same with normal coastal beach change model and this is can be written as follows:

(1) The sediment equation by Dally (1980) and Dally et al. (1985) is used in calculation of the wave transformation in this study.

(2) In order to calculate cross-shore sediment transport rate, minutely, the coastal beach section is divided into 4 sections in this study, based on the division of the profile applied in near-shore wave dynamics and the physical characteristic of sediment transport under various flow conditions. And, the cross-shore sediment transport rate is basically calculated by energy dissipation per unit day in broken wave zone.

(3) The coastal beach profile calculation by the continuity equation of exposed non-erodible bottom is based on the cross-shore sediment transport rate of time lever of two.

Like this, this study is organized as three sub models. The coastal beach erosion behavior is studied using SBEACH model, and the numerical analysis of the coastal beach with an artificial reef which is applied to exposed non-erodible bottom is carried out through numerical simulation.

CHAPTER 2: MODEL OF THE COASTAL BEACH EROSION

2.1 Schematization of the Equation of the Coastal Beach Profile

Since coastal beach is specified as particle size of sediment, breaking wave height, water surface rising height and so on, Dean (1977) proposed following equation (1) of the coastal beach profile as shown in Fig. 1.

$$h(x) = Ax^{2/3} \tag{1}$$

where h is the water depth, A is the shape parameter and this shape parameter A can be solved using equation (2).

$$A = \left\{ \frac{24}{5} \left(\frac{D_s}{d_r k^2 g^{1/3}} \right) \right\}^{2/3} \tag{2}$$

where D_s denotes the particle size of sediment, d_r denotes the weight of sediment and k denotes the non-dimensional breaking number. Generally, this non-dimensional breaking number has the value of 0.78 in this study. Normally, A has the value from 0.079 to 0.398 and this A has the value of next equation (3) including fall velocity in this study.

$$A = 0.067w^{0.44} \tag{3}$$

where w is the fall velocity, and equation (3) is used in this study.

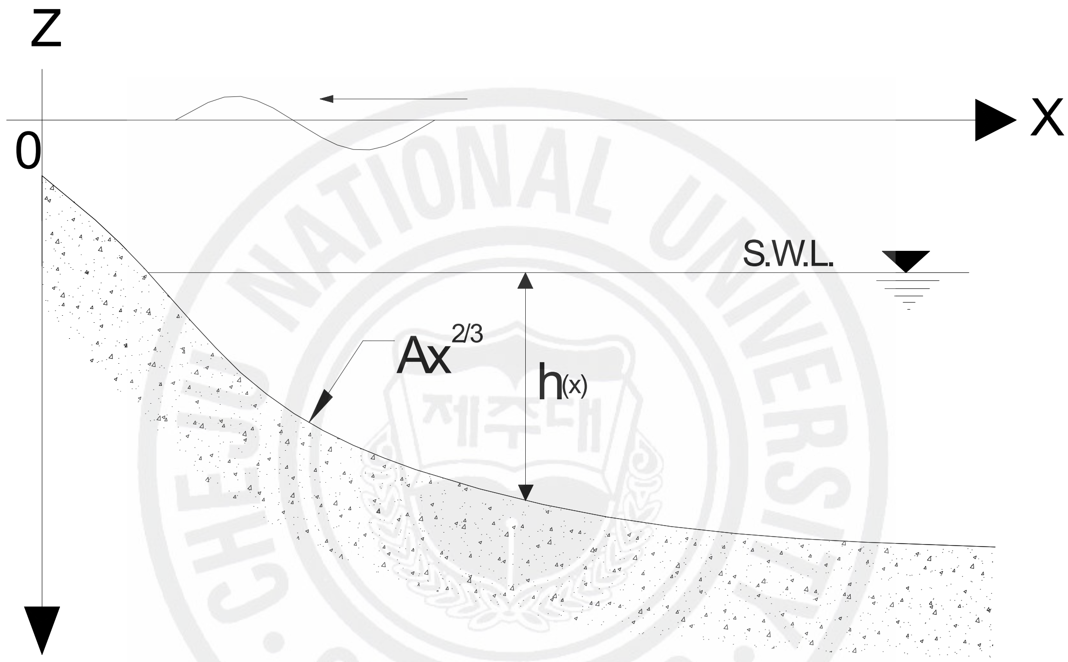


Fig. 1 Schematization of the equation of the coastal beach profile

2.2 Calculation of the Wave Transformation

On the calculation of the wave transformation, coordinate system used in the calculation of the wave transformation is defined as shown in Fig. 2.

The basic equation of the wave transformation can be written as following by the sediment equation by Dally et al. (1980, 1985).

$$\frac{\partial}{\partial x}(F \cdot \cos\theta) + \frac{\partial}{\partial u}(F \cdot \sin\theta) = \frac{k}{d}(F - F_s) \tag{4}$$

where F is the wave energy flux, F_s is the stable wave energy flux, k is the empirical wave decay coefficient, d is the total water depth and θ is the incident wave angle.

It is assumed that the incident wave comes into as 0° to the coastal beach and it is assumed that the wave conditions to be uniform alongshore and the bottom contours to be straight and parallel in this study. So, if θ is applied to 0 in equation (4), equation (4) may be reduced to

$$\frac{\partial F}{\partial x} = \frac{k}{d}(F - F_s) \tag{5}$$

The stable wave energy flux is given by

$$F_s = E_s \cdot C_g \tag{6}$$

where E_s is the wave energy density and C_g is the wave group speed. The wave energy density is written using linear wave theory as

$$E_s = \frac{1}{8}\rho g H_s^2 \tag{7}$$

where ρ is the density of water, g is the acceleration of gravity and $H_s(m)$ is the stable wave height. The stable wave energy flux corresponds to a stable wave height that is a function of the water depth

$$H_s = \Gamma h \tag{8}$$

where h is the water depth and Γ is the stable wave height coefficient (empirical). Γ has the value of 0.4 in this study (Larson and Kraus, 1989). The energy flux F_s can be written by substituting the group velocity of the shallow water wave as follows:

$$F_s = \frac{1}{8}\rho g(\Gamma h)^2\sqrt{gh} \tag{9}$$

where ρ is the density of water, g is the acceleration of gravity, Γ is the stable wave height coefficient (empirical) and h is the water depth.

The radiation stress component S_{xx} is given by linear wave theory for an arbitrary wave angle of incident as

$$S_{xx} = \overline{\int_{-h}^{\eta}\left(p + pu^2\right)dz} - \int_{-h}^{\bar{\eta}} p_0 dz = F - \frac{1}{2}\rho g(h + \bar{\eta})^2 \tag{10}$$

where $\bar{\eta}$ is the wave setup or setdown, p is the bottom pressure, F is the wave energy flux, ρ is the density of the water, g is the acceleration due to gravity and h is the water depth.

The minus flux of the horizontal momentum by bottom pressure p_h that its bottom is not horizontal is existed.

Equilibrium condition equation of surrounded body of water is given by

$$F + \frac{dF}{dx}dx - F = \overline{p_h}\frac{dh}{dx}dx \tag{11}$$

where $\overline{p_h}$ is the average of bottom pressure, in case of that bottom slope is mild, equation (11) is can be written by using Longuet-Higgins, Stewart (1962) and Euler equation as follows:

$$\overline{p_h} = \rho g(h + \bar{\eta}) \tag{12}$$

Substituting equation (12) for equation (11), next equation is given by

$$\frac{dF}{dx} = \rho g(h + \bar{\eta})\frac{dh}{dx} \tag{13}$$

As waves propagate toward shore, a flux of momentum (radiation stress) arises and causes displacement of the mean water elevation if changes in this flux occur due to shoaling or breaking. Seaward of the break point, shoaling produces an increase in wave height, which causes a corresponding increase in the momentum flux. This flux increase is balanced by lowering of the mean water elevation, called setdown (Longuet-Higgins and Stewart, 1962). Inside the surf zone, as saves continue to break and decrease in height, the momentum flux decreases, and increase in mean water elevation occurs (setup).

Displacement of the mean water surface (setup of setdown) may be determined from the momentum equation

$$\frac{dS_{xx}}{dx} = -\rho g d\frac{d\bar{\eta}}{dx} \tag{14}$$

where S_{xx} is the radiation stress component directed onshore, $\bar{\eta}$ is the fluctuation of mean water level and $d(= h + \bar{\eta})$ is the total water depth.

From the wave properties, it is possible to determine analytically the setdown at the most seaward point (Longuet-Higgins and Stewart, 1962).

$$\bar{\eta} = -\frac{\pi H^2}{4L\sinh\left(\frac{4\pi d}{L}\right)} \tag{15}$$

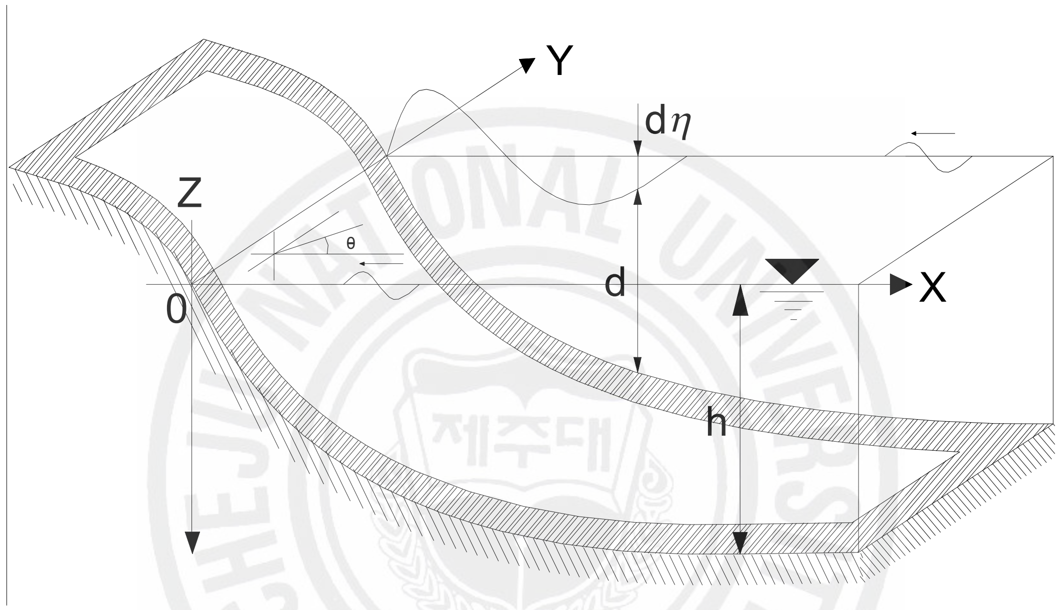


Fig. 2 Coordination system used in calculation of the wave transformation

2.3 Calculation of the Cross-Shore Sediment Transport Rate

When the wave is occurred, based on wave energy dissipation, the basic equation of the cross-shore sediment transport rate can be written as follows:

$$q_s = K(D - D_{eq}) \tag{16}$$

where q_s is the net cross-shore sand transport rate, K is the sand transport rate coefficient, D is the wave energy dissipation per unit water volume and D_{eq} is the equilibrium wave energy dissipation per unit water volume.

In order to accurately calculate cross-shore sediment transport rate, based on the division of the profile applied in near-shore wave dynamics and the physical characteristics of sediment transport under various flow conditions, four different zones of transport (Fig. 3) were introduced (Larson, Kraus and Sunamura, 1998; Larson and Kraus, 1989). These zones are:

a. Zone I: From the seaward depth of effective sand transport to the break point (pre-breaking zone).
b. Zone II: Form the break point to the plunge point (breaker transition zone).
c. Zone III: From the plunge point to the point of wave reformation or to the swash zone (broken wave zone).
d. Zone IV: From the shoreward boundary of the surf zone to the shoreward limit of run-up (swash zone).

The cross-shore sediment transport rate of the pre-breaking zone (zone I) can be written as follows:

$$q = q_b e^{-\lambda_1 (x - x_b)} \tag{17}$$

where q_b denotes the cross-shore sediment transport rate at breakpoint, λ_1 denotes an empirical coefficient characterizing the rate of decay and x_b denotes the location of the breakpoint.

Empirical expressions for the spatial decay coefficients were derived from large wave tank data (Larson and Kraus, 1989). The decay coefficient in Zone I was empirically related to median grain size (D_{50}) and breaking wave height (H_b) as (with D_{50} in mm and H_b in m)

$$\lambda_1 = 0.4 \times \left(\frac{D_{60}}{H_b} \right)^{0.47} \tag{18}$$

where D_{50} is the sand grain size and H_b is the breaking wave height.

The cross-shore sediment transport rate in breaker transition zone (zone II) becomes:

$$q = q_p e^{-\lambda_2 (x - x_p)} \tag{19}$$

where q_p is the cross-shore sediment transport rate at the plunge point and λ_2 is an empirical coefficient. This λ_2 has $0.2 \sim 0.5$ times of decay coefficient λ_1 used in Zone (I). And, x_p is the location of the break point. This x_p is defined as $x_p = x_b - 3H_b$ (Larson and Kraus, 1989).

The cross-shore sediment transport rate at broken wave zone (zone III) can be written as below equation. Larson and Kraus (1989) modified equation (16) to include a slope term:

$$\begin{Bmatrix} q = K(D - D_{eq} + \dfrac{\varepsilon}{K}\dfrac{\partial h}{\partial x} for D \rangle \left(D_{eq} - \dfrac{\varepsilon}{K}\dfrac{\partial h}{\partial x} \right) \\ q = 0 \, for D \le \left(D_{eq} - \dfrac{\varepsilon}{K}\dfrac{\partial h}{\partial x} \right) \end{Bmatrix} \tag{20}$$

where h is the still-water depth, K is the sand transport rate empirical coefficient and ε is the slope-related transport empirical coefficient. The slope term was introduced to account for the effect of gravity in limiting the steepness of the beach profile and to improve numerical stability in the vicinity of the breakpoint bar. The application of equation (16) and (20) in predicting transport magnitude and direction has varied slightly. In equation (20), during storm conditions, when D is expected to be much greater than D_{eq}, equation (16) and (20) will predict similar values of the transport rate. When D is less than D_{eq}, equation (16) yields a negative transport rate, implying onshore transport of material. However, it has been shown in LWT data that accretion often occurs when D is greater than D_{eq} (Larson and Kraus, 1989), making equation (16) unsuitable for predicting such events. D and D_{eq} is defined by Moore (1982).

$$D = \frac{1}{h}\frac{\partial F}{\partial x} \tag{21}$$

where h is the still-water depth and F is the energy flux of the waves.

By the equation (5) and (21), the energy dissipation per unit water volume D is given by

$$D = \frac{k}{d^2}(F - F_s) \tag{22}$$

where k is the empirical wave decay coefficient and d is the total water depth.

Substituting equation (9) for equation (21), the equation (22) can be written as follows:

$$D = \frac{5}{16}\rho g^{3/2}\gamma^2 h^{1/2}\frac{\partial h}{\partial x} \tag{23}$$

After substituting the energy dissipation per unit water volume of equilibrium coastal beach profile (D_{eq}) for equation (23), then integrating equation (23) for x, following equation (24) is given by

$$h = \left(\frac{24D_{eq}}{5\rho g^{3/2}\gamma^2}\right)^{2/3} x^{2/3} \tag{24}$$

By the equation (24) and (1), the energy dissipation per unit water volume of equilibrium coastal beach profile (D_{eq}) is defined as the shape parameter, which can be written as follows:

$$D_{eq} = \frac{5}{24}\rho g^{3/2}\gamma^2 A^{3/2} \tag{25}$$

where A is the shape parameter and γ is the ratio between the wave height and the water depth at breaking zone($= H_b l h_b$).

About swash limit of swash zone of Zone (IV), the equation (26) that is surf similarity parameter function is used in this study as follows:

$$\frac{Z_\gamma}{H_0} = 1.47\left(\frac{\tan\beta}{\sqrt{H_0/L_0}}\right)^{0.79} \tag{26}$$

where Z_γ is the swash height, $\tan\beta$ is the local beach slope seaward of the break point and H_0/L_0 is the wave steepness of deep water wave. And, assuming the cross-shore sediment transport rate is straightly decreased from broken wave zone to end of swash zone, topography is regularly occurred in swash zone. The cross-shore sediment transport rate of the swash zone is expressed as

$$q = q_z\left(\frac{x - x_\gamma}{x_z - x_r}\right)^n \tag{27}$$

where q_z denotes the cross-shore sediment transport rate at the end of the swash zone, x_γ denotes the location of the swash zone, γ denotes the runup limit, x_z denotes the location of the end of the swash zone and n denotes the undecided coefficient. n has 1.5 from the numerical analysis result of the Horikawa and Sunamura (1996) in this study.

Since net cross-shore sediment transport rate is only carried out using equation (27), sediment transport direction should be considered. This sediment transport direction is can be written by Kraus et al. (1991).

$$\begin{Bmatrix} \dfrac{H_0}{L_0} \rangle M\left(\dfrac{H_0}{wT}\right)^3, erosion \\ \dfrac{H_0}{L_0} \langle M\left(\dfrac{H_0}{wT}\right)^3, accretion \end{Bmatrix} \tag{28}$$

in which, $M = 0.0007$ is an empirically determined coefficient, w is the fall velocity of sediment particle and T is the wave period. If the left side of equation (28) is less (greater) than the right side, the profile is predicted to erode (accrete). Wave steepness describes the wave asymmetry, whereas wave height and period appearing in the fall speed parameter account for the absolute magnitudes of those quantities. The fall speed accounts for the settling characteristics of sand particles.

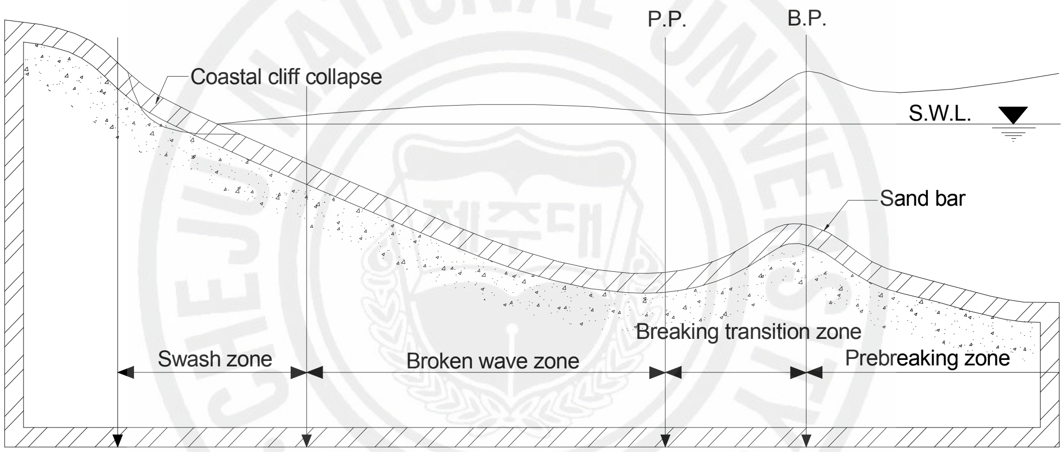


Fig. 3 Principal zones of the cross-shore transport

2.4 Calculation of the Continuity Equation of Sediment

When the coastal beach change is considered, the coastal beach volume conservation equation can be written as follows:

$$\frac{\partial h}{\partial t} = \left(\frac{\partial q_x}{\partial x} + \frac{\partial q_y}{\partial u} \right) \tag{29}$$

where h is the profile elevation, taken positive below the still water level (S.W.L.); q_x is the cross-shore sediment transport rate of x-direction; q_y is the cross-shore sediment transport rate of y-direction (per unit hour and volume).

