A COASTAL AREA MODEL CONSIDERING SAND NOURISHMENT PROCESS

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This paper presents a 3 D morphodynamic model with shoreline change based on quasi-3D nearshore current model. In this model, sand nourishment process with sand dredging and charging was newly considered. First, in order to investigate the performance the present model, it is applied to the prediction of 3D beach evolution with sand bypassing system around a model port and sand recycling system between two groins. Secondly, the developed model was applied to morphodynamics after sand nourishment in a sand recycle project conducted Kaike Coats, Tottori,Japan. Finally, the applicability of the model was investigated and discussed.

Keywords: sediment transport; beach nourishment; morphodynamic; numerical model

INTRODUCTION

The causes of sandy beach erosion are decrease of discharged bed material from rivers, interruption of alongshore sediment transport due to construction of coastal structures, and influence of wave shelter zone due to construction of offshore breakwater etc. Erosion may occur even though coastal structures such as groins, detached breakwaters and so on are constructed in order to protect coastal area. Furthermore, we are in the face of serious environmental problems such as sea-level rise, climate change and extreme storm attacks due to the global warming effect. Especially, sandy beach erosion problems due to sea-level rise and extreme stormy wave attacks become more serious problems.

Sand nourishment such as sand bypassing or recycling system is an effective technique for recovering eroded beaches as measures against such erosion problems. In the last decade, many projects in the world have been performed (van Duin et al. 2004, Grunnet and Ruessink 2005, Ojeda et al. 2008, Bruno et al. 2009, Mulder and Tonnon 2012, Shibutani et al. 2013).

The estimation of the suitable nourishing amount and the selection of nourishment area are needed to evaluate future beach evolution and running cost for the projects, therefore, the prediction of the beach evolution after nourishments are required. Conventionally, numerical models for prediction of the beach evolution can be classified into three types, i.e. coastline model, coastal profile model and coastal area model (de Vriend et al. 1993). The coastal area model has been conventionally employed to determine the topographical change due to the construction of breakwaters and jetties. This study deals with a coastal area model, which is three-dimensional beach evolution model.

The final goal of this study is to develop a numerical model that can predict 3D morphodynamics considering sand nourishments. In this study, the previous model presented by Kuroiwa et al. (2012) was modified so as to be capable to simulate the nourishing process of sand and the 3D morphodynamcs after the nourishment. Two model tests associated with sand bypassing and recycling were carried out. Furthermore, the applicability of the presented model to a field site where sand recycling project has been implemented was investigated.

NUMERICAL MODEL

The developed coastal area model was based on the hybrid model proposed by Kuroiwa et al. (2006,2010). The coastal area model presented in this study consists of three modules; 1) a wave module, 2) a nearshore current module, 3) a sediment transport and a water depth change evolution module, as shown in Fig.1.

Wave module

The wave module is based on the multi-directional random wave model, which is based on the wave action balance equation associated with energy dissipation terms for the wave breaking and wave diffraction (Mase et al., 2004). The governing wave action balance equation with the wave diffraction effects is

$$\frac{\partial(C_x N)}{\partial x}+\frac{\partial(C_y N)}{\partial y}+\frac{\partial(C_\theta N)}{\partial \theta}=\frac{\kappa}{2\sigma}\left\{\left(CC_g\cos^2\theta N_y\right)_y-\frac{1}{2}CC_g\cos^2\theta N_{yy}\right\}-\varepsilon_b N \qquad (1)$$

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where N is the wave action density, defined as the wave energy density divided by the angular frequency σ relative to the current (Doppler shift). The horizontal coordinates are x and y, and θ is the wave direction measured counterclockwise from the x-axis. κ is the diffraction intensity parameter, which is set to 2.5. C and C_g are the wave celerity and group velocity, respectively. The characteristic wave velocities with respect to x, y, and θ coordinates are accordingly C_x, C_y and C_θ as defined by

$$C_x = C_g \cos\theta + \tilde{U} \tag{2}$$

$$C_y = C_g \cos\theta + \tilde{V} \tag{3}$$

$$C_\theta = \frac{\sigma}{\sinh 2kh}\left(\sin\theta\frac{\partial h}{\partial x} - \cos\theta\frac{\partial h}{\partial y}\right) + \cos\theta\sin\theta\frac{\partial \tilde{U}}{\partial x} - \cos^2\frac{\partial \tilde{U}}{\partial y} + \sin^2\theta\frac{\partial \tilde{V}}{\partial x} - \sin\theta\cos\theta\frac{\partial \tilde{V}}{\partial y} \tag{4}$$

where $\tilde{U}$ and $\tilde{V}$ are the depth-averaged steady currents in the x and y direction, and k is the wave number. σ is the relative angular frequency with a relationship among the absolute angular frequency ω, the wave number and the current velocity.

In Eq. (1), the parameterized function ε_b describes the mean energy dissipation rate per unit horizontal area due to the wave breaking. The importance of this function was examined for four wave breaking formula by Zheng et al. (2008). In this study, the parameterized wave breaking function for wave energy dissipation is calculated from the following expression for bulk energy dissipation with the ambient current, which proposed by Chawla and Kirby (2002).

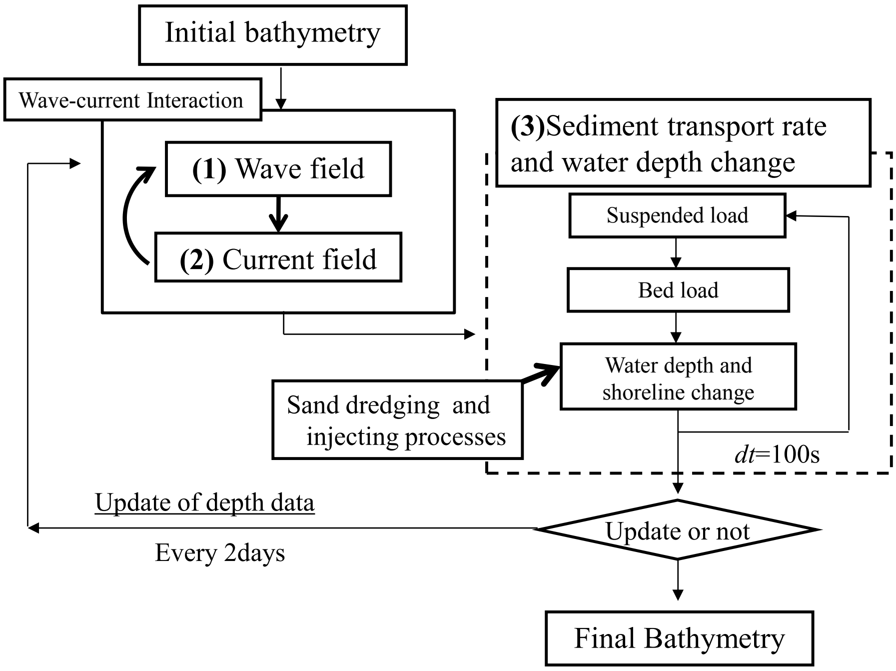

Figure 1. Outline of the 3D model considering sand dredging and injecting processes.

