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Development of N-Line Numerical Model Considering the Effects of Beach Nourishments

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ABSTRACT

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This study is concerned with N-line model that takes into account the contour line changes after beach nourishment. The behavior of the sand materials after the beach nourishments is represented using two-dimensional advection diffusion equation in the horizontal plane. The effect of grain size of the nourished sand is considered in the advection diffusion equation. The contour line changes are calculated by solving the fundamental equation for the conservation of bed material, and combined with the advection diffusion equation. In this paper, firstly, the performance of the model is investigated by three model tests with the beach nourishment. Secondly, two model tests are carried out in order to investigate the influence of the effect of the grain size. Finally, the presented model is applied to the sand recycle project at Yumigahama coast, Japan, in order to investigate the applicability of the model.

ADITIONAL INDEX WORDS: *N-line model, Beach nourishment, Contour line changes, Grain size*

INTRODUCTION

The coastal erosions lead to serious problems in sandy beaches around the world. The artificial beach nourishment method has been accepted as an effective and environmentally favored work for the restoration of shoreline in eroded area.

For the successful shore protection, to place the nourished sands near beach face is desirable. But the sand is often injected in offshore area because of the reason for the easy transportation and cost reductions. However, in case of sand fill in offshore area, it was very difficult to estimate the shoreline and volumetric changes after nourishment. In the implementation of the beach nourishment in the offshore area, a numerical n-line model, which takes into account the changes of depth contour lines after the beach nourishment, is needed.

Previously, the shoreline changes in long term have been evaluated by one-line models such as SHIBUTANI *et al* (2007). Then n-line models have been proposed such as UDA *et al* (1996) and DABEES *et al* (2000). Furthermore, n-line model with the influence of nourished sand materials was proposed by SHIBUTANI *et al* (2008). In this study, a numerical model which takes into account the influence of nourished bed material of grain size based on SHIBUTANI *et al* (2008) is proposed.

N-LINE NUMERICAL MODEL

The new n-line model takes into account for the changes of depth contour lines as well as the shoreline changes after the beach nourishment. The behavior of the sand materials after beach nourishment is estimated by solving the two-dimensional advection diffusion equations. Also the effects of the grain size on the alongshore sediments transport rate and the advection diffusion terms in the model were considered. The new n-line model presented in this study consists of four modules. Which includes the computations of waves, alongshore sediment transport rates, behavior of the injected materials, and depth contour line changes. (Fig.1)

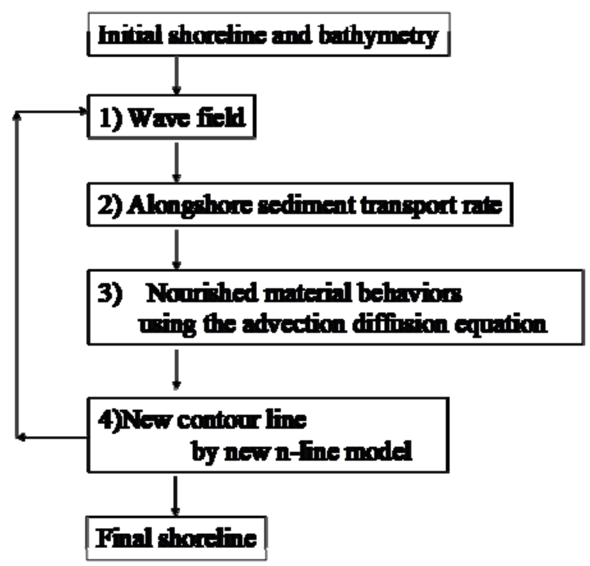

Figure 1. Computation flow chart

Wave Model

The wave direction and height, at the breaking point in the sediment transport rate formula, were determined by the energy balance equation with the diffraction effects as proposed by MASE (2001), is given by

