Model for Predicting Beach Changes using Cellular Automaton Method

M. Endo[1], A. Kobayashi[1], T. Uda[2], M. Serizawa[3] and Y. Noshi[4]

[1]Department of Oceanic Architecture & Eng., College of Science & Technology, Nihon University, 7-24-1 Narashinodai, Funabashi, Chiba 274-8501, Japan (csmt10001@g.nihon-u.ac.jp)
[2]Public Works Research Center, 1-6-4 Taito, Taito, Tokyo 110-0016, Japan (uda@pwrc.or.jp)
[3]Coastal Engineering Laboratory Co., Ltd., 1-22-301 Wakaba, Shinjuku-ku, Tokyo 160-0011, Japan (coastseri@nifty.com)
[4]ICOMNET, Co., Ltd., 2-7-4-627 Aomi, Koto-ku, Tokyo 135-0064, Japan

INTRODUCTION

Sand deposition on the gently-sloping revetment, the slope of which is steeper than the equilibrium slope of sand, is often observed when storm waves ran up the beach. Serizawa et al. (2006) have developed the BG model (a model for predicting 3-D beach changes based on the Bagnold's concept), in which the cross-shore sand transport depends on the balance between the equilibrium slope of sand and the local slope of the beach, and seaward sand transport will occur when the local slope of the beach or the structure is larger than the equilibrium slope. This implies that shoreward sand transport on the slope steeper than the equilibrium slope of sand cannot be predicted by the BG model. This is because the fundamental equation of the BG model is expressed by the net sand transport defined by the sum of the sand transport under the ongoing and outgoing waves. In this study, sand transport under the ongoing and outgoing waves is independently taken into account, while retuning the fundamental concept of the BG model and a new model for predicting beach changes is developed using the cellular automaton method (Baxter, 1990; Landry, 1994) to predict the phenomenon mentioned above.

NUMERICAL MODEL

The beach topography is divided by a number of grids, and a rule, by which the amount of sand transport and transport distance of sand from a cell to another cell under waves are given, is designated for each cell. Applying this procedure to all the cells, sand transport in the entire zone is determined. **Figure 1** and **Table 1** show the schematic diagram of the model and the fundamental equations. The rate of sand transport was separated into the sand transport V^+ and V^- under the ongoing and outgoing waves, respectively, taking into account of the Bowen (1980)'s sand transport equation, in which a linear approximation was made for the sand transport equation of the unidirectional flow proposed by Bagnold (1963) in terms of the seabed slope. The actions under the ongoing and outgoing waves were considered alternately in each time step; under the ongoing waves, sand transport of V^+ occurs from each cell to the nearby cell and V^- under the outgoing waves. In Eqs. (1) and (2), the ratio of the local slope, $\tan\beta_i$, relative to the angle of repose slope of $\tan\phi$ has a vital role in determining the sand transport. The sand transport on the upslope becomes smaller than that on flat bed because of the gravity effect, whereas sand transport on the downslope becomes large. When sand transport under the ongoing and outgoing waves is equivalent, net sand transport becomes 0 and the slope satisfying this condition is the equilibrium slope, $\tan\beta_C$. In this case, Eq. (3) must be satisfied. Substituting Eqs. (1) and (2) into Eq. (3), and using the relationship of $\tan\beta_i = \tan\beta_C$, Eq. (4) is derived by solving $\tan\beta_C$. Eq. (4) is equal to the equation for the equilibrium slope derived by Inman and Bagnold (1963). b ($0 \leqq b \leqq 1$) in Eq. (4) is the factor expressing the asymmetry of the wave action and is equivalent to the ratio of energy dissipation of the ongoing waves relative to that of the outgoing waves (Inman and Bagnold, 1963). Solving Eq. (4) for b, Eq. (5)

Table 1. Fundamental equations.