The coastal beach profile changes is consisted of the long-shore sediment transport (y-direction) and cross-shore sediment transport (x-direction). Considering only incident wave coming at a right angle to shore, equation (29) becomes as follows:

$$\frac{\partial h}{\partial t} = \frac{\partial q_x}{\partial x} \tag{30}$$

Therefore, the coastal beach change can be computed by a conservation equation (30). In order to raise the safety of calculation, cross-shore sediment transport rate is used by two times step Δt as following:

$$\frac{h_i^{k+1} - h_i^k}{\Delta t} = \frac{1}{2} \left(\frac{q_{i+1}^{k+1} - q_i^{k+1}}{\Delta x} + \frac{q_{i+1}^k - q_i^k}{\Delta x} \right) \tag{31}$$

where Δt is the unit distance, k is the time lever and i denotes the number of grid.

2.5 Organization of the Numerical Analysis

The numerical analysis is carried out as shown in Fig. 4. Fig. 4 depicts calculative flow chart of numerical analysis used in this study.

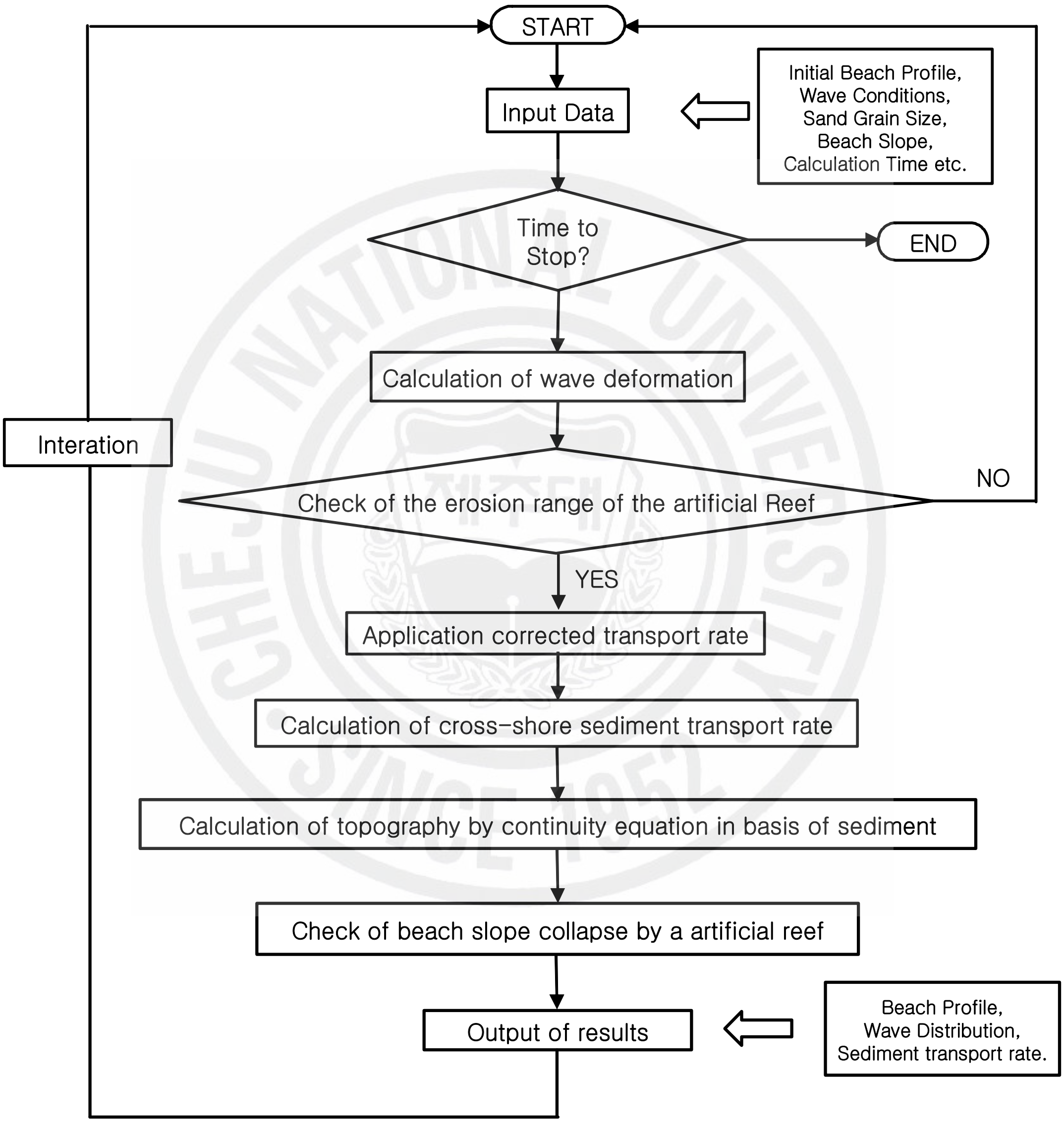


Fig. 4 Flow chart of the numerical simulation

2.6 Application of the Artificial Reef

In this study, an artificial reef is applied to exposed non-erodible bottom in broken wave zone as shown in Fig. 5 and Fig. 6. As shown Fig 5, the bottom of the dune-beach profile is composed of non-erodible bottom, such as rock and erodible bottom, such as sand. First, on all part of coastal beach sections, if it is assumed that the coastal beach section is constituted of sand which is eroded, the cross-shore sediment transport rated is calculated without non-erodible bottom. Then, an artificial reef is applied. The availability of a limited volume of sand yields the following condition in the change in transport Δq_i in Fig. 5.

$$\Delta V_i = \Delta q_i \Delta t = (h_{b,i} - h_i)\Delta x \tag{32}$$

where ΔV_i is the availability of a limited volume of sand, h_b is the elevation of non-erodible profile, taken in a positive direction below the still water level (S.W.L.), i denotes the number of grid, h_i is the elevation of erodible profile and Δq_i is the cross-shore sediment transport rate.

If a non-erodible bottom is already exposed in a particular cell as shown in Fig. 5, $h_{b,i} = h_i$ and $\Delta q_i = 0$ at the start and the end location of the non-erodible bottom. Precisely, this means that there is no change of the cross-shore sediment transport rate in the section of the exposed bottom because the start and the end location of the non-erodible bottom is same with the location of the erodible bottom.

The accretion process does no affect a non-erodible bottom. However, a non-erodible bottom is affected by the erosion process. According to the change of depth by the time lapse, the erosion and accretion are divided into equation (33):

$$\begin{Bmatrix} \dfrac{\partial h}{\partial t} \rangle 0, erosion \\ \dfrac{\partial h}{\partial t} \langle 0, accretion \end{Bmatrix} \tag{33}$$

To apply of non-erodible bottom, during erosion process computation, it is important to know whether or not a non-erodible bottom is exposed. It can be known from the following equation (34).

$$\left\{ \begin{array}{l} h_i^k \rangle h_{b,i}^k, \ \ \text{exp}osure \\ h_i^k \le h_{b,i}^k, non-\text{exp}osure \end{array} \right\} \tag{34}$$

where h_i is the elevation of erodible bottom, h_b is the elevation of non-erodible bottom, k is the time level and i is the number of grid. Equation (34) implies that a non-erodible bottom is eroded and that the cross-shore sediment transport rate needs to be corrected.

Therefore, since an artificial reef is considered as exposed non-erodible bottom in this study, the cross-shore sediment transport rate needs to be modified using the following equation (35) with a scouring attenuation coefficient (λ_{hb}) by Larson and Kraus (1998).

$$q = q_p + (q_{hb} - q_p)e^{-\lambda_{hb}(x - x_{hb})} \tag{35}$$

where q_{hb} is the cross-shore sediment transport rate at x_{hb}, x_{hb} is the non-erodible bottom area where an artificial reef is applied and λ_{hb} is the scouring attenuation coefficient. The bigger value of λ_{hb} is, the larger the hollow is generated. So, this study has $\lambda_{hb} = 1.0m^{-1}$. Equation (35) produces $q = q_{hb}$ if $x = x_{hb}$ and $q = q_p$ if $x \to \infty$.

Fig. 6 depicts sketch of the artificial reef which is applied to exposed non-erodible bottom in this study.

where h is the water depth, h_1 is the distance between the top of the artificial reef and the surface of the water, h_2 is the height of the artificial reef and B is the width of the artificial reef.

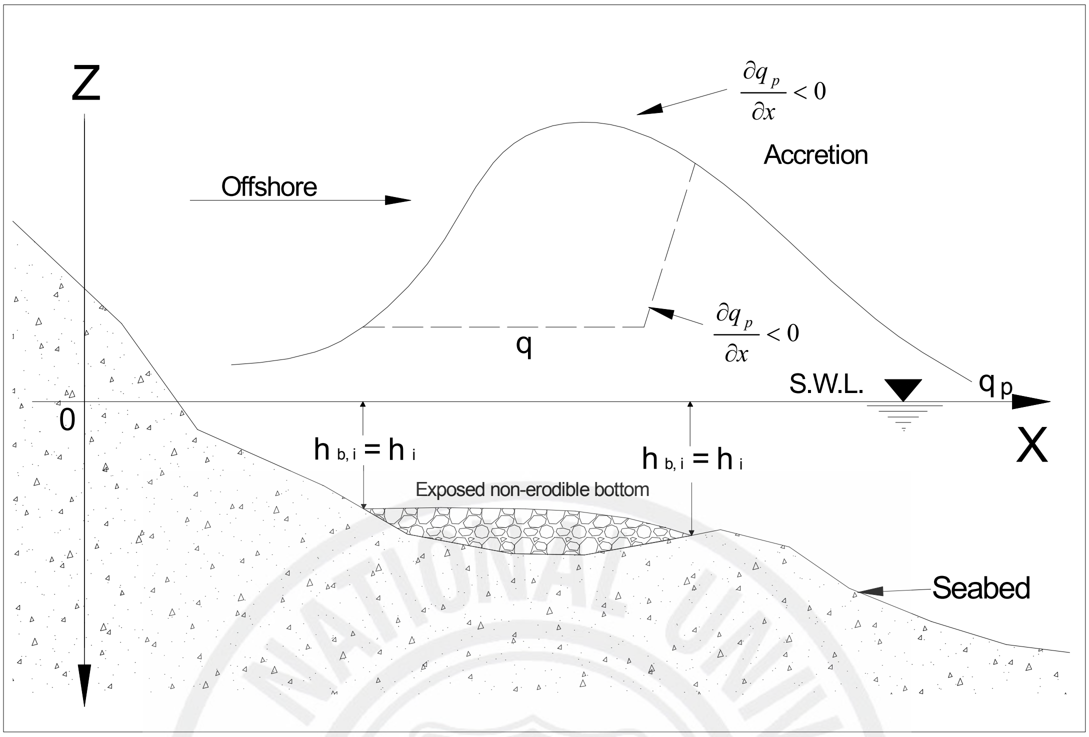


Fig. 5 Sketch of the effect of transport corrections of exposed non-erodible area

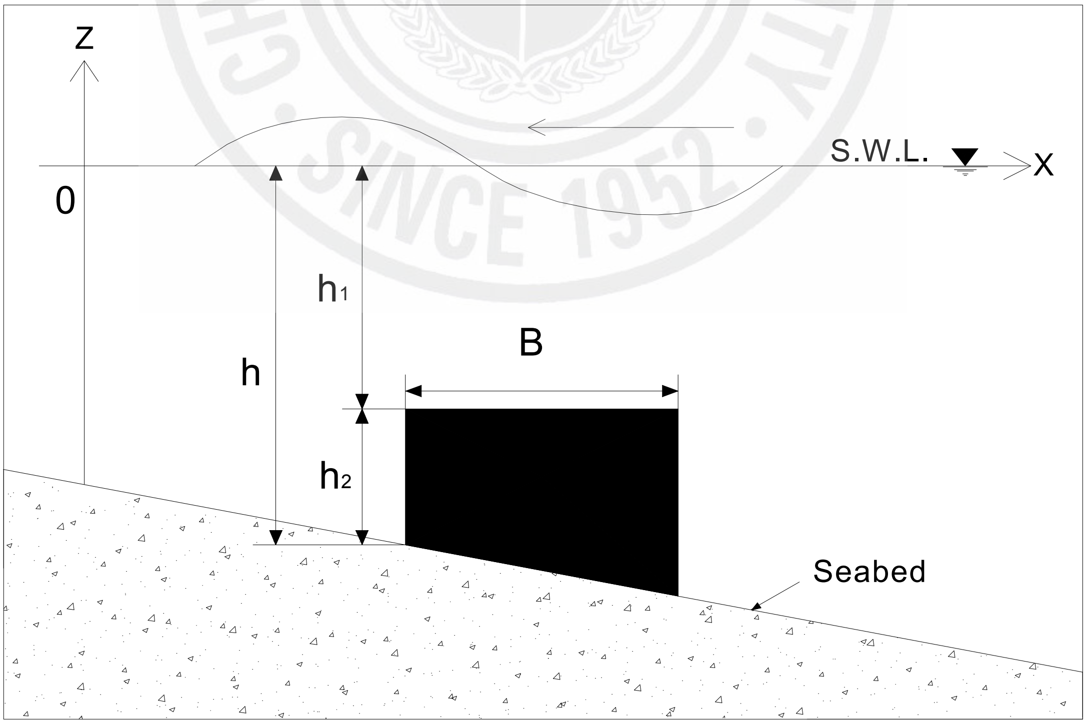


Fig. 6 Sketch of the artificial reef established in broken wave zone

CHAPTER 3: VERIFICATION OF THE COASTAL BEACH EROSION MODEL

3.1 Verification of the Erodible Model

For the verification of the erodible numerical model, the results obtained form this numerical analysis are compared with Larson (1994). Larson (1994) performed a numerical model in German Large Wave Thank, which is seaward slope of 1:10 (V:H). The experiment conditions are sand grain size $D_{50} = 0.22mm$, $H = 0.57m$ and $T = 3.0\sec$, during a time of 400 minutes. Fig. 7 compared numerical results with measured data by Larson (1994) and displays that calculated data is bigger than in measured date by Larson (1994). However, two graphs show the close tendency and good agreement.

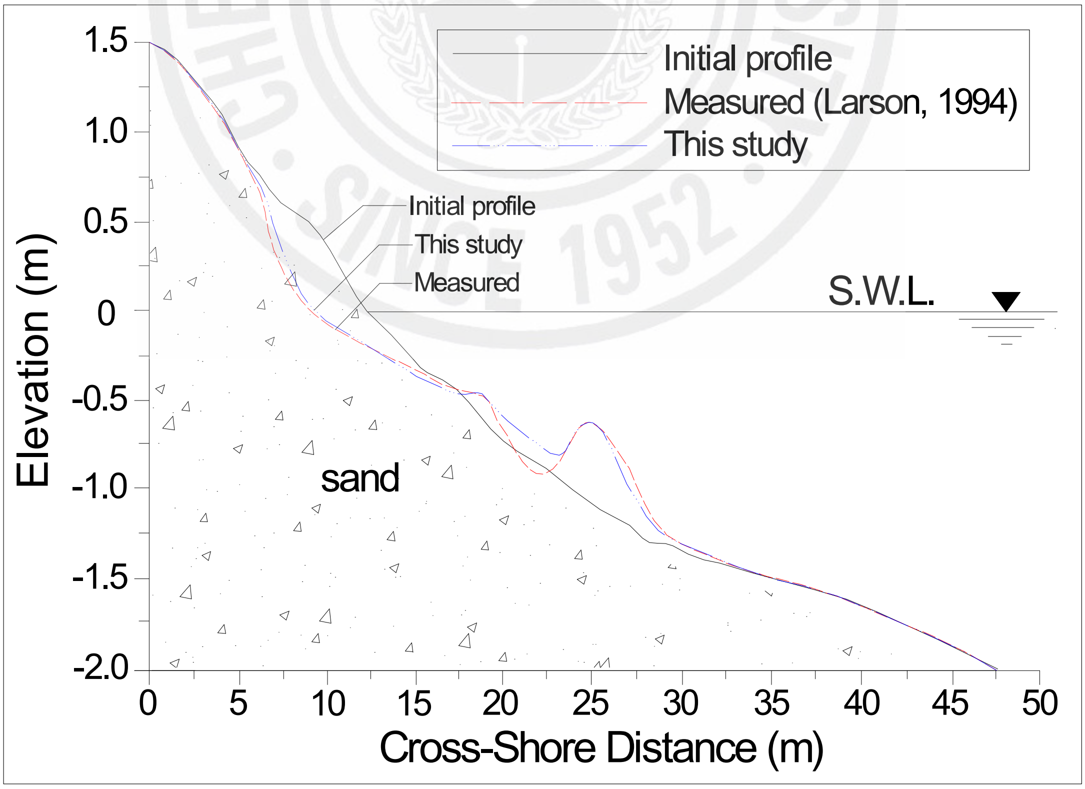


Fig. 7 Comparison and verification of the numerical model with erodible bottom

3.2 Verification of the Non-Erodible Model

For the verification of the non-erodible numerical model, Dette and Uliczka (1986) performed a numerical analysis with non-erodible bottom in a German Large Wave Tank, which is seaward slope of 1:4 (V:H) from a height at $2m$ above the S.W.L. to the bottom of the tank, located $5m$ below S.W.L.. The sand grain size is $D_{50} = 0.33mm$. About $2m$ were nourished for initial profile and the experiment was performed using waves with height at $1.5m$ and period of $6.0\sec$, during a time of 176 minutes. Fig. 8 compared numerical results with measured data by Dette and Uliczka (1986). Fig. 8 depicts that the head of a sandbar is bigger in calculated data than in measured data. However, on the whole, two graphs show the same tendency and close agreement. Furthermore, the value of this numerical simulation is shown to be closer to the measured data than that of the numerical simulation, performed by Larson and Kraus (1998).

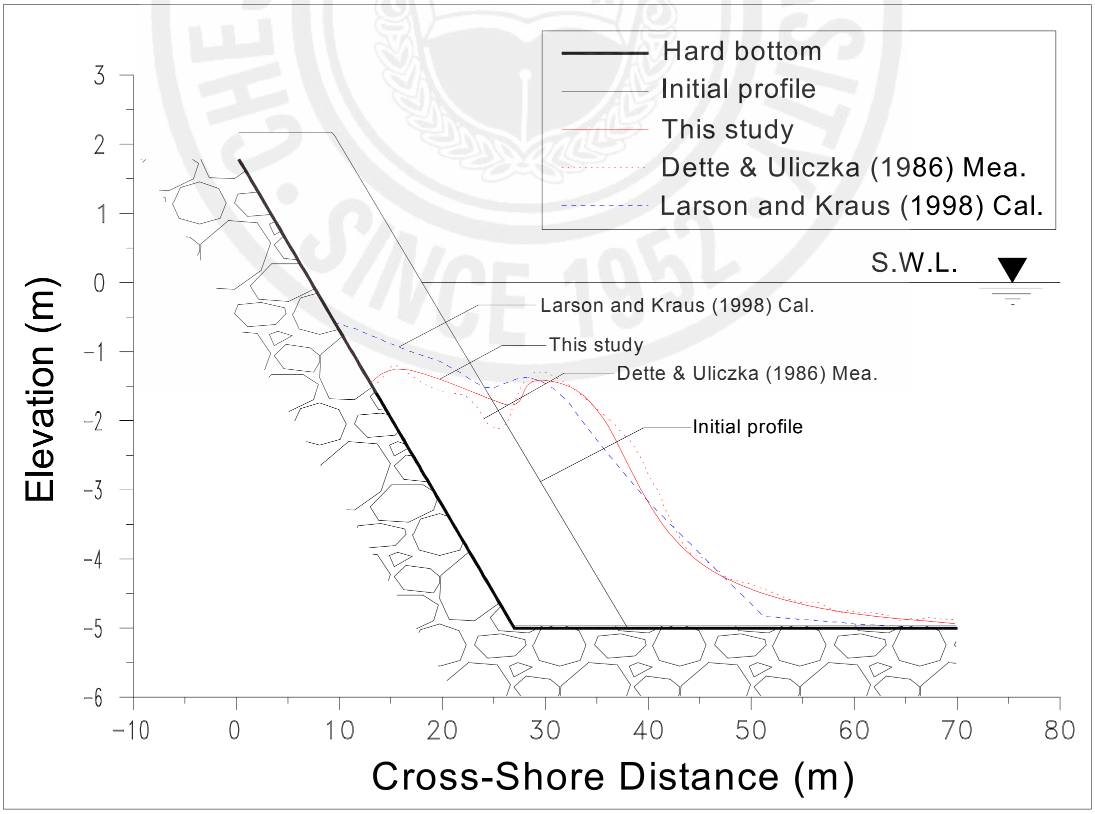


Fig. 8 Comparison and verification of the numerical method with non-erodible bottom

3.3 Verification of the Model with an Artificial Reef

For the verification of the numerical model with an artificial reef, the results obtained form this numerical analysis are compared whit experimental results by Uda el al. (1984). This numerical computation is carried out under the same experimental conditions that Uda et al. (1984). The incident wave condition used in this numerical computation is $H = 6.0cm$ and $T = 1.13\sec$.