$$\frac{\partial(Sv_x)}{\partial x}+\frac{\partial(Sv_y)}{\partial y}+\frac{\partial(Sv_\theta)}{\partial \theta} = \frac{\kappa}{2\omega}\left\{\left(CC_g S_y \cos^2\theta\right)_y - \frac{1}{2}CC_g S_{yy}\cos^2\theta\right\} - \varepsilon' S \quad (1)$$

where S is the angular-frequency spectral density, and v_x , v_y and v_θ are the propagation velocities. θ is the wave direction. The first term on the right-hand side represents the diffraction term. κ is a free parameter, which is optimized in order to change the degree of diffraction effect. The second term on the right-hand side represents the energy dissipation rate due to wave breaking.

Alongshore Sediment Transport Rates

The total sediment transport rate in the longshore direction is based on the Ozasa-Bramptom formula (Ozasa *et al*, 1980) as follows:

$$Q = AH_{bs}^{\ 2}C_{gb}\left(\hat{K}_1 \sin 2\theta_{bs} - \hat{K}_2 \cos\theta_{bs}\cot\beta \frac{\partial H_{bs}}{\partial y}\right) \quad (2)$$

where H_{bs} and C_{gb} are the significant wave height and group velocity at breaking point, respectively. A is the coefficient with the grain size effect, given by Kamphuis *et al*. (1986),

$$A = A_d \big/ \sqrt{d_{50}} \quad (3)$$

Where d_{50} is the median diameter of sand, A_d is a calibrating coefficient with the unit of $m^{0.5}$. $\hat{K}_1$ and $\hat{K}_2$ in Eq.(2) are determined by

$$\hat{K}_1 = K_1 \big/ \left\{16(\rho_s/\rho - 1)(1-\lambda)1.416^{5/2}\right\} \quad (4)$$

$$\hat{K}_2 = K_2 \big/ \left\{8(\rho_s/\rho - 1)(1-\lambda)1.416^{5/2}\right\} \quad (5)$$

Advection Diffusion Equation for Injected Sand

The behavior of the injected sand materials can be represented by two-dimensional advection diffusion equation given by

$$\frac{\partial q_n}{\partial t} + C_1 U_s \frac{\partial q_n}{\partial x} + C_2 V_s \frac{\partial q_n}{\partial y} = C_3 K_x \frac{\partial^2 q_n}{\partial x^2} + C_4 K_y \frac{\partial^2 q_n}{\partial y^2} \quad (6)$$

where q_n is the supplied sediment rate per length in the longshore direction. U_s and V_s are the moving velocities in the cross- and alongshore direction, respectively. C_1, C_2, C_3 and C_4 are the coefficients with the grain size effect of the nourishment sand, which given by

$$C_l = C_{ld} \big/ \sqrt{dd_{50}} \qquad (l=1\sim 4) \quad (7)$$

where, C_{ld} is the calibration coefficient.

U_s is determined using the maximum wave orbital velocity at the sea bottom, and given by

$$U_s = C_u \frac{\pi H_s}{T_s}\frac{1}{\sinh kh} \quad (8)$$

where, H_s is the local significant wave height, T_s is the period, k is the wave number, h is the water depth and C_u is the dimensionless coefficient, which is a coefficient to judge the direction of injected bed material. To judge the moving direction of sand, a dimensionless parameter presented by Sunamra et al.(1974) was used. The parameter is given by

$$C_s = \frac{Ho/Lo(\tan\beta)^{0.27}}{(d_{50}/Lo)^{0.67}} \quad (9)$$

where, Ho and Lo are the wave height and length in deep water. $\tan\beta$ is the gradient of sea bottom. In Eq.(9), when $C_s > 18$, the shoreline is retreated, namely sand movement is set to offshore direction. On the other hand, when $C_s < 18$, the sand movement is set to onshore direction. Vs is determined by the relationship of $V_s = 0.01V$, which was derived by Nadaoka *et al* (1981). V is longshore current velocity, given by the Inman and Quinn formula (Inman and Quinn, 1951)

K_x and K_y in Eq.(6) are the diffusion coefficients for injected sand materials, which are determined by a relationship associated with wave conditions. Figs.2 (a) and (b) show the relationship between the diffusion coefficients and wave characteristics, which derived from the field investigation of sand drift in the surf zone using fluorescent sand tracer in a sandy beach, conducted by Kuroiwa *et al*.(1994).