$$V^+ = V_0\left(1 - \frac{\tan\beta_i}{\tan\phi}\right) \quad (1) \qquad V^- = b\cdot V_0\left(1 + \frac{\tan\beta_i}{\tan\phi}\right) \quad (2)$$

$$V = V^+ + \left(-V^-\right) = 0 \quad (3) \qquad \tan\beta_C = \left(\frac{1-b}{1+b}\right)\cdot\tan\phi \quad (4)$$

$$b = \frac{\tan\phi - \tan\beta_C}{\tan\phi + \tan\beta_C} \quad (5)$$

V^+ : sand transport under ongoing waves
V^- : sand transport under outgoing waves
$\tan\beta_i$: local slope
V_0 : sand transport when $\tan\beta_i$=0
b : ratio between V^+ and V^- when $\tan\beta_i$=0 (0<b<1)
$\tan\phi$: angle of repose of sand
$\tan\beta_C$: equilibrium slope of sand

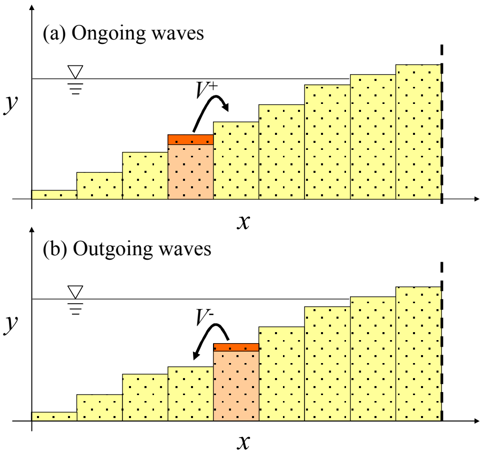

Fig. 1 Schematic diagram of model.

Fig. 2 Sand deposition on steps of gently-sloping revetment on Katsuyama coast.

is derived. Given the initial conditions, sand transport under the ongoing waves in each cell is first calculated and the calculation of sand movement in the entire cells is followed. The calculation under the outgoing waves is carried out in the same way. Given the equilibrium slope, $\tan\beta_C$, the same as in the BG model, b is determined from Eq. (5). In this study, the distance of sand transport is assumed to be one cell and the asymmetrical case with three cells forward and one cell backward was also considered. Furthermore, sand transport is set to be 0 in the zones deeper than the depth of closure, h_C, and higher than the berm height, h_R. These concepts were incorporated into the model, and applied to the cases to which the BG model was unable to apply. **Figure 2** shows the sand deposition on steps of the gently-sloping revetment on the Katsuyama coast in Chiba Prefecture. It was observed that sand was deposited on each step of the gently-sloping revetment. This sand deposition on the gently-sloping revetment was numerically simulated in Case 1. In Cases 2 and 3, the trapping of shoreward sand transport by the excavation holes formed by coral reef mining was simulated.

RESULTS AND CONCLUSIONS

Although the initial beach slope is equal to the equilibrium slope of 1/9 in Case 1, shoreward sand transport occurred because the seabed was flat in the zone offshore of X = 30 m, as shown in **Fig. 3**, and sand was deposited on the steps of the gently-sloping revetment. Even though the local slope on the steps of the gently-sloping revetment is steeper than the angle of repose of sand, sand was able to be transported to the upper steps after sand was deposited in front of the steps while forming a local slope gentler than the repose slope of 1/2. Because of the sand deposition on the steps, a gentle slope covered with sand was gradually formed from the lowest step to the upper step, and the sand deposited on the steps became stable. Thus, when the actions under the ongoing and outgoing waves are separately taken into account, the landward movement of sand on the slope steeper than the equilibrium slope could be predicted, which was difficult to predict by the BG model. In Case 2, sand supplied from the offshore zone was transported shoreward and was trapped in the hole on the reef flat until 2×10^4 steps, resulting in the blockage of shoreward sand transport, as shown in **Fig. 4**. After part of the hole deeper than the depth of closure was filled with sand until 3×10^4 steps, a slope with the equilibrium slope was formed on the shoreward side of the excavated hole. Even if sand supplied in the offshore zone falls into the excavation hole, such sand can move up from the bottom of the excavation hole, and finally reaches the shoreline. After 7×10^4 steps, the longitudinal profile attained a stable form and a beach was formed on the landward side of the hole. In Case 3 with multiple holes, the shoreward sand transport occurred as in Case 2 and beach was formed. Thus, the phenomenon in which sand is deposited on the slope steeper than the equilibrium slope, which was difficult to predict by the BG model, was possible to be simulated and the impact of the offshore dredging on the reef flat to the beach was able to predict.