The computation result after $10hrs$ is compared with experimental results by Uda et al. (1984) as shown in Fig. 9. Form this comparison, there is a small different, but the tendency shows very close agreement. Therefore, this model can be applied to the numerical erosion analysis in the coastal beach.

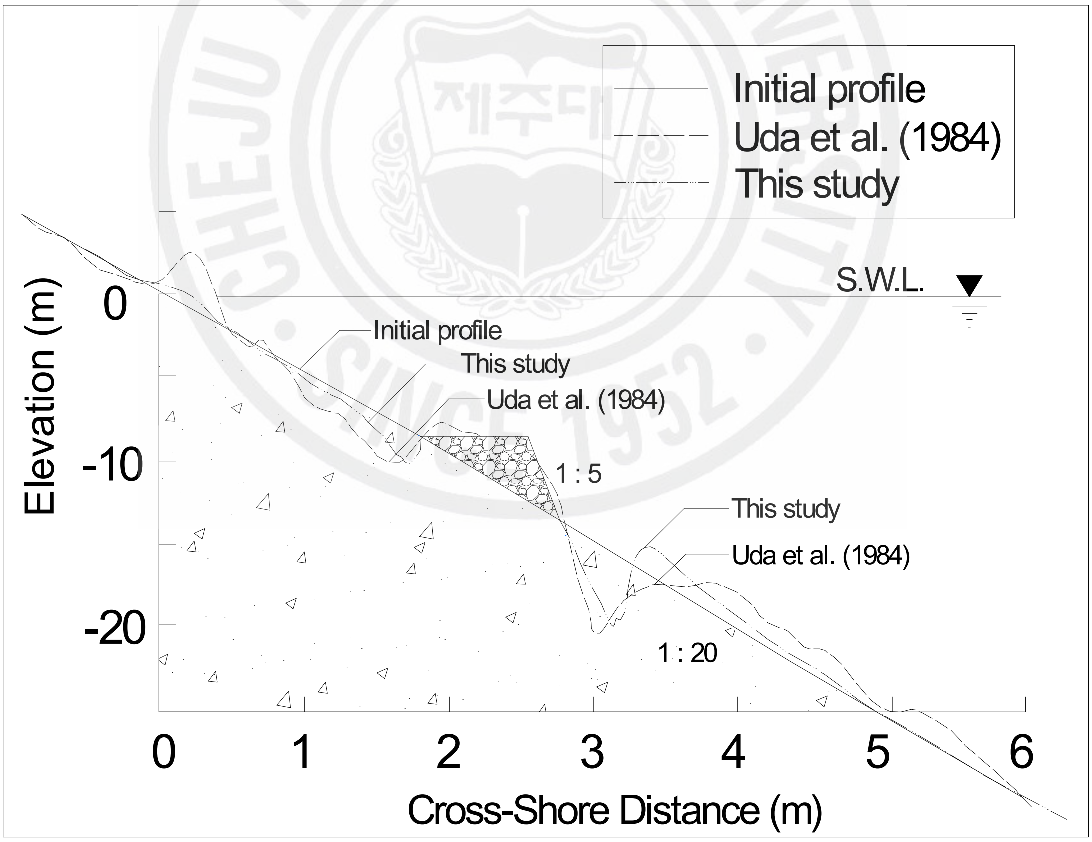


Fig. 9 Comparison and verification of the numerical model with an artificial reef

CHAPTER 4: RESULTS AND REMARKS OF EROSION ANALYSIS OF THE COASTAL BEACH

4.1 Erosion Analysis of the Coastal Beach with and without an Artificial Reef

The numerical analysis of the coastal beach with and without an artificial reef is carried out in order to investigate erosion control effect of the coastal beach by an artificial reef.

First, the numerical computation results of the erosion behavior for the coastal beach without an artificial reef are depicted in Fig. 10(a) and (b). As shown in Fig. 10(a) and (b), the coastal beach profile, described by Kim and Mun (2007), is used in this study. And this coastal beach profile has slope of $1:81.20$. As shown in Fig. 10(a) and (b), the numerical computation is carried out with for each $H = 0.3m$, $1m$, $3.0m$ and $5.0m$, respectively. The wave condition used in this numerical analysis is the wave period of $6.0\sec$, during $30hrs$.

As shown in Fig. 10(a) and (b), the computation results show that the erosion of the coastal beach is greater than other conditions of the wave height when the wave height is $5.0m$. Also, form the Fig. 10(a) and (b), it is shown that the higher the wave height is, the bigger the coastal beach erosion occurs.

Next, in order to investigate about erosion control effect of the coastal beach by an artificial reef, the computation results of the erosion behavior for the coastal beach by an artificial reef are presented in Fig. 11. As shown in Fig. 11, an artificial reef is established at $18m$ distance from the shoreline in broken wave zone. The conditions of the artificial reef are the height of the artificial reef $H = 0.5m$ and the width of the artificial reef $B = 10m$, which is non-porous artificial reef. And the numerical computations of the erosion behavior for the coastal beach with an artificial reef are carried out with same calculative conditions of Fig. 10.

From the Fig. 10 and 11, the computation results show that it is more effective for the case with an artificial reef than without an artificial reef in controlling the coastal beach erosion.

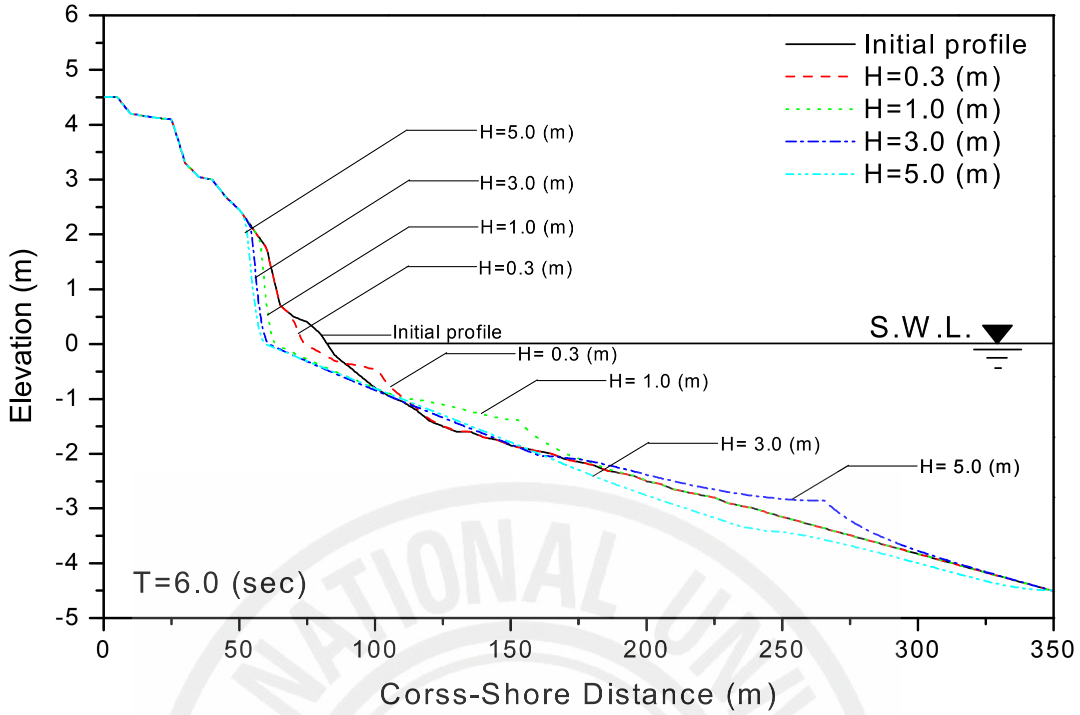
But the amount of erodible coastal beach can be discerned by naked eye with the Fig. 10 and 11, in order to minutely know about erosion control effect with accurate numerical value, the erosion height and the regression velocity of the coastal cliff due to the existence and nonexistence of the artificial reef are given as shown in Fig. 12(a) and (b) and Table 1 and Table 2.

Fig. 12(a) provides the erosion height of the coastal cliff for each height $H = 0.3m$, $1.0m$, $3.0m$ and $5.0m$ with and without an artificial reef. And, Fig. 11(b) presents the regression velocity of the coastal cliff for each height.

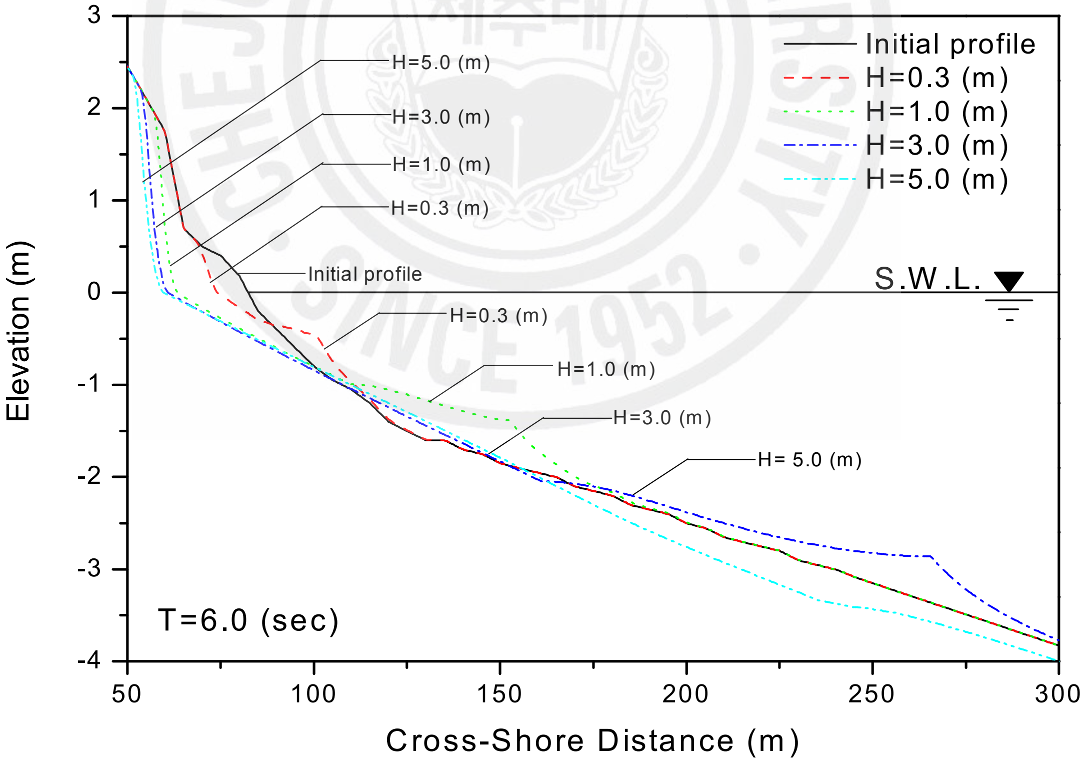
As shown form Fig. 12(a) and (b), it is shown that the erosion control for the case with an artificial reef is more effective than the results of the erosion behavior without an artificial reef in controlling the coastal beach erosion. It is also shown that the erosion height of the coastal cliff with an artificial reef is lower than the results of the erosion behavior without an artificial reef, and the regression velocity of the coastal cliff with an artificial reef is slower than the results of the erosion behavior without an artificial reef. This reason is considered because the erosion of the coastal beach is controlled by an artificial reef established in broken wave zone, and the wave force is weakened by an artificial reef.

Next, Table 1 and Table 2 give the numerical value of the erosion height and the regression velocity of the coastal cliff for each wave height of Fig. 10 and Fig. 11. The numerical analysis both with and without an artificial reef results show that the higher the wave height is, the smaller the difference of the erosion height of the coastal cliff becomes, as shown in Table 1.

And it is shown that the higher the wave height is, the larger the coastal beach erosion occurs. Also, it is shown that the erosion height of the coastal cliff for the case with an artificial reef is lower than for the case without an artificial reef, and the regression velocity of the coastal cliff for the case with an artificial reef is slower than for the case without an artificial reef as shown in Table 2.

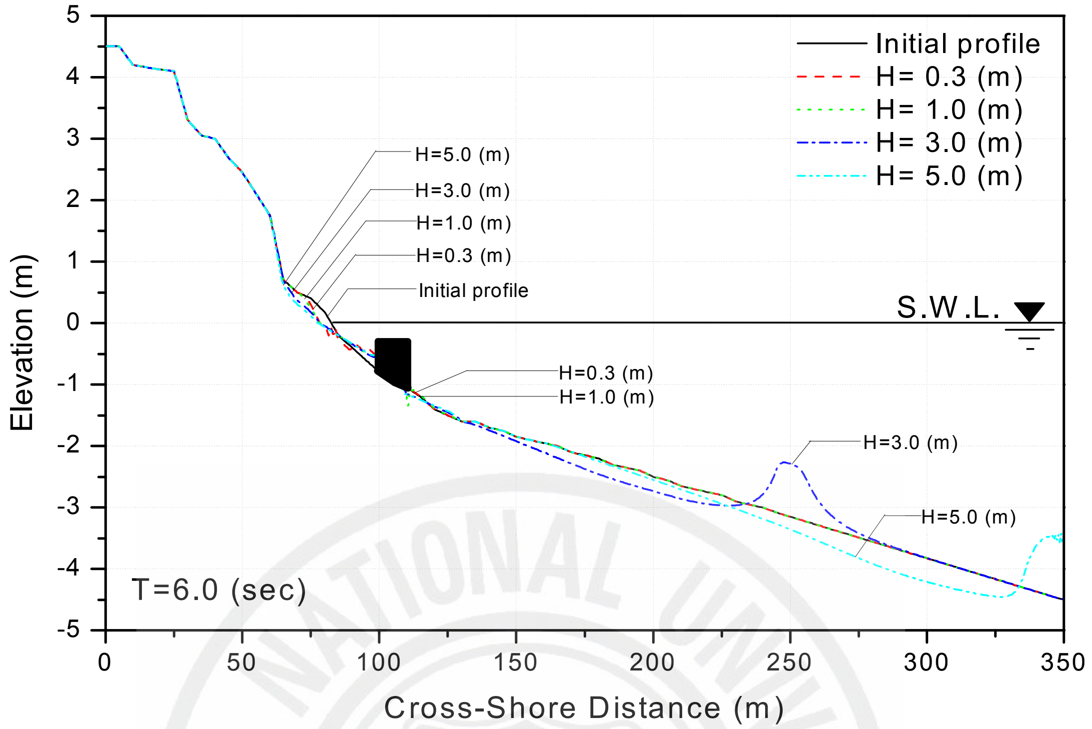


(a) Whole profile

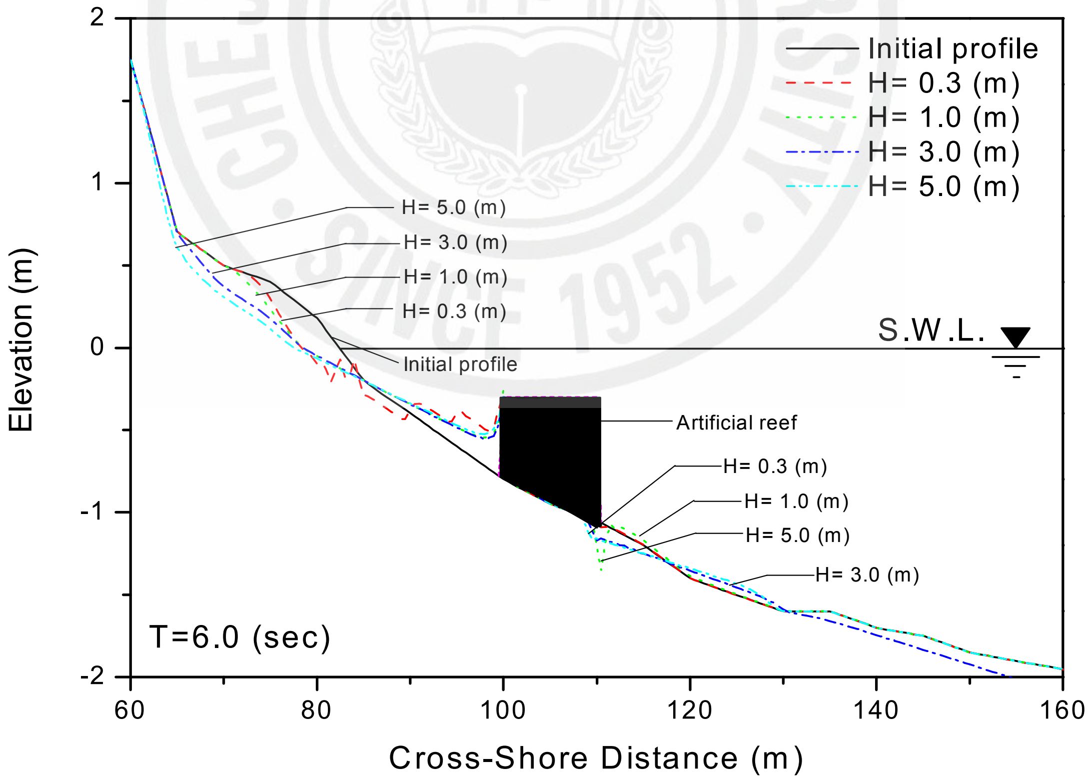


(b) Enlargement of the both-hand side of the Fig. 10(a)

Fig. 10 Change of the coastal beach profile without an artificial reef after 30*hrs*