Conservation Equation

The fundamental equation for the conservation of bed material is given by

$$\frac{\partial x_m}{\partial t} + \frac{1}{D_m}\left(\frac{\partial Q_m}{\partial y} - q_{sm}\right) = 0 \quad (10)$$

where x_m is the contour line position at m_{th}. Q is the alongshore sediment transport rate at each contour interval. D_m is the characteristic height of beach changes. q_{sm} is the supplied sediment rate per length in the longshore direction. The q_{sm} is estimated from the relationship of

$$q_{sm} = K_p q_n \quad (11)$$

where q_n is the volume of bed materials. K_p is the coefficient for changing the unit of m^3 into m^2/s in Eq.(11). In this study, K_p is set to $1/\Delta y \Delta t$, where Δy is the grid the size in the alongshore direction and Δt is the time interval of computation. The Q_m is

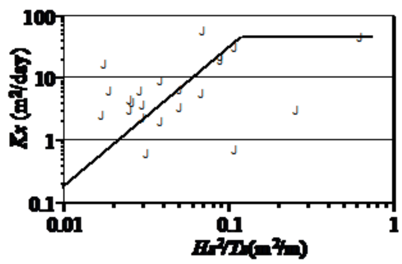

Figure 2(a). Diffusion coefficient in the offshore direction

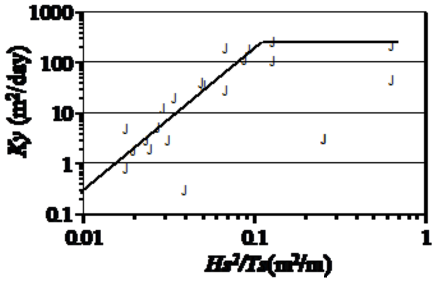

Figure 2(b). Diffusion coefficient in the longshore direction evaluated as follows:

$$Q_m = \mu_m Q \tag{12}$$

μ_m is a coefficient of logshore sediment transport rate for each water depth, given by

$$\mu_m = \int_{z_m}^{z_{m+1}} \xi(z)dz \Big/ \int_{-hc}^{hr} \xi(z)dz \tag{13}$$

$$\sum_{m=1}^{N} \mu_m = 1 \tag{14}$$

COMPUTED RESULTS

Model Tests

Model Verification with Beach Nourishment

Firstly, three model tests were carried out to investigate the model performance. The N-line model was applied to the sandy beach between two fixed boundaries, such as the large pocket beach. The computation of wave field was performed in an area of 2.0km in the alongshore direction and 1.0km in the offshore direction. The bottom slope was 1/50. The initial contour lines are shown in Fig.3. The computation of three cases with different injection points at water depth of 0.8m, 6m and 11m, were performed. In the beach nourishment, the sand material with a volume of 30,000m^3 was injected at each case. The computation conditions are listed in Table 1.

The behaviors of the time variation of sand material distribution for Case 1 are shown in Fig.4 (a) and (b). It was found that the injected sand materials are advected and diffused with time. The time variations of contour line changes are shown in Fig.5 (a) and (b). From these figures, it was found that the contour lines are advanced at injection point when the nourishment started, and was gradually retreated with time. Fig.6 shows the deference of contour lines at each case between nourishment and non-nourishment at 11m, 6m, 2m and shoreline after 1 year.