Nearshore Current Module

The nearshore current module is based on the Hybrid model with Q-3D mode and 2DH mode, proposed by Kuroiwa et al. (2006). The 2DH mode is based on the model of Nisimura (1988). The Q-3D is selected when the undertow filed in the surf zone should be estimated under stormy waves and then the Q-3D mode is based on the model using the fractional step method. The equations of motion and continuity in Q-3D mode are represented by

$$\left.\begin{aligned}\frac{dU}{dt}&=-g\frac{\partial\bar{\zeta}}{\partial x}-\frac{\partial R_{xx}}{\partial x}-\frac{\partial R_{xy}}{\partial y}+\frac{\partial}{\partial x}\left(\nu_h\frac{\partial U}{\partial x}\right)+\frac{\partial}{\partial y}\left(\nu_h\frac{\partial U}{\partial y}\right)+\frac{\partial}{\partial z}\left(\nu_v\frac{\partial U}{\partial z}\right)\\ \frac{dV}{dt}&=-g\frac{\partial\bar{\zeta}}{\partial y}-\frac{\partial R_{yx}}{\partial x}-\frac{\partial R_{yy}}{\partial y}+\frac{\partial}{\partial x}\left(\nu_h\frac{\partial V}{\partial x}\right)+\frac{\partial}{\partial y}\left(\nu_h\frac{\partial V}{\partial y}\right)+\frac{\partial}{\partial z}\left(\nu_v\frac{\partial V}{\partial z}\right)\end{aligned}\right\}\tag{5}$$

$$\left.\begin{aligned}\frac{\partial U}{dx}+\frac{\partial V}{\partial y}+\frac{\partial W}{\partial z}&=0\\ \frac{\partial\bar{\zeta}}{\partial t}+\frac{\partial\tilde{U}(h+\zeta)}{\partial x}+\frac{\partial\tilde{V}(h+\zeta)}{\partial y}&=0\end{aligned}\right\}\tag{6}$$

where U , V and W are the local nearshore current velocities in the cross-shore(x), alongshore (y) and vertical (z) directions, respectively. $\tilde{U}$ and $\tilde{V}$ are the depth-averaged current velocities. $\bar{\zeta}$ is the mean water level. R_{xx}, R_{xy}, R_{yx} and R_{yy}, represent the excess momentum fluxes based on the linear wave theory. ν_v and ν_h represent the turbulent eddy viscosity coefficients in the vertical and horizontal direction, respectively.

Sediment Transport and Water Depth Change

The total sediment transport considers bed and suspended load. The suspended load is determined by flux model, which is based on the two-dimensional advection diffusion equation, proposed by Sawaragi et al. (1984). The bed load is determined by the model based on Kuroiwa et al. (2006). In this model, the sediment transport rate due to alongshore steady current in the run-up region is taken into account in order to predict the shoreline change.

To consider the sand dredging and discharge process associated with sand bypassing or back-passing system, the dredging sediment flux q_{d} and discharged sediment flux q_{i} are added to the sand mass conservation equation, as follows;

$$\frac{\partial h}{\partial t}=\frac{Q_s}{1-\lambda}+\frac{1}{1-\lambda}\left\{\frac{\partial}{\partial x}\left(q_{bx}+\varepsilon_s\left|q_{bx}\right|\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(q_{by}+\varepsilon_s\left|q_{by}\right|\frac{\partial h}{\partial y}\right)\right\}+q_d-q_i\tag{7}$$

where, h is the water depth, t is time, q_{bx} and q_{by} are bed load due to steady currents. ε_s is the dimensionless coefficient. Qs is the difference between the settling flux $w_f c$ and the picking-up flux F_z of bed material, as given by

$$Q_s=F_z-w_f c\tag{8}$$

$$F_z=(1-\gamma)C_0\alpha w_f\left(\frac{u_*}{w_f}-1\right)\qquad\begin{pmatrix}u_*\geq w_f:\gamma=0\\ u_*\leq w_f:\gamma=1\end{pmatrix}\tag{9}$$

where α is the dimensionless coefficient, C_0 is the concentration at reference point, $C_0=0.347N_c^{1.77}$.

$$N_c=\frac{0.688\hat{u}_w^2}{1.13(s-1)gw_fT}\tag{10}$$

$\hat{u}_w$ is the maximum orbital velocity at bottom, s is the specific gravity of sand, T is the wave period. c is determined by solving the following advection diffusion equation, as given by,

$$\frac{\partial c}{\partial t}+U\frac{\partial c}{\partial x}+V\frac{\partial c}{\partial y}=\frac{\partial}{\partial x}\left(k_x\frac{\partial c}{\partial x}\right)+\frac{\partial}{\partial y}\left(k_y\frac{\partial c}{\partial y}\right)+\frac{Q_s}{\bar{\eta}+h}\tag{11}$$

where, k_x and k_y are the diffusion coefficients, which are determined as a function of current velocity and water depth.