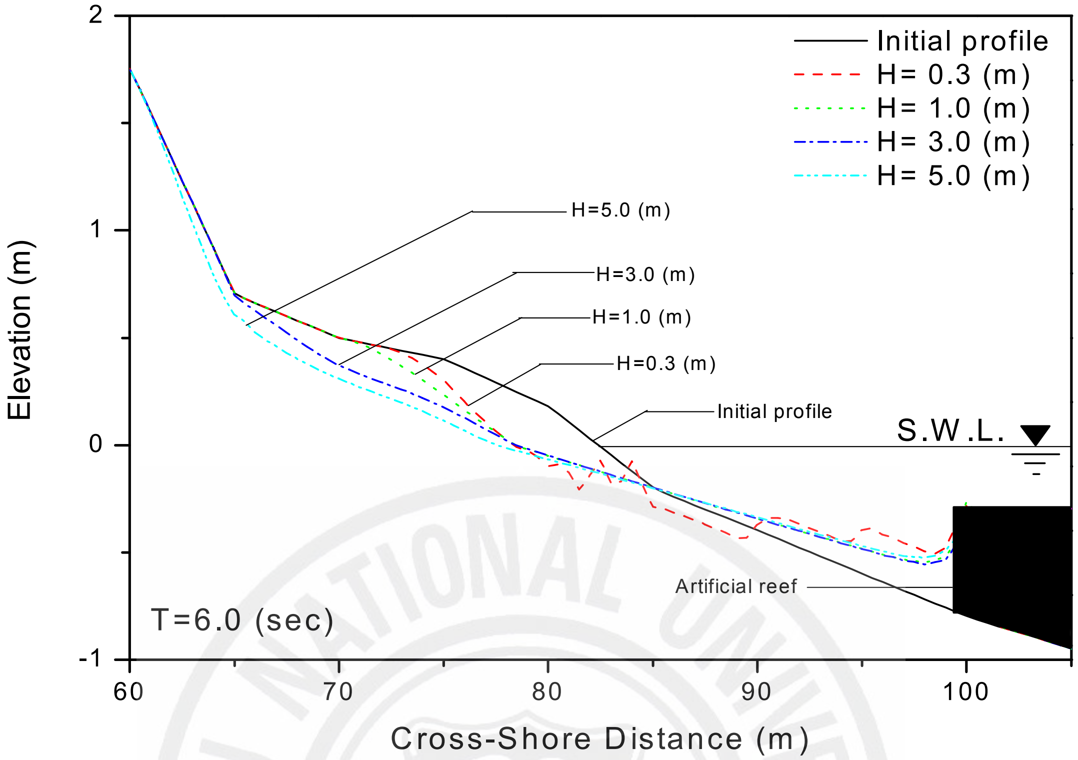


(a) Whole profile

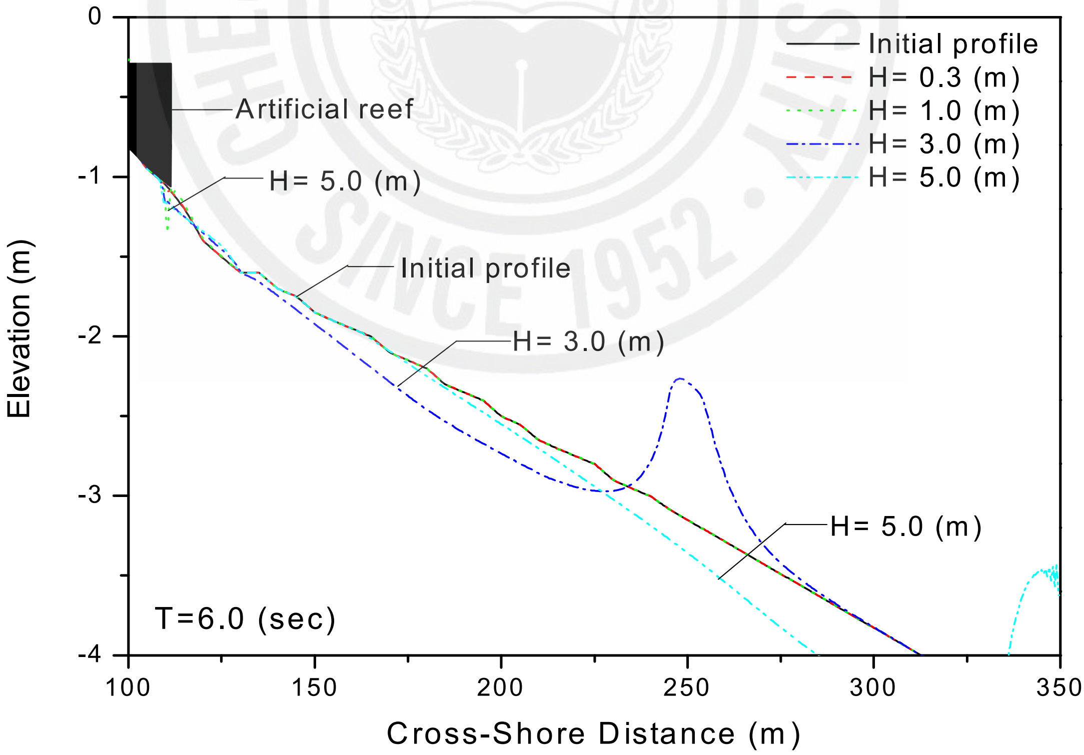


(b) Both-hand side

Fig. 11 Change of the coastal beach profile with an artificial reef after $30hrs$ [(a) ~ (b)]



(c) Left-hand side



(d) Right-hand side

Fig. 11 Change of the coastal beach profile with an artificial reef after $30hrs$

[(c) ~ (d)]

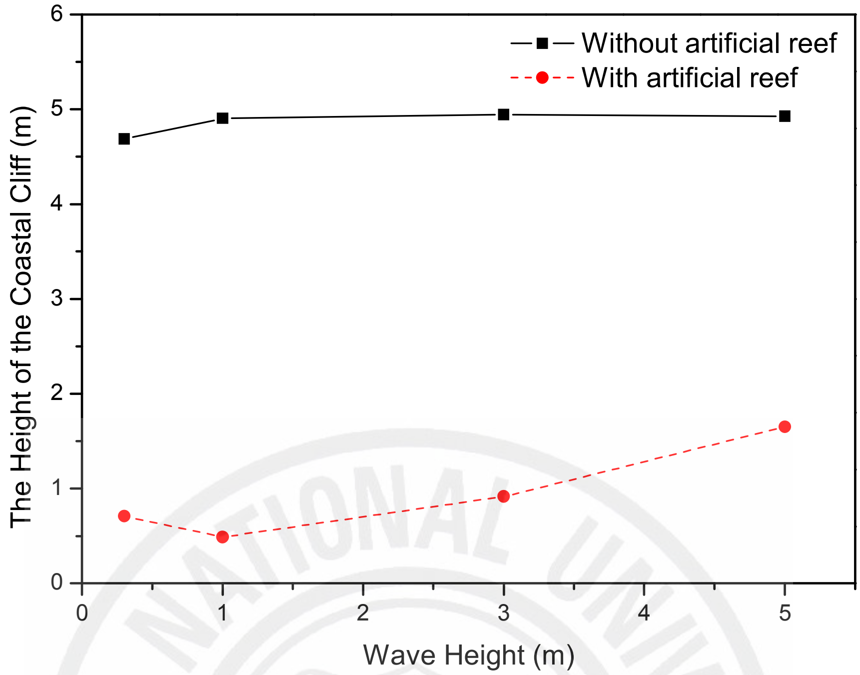


Fig. 12(a) Change of the coastal cliff height with and without an artificial reef after $30hrs$.

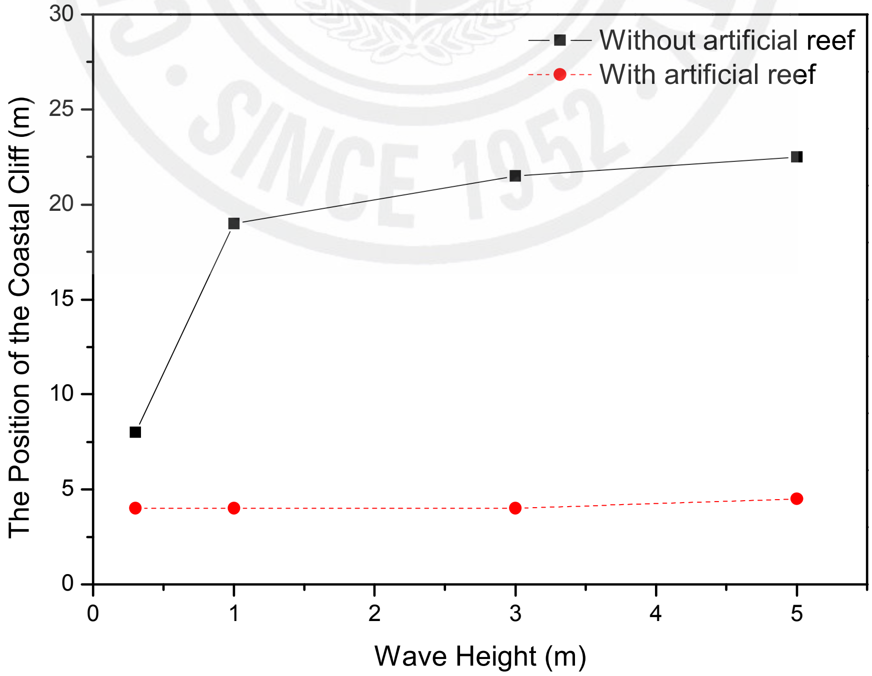


Fig. 12(b) Regression velocity of the coastal cliff with and without an artificial reef after $30hrs$.

Table 1 Change of the erosion height of the coastal cliff due to the waves

(Unit: m)

Wave Height \ Height of Cliff	Without an Artificial Reef	With an Artificial Reef
0.30	4.68816	0.70800
1.00	4.90534	0.48765
3.00	4.94330	0.91730
5.00	4.92497	1.65138

Table 2 Regression velocity of the coastal cliff due to the waves

(Unit: m)

Wave Height \ Height of Cliff	Without an Artificial Reef	With an Artificial Reef
0.30	8.000	4.00
1.00	19.90	4.00
3.00	21.50	4.00
5.00	22.50	4.50

4.2 Erosion Analysis of the Coastal Beach Due to the Offshore Distance of the Artificial Reef

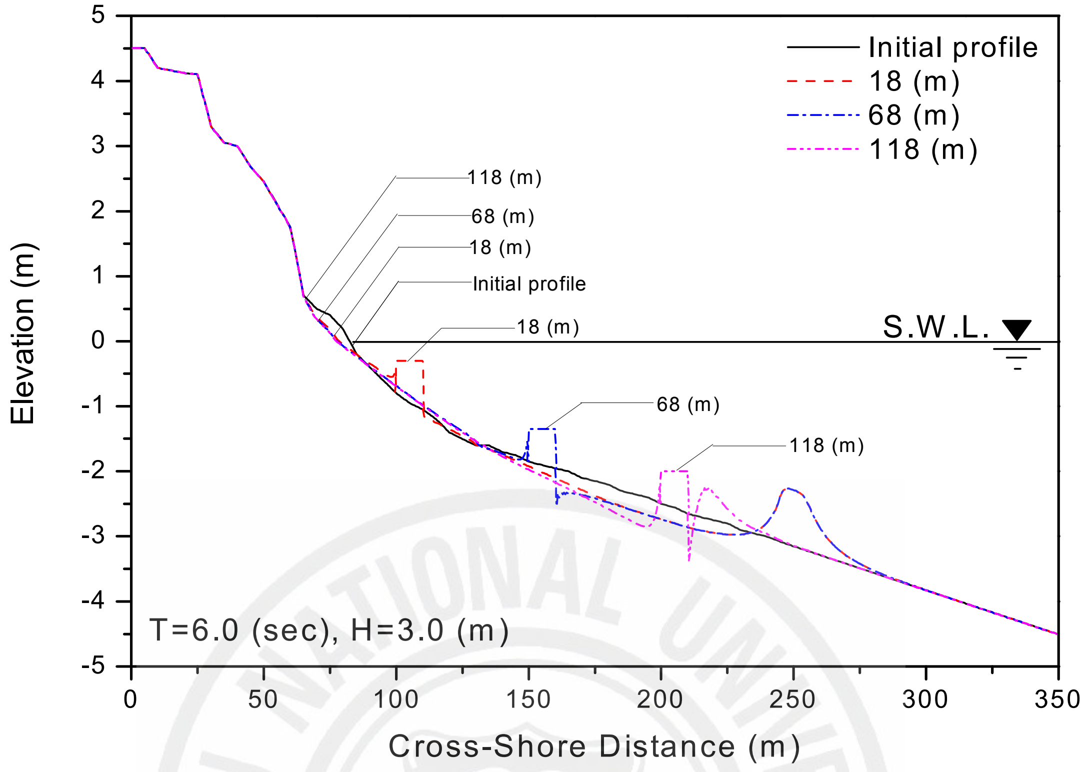
The numerical analysis of the coastal beach due to the offshore distance of the artificial reef is carried out to investigate erosion control effect due to the offshore distance of the artificial reef.

The numerical computation results of the coastal beach erosion behavior for each offshore distance $18m$, $68m$ and $118m$ are displayed in Fig. 13. The numerical computation of the Fig. 13 carried out with $H = 3.0m$ and $T = 6.0\sec$. And, an artificial reef is established at $18m$ from the shoreline in broken wave zone because erosion control effect of the coastal beach due to the offshore distance of the artificial reef when an artificial reef is established in broken wave zone is the greatest. This artificial reef has conditions of the height $h_2 = 0.5m$ and the width $B = 10m$ as shown in Fig. 6.

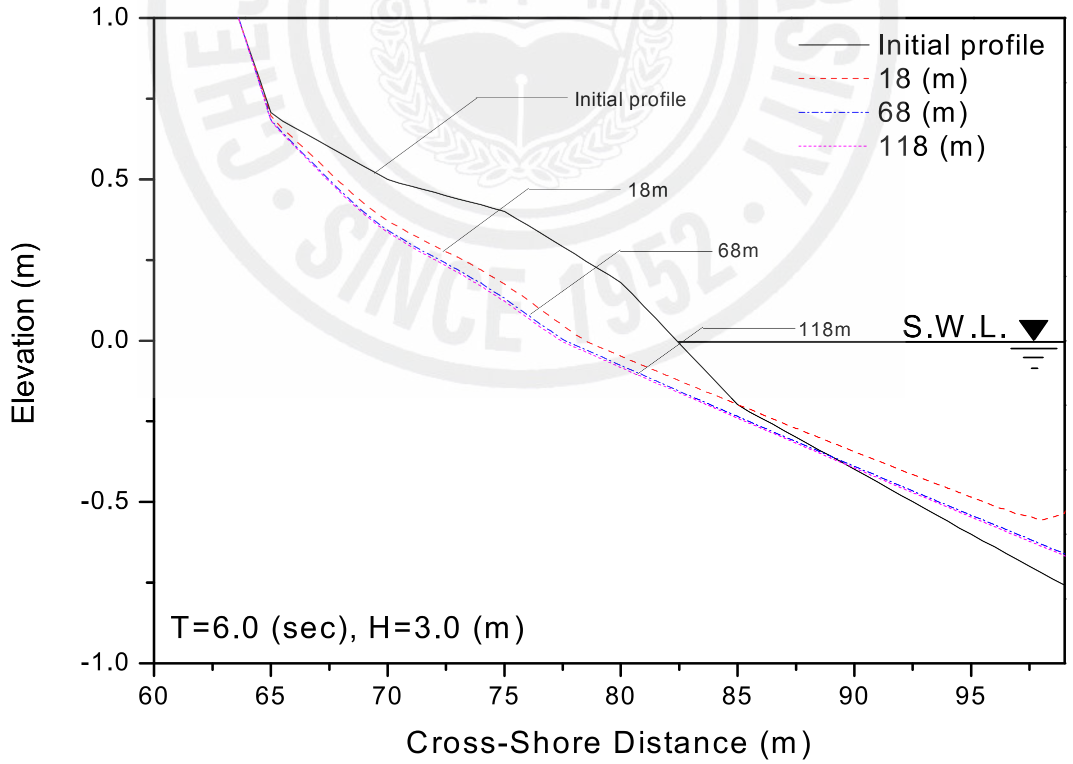
The erosion height and the regression velocity of the coastal cliff due to the offshore distance of the artificial reef are presented in Fig. 14(a) and (b). And, the numerical value of the erosion height and the regression velocity of Fig. 14(a) and (b) are given in Table 3.

As shown in Fig. 13, the computation results show that the farther the offshore distance of the artificial reef form the shoreline is, the deeper the scouring depth at the inside of the artificial reef becomes. And the computation results also show that the farther the offshore distance of the artificial reef from the shoreline is, the greater the coastal beach erosion occurs. And, it is shown that the farther the offshore distance of the artificial reef form the shoreline is, the broader the eroded area at the outside of the artificial reef occurs. Also, it is appeared the sandbar is formed at the $170m$ from the shoreline when the offshore distance of the artificial reef is $18m$, and it is also appeared that the closer the artificial reef from the shoreline is, the more effective the erosion control of the coastal beach is.

From the numerical results of the erosion behavior for the coastal beach due to the offshore distance of the artificial reef, it is shown that offshore distance $18m$ is more effective than any other case in controlling the coastal beach erosion.



(a) Whole profile



(b) Left-hand side

Fig. 13 Change of the coastal beach profile due to the offshore distance of the artificial reef after $30hrs$

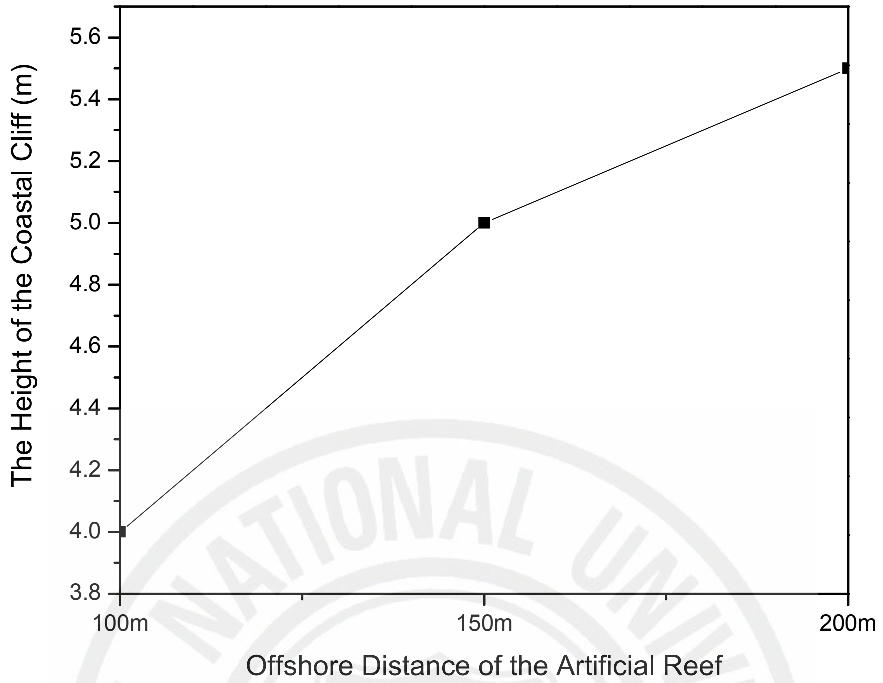


Fig. 14(a) Change of the coastal cliff height due to the offshore distance of the artificial reef after $30hrs$

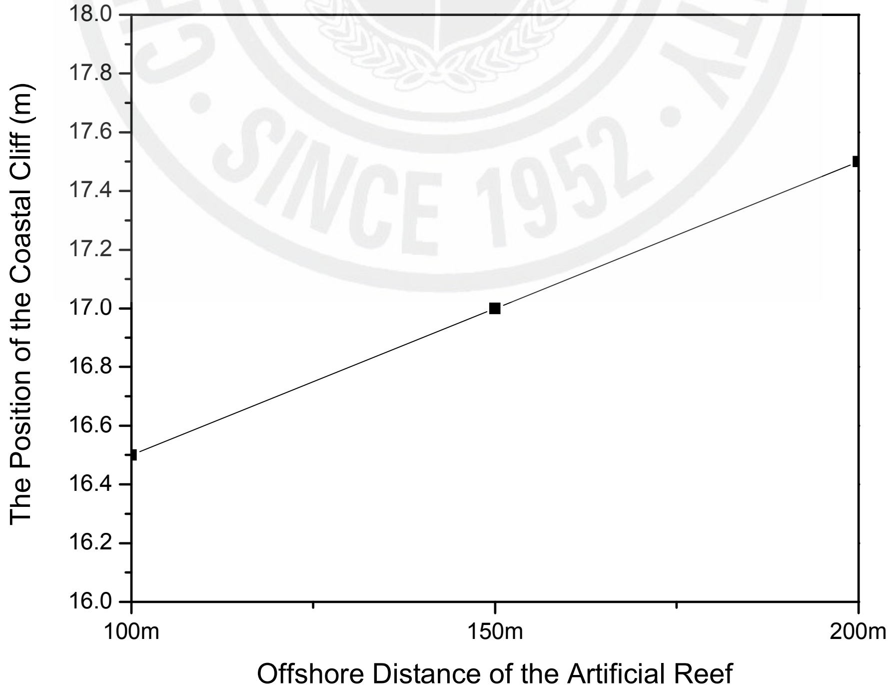


Fig. 14(b) Regression velocity of the coastal cliff due to the offshore distance of the artificial reef after $30hrs$

Table 3 Change of the erosion height and the regression velocity of the coastal cliff due to the offshore distance of the artificial reef

(Unit: m)

Offshore Distance of the Artificial Reef	Height of the Cliff	Velocity of the Regression
100	4.00	16.50
150	5.00	17.00
200	5.50	17.50

4.3 Erosion Analysis of the Coastal Beach Due to the Height of the Artificial Reef

The numerical analysis of the coastal beach due to the height of the artificial reef is carried out to investigate erosion control effect of the coastal beach due to the height of the artificial reef. The numerical computation results of the erosion behavior of the coastal beach for the each height of the artificial reef $h_2 = 0.3m$, $0.5m$ and $0.7m$ are shown in Fig. 15. The numerical computation of the Fig. 15 is carried out with $H = 3.0m$ and $T = 6.0\sec$. An artificial reef is established at $18m$ from the shoreline in broken wave zone, and this artificial reef has condition of $B = 10m$ for each artificial reef's height.