From Fig.6 (a), it was found that the contour lines in shallow water depth advanced. However, the sand material injected in offshore area was not contributed to restoration of shoreline (Fig.6 (b) and (c)). These computed results indicate the nourishment of injected sand near the shoreline is more effective

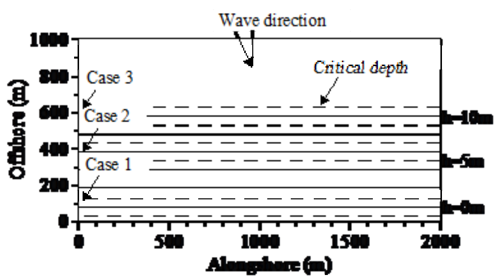

Figure 3. Computation area and initial contour lines

Table 1: Wave condition and coefficients used in sediment transport formulas

$H_{1/3}$(m)	$T_{1/3}$(s)	S_{max}	α	d_{50}(mm)
1.20	7.0	75	5.0	0.25
K_1	K_2	Vs(m/s)	Kx(m^2/s)	Ky(m^2/s)
0.2	0.324	0.00123	0.00057	0.0023
C_{ld}(m$^{0.5}$)	A_d(m$^{0.5}$)	C_u(m/s)	dd_{50}(mm)	tan θ
0.014	0.016	-0.023	0.25	1/50

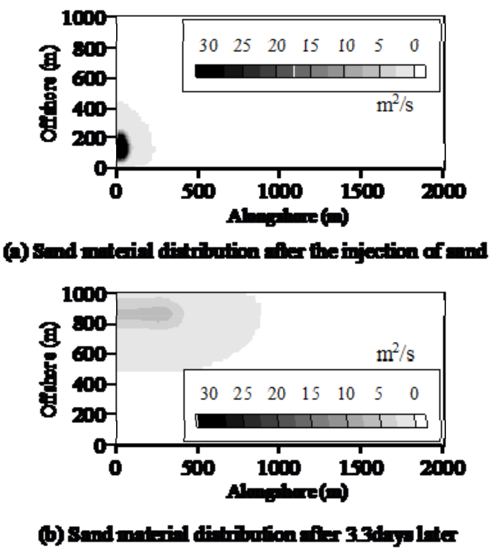

Figure 4. Time variation of sand material distribution for Case 1

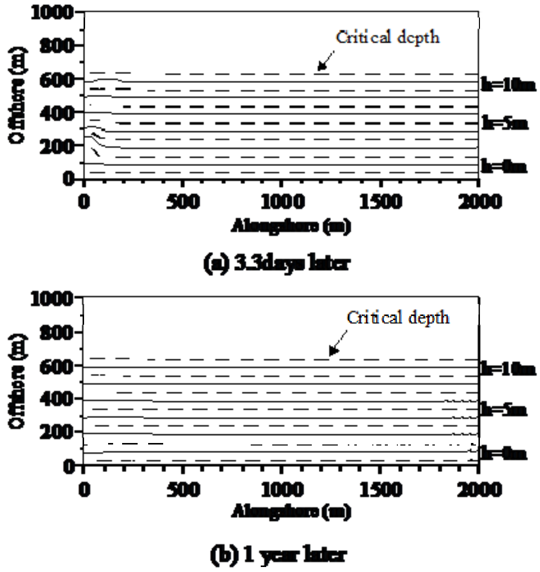

Figure 5. Time variation of contour line changes for Case 1

Model Verification with Grain Size Effect

Secondly, in order to examine the influence of the effects of grain size of the sand, two model tests were calculated. Initial contour lines are shown in Fig.3, and the computations condition are listed in Table 1. In the model tests, the simulations were carried out in Case 1 and 2 using three types of grain size, dd_{50}=0.15mm, 0.25mm and 0.4mm. The computed results for Case 1 and 2 are shown in Fig.7 and 8. These figures show the difference of the nourished sand of grain size. From Fig.7, nourishments with large grain size sands are found to be more effective around the injection points. In Case2 (nourishments in 6m), there is no difference in shore line. But in depth of 6m, large grain size of sands are more stable to the confirmation of the beach. From these results, the large grain size of the nourished sand are more effective than smaller one.