The bed load is estimated using the bottom friction factor proposed by Watanabe et al(1986). The total bed loads are given by

$$\overrightarrow{q_b} = \overrightarrow{q_w} + \overrightarrow{q_c} = \begin{Bmatrix} q_{bx} = q_{wx} + q_{cx} \\ q_{by} = q_{wy} + q_{cy} \end{Bmatrix} \quad (12)$$

$\overrightarrow{q_w}$ is due to wave orbital velocities at bottom. $\overrightarrow{q_c}$ is due to steady current velocity. These are estimated by

$$\left.\begin{aligned} \overrightarrow{q_w} &= A_w \left(u_*^2 - u_{*c}^2\right) \overrightarrow{\hat{u}_w} / g \\ \overrightarrow{q_c} &= A_c \left(u_*^2 - u_{*c}^2\right) \overrightarrow{U} / g \end{aligned}\right\} \quad (13)$$

where A_w and A_c are dimensionless coefficients, u_* is the friction velocity, u_{*c} is the critical friction velocity, and $\vec{U}$ is the steady current vector. In case of the Q3D mode usage, the bed load is determined by using bottom current velocities. The coefficients A_w and A_c are given by a function of the median diameter d_{50} (Shimizu et al, 1996) as

$$\left.\begin{aligned} B_w &= C_w \left(\sqrt{d_{50}} / w_f\right)^3 \\ A_w / B_w &= w_f \sqrt{0.5 f_{cw}} / \left\{(1-\lambda) s \sqrt{s g d_{50}}\right\} \\ A_c &= \beta A_w \end{aligned}\right\} \quad (14)$$

where C_w is a dimensionless coefficient, w_f is the fall velocity of sand, f_{cw} is the sea-bottom friction factor, λ is the porosity of the bed, and s is the specific gravity in the water.

MODEL TESTS

Sand Bypassing Test

A model case that a port was constructed as interrupting alongshore sediment transport was shown in Fig.2. Firstly, a computation of bathymetry change around the port without sand nourishment was conducted. The initial bathymetry is illustrated in Fig. 2. The sea-bottom slope in the sea area was 1/50. The computation domain was an area of 2000 m along the shore and 700 m across the shore. The grid sizes of Δx and Δy were set to 10m. Incident significant wave height and period at offshore boundary were set to 1.5 m and 7.0 s, respectively. Wave direction was 20 degrees. Figs.3 and 4 show the computed wave height distribution and nearshore current field corresponding to initial bathymetry. In the computation of the wave field, the iteration of wave and current computations was carried out two times. Figure 5 shows the computed result of bathymetry change without sand dredging and nourishment at 180 days later. From these computed results, we found that the sand deposition in the right side of the port, the sea bottom erosion and shoreline retreated in the left side were reproduced.

Secondly, we computed the bathymetry change for considering sand dredging and injecting processes. Figure 6 shows time history of wave data input at offshore boundary. The bathymetry change without sand dredging at the deposition area of port and sand nourishment was computed. After 120 days, sand dredging and injecting around the port were performed for 40 days. Until obtained the final bathymetry, the bathymetry was updated every two days, namely the computations of wave and nearshore current modules were totally carried out 60 times. The computed results after 120, 160 and 180 days are shown in Figs. 7 (a), (b) and (c). Accretion in the right hand and erosion in the left hand side of the port were demonstrated. Moreover the sand bypassing was carried out for 40 days under calm wave condition in order to recover the erosion area in the left hand side of the port, as shown in Fig. 7 (b), namely the bed material was dredged in the right hand side of the port and injected into the erosion area. Figures 8(a) and (b) shows beach profile changes at dreading area and discharging area, respectively. These results provided that the eroded area was recovered although shoreline slightly advanced. These computed results show that sand bypassing is appropriate measures for beach erosion and port mouth deposition problems. We found that the developed model gives qualitatively available computed results.

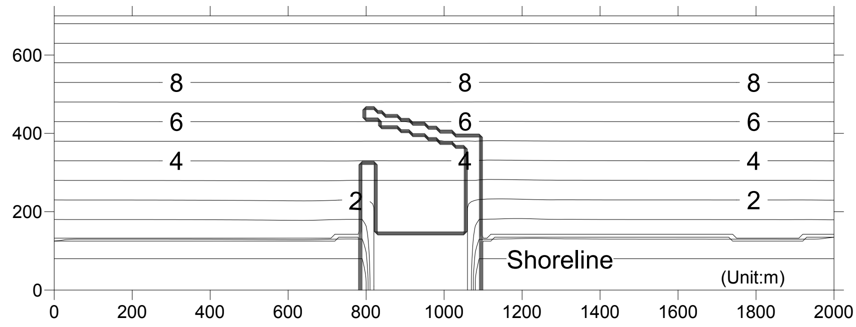

Figure 2. Computational domain and initial bathymetry.

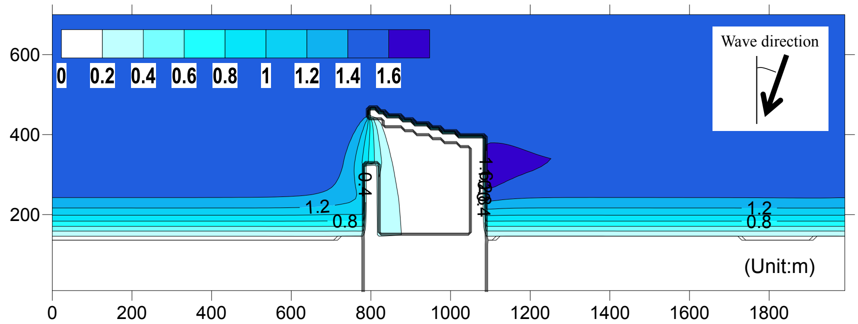

Figure 3. Computed significant wave height distribution around a port.

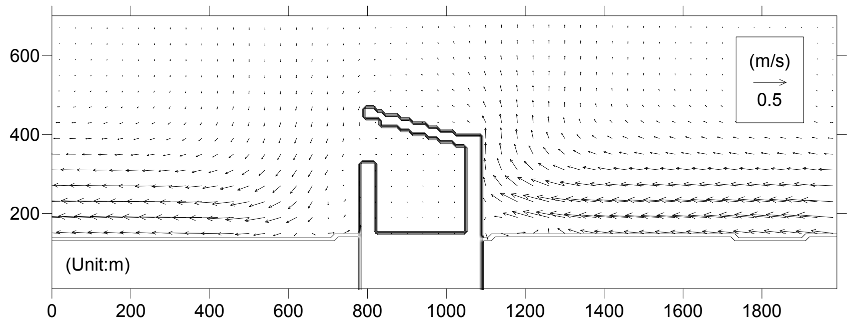

Figure 4. Computed nearshore current field around a port.