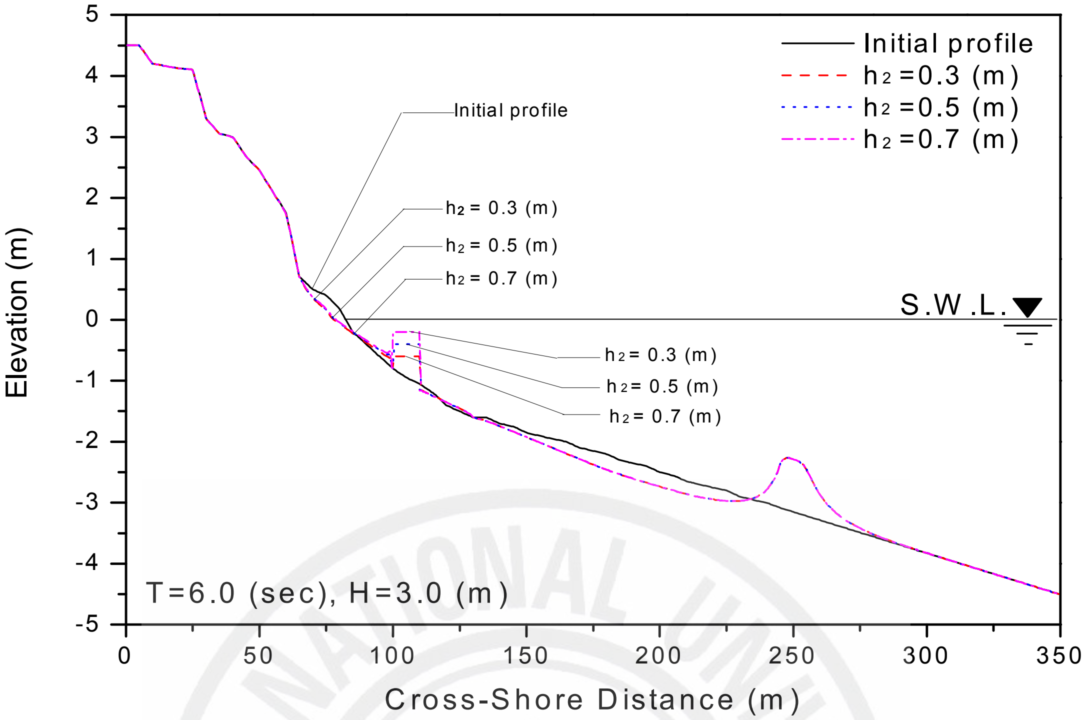
Form the numerical computation results due to the offshore distance of the artificial reef. The reason why an artificial reef is established at $18m$ form the shoreline in erosion analysis due to the height of the artificial reef is that it is more effective for the case of that an artificial reef is established at $18m$ than other cases in controlling the coastal beach erosion.

As shown in Fig. 15(a) and (b), it is shown that the higher the height of the artificial reef is, the smaller the coastal beach erosion occurs.

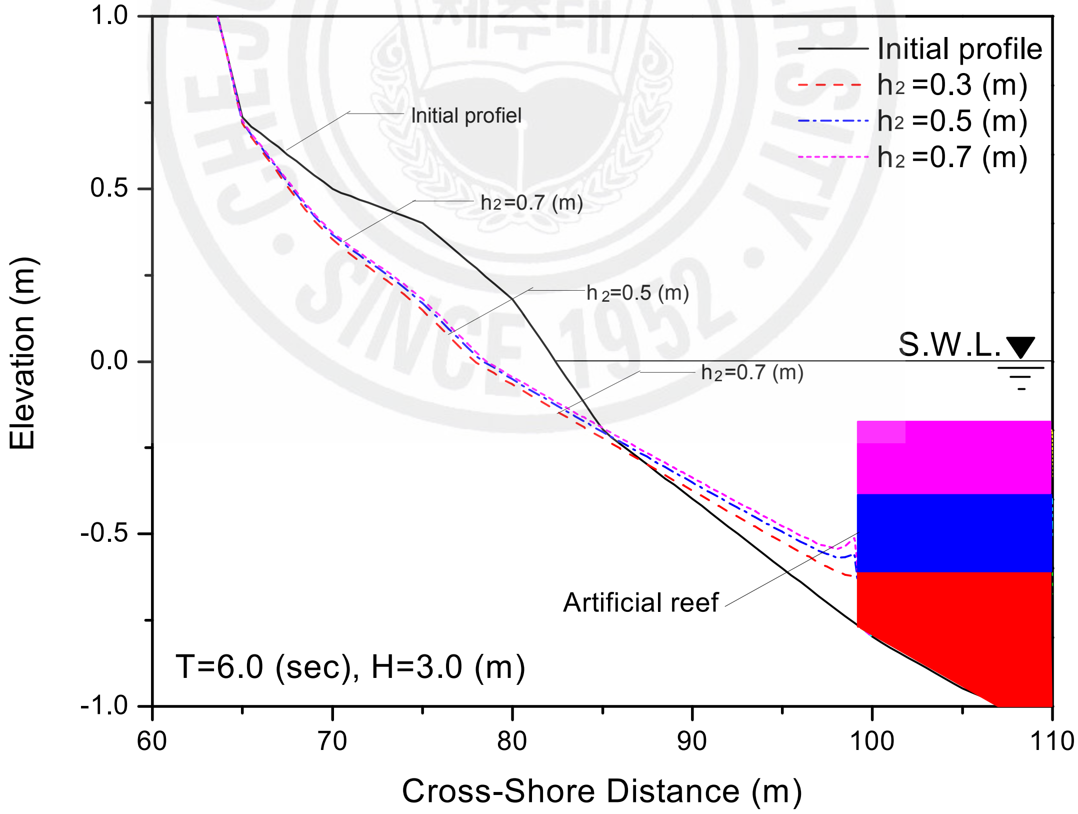
The erosion height and the regression velocity of the coastal cliff due to the height of the artificial reef are depicted in Fig. 16(a) and (b), and Table 4 provides the numerical value of the erosion height and the regression velocity of the coastal cliff due to the height of the artificial reef.

As shown in Fig. 15(a) and (b) and Fig. 16(a) and (b) and Table 4, the numerical results showed that the higher the height of the artificial reef is, the smaller the coastal beach erosion occurs. Also, the numerical results showed that the scouring phenomenon is discovered at the outside of the artificial reef, and sandbar is formed at $170m$ form the shoreline.

But, comparing erosion control effect due to the height of the artificial reef with erosion control effect due to the offshore distance of the artificial reef, the erosion control ability due to the height of the artificial reef is not effective than erosion control ability due to the offshore distance of the artificial reef.



(a) Whole profile



(b) Left-hand side

Fig. 15 Change of the coastal beach profile due to the height of the artificial reef after $30hrs$

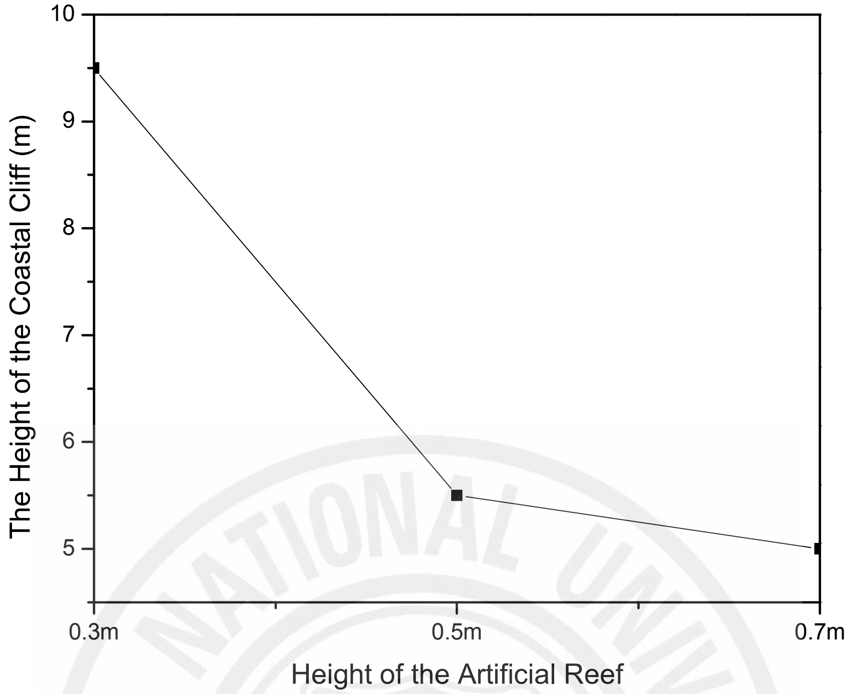


Fig. 16(a) Change of the coastal cliff height due to the height of the artificial reef after $30hrs$

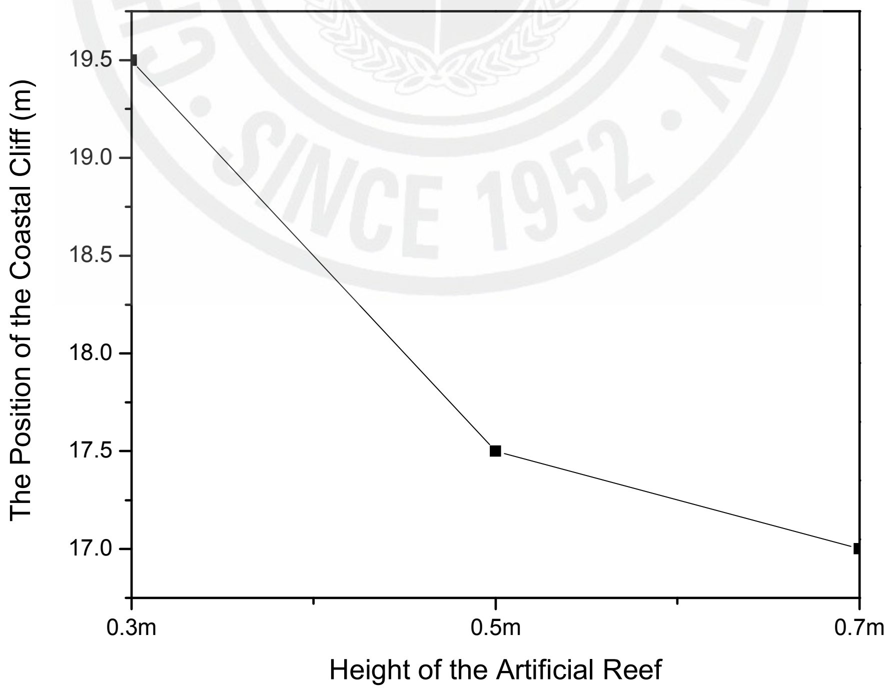


Fig. 16(b) Regression velocity of the coastal cliff due to the height of the artificial reef after $30hrs$

Table 4 Change of the erosion height and the regression velocity of the coastal cliff due to the height of the artificial reef

(Unit: m)

Height of the Artificial Reef	Height of the Cliff	Velocity of the Regression
0.30	9.50	19.50
0.50	5.50	17.50
0.70	5.00	17.00

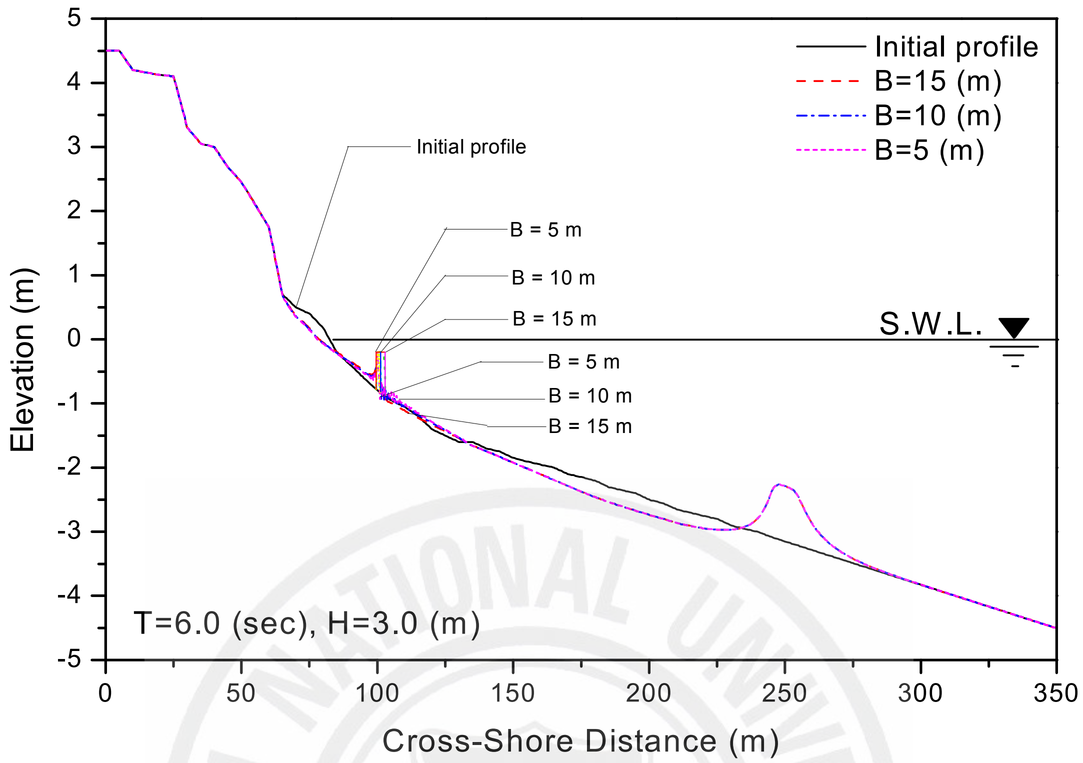
4.4 Erosion Analysis of the Coastal Beach Due to the Width of the Artificial Reef

The numerical analysis of the erosion behavior of the coastal beach for each the width of the artificial reef $B = 5m$, $10m$ and $15m$ is carried out in order to know about erosion control effect due to the width of the artificial reef. An artificial reef is established at $18m$ from the shoreline in broken wave zone, and this numerical computation of the Fig. 17 carried out with $H = 3.0m$ and $T = 6.0\sec$.

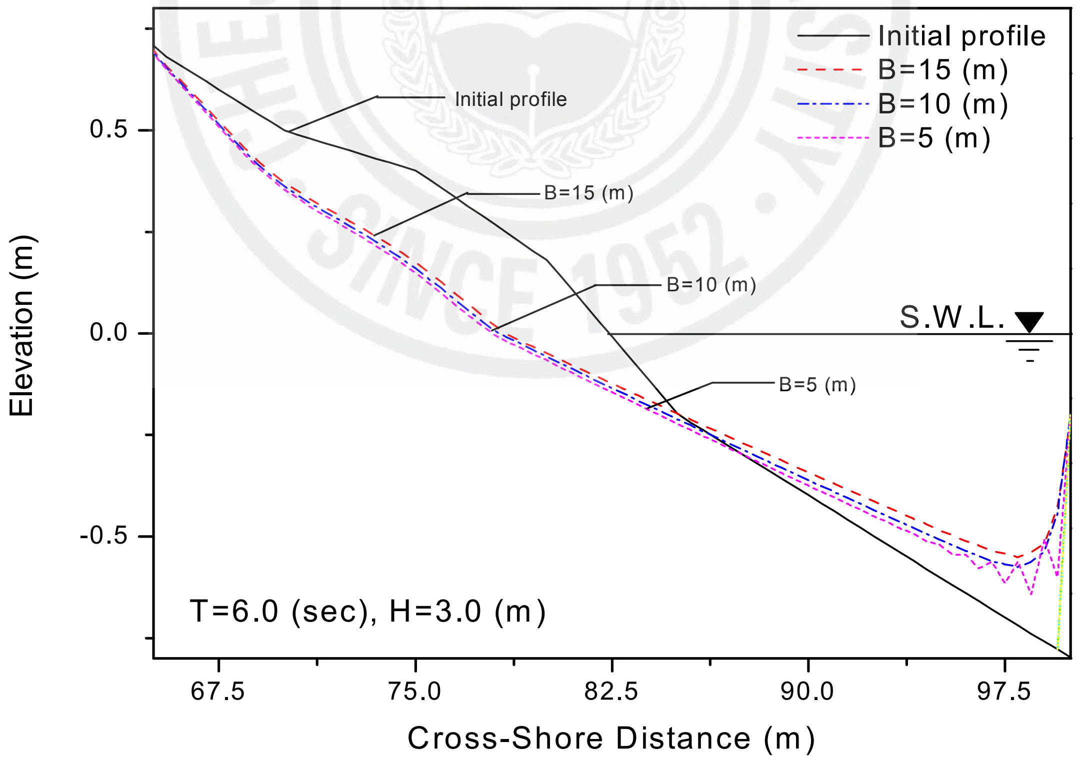
The numerical computation results of the coastal beach due to the width of the artificial reef are given in Fig. 17(a) and (b). And Fig. 18(a) and (b) show the erosion height and the regression velocity of the coastal cliff due to the width of the artificial reef, and Table 5 gives the values of the erosion height and the regression velocity of the coastal cliff.

