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A Numerical Simulation on the Coastal Cliff Change with Non-Erodible Bottom

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ABSTRACT : *해안단애의 형성과 침식에의한 해안선의 후퇴를 저지하기 위해 방조벽을 설치하여 해빈의 침식 변화과정에 관한 수치모의를 수행하였다. 평균수위의 상승을 동반하는 폭풍해일이 내습하는 경우 평균수위의 상승이 방조벽의 세굴을 가속화시킨다. 그러므로 본 연구는 사빈 해안에 방조벽을 설치하는 경우 해빈 침식의 거동을 예측하는데 이용할 수 있겠다.*

1. Introduction

The shoreline zone is the boundary between land and sea, a shock-absorbing zone referred to as a dune. The dune not only protects land from erosion caused by wave motion, but controls both wind-blown sand and wind-blown salt.

It is the supplier of bottom material sediment when the beach is eroded and plays an important role as a shock-absorbing zone. It is necessary that the dune be suitably managed, because it is used as waterfront space.

When a storm surge with wave setup comes to a sand beach, erosion topography called coastal cliffs may occur on a sand beach. Following erosion, the coastal cliff may have a bad effect on the restoration of the sand beach. In advance, if the foundation of the coastal cliff is scoured by wave motion, it is easy for the coastal cliff to produce slope failure. Therefore, it accelerates the regression of the coastal cliff. The regression of the coastal cliff by erosion results in the regression of the dune. In addition, the regression not only loses real estate in the hinterland, but also ruins the shock-absorbing zone between land and sea. So the destruction of the dune may lead to a loss of the habitat or egg-laying grounds of living creatures. A numerical simulation on the formation and erosion of coastal cliffs has actively been studied. There is a sea cliff in the shore, which is externally similar to a coastal cliff.

Horikawa and Sunamura(1969, 1970, 1972) clarified the behavior of sea cliff erosion by air photos and tests. In the case of sea cliff, the resisting force against wave motion is much bigger than that of the sand beach. This is why the sea cliff is generally made of rock. Then, the long time scale was applied to perform the numerical simulation of the sea cliff. However, in the case of the sand beach, the sand beach process that is eroded by wave motion is taken in the short time scale, and the sand beach process repeats the deposition and erosion.

Van 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, Sargent and Brikemeier(1985) applied a numerical model to the beach profile at the eastern coast of America and the Gulf of Mexico. Further-more, Huges and Chiu(1981) performed indoor experiments about the erosion of dune. The erosion model of dunes, according to time, was developed by Kriebel and Dean(1984, 1985), Kriebel(1990), Larson and Kraus(1989, 1990). However, Kriebel's model did not reproduce a sandbar, because it was based on Dean's theory about the equilibrium profile. Fundamentally, a wave setup is the principal factor of the sand beach change, and the influence of wave setup on the sand beach change was not solved this time. Moreover, Kim et al. (2002) performed a numerical simulation on the generation of a coastal cliff when storm surge was accompanied with wave setup on a sand beach.

The generation and regression of coastal cliff, as mentioned above, results in damages to the hinterland; therefore, the protection of erosion and regression in the shoreline is considered to be of primary importance. This study used the numerical method preformed by Kim et al. (2002) on the formation of coastal cliff.

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The numerical method is applied to the behavior of sand beach with and without a sea wall, in three cases. Also, the model is compared with observation and calculation of the erosion process.

2. Basic Equation

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

$$\left(\frac{\partial q_x}{\partial x}+\frac{\partial q_y}{\partial y}\right)=\frac{\partial h}{\partial t} \qquad (1)$$

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.

Considering only incident wave coming at a right angle to shore, equation (1) becomes as follows :

$$\frac{\partial q}{\partial x}=\frac{\partial h}{\partial t} \qquad (2)$$

Therefore, the sand beach change can be computed by a conservation equation (2). In order to raise the safety of calculation, cross-shore sediment transport rate is used by two times, step Δt as following:

$$\frac{h_i^{k+1}-h_i^k}{\Delta t}=\frac{1}{2}\left(\frac{q_{i+1}^{k+1}-q_i^{k+1}}{\Delta x}+\frac{q_{i+1}^{k}-q_i^{k}}{\Delta x}\right) \qquad (3)$$

where, Δx is unit distance, k denotes time level, i denotes the number of grid.