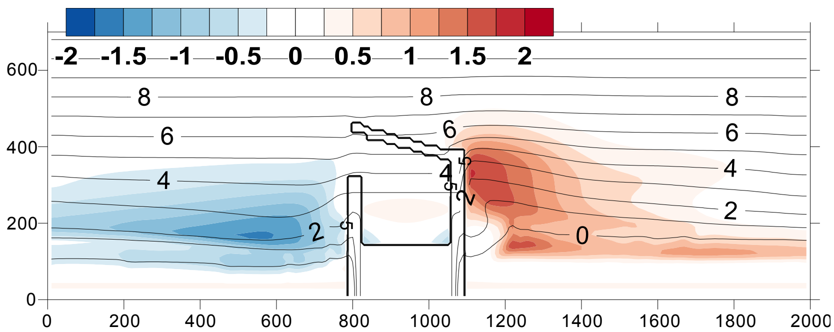

Figure 5. Computed bathymetry change after 180 days without sand nourishment.

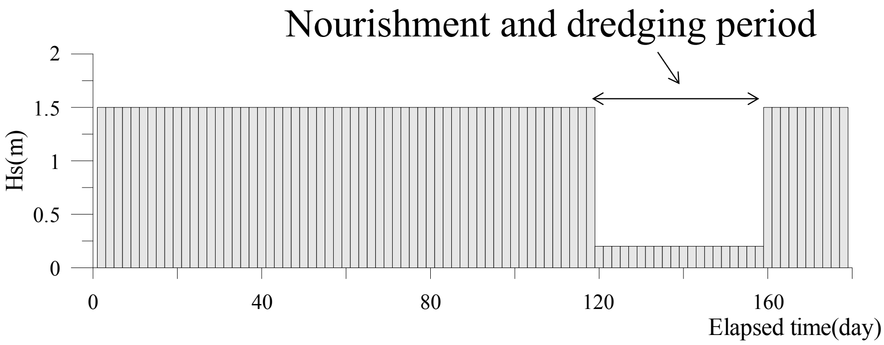

Figure 6. Time series of incident significant wave height Hs.

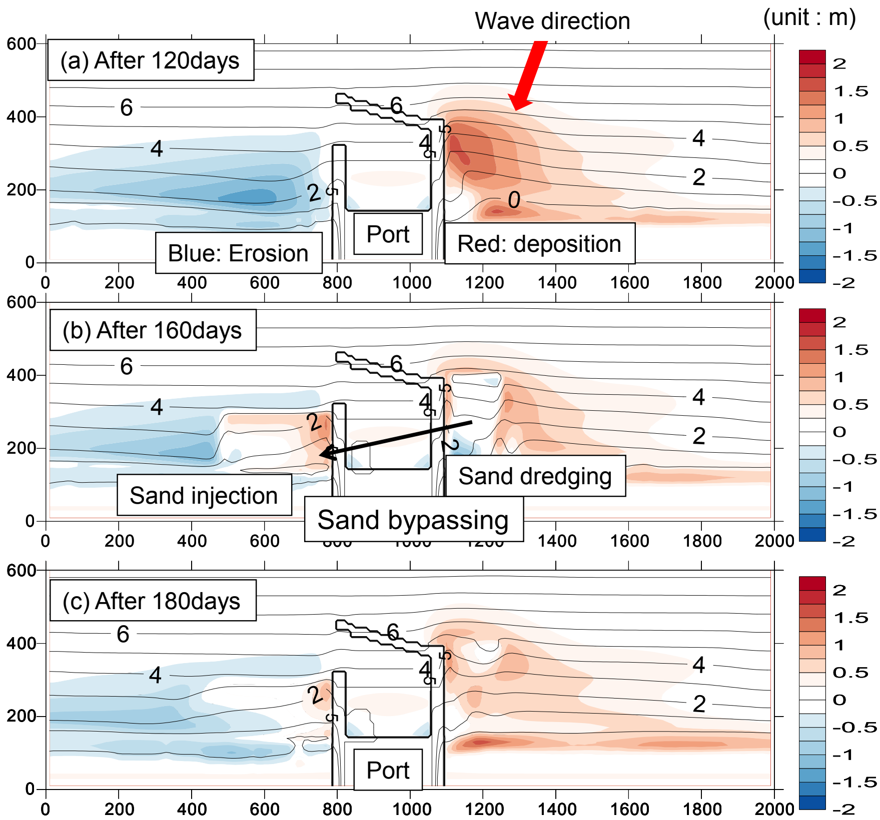

Figure 7. Computed bathymetry change after 180 days after sand nourishment.

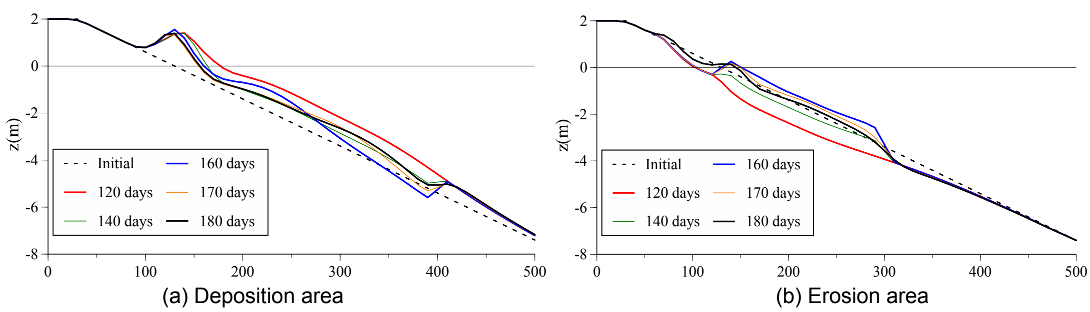

Figure 8. beach profile changes in deposition(dredging) and erosion(nourishment) areas

Sand Recycling Test

A model test associated with sand recycling between two groins was conducted. The computational domain was set to an area of 700 m in the cross-shore direction and 2000 m in the longshore direction. Incident significant wave height and period at offshore boundary were set to 1.5 m and 7.0 s, respectively. Wave direction was 20 degrees. Computed significant wave and nearshore current fields were shown in in Figs. 9 and 10. Figure 11 shows computed bathymetry after 180 days without sand dredging and nourishment. Accretion in the left hand and erosion in the right hand side, in the closed beach, were demonstrated.