As shown in Fig. 16 and Fig. 17(a) and (b) and Table 5, but there is no much difference in erosion of the coastal beach at the inside of the artificial reef, it is shown that the narrower (broader) the width of the artificial reef is, the bigger (smaller) the scouring depth and area at the outside of the artificial reef occurs. This reason is considered because the narrower (broader) the width of the artificial reef is, the bigger (smaller) the wave force which is controlled by an artificial reef becomes. And, it is shown that sandbar is formed at $250m$.

Alike with the erosion behavior results of the coastal beach due to the height of the artificial reef, it is shown that the erosion control ability due to an artificial reef's width is not effect than the erosion control ability due to the offshore distance of the artificial reef in controlling the coastal beach erosion.



(a) Whole profile



(b) Left-hand side

Fig. 17 Change of the coastal beach profile due to the width of the artificial reef after $30hrs$

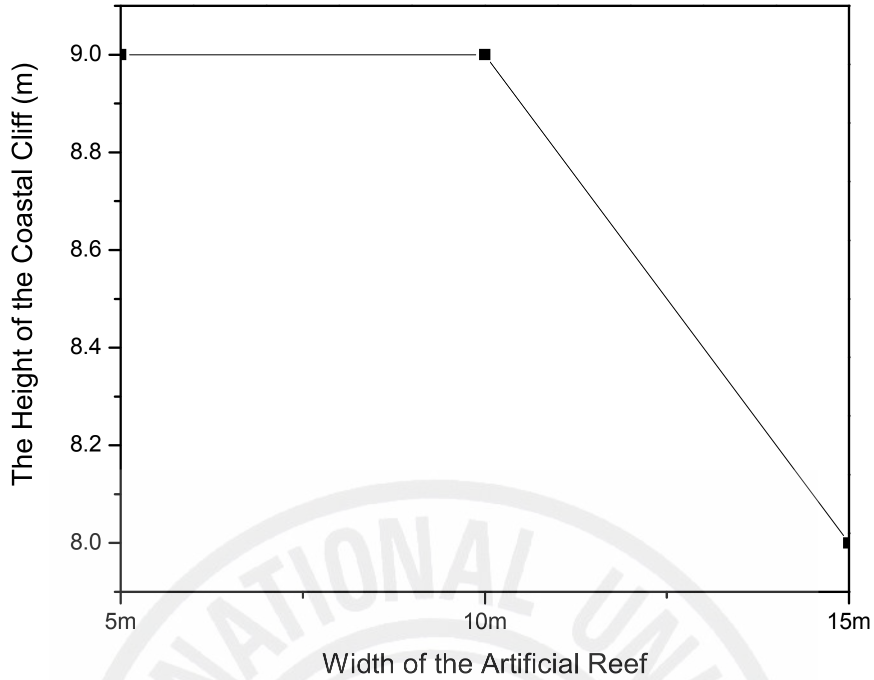


Fig. 18(a) Change of the coastal cliff height due to the width of the artificial reef after $30hrs$

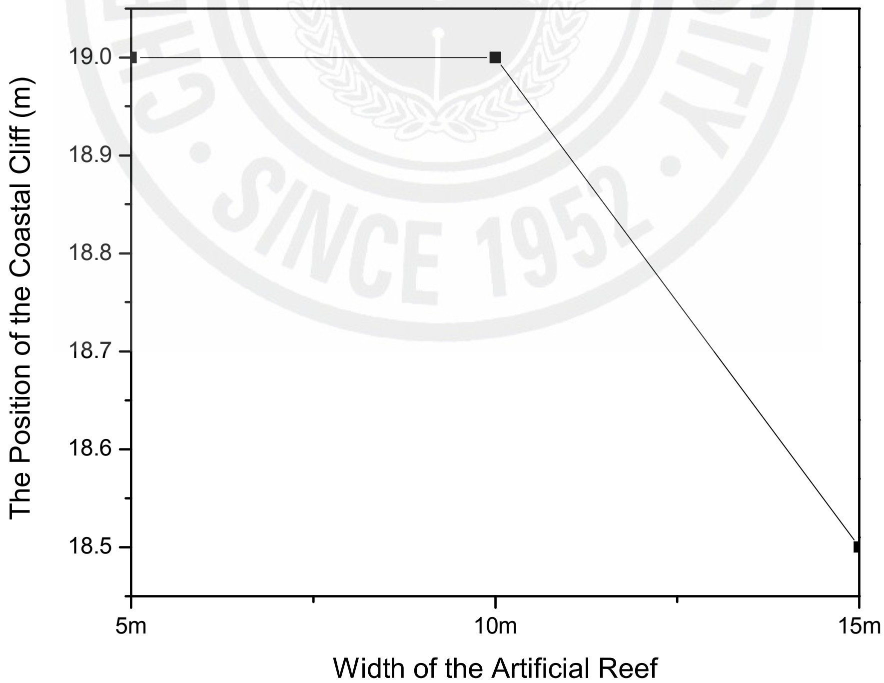


Fig. 18(b) Regression velocity of the coastal cliff due to the width of the artificial reef after $30hrs$

Table 5 Change of the erosion height and the regression velocity of the coastal cliff due to the width of the artificial reef

(Unit: m)

Height of the Artificial Reef	Height of the Cliff	Velocity of the Regression
5	9.00	19.00
10	9.00	19.00
15	8.00	18.50

4.5 Erosion Analysis of the Coastal Beach Due to the Berm Location of the Artificial Reef

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As mentioned above, an artificial reef with a berm is applied as exposed non-erodible bottom as shown in Fig. 5 in this study. The sketch of the artificial reef with a berm used in this study is depicted in Fig. 19. And in Fig. 19, h denotes the water depth, h_1 denotes the distance between the top of the artificial reef with a berm and the surface of the water, h_2 denotes the total height of the artificial reef, h_3 denotes the height of the berm, B_1 denotes the width of the artificial reef without berm and B_2 denotes the width of the berm.

In order to investigate about erosion control effect of the coastal beach due to the location of the berm, when a berm is located at left-hand side, right-hand side and both-hand side, the numerical analysis of the coastal beach due to the location of the berm was carried out, respectively.

The numerical computation results of the erosion behavior of the coastal beach due to the location of the berm are shown in Fig. 20. An artificial reef is established at $18m$ from the shoreline in broken wave zone, and this numerical computation of the Fig. 20 carried out with $H = 3.0m$ and $T = 6.0\sec$.

As shown in Fig. 20, it is shown that an artificial reef with a left-hand side berm is more effective than any other condition in controlling the coastal beach erosion. And it is also shown that the scouring area in artificial reef with a left-hand side berm is greater than other two cases; the scouring depth is the smallest.

But the amount of eroded coastal beach can be discerned by naked eye from the Fig. 20, in order to minutely know about erosion control effect with accurate numerical value, the erosion height and the regression velocity of the costal cliff due to the location of the berm is presented in Fig. 21(a) and (b).

As shown in Fig. 21(a) and (b), the numerical results show that an artificial reef with a left-hand side berm is more effective than any other case in controlling the coastal beach erosion.

Next, Table 6 gives the numerical values of the erosion height and the regression velocity of the coastal cliff due to the location of the berm from the Fig. 20.

As shown in Table 6, but there is no much difference in the erosion height of the coastal cliff, as the optimum condition of the erosion control of the coastal beach due to the location of the berm, it is shown that an artificial reef with a left-hand side berm is more effective than other two cases in controlling the coastal beach erosion. Also, it is appeared that the scouring area in artificial reef with a left-hand side berm is greater than other conditions; the scouring depth is the smallest.

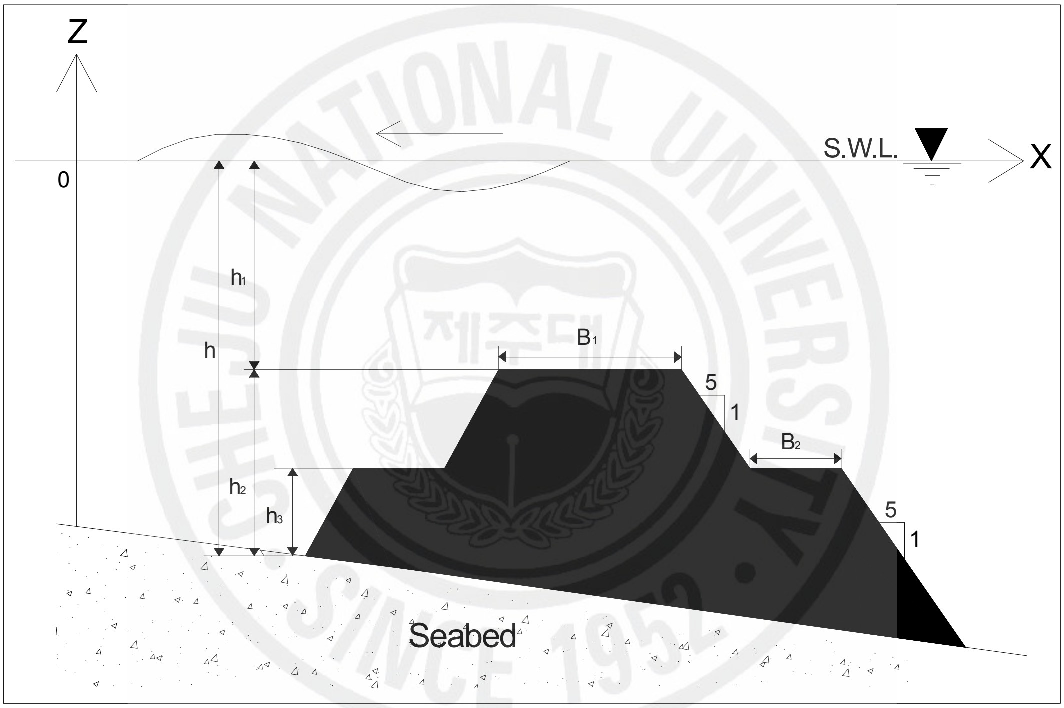
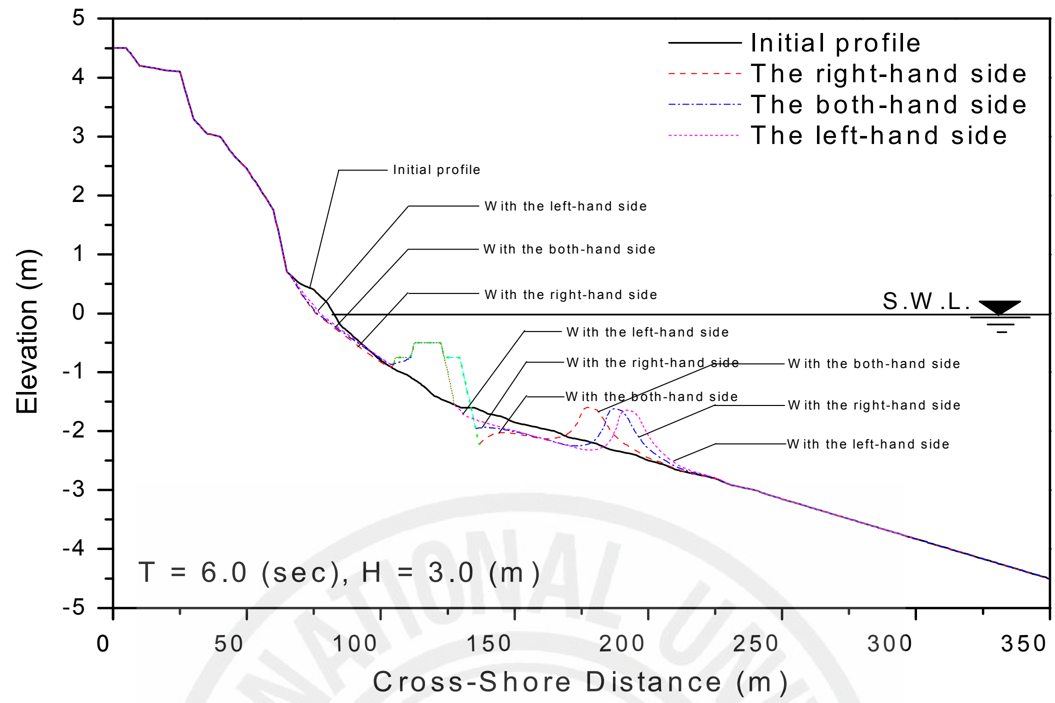
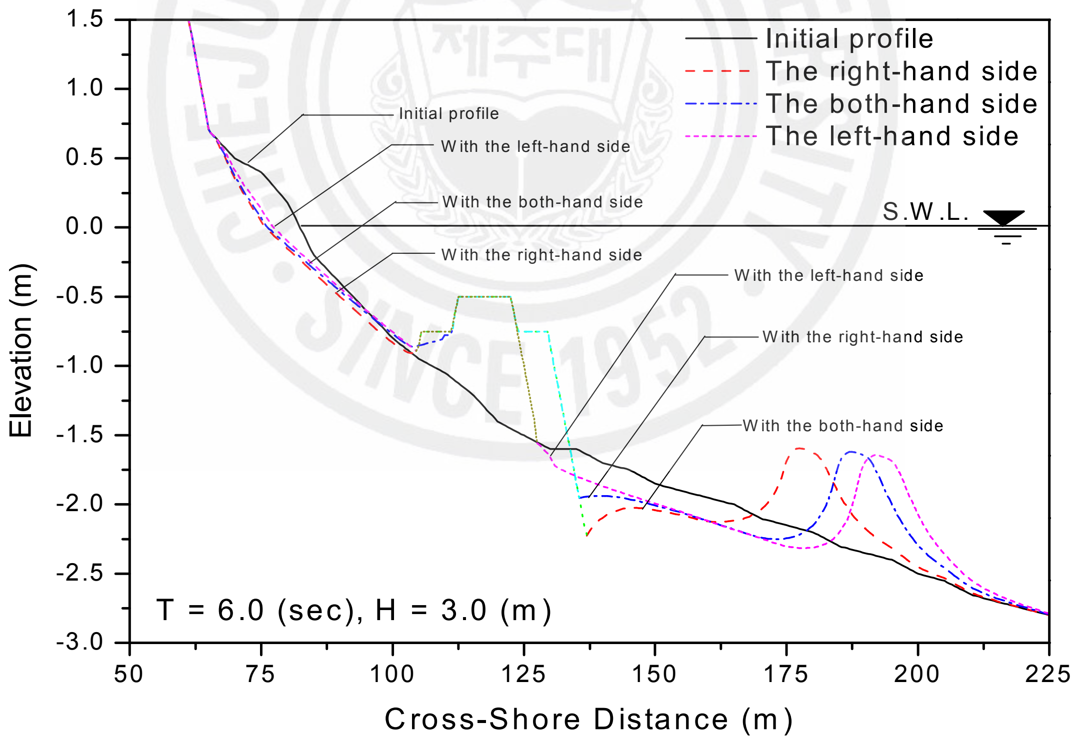


Fig. 19 Sketch of the artificial reef with a berm



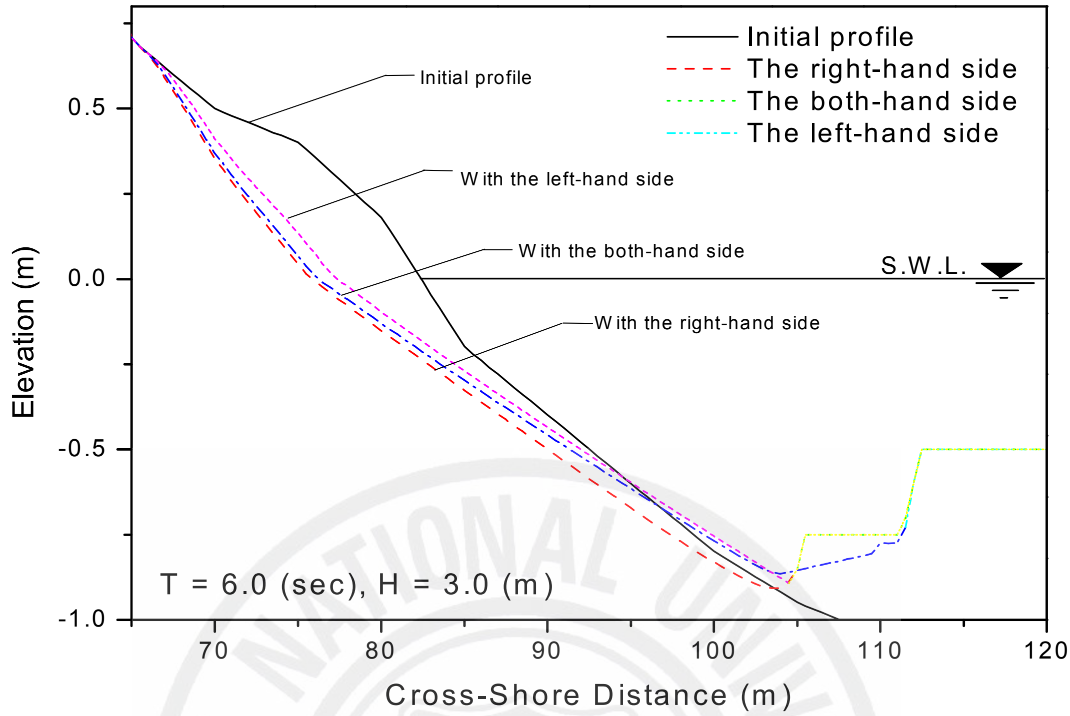
(a) Whole profile



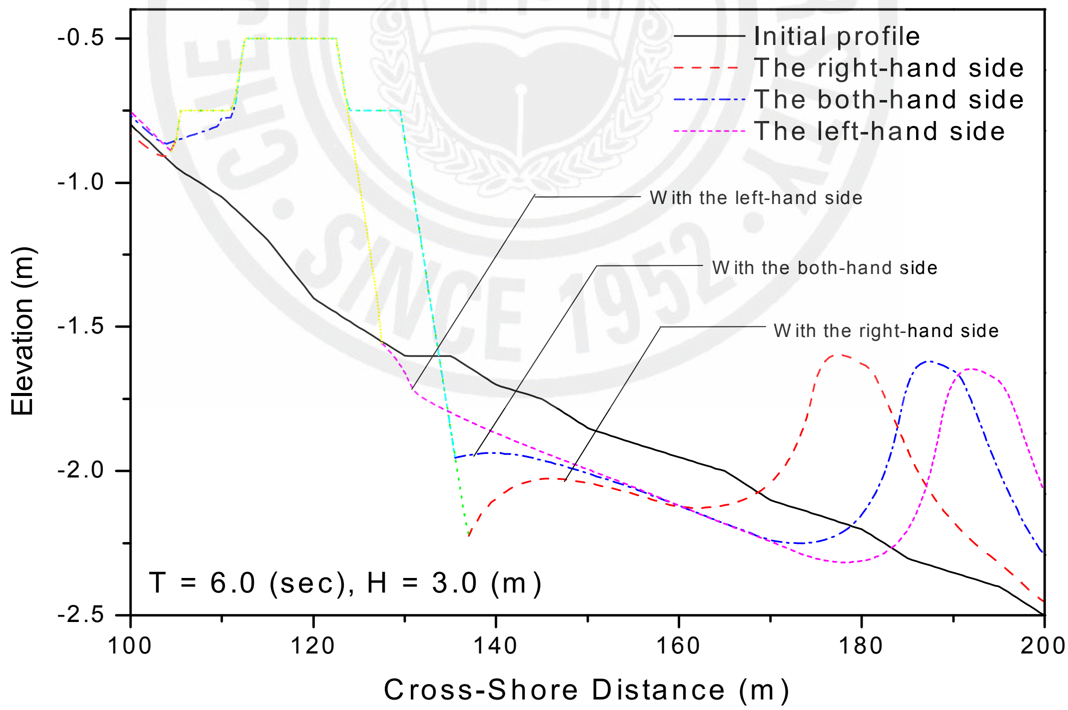
(b) Both-hand side

Fig. 20 Change of the coastal beach profile due to the berm location of the artificial reef after $30 hrs$