REFERENCES

Bagnold, R. A. 1963. Mechanics of marine sedimentation, in The Sea, M. N. Hill ed., Vol. 3, pp. 507-528, New York, Wiley.

Baxter, G. W. and Behringer, R. P. 1990. Cellular Automata models of granular flow, Physical Review, A42, p. 1017.

Bowen, A. J. 1980. Simple models for nearshore sedimentation; beach profiles and longshore bars, in *The Coastline of Canada*, The Geological Survey of Canada, S.B. McCanann ed., Paper 80-10, pp. 1-11.

Inman, D. L. and Bagnold, R. A. 1963. Littoral processes, in The Sea, M. N. Hill ed., Vol. 3, pp. 529-533, New York, Wiley.

Landry, W. and Werner, B. T. 1994. Computer simulations of self – organized wind ripple patterns, Physica D 77, p. 238.

Serizawa, M., Uda, T., San-nami, T. and Furuike, K. 2006. Three-dimentional model for predicting beach changes based on Bagnold’s concept, Proc. 30th ICCE, pp. 3155-3167.

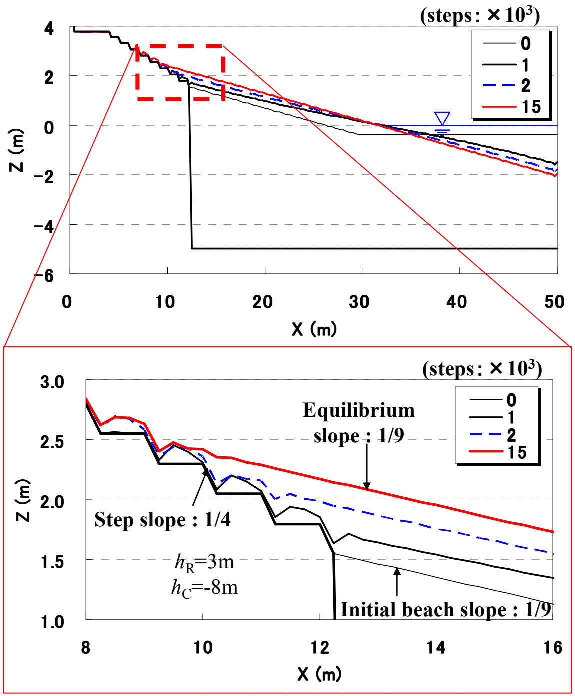

Fig. 3 Results of calculation (Case 1).

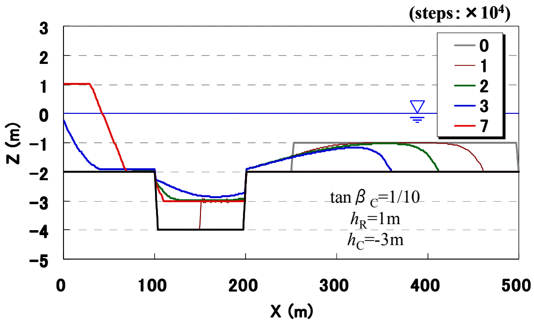

Fig. 4 Results of calcula1tion (Case 2).

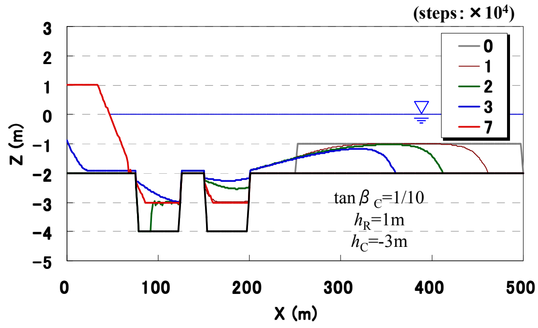

Fig. 5 Results of calculation (Case 3).