Time history of wave data and sand dredging and injecting processes were set same as the case of the sand bypassing test in order to perform sand recycling test. Until 120 days, bathymetric change without sand dredging and nourishment was computed. Figs.12 (a), (b) and (c) are computed bathymetries after 120, 160 and 180 days. From comparing between Fig. 11 and 12 (c), it was found that the eroded area in the right side was recovered although shoreline slightly advanced, by conducting sand recycling.

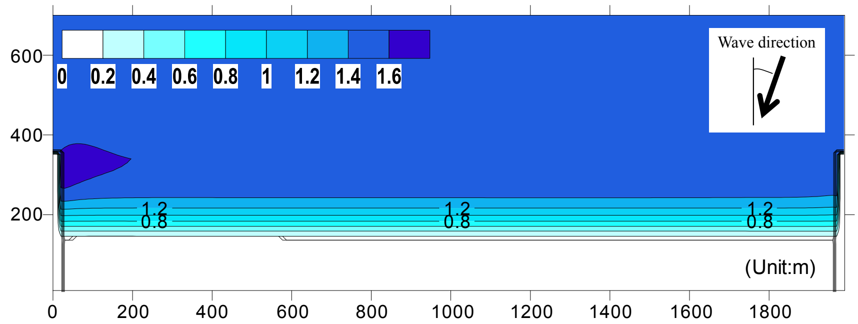

Figure 9. Computed significant wave height distribution between two groins.

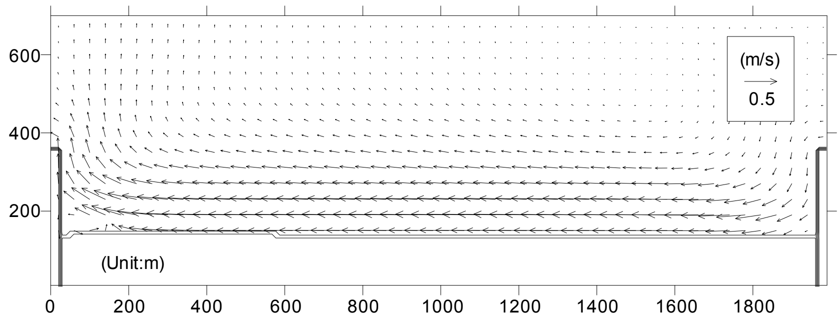

Figure 10. Computed nearshore current field.

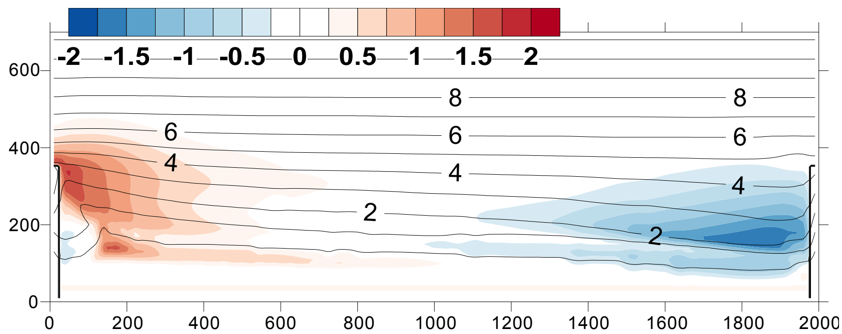

Figure 11. Computed bathymetry change after 180 days without sand nourishment..

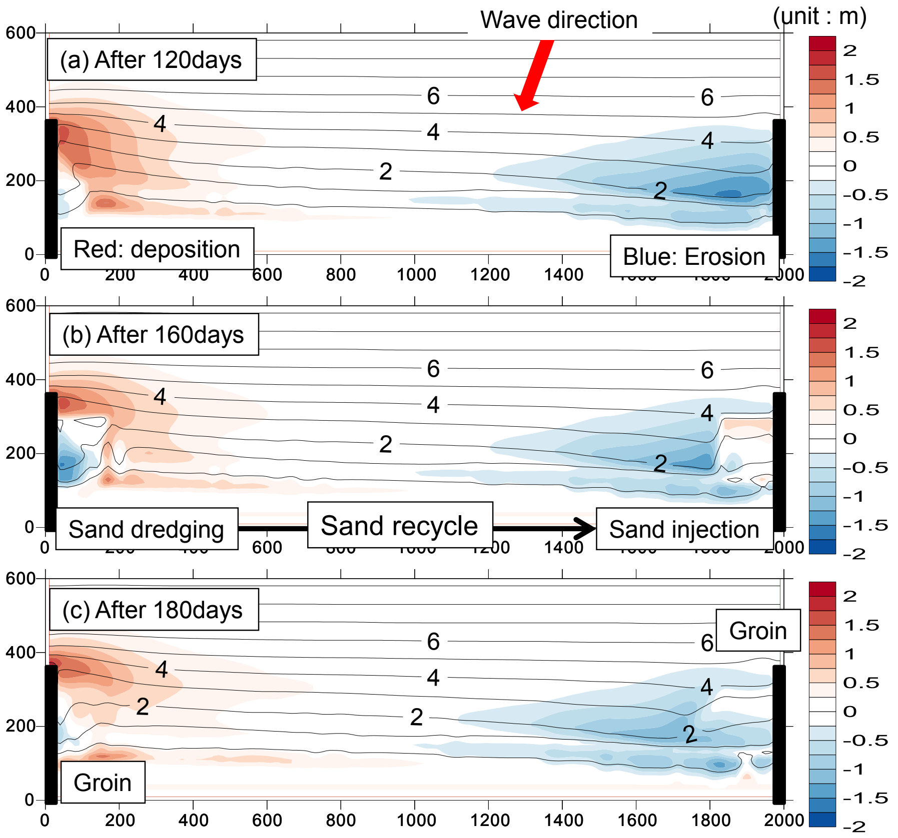

Figure 12. Computed bathymetry change after 180 days after sand nourishment..

FIELD VERIFICATION

Field Site

The presented model was applied to a field observation associated with a sand recycling project conducted in Yumigahama Coast, Tottori, Japan.