[(a) ~ (b)]



(c) Left-hand side



(d) Right-hand side

Fig. 20 Change of the coastal beach profile due to the location of the berm after $30hrs$

[(c) ~ (d)]

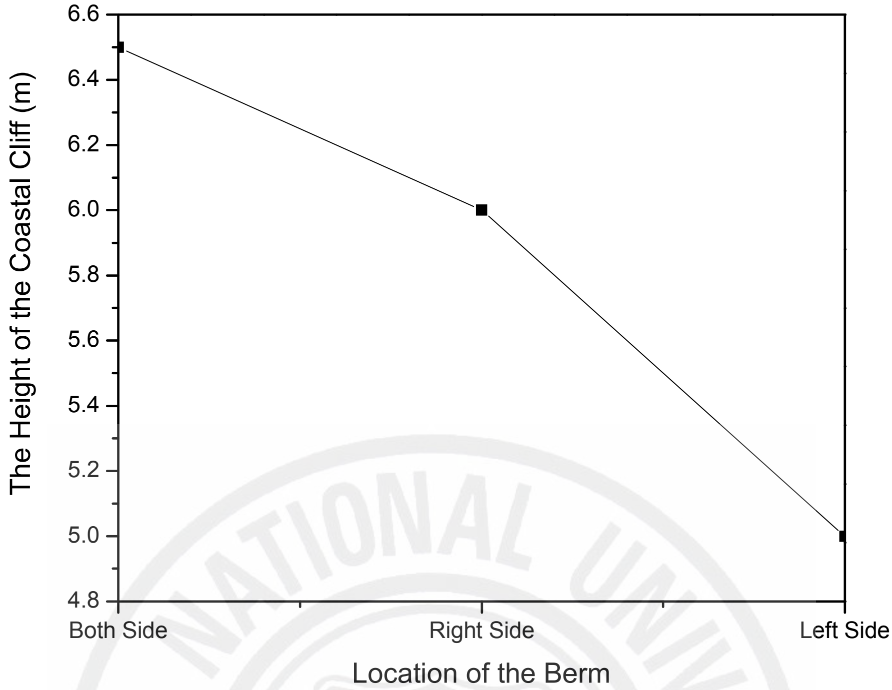


Fig. 21(a) Change of the coastal cliff height due to the berm location of the artificial reef after $30hrs$

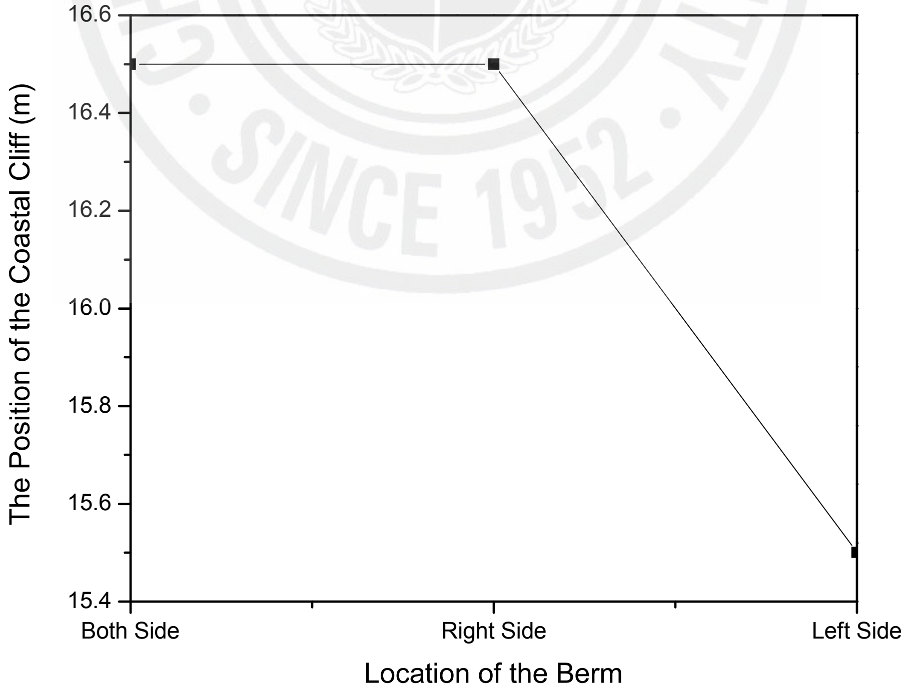


Fig. 21(b) Regression velocity of the coastal cliff due to the berm location of the artificial reef after $30hrs$

Table 6 Change of the erosion height and the regression velocity of the coastal cliff due to the berm location of the artificial reef

(Unit:m)

Location of the Berm	Height of the Cliff	Velocity of the Regression
The Both-Hand Side	6.5	16.5
The Right-Hand Side	6.0	16.5
The Left-Hand Side	5.0	15.5

4.6 Erosion Analysis of the Coastal Beach Due to the Incident Wave Angle

The equation (4) of the wave transformation by Dally et al. (1980, 1985) is used in the erosion analysis of the coastal beach due to the incident wave angle. As shown in Fig. 22, in order to investigate about the erosion behavior of the coastal beach due to the incident wave angle, the erosion analysis of the coastal beach due to the incident wave angle is carried out when the incident wave comes into as 0°, 15°, 30°, 45°, 60°, respectively.

In this study, since it is assumed that the incident wave comes into as 0° to the shoreline (y-direction), the equation (4) can be written using equation (36) when incident wave comes into as 0°.

$$\frac{\partial}{\partial x}(F \cdot \cos\theta) = \frac{k}{d}(F - F_s) = D \tag{36}$$

Therefore, the coastal beach erosion behavior due to the incident wave angle can be expressed as the energy dissipation (D) as shown in the equation (36).

where F is the energy flux of the wave, F_s is the stable energy flux of the wave, k is the empirical wave decay coefficient, d is the total water depth, θ is the incident wave angle and D is the energy dissipation per unit water volume.

On the erosion analysis of the coastal beach due to the incident wave angle, an artificial reef is established at $18m$ from the shoreline in broken wave zone. The numerical analysis of the coastal beach due to the incident wave angle is carried out in order to investigate about difference of the coastal beach erosion due to the incident wave angle, respectively .

The numerical computation results of the erosion behavior of the coastal beach for each incident wave angle is 0°, 15°, 30°, 45° and 60° are provided in Fig. 23. The numerical computation of the Fig. 23 carried out with $H = 3.0m$ and $T = 6.0\sec$. And, Fig. 24(a) and (b) depict the erosion height and the regression velocity of the coastal cliff due the incident wave angle. The numerical values of the erosion height and the regression velocity of the coastal cliff due to the incident wave angle are given in Table 7.

As shown in Fig. 23 and Fig. 24(a) and (b) and Table 7, the numerical results show that the smaller (larger) the incident wave angle is, the larger (smaller) the coastal beach erosion occurs. That is, it is shown that when incident wave comes into as 0° to the shoreline, the coastal beach erosion is the greatest. And, when the incident wave comes into as $15°$, the scouring area is the greatest at the outside of the artificial reef. Also, it is appeared that the coastal beach erosion is not seriously affected when the incident wave angle comes into as $45°$ and $60°$.

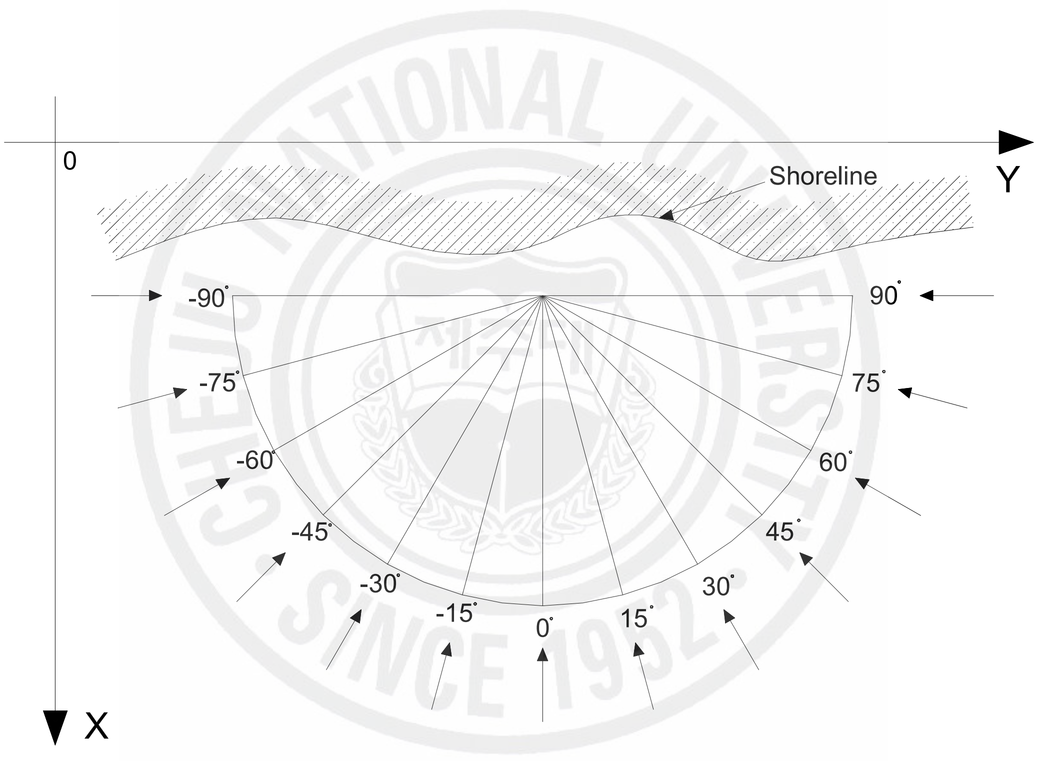
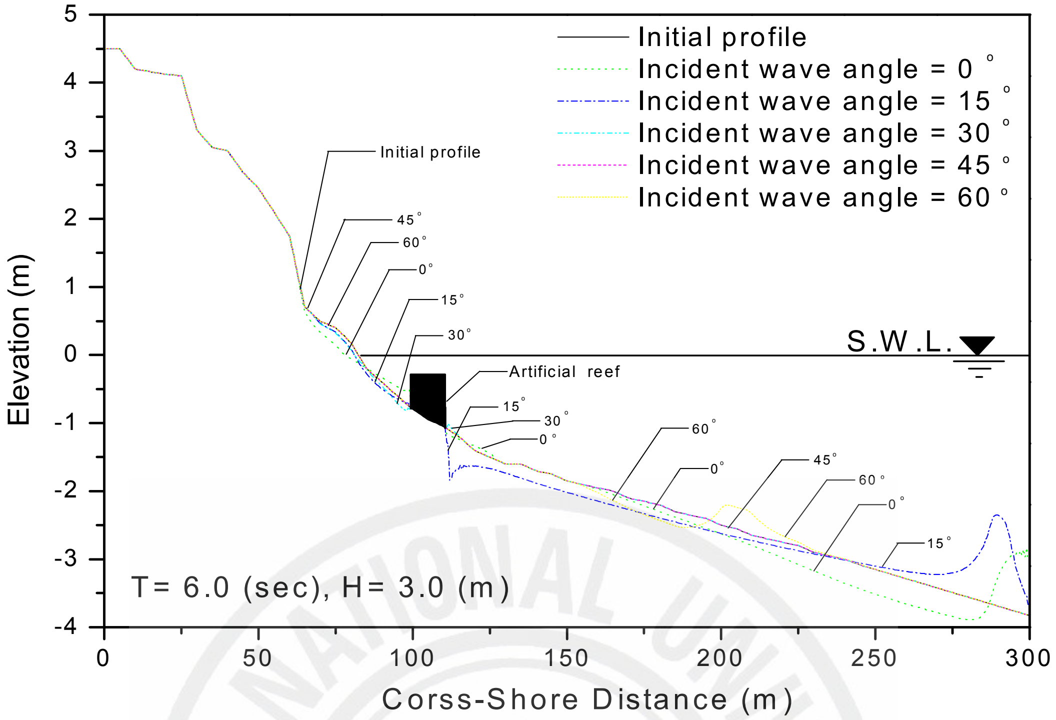
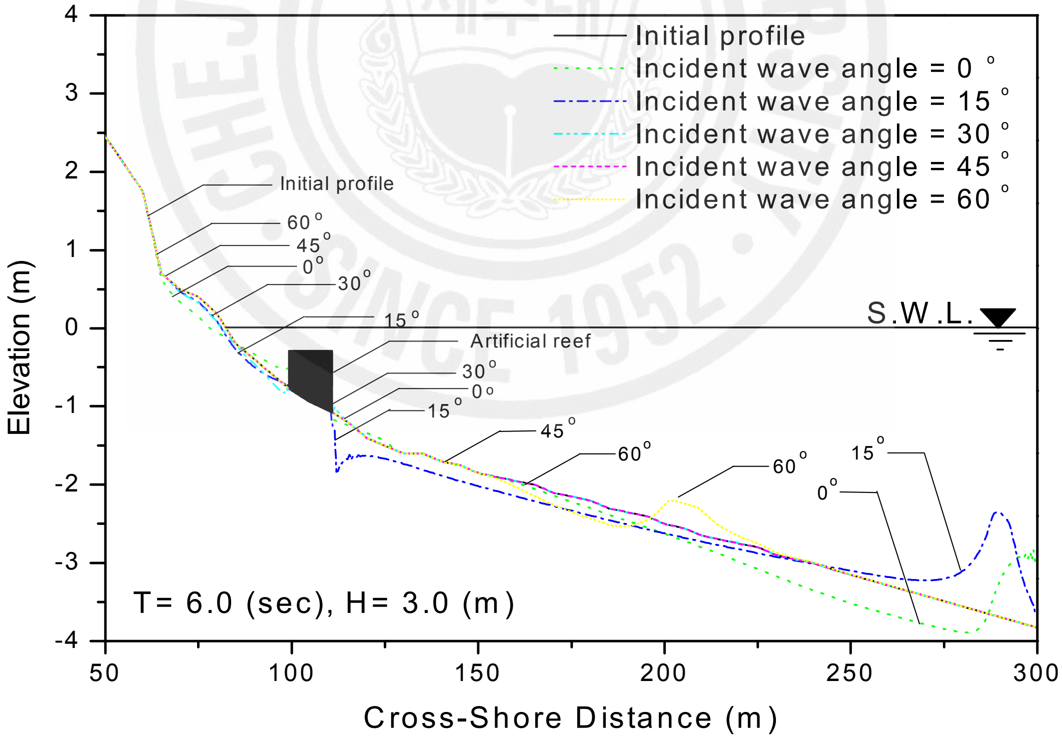


Fig. 22 Sketch of the incident wave angle

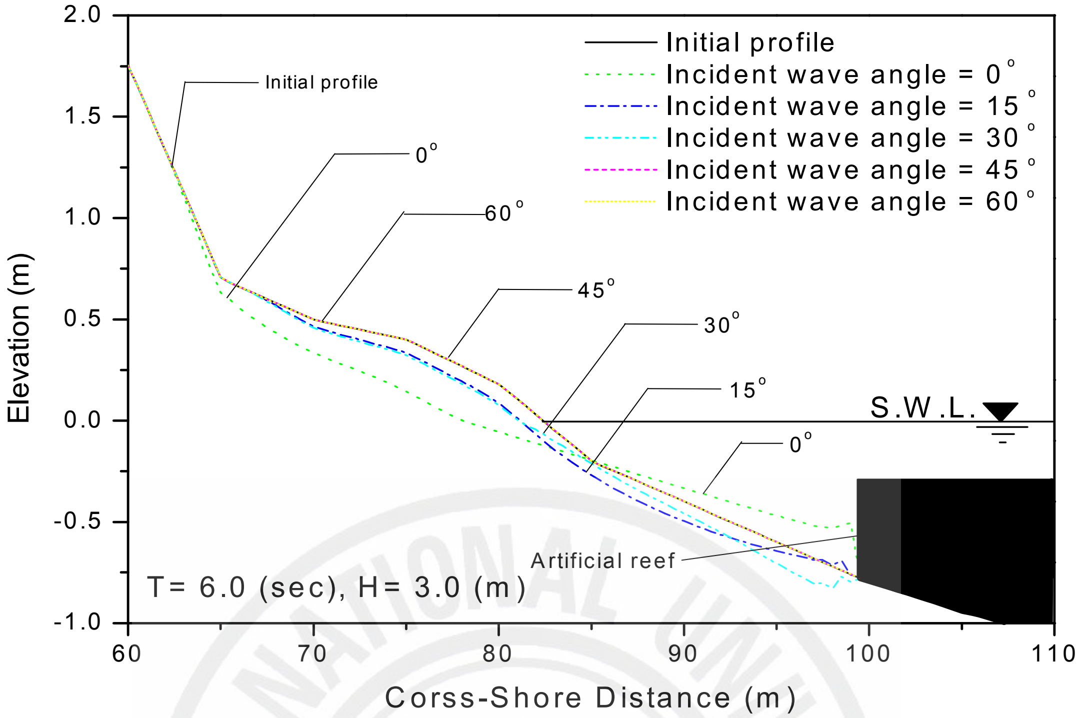


(a) Whole profile

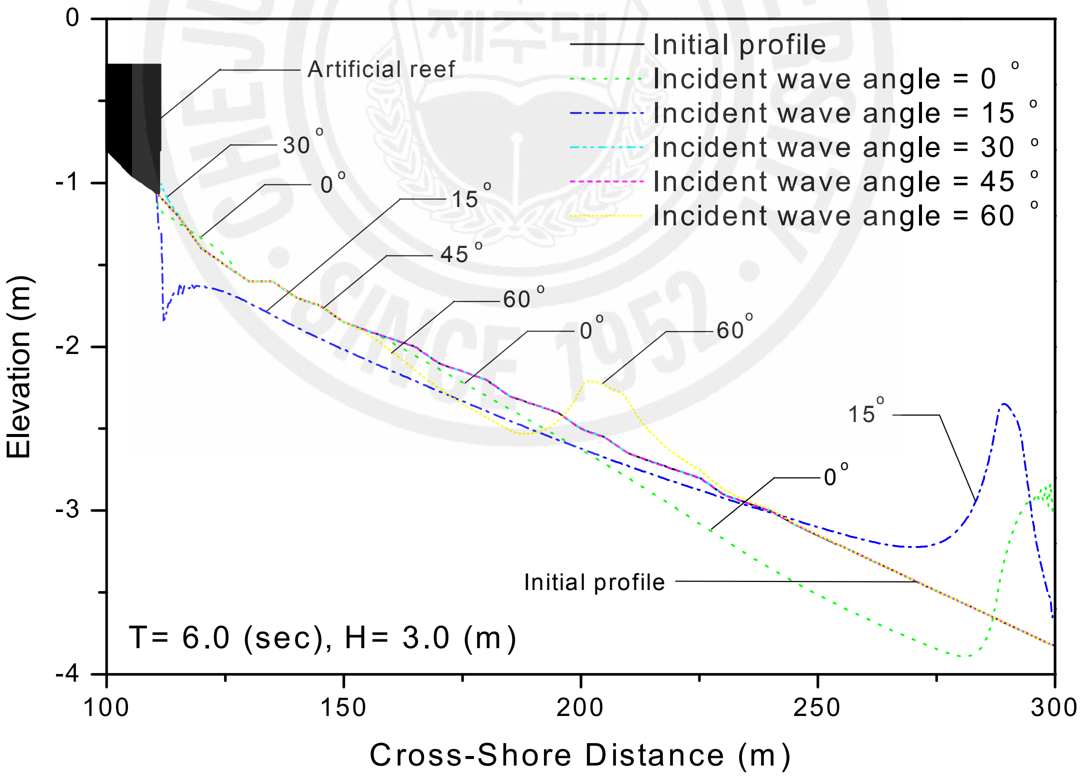


(b) Both-hand side

Fig. 23 Change of the coastal beach profile due to the incident wave angle after $30hrs$ [(a) ~ (b)]