3. Application of Non-erodible Bottom

As shown Fig. 1, the bottom of the dune-beach profile is constituted of non-erodible bottom, such as rock and erodible bottom, such as sand.

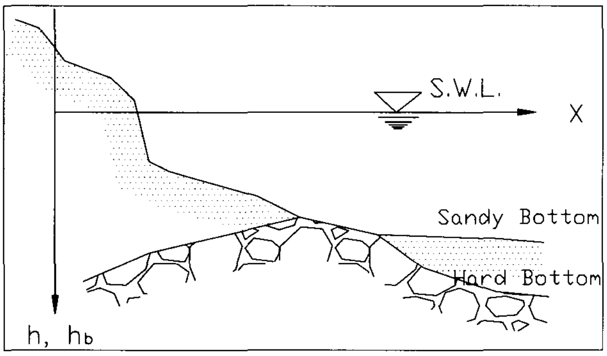


Fig. 1 Definition nonerodible bottom and coordinate system

The availability of a limited volume of sand yields the following condition in the change in transport Δq_i ,

$$\Delta V_i=\Delta q_i\Delta t=(h_{b,i}-h_i)\Delta x \qquad (4)$$

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. If a non-erodible profile is already exposed, in a particular cell, $h_{b,i}=h_i$ and $\Delta q_i=0$. If the non-erodible profile is exposed, cross-shore transport rate is uniformed.

The deposition process does not 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 deposition are divided into equation (5) :

$$\frac{\partial h}{\partial t}>0 \quad \textit{erosion} \ , \quad \frac{\partial h}{\partial t}<0 \quad \textit{deposition} \qquad (5)$$

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 (6),

$$h^k_{p,i}>h^k_{b,i} \qquad (6)$$

where, h_p is the profile elevation, taken in a positive direction below the still water level; where non-erodible bottom was removed. h_b is the elevation of non-erodible profile, taken in a positive direction below the still water level; k is the time level; i is the number of grid. Equation (6) implies that a non-erodible bottom is eroded, and that the cross-shore sediment transport rate needs to be corrected.

The cross-shore sediment transport rate needs to be modified using the following equation (7) with a scouring attenuation coefficient(λ_{hb}) by Larson and Kraus(1995).

$$q=q_p+(q_{hb}-q_p)e^{-\lambda_{hb}(x-x_{hb})} \qquad x\geq x_{hb} \qquad (7)$$

where, q_{hb} is the cross-shore sediment transport rate at x_{hb}, ; λ_{hb} is the scour attenuation coefficient. The bigger value of λ_{hb} is, the larger the hollow that is generated. So, this study used $\lambda_{hb}=1.0m^{-1}$. Equation (7) produces $q=q_{hb}$ if $x=x_{hb}$ and $q=q_p$ if $x\rightarrow\infty$.

4. Comparison and Verification

For the verification of numerical simulation, Dette and Uliczka

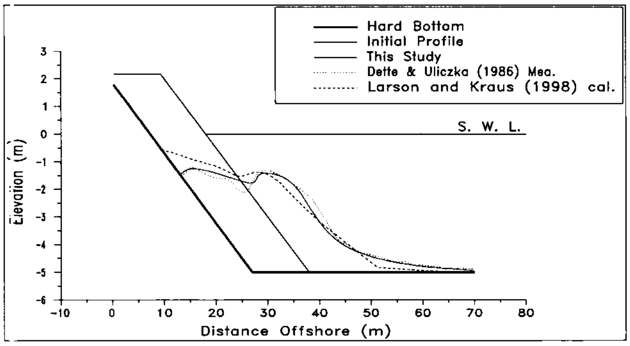


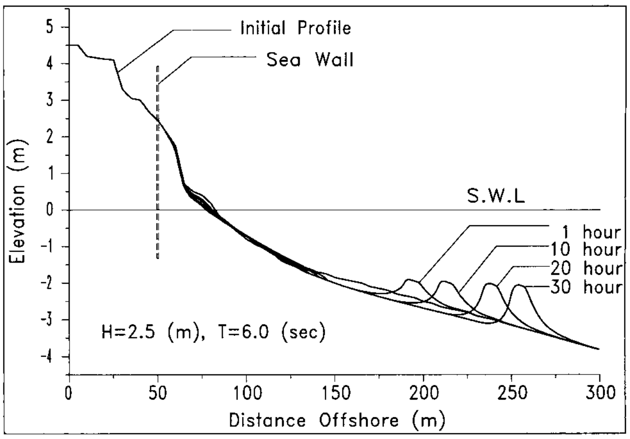
Fig. 2 Comparison and verification

(1986) performed a 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 $D_{50} = 0.33\ mm$. About 2m were nourished for initial profile, and the experiment was performed using waves with heights at 1.5m and periods of 6.0sec, during a time of 176 minutes. Fig. 2 compared numerical results with measured data by Dette and Uliczka (1986).