Figure 13 shows Yumigama Coast, which is sandy beach with a distance of 16 km, facing the Sea of Japan. Yumigahama Coast was formed with sand sourced from Hino River. The dominant direction of alongshore sediment is from Hiro River to Sakai-minato marina (B shown in Fig.13). Retreat of shoreline on the west side of Hino River started around 1960, caused by decreasing of sand supplied from Hino River. In the erosion area, breakwaters and groins were constructed to recover the retreated shoreline. However, the erosion area was more extended at Tomimasu area on the western side of the coastal area. On the other hand, alongshore sediment has been trapped at Sakai-minato Marina at the end of Yumigahama Coast and extreme accretion has been occurred. In order to solve both problems of beach erosion at Tomimasu area and deposition around the marina, a sand recycling project, which transports sand dredged around Sakami-minato Marina into Tominasu area by trucks, has started since 1992. The sand volume is an average of 30,000 m^3 per year. Despite of such sand nourishment project, the maintenance of shoreline was insufficient. In order to recover the eroded shoreline, four submerged breakwaters, which are called "artificial reefs," were constructed, as shown the left picture in Fig.13. Figures 14 and 15 show aspects of sand dredging area at Sakaminato Marina and erosion area at Tominasu Area, respectively.

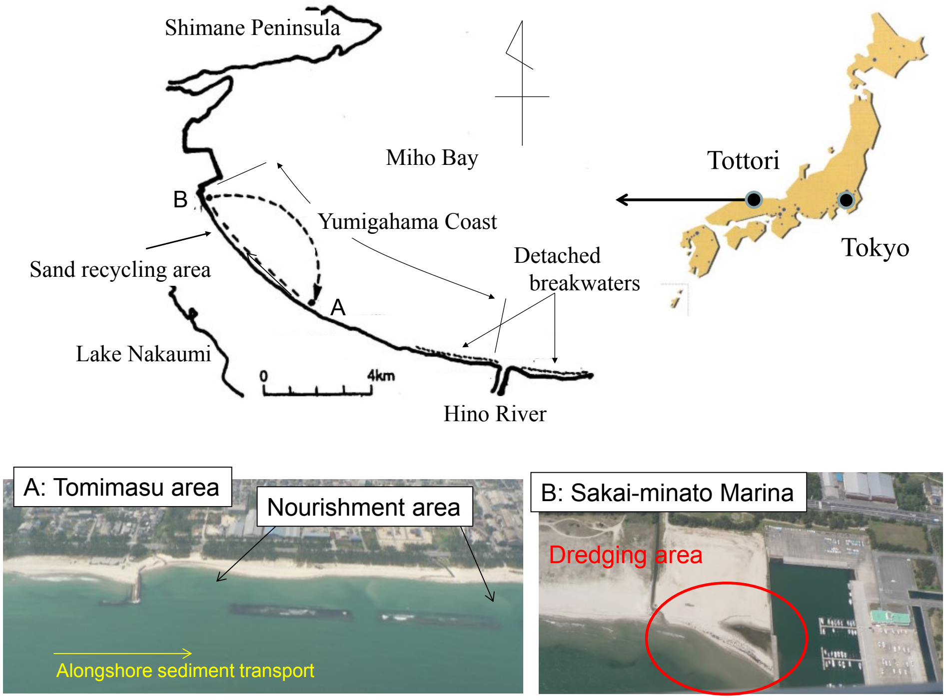

Figure 13. Sand recycling project in Yumigahama Coast. The sand recycling is performed Sakai-minato Marina to Tomimasu area.

(a) Sand deposition **(b) Sand dredging**

Figure 14. Sakai-Minato Marina(Dec,2012)

(a) Beach erosion,Dec.,2012 **(b) Sand nourishment, Mar.,2013**

Figure 15. Sand nourishment area at Tomimasu Area(Sakai-Minato Marina(Dec,2012)

Computational Conditions

In this study, to apply the model into the whole area of the sand recycling project is difficult because of many run time and computation capacity. Therefore, the model was applied to Tominasu area of sand nourishment with 2.3 km long in the alongshore direction. Figure 16 shows the computational domain and the measured bathymetry in July, 2009. In 2009, four artificial reefs were constructed to protect Tomimasu area. The bathymetry result was employed as an initial bathymetry in the computation. Figure 17 shows bathymetry measured in 2010. In this figure, red and blue areas present erosion and deposition areas, respectively. The erosion/deposition plots were described using the difference of the measured water depth for one year from 2009 to 2010.

The bathymetry change after 1 year was reproduced using the developed model to investigate the model performance. In this period, total sand volume nourished at Tomimasu area was approximately 15,000 m^3 from January to March, in 2010. The red square in Fig. 16 represents nourishment area. Figure 18 shows time series of significant wave height *H*s used in this computation, which was arranged the wave data sets observed Tottori Port and Tomimasu offshore observatory station at the water depth of 10 m. The detailed value of the wave height and period are shown in Table 1. The computations of the wave and current modules were roughly 75 times to reach the 150 days. The sand injection was carried out for 40 days as shown in Fig.17. The wave direction was set to -10 degrees at offshore boundary. The median diameter of sand particle was 0.2mm. In this computation, we did not consider the interaction of the wave and current computations because of stability of the computations. Q3D mode was only selected under stormy wave condition (wave 3 in Table 1).

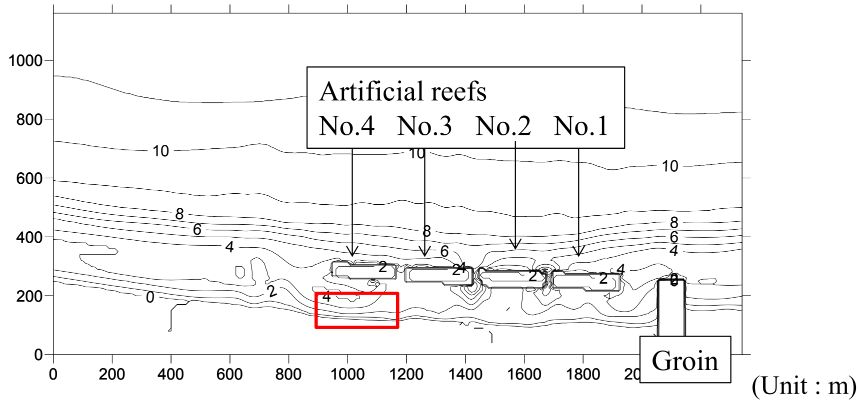

Figure 16. Computational domain and measured bathymetry in July, 2009. (Red square represents sand nourishment area)