(c) Left-hand side



(d) Right-hand side

Fig. 23 Change of the coastal beach profile due to the incident wave angle after $30hrs$

[(c) ~ (d)]

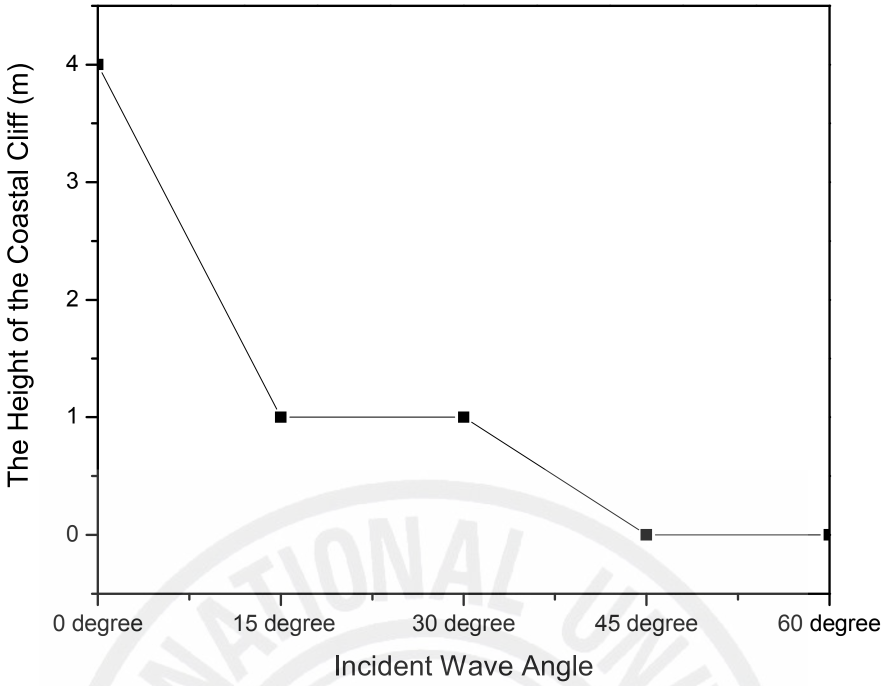


Fig. 24(a) Change of the coastal cliff height due to the incident wave angle after $30hrs$

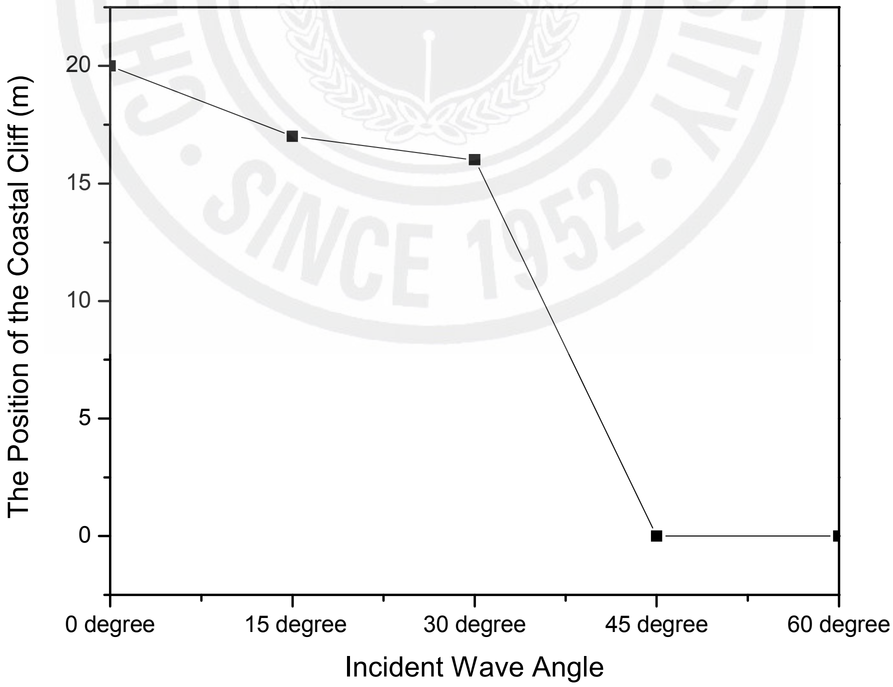


Fig. 24(b) Regression velocity of the coastal cliff due to the incident wave angle after $30hrs$

Table 7 Change of the erosion height and the regression velocity of the coastal cliff due to the incident wave angle

(Unit: m)

Incident Wave Angle	Height of the Cliff	Velocity of the Regression
0°	**4**	**20**
15°	**1**	**17**
30°	**1**	**16**
45°	**--**	**--**
60°	**--**	**--**

CHAPTER 5: CONCLUSIONS AND FUTURE WORK

5.1 Conclusions

In order to solve the problems related in preservation and utilization of the coastal beach, when it comes to these coastal beach erosion behaviors, numerical simulations for the erosion behavior and erosion process in the coastal zone has actively been studied all over the world. Prediction of the coastal beach erosion behavior using numerical simulation has been used as one method, which solve many problems related in preservation and utilization of the coastal beach.

In this study, the numerical analysis of the coastal beach with and without an artificial reef was carried out in order to control the coastal beach erosion and reduce the damages of the coastal beach by the erosion motion through numerical simulation. And the numerical analysis of the coastal beach due to the offshore distance, the height and the width of the artificial reef was carried out to investigate about the optimum conditions of the artificial reef in controlling the coastal beach erosion. The erosion analysis of the coastal beach due to the location of the berm was carried out in order to investigate erosion control effect of the coastal beach due to the location of the berm. Also, in order to investigate about the difference of the coastal beach erosion due to the incident wave angle, the erosion analysis of the coastal beach due to the incident wave angle was carried out. In the numerical analysis due to the incident wave angle, the incident wave angle was applied to $0°$, $15°$, $30°$, $45°$ and $60°$, respectively.

The results obtained from this erosion analysis were compared with Uda et al. (1984), and from the comparison and verification, it is shown that obtain very good agreement. The major results gained form these numerical analyses are as follows:

(1) The numerical result shows that the result is more effective for the case with an artificial reef than without an artificial reef in controlling the coastal beach erosion.

(2) From the erosion analysis of the coastal beach due to the offshore distance of the artificial reef, the numerical computation results showed that the closer the offshore distance of the artificial reef from the shoreline is, the smaller the coastal beach erosion occurs. But, the farther (closer) the offshore distance of the artificial reef form the shoreline is, the deeper (smaller) the scouring depth at the inside of the artificial reef occurs. Also, the numerical results showed that the farther the offshore distance of the artificial reef is, the bigger the eroded area of the coastal beach at the outside of the artificial reef occurs.

(3) From the results of the numerical erosion analysis due to the height of the artificial reef, it is shown that the higher the height of the artificial reef is, the smaller the coastal beach erosion occurs.

(4) On the erosion analysis of the coastal beach due to the width of the artificial reef, but there is no much difference in coastal beach erosion, the numerical results showed that the narrower (broader) the width of the artificial reef is, the deeper (smaller) the scouring depth occurs. Also, the results showed that the narrower the width of the artificial reef is, the larger the scouring area at the outside of the artificial reef becomes.

(5) As the optimum conditions of the artificial reef to control the coastal beach erosion, it is shown that as the offshore distance is close to the shoreline, as the height of the artificial reef is high and as the width of the artificial reef is broad, the coastal beach erosion is well controlled by an artificial reef. But, it is shown that offshore distance of the artificial reef is more important condition than the condition of the height and the width of the artificial reef in controlling the coastal beach erosion.

(6) On the erosion analysis of the coastal beach due to the location of the artificial reef's berm, it is shown that an artificial reef with a left-hand side berm is more effective than any other condition in controlling the coastal beach erosion. And it is also shown that the scouring area in artificial reef with a left-hand side berm is greater than other two cases; the scouring depth was the smallest.

(7) Form the erosion analysis of the coastal beach due to the incident wave angle, the numerical results showed that the smaller (bigger) the incident wave angle is, the bigger (smaller) the coastal beach erosion occurs. That is that, the coastal beach erosion is the most greatest when the incident wave comes into as 0° to the shoreline. And, it is also shown that when the incident wave comes into as 15°, the scouring area is the greatest at the outside of the artificial reef. Also, it is shown that the coastal beach erosion is not seriously affected when the incident wave comes into as 45° and 60°.

Therefore, this numerical method will be broadly used in prevent erosion and protect eco-system in the coastal beach zone in the future. And the results obtained by this erosion analysis will usefully be used to control the erosion process.

5.2 Future Work

The topics of research, which need to be addressed in the future, are listed below.

In this study, the numerical simulation of the coastal beach erosion behavior, including erodible bottom, non-erodible bottom and exposed non-erodible bottom was carried out. But it is necessary to study in order to raise accuracy of the numerical analysis.

The compacted effect of sand dune surface, the covering effect by landing treatment, the recovering of eroded area by wind-blown sand, the flow effect by the storm waves or tsunami and the formative factor are should be considered in the future. Also, the difference of the coastal beach by porous and non-porous of the artificial reef should be considered. And the improvement of the numerical simulation by field surveying is necessary in the future.

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ACKNOWLEDGEMENT

The thesis work was done at the Department of Civil and Environmental Engineering, Graduate School of Engineering, Cheju National University, Korea. It could not have been accomplished without the support and assistance of professors, colleagues, and my family, to whom I would like to express my gratitude.

I owe special words of thanks to my supervisor Professor Nam-Hyeong Kim for his help to bring me to this course, for the thesis ideas, for his patience, support, direction, and valuable advice. His experience in the field and vast knowledge were great important to this thesis. Without his encouragement in both academic and personal concerns, this work could not have been completed. It has been a really great opportunity for me to be one of his students over the past two year.

I am also deeply indebted to Associate professor Sang-Jin Kim and Dong-Wook Lee, for his invaluable suggestions and discussions on the research topic. My study would not be nearly as successful without any his contribution. I also owe particular thanks to Professor Seong-Gi Yang, Jung-Man Nam, Byeong-Geol Lee and Sang-Yeol Park, for his invaluable suggestions and discussions on the research topic and his support with the experimental works.

Warm thanks go to all of my present and graduated colleagues, Hang-Sik, Hyang-Hye, Min-Su, Gyeong-Bo, in the laboratory of Coastal and Harbor Engineering, for their friendship, helping, and warm encouragement. And I would like to express thankfulness to Cao Tan Nok Tan, Kim Seung-Hyun, Tae-Hyeok, Do-Hyeong, Jong-Wan, Hyeok-Chun, Woo-Yul, Sang-Bong, Seung-Hyun, Hyeong-Gun, Bong-Gwon, Dong-Meoung, Su-mi, Gyeong-Bong, Se-mi, Sun-Yeong, Hye-yeong, Seong-Ryong, Gyeong-Nam, Gyeong-Tae, Seong-Hyeop. And I hope that good future spread out before them.

I would like to represent gratitude to seniors, the same classes, juniors in school and my friends, for their friendship, helping, and warm encouragement – Hyeong-Chul, Sung-Hwan, U-Suk, An Seung-Hyun, Chang-Lim, Hyun-Chul, Jin-Hwan, Tae-Kun, Chang-Sun, Young-Min, An Hyun-Jung, Su-jung, Ko Hyun-Jung, Sun-Young, Sang-Un, Sung-Yun.

On top of that, my deep thanks to my family including my father Mun Sung-Hwan, my mother Jung Meoung-Hee, for their warm encouragement and tremendous love, and my younger sister Ji-Young, and my younger brother Suk-Won.

감사의 글

우선, 이 논문을 완성할 수 있도록 대학원생활 동안 끊임없는 사랑과 배려로 지도해주시고, 여러 가지로 많이 부족한 저에게 항상 변함없는 조언과 질책으로 큰 어려움 없이 석사과정을 마칠 수 있도록 보살펴 주신 김남형 교수님께 깊은 감사를 드리며 항상 건강하시길 기원합니다. 또한 바쁘신 와중에도 심사를 맡으셔서 세심한 지도를 해 주신 김상진 교수님과 이동욱 교수님께도 진심으로 감사를 드립니다. 아울러 학위과정 중 학문으로 다가갈 수 있는 기초를 마련해 주신 양성기 교수님, 남정만 교수님, 이병걸 교수님, 박상렬 교수님께도 진심으로 감사를 드립니다.

대학원 생활 동안 항상 함께 생활하면서 싸우기도 많이 싸우고 투덜거렸지만 보이지 않게 많은 도움과 항상 힘이 되어준, 그래서 곰이라고 불러주었기에 더 더욱 고마운 행식오빠와 서로 너무 다르면서도 너무나 비슷했기에 항상 옥신각신 하면서도 같은 동기였기에 더 더욱 힘을 낼 수 있었던 향혜, 그리고 마지막으로 타국으로 유학을 와서 고생하면서도 언제나 나에게 “Don’t worry, you can do everything, and cheer up! 이라고 말하며 힘을 준 Than오빠에게 고마운 마음을 전합니다.
그리고 웃는 얼굴로 얼마 안 남았다고 힘내라며 말해주고 궂은 일들을 성실히 맡아 해 주었던 승현오빠, 창림오빠, 현철오빠에게도 고마운 마음을 전합니다. 부득이한 사정으로 이번에 대학원을 진학하지 못해 아쉬움이 너무나 큰 승만오빠와 언제나 구수한 사투리로 우리 항만 실험실을 웃음 바다로 만들어 주었던 긍께 진환오빠, 경배오빠, 진석오빠, 남호오빠 그리고 행석이에게도 고마운 마음과 함께 앞으로 밝은 미래가 함께하길 빕니다. 그리고 대학원 생활을 같이 보내며 많은 조언과 힘이 되 주었던, 언제나 친 오빠 같았던 민수오빠와 경보오빠에게도 고마운 마음을 전합니다.

그리고 타국으로 유학을 가 고생을 하시면서도 간간히 연락하며 많은 조언을 해 주시고 큰 용기를 주신 영택선배, 현우선배, 순보선배, 지훈선배, 형철선배, 상민선배, 덕건선배께도 진심으로 감사드립니다.

그리고 비록 다른 실험실이지만 대학원 생활을 같이하며 같은 시름을 달래고 서로 격려해 주었던 승현오빠, 태혁오빠, 도형오빠, 우열오빠, 상봉오빠, 성룡오빠, 종완오빠, 혁춘오빠, 승혁오빠, 봉권오빠, 동명오빠, 형건오빠, 성협오빠, 경태오빠, 경남오빠, 승호오빠, 웅규오빠, 정우오빠, 용현오빠, 현탁오빠, 경봉오빠, 정훈오빠,

성윤오빠, 상운오빠에게도 고마운 마음을 전합니다. 그리고 대학원 생활 동안 너무나 많은 도움을 받고 인생에 대해 많은 고민을 들어주었던 수미언니와 경연언니, 그리고 언제나 나의 숨은 조력자이며 산책의 동반자였던 세미언니, 그리고, 나의 소중한 친구이자 오기로 힘든 대학원 생활을 같이 버틴 혜영이, 그리고 나의 소중한 친구이자 산책 파트너이고 기혁오빠의 여자친구 선영이, 장난스레 투덜거리면서도 대학원 생활 동안 많은 격려를 해준 기혁오빠에게도 고마운 마음과 함께 이들 앞에 밝고 희망찬 미래가 펼쳐지기를 바랍니다.

또한, 대학원 생활 동안 끊임없는 격려를 해준 성환오빠, 우석오빠, 태건오빠, 영민오빠, 창선오빠, 정운이에게도 고마운 마음을 전합니다. 그리고 지금은 연세대 대학원에 진학하여 네이트온으로 서로의 외로움을 달래며 미래에 꼭 성공하리라 같이 마음먹었던 현정이, 먼 훗날 나의 아픈 몸을 진찰해 줄 미래의 유망한 내 의사친구이며 성공한 모습으로 만나자며 항상 격려해준 수정이, 스트레스 쌓일 때 마다 전화해 항상 괴롭히면서도 힘내라고 말해준 현정이, 나도 아가씨라며 잘 될 거라고 걱정하지 말라며 힘을 준 선영이, 그리고 유리와 지금은 애기 엄마가 된 인영이, 그리고 나의 더 없이 소중한 친구들 은경이, 수지, 우영이, 영경이, 미랑이, 연성이에게도 고마운 마음을 전합니다. 그리고 나의 성공을 진정으로 바라주는 나리에게도 고마운 마음을 전합니다.

끝으로 오늘이 있기까지 많은 배려와 항상 믿고, 묵묵히 지켜봐 주시면서 많은 용기를 주셨던 너무나도 사랑하는 우리 가족 나의 모든 것인, 아버지와 어머니, 언니 파이팅이라며 잘하라고 그래서 항상 미안한 동생 지영이, 멋을 부리기에 항상 바쁜, 아직은 어려 철이 없지만 누나에게 그 자체만으로도 힘이 되어준 석원이, 우리 가족 모두에게 이 논문으로써나마 고마운 마음을 전하며 항상 건강하길 빕니다. – 내가 아는 모든 이가 상상하는 꿈들이 현실이 되었으면 합니다.

상상은 현실이 된다. 상상은 현실을 바꾼다.

불가능해 보이는 목표라 할지라도, 그것을 꿈꾸고

상상하는 순간 이미 거기에 다가가 있는 셈이다.

상상력은 생존의 힘이다.

- 에란 카츠의 <천재가 된 제롬> 중에서 -

2008년 2월

List of Papers

◈ Refereed Journal Paper

① "The Erosion Analysis of the Coastal Beach by an Artificial Reef." *KSCE Journal of Civil Engineering*, Vol. 27, No. 4B, pp. 455-460, 2007 (in Korean).

◈ Proceedings of Annual Conference

① "The Erosion Analysis of the Coastal Cliff by the Artificial Reef." *Proceeding of the Korean Annual Conference on Civil Engineering*, pp. 2685-2688, 2006 (in Korean).

② "The Erosion Analysis of the Artificial Reef with a Berm." *Proceeding of the Korean Annual Conference on Coastal & Ocean Engineering*, pp. 2377-2380, 2007.

③ "The Erosion Analysis of the Coastal Beach According to the Incident Wave Angle." *Proceeding of the Korean Annual Conference on Civil Engineering*, pp. 3647-3650, 2007.

④ "Field Survey on the Seasonal Topography Process of Iho Beach in Jeju." *Proceeding of the Korean Annual Conference on Marine Environmental Engineering*, pp. 331-336, 2007 (in Korean).

◈ Award

① "인공리프에 의한 사빈의 침식제어", 2007년 제2회 해양과학기술 분야 아이디어 및 논문공모전 - 논문 부문 해양수산부 장관상(대상) 수상.