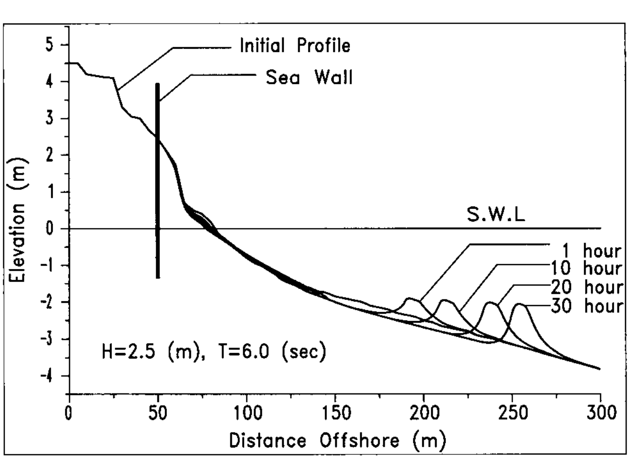
Fig. 2 shows that the head of a sandbar is bigger in calculated data than in measured data. However, on the whole, two graphs show the same tendency and close agreement. Furthermore, the value of this numerical simulation is shown to be closer to the measured data than that of the numerical simulation, performed by Larson and Kraus (1998).

5. The Behavior of Sand Beach Erosion with and without the Seawall

The seawall was set up in the place where erosion was generated; it serves to protect a sand beach from erosion by wave motion. The numerical simulation was performed on sand beach erosion with a seawall, and it was used to a sand beach with a non-erodible bottom. To determine the behavior of a sand beach erosion, the numerical simulation method, performed by Kim et al. (2002) in dune-beach profile, was used. The wave conditions for this study are the wave height of 2.5m and the wave period of 6sec.The numerical computations in three cases are carried out; for each case, the simulation is carried out with and without a seawall, respectively.The seawall is set up at 50m from the start of the sand beach profile, and presented wave conditions. Fig. 3 shows the erosion in coastal cliff and the generation of a sandbar offshore. But there is no difference between Fig. 3(a) with a seawall and Fig. 3(b) without a seawall. Because the wave run-up is relatively small and did not affect the seawall, the erosion in coastal cliff is almost identical.



(a) Without a seawall

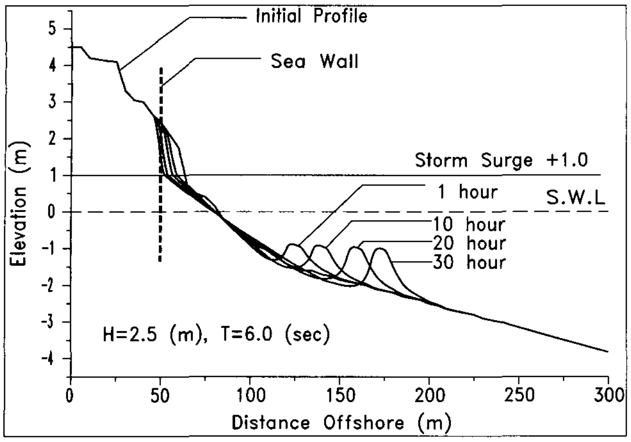


(b) With a seawall

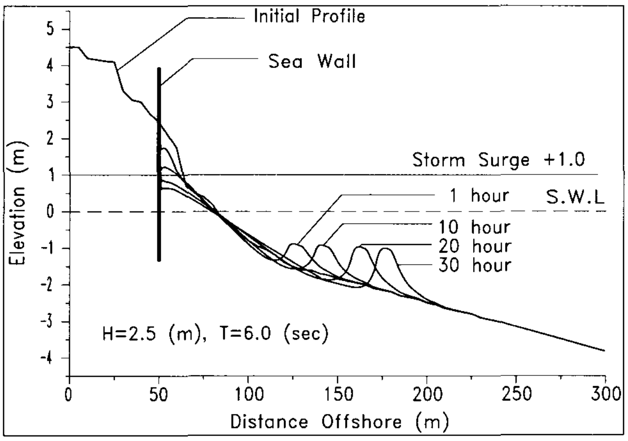
Fig. 3 The behavior of a sand beach during storm surge without wave setup.