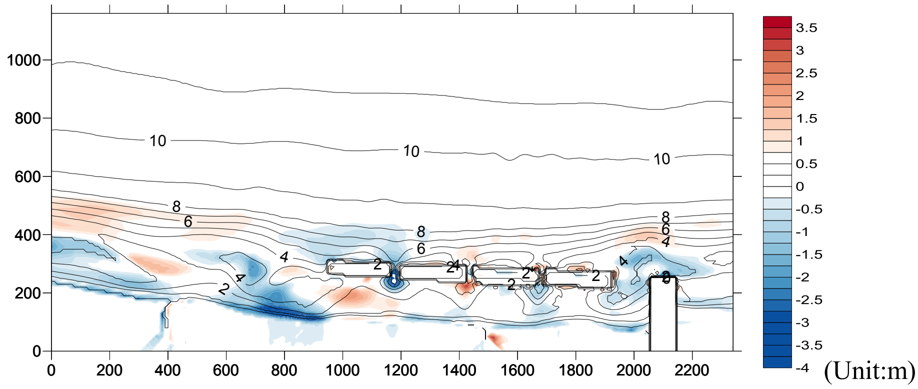

Figure 17. Measured bathymetry in July, 2010 (Red : deposition area , Blue : erosion area)

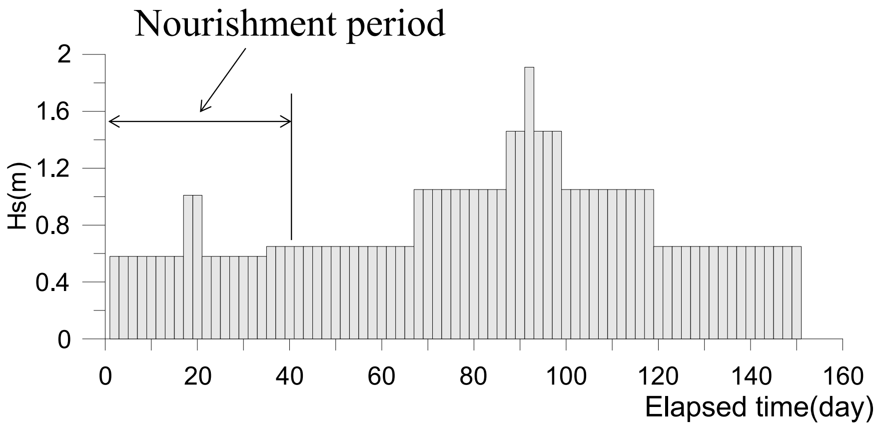

Figure 18. Time series of incident significant wave height H_S with two stormy wave conditions.

Table 1. Wave condition

	Hs(m)	Ts(s)	days
Wave1	1.01	6.77	4
Wave2	0.58	5.51	30
Wave3	1.91	8.19	2
Wave4	1.46	7.52	10
Wave5	1.05	6.85	40
Wave6	0.65	6.04	64

Computed Results

Figure 19 shows an example of computed nearshore current field. Strong currents occurred behind the artificial reefs and the direction of the currents at the left side of the reef No. 4 is the North-East. The shoreward current on the reef No. 4 was changed into the offshore direction.

Figure 20 shows (a) and (b) show computed bathymetry changes after 40 days and 150 days, respectively. Sand injection at the circle area as shown in Fig. 20 (a) was carried out for 40 days. After implementation of nourishment, the injected sand behind the artificial reef No. 4 was remained. However, the sand material was gradually decreased up to 150 days. At the left side of the reef No. 4, the sea bottom was eroded. The computed results around the reef No. 4 qualitatively agree with the measured bathymetry in 2010 shown in Fig. 17.

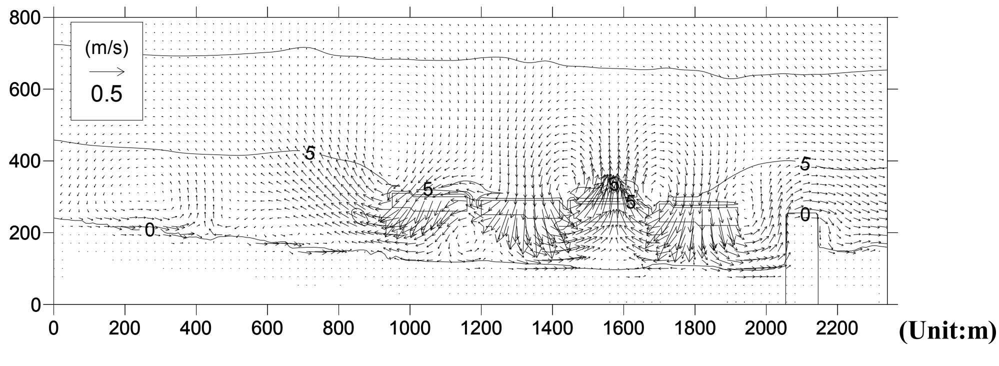

Figure 19. An example of computed nearshore current field in Tominasu area.

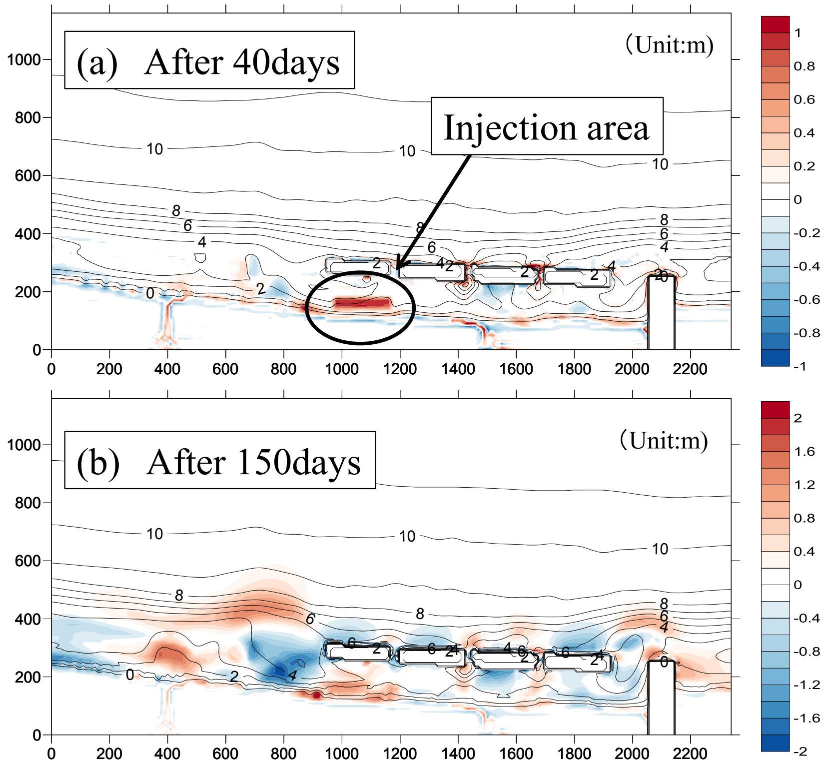

Figure 20. Computed bathymetry changes after 40 days and 150 days.

CONCLUSIONS

In this study, a simple 3D model for predicting the beach evolution after sand nourishment was developed. Firstly, two model tests associated with sand bypassing and recycling were carried out in order to investigate the performance of the model. Secondly, model verification against the field observation regarding to sand recycling project conducted at Kaike Coast, Tottori, Japan. From the computed results, some conclusions are derived as follows:

Model Tests

Two model tests associated with sand dredging and discharging, which are sand bypassing around a port and sand recycling between two closed boundaries, were carried out in order to investigate the performance of the developed model. It was confirmed that the shoreline advance due to sand nourishment was able to be demonstrated. The validity of the presented model was confirmed. We found that the developed model gives qualitatively available computed results.

Field Verification

The developed model was applied to a sand recycling project conducted by Kaike Coast, Tottori, Japan, in order to investigate the applicability of the model. Bathymetry change around artificial reef after sand nourishment was computed. The computed result qualitatively agreed with the measured bathymetry. However, the computation of hydrodynamics with the interaction between wave and current is fairly difficult as the strong current is generated around artificial reef. Therefore we need reinvestigate and modify the presented model.

In this model, beach nourishment that sand material is placed at the berm area was not performed because shoreline changes are not sufficiently determined. In order to get more good accuracy of the prediction after sand nourishment, the model presented in this study should be modify so as to take account sediment transport in the run-up region.

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REFERENCES

Bruno C., I.L.Turner, X. Bertin, and Tomlinson, R. 2009. Beach nourishments at Coolangatta Bay over the period 1987-2005: Imoacts and lessons, *Coastal Engineering*, 56: 940-950.

Chawla, A., and J.T.Kirby, 2002. Monochromatic and random wave breaking at blocking points. *Journal of Geophysical Research*, 107, No. C7.

De Vriend, H.J., J. Zyserman, J. Nicholson, J.A. Roelvink, P. Pechon, and H.N. Southgate. 1993. Medium-term 2DH coastal area modeling, *Coastal Engineering*, 21, 193-224.

Grunnet, N.M. and B. G. Ruessink. 2005. Morphodynamic response of nearshore bars to a shoreface nourishment, *Coastal Engineering*, 52: 119-137.

Kuroiwa,M., T.Kuchiishi, and Y.Matsubara. 2006. Prediction System of 3D Beach Evolution with 2DH and Q3D Hydrodynamic Modes, *Proceedings of 16th International Offshore and Polar Engineering Conference*, 751-757.

Kuroiwa,M., Y.Shibutani, Y.Matsubara, T. Kuchiishi, and M.Abualtyef. 2010. Numerical model of 3D morphodynamic after offshore nourishment, *Proceedings of 31th International Conference On Coastal Engineering*, No. 32, Paper #: sediments. 55. Retrieved from http://journals.tdl.org/ICCE/

Ojeda, E., B.G. Ruessink, and J. Guillen. 2008. Morphodynamic response of a two-barred beach to a shoreface nourishment, *Coastal Engineering*, 55, 1185-1196.

Mase, H. 2001. Multi-directional random wave transformation model based on energy balance equation, *Coastal Engineering Journal*, 43, No. 4: 317-337.

Mase, H., M.Yuhi, H.Amamori, and T.Takayama. 2004. Phase Averaging wave prediction model with breaking and diffraction effects in wave-current coexisting field. *Annual Journal of Coastal Engineering*, JSCE., 51, No.1: 6-10. (In Japanese).

Mulder, J. P. M. and P.K. Tonnon. 2010. "Sand Engine": Background and design of a mega-nourishment pilot in the Netherlands, *Proceedings of 31th International Conference On Coastal Engineering*, No. 32, Paper #: manegment.34. Retrieved from http://journals.tdl.org/ICCE/

Nishimura, H. 1988. Computation of nearshore current, Neashore Dynamics and Coastal Process - Theory, Measurements and Predictive Models-(ed. Horikwa, K), University of Tokyo Press, 271-291.

Sawaragi, T., J.S. Lee, and I. Deguchi. 1986. A new model for prediction of beach deformation around river mouth, *Proceedings of International Symposium on Ocean Space Utilization* '85, 229-236.

Shibutani,Y., Y. Matsubara, and M. Kuroiwa. 2013. Effect of the coastal conservation due to beach nourishment of Tottori Sand Dune Coast, *Proceedings of the 7th International Conference on Asian and Pacific Coasts*, 79-84.

Shimizu,T., A. Yamada, and A. Watanabe. 1996. Coefficient and cross-shore distribution of alongshore sediment transport rate, *Proceedings of Coastal Engineering*, JSCE, 43, 571-575.(in Japanese)

van Duin,M.J.P., N.R. Wiersma, D. J. R.Walstra, L.C. van Rijn, and M.J.F. Stive. 2004. Nourishing the shoreface: observation and hind-casting of the Egmond case, The Netherlands, *Coastal Engineering*, 51: 813-837.

Watanabe, A., K. Maruyama, T. Shimizu, and T. Sakakiyama. 1986. A numerical prediction model of three-dimensional beach deformation around a structure, *Coastal Eng. in Japan,* 29, 179-194.

Zheng, J., H.Mase, Z. Demirbilek, and L. Lin. 2008. Implementation and evaluation of alternative wave breaking formula in a costal spectral wave model. *Ocean Eng*, 35, 1090-1101.