Fig. 4 shows the computation of wave setup; 1.0m accompanied by storm surge. There is no difference in the sandbar between Fig. 4(a) and Fig. 4(b). But the difference for the erosion in coastal cliff is clear. Fig. 4(a) without a seawall shows the erosion in coastal cliff and generation of a sandbar offshore, and according to time lapse, the erosion in coastal cliff occurs much more frequently. But Fig. 4(b) with a seawall shows that the erosion in coastal cliff does not advance to forward direction, and the erosion occurs along the seawall, vertically. Fig. 4(b) shows that the erosion in coastal cliff in front of the seawall transforms into scouring, according to how much time has lapsed.

Fig. 5 shows the computation of wave setup, 2.0m accompanied by storm surge. There is no difference in sandbar between Fig. 5(a) and Fig. 5(b). However, the difference for the erosion in coastal cliff is presented clearly. Fig. 5(a) without a seawall shows the erosion in coastal cliff and the generation of a sandbar offshore, and according to



(a) Without a seawall



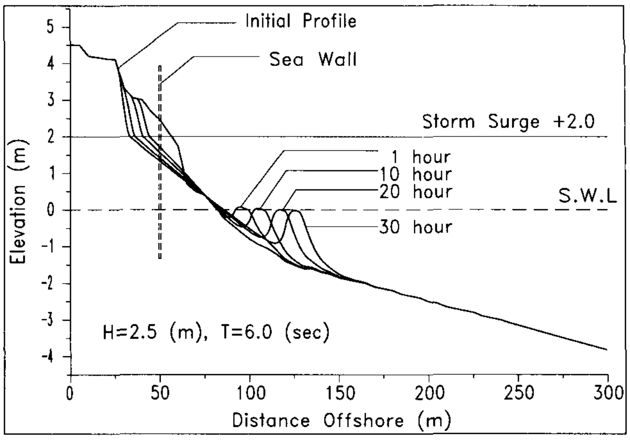
(b) With a seawall

Fig. 4 The behavior of a sand beach during storm surge with wave setup +1.0m.

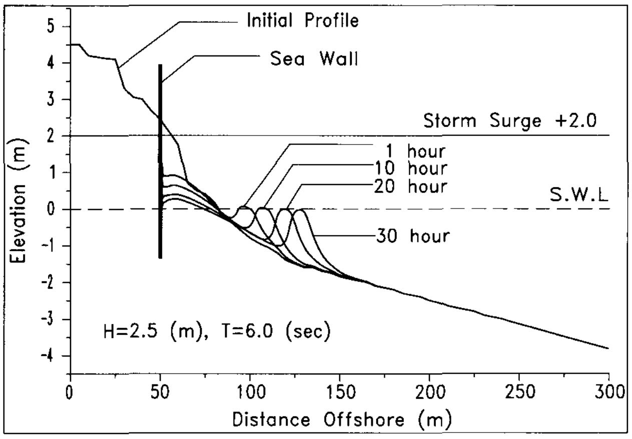
the time lapse, the erosion in coastal cliff occurs much more frequetly than in the other two cases. But Fig. 5(b) with a seawall shows that the erosion in coastal cliff does not advance to forward directions, and the erosion occurs along the seawall, vertically. Much scouring at the initial time of storm surge is shown in Fig. 5(b).

6. Conclusions

This numerical method is applied to the sand beach profile with a non-erodible bottom. Through this simulation on the sand beach profile change with a non-erodible bottom, this numerical method can be applied on various sand beaches, regardless of the condition of the sea bottom. The seawall is one of the methods to protect a sand beach from erosion by wave run-up. Also, the seawall protect a shoreline zone from regression by erosion. However, the higher the wave setup is, the much more scouring occurs. This is why much more of the wave is obstructed by a seawall.



(a) Without a seawall



(b) With a seawall

Fig. 5 The behavior of a sand beach during storm surge with wave setup +2.0m.

Then, this method is considered only a non-erodible bottom as a boundary condition. But the difference of the material grain size, compaction effect, armor by a plant, and so on are not considered. These factors must be considered in order for accuracy in future research.

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