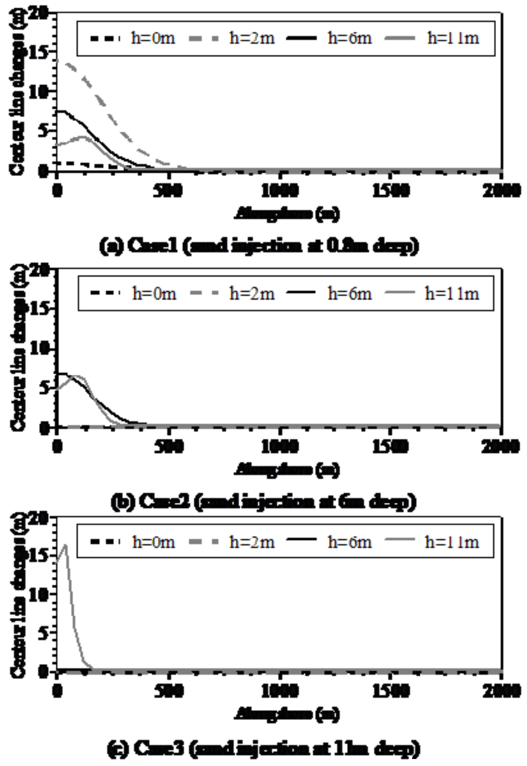

Figure 6. Difference of contour lines between nourishment and non-nourishment during 1 year

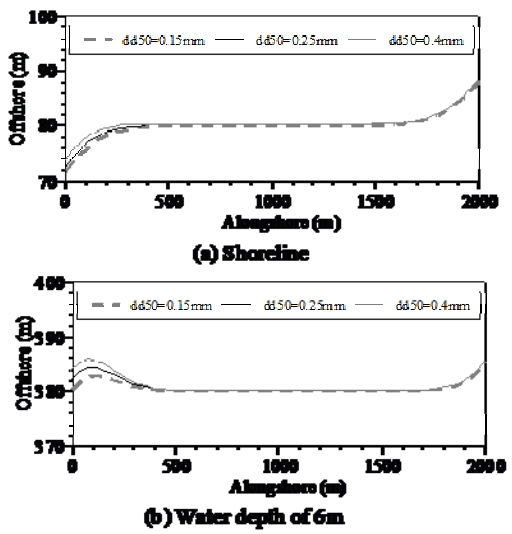

Figure 7. Difference of the nourished sand of the grain size for Case 1

Field Verification

Finally, the presented model was applied to erosion problem for Yumigahama coast, Japan such as (SHIBUTANI et al ICS2007). Yumigahama coast is a sandy beach with a length of 16km, facing the Sea of Japan, in the Yumigahama coast in Tottori Prefecture. The sandy beach of Kaike coast, in the eastern part of Yumigahama coast was started erosion around 1946. On the other hand the marina port of the eastern area faces a problem of

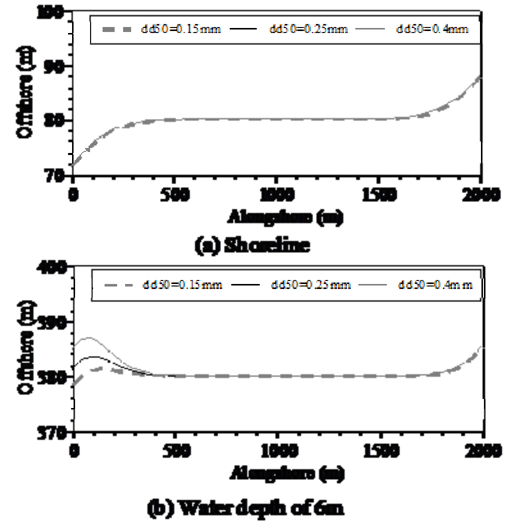

Figure 8. Difference of the nourished sand of the grain size for Case 2

deposition of sand. Where as sand recycle project started to recover the erosion in 1994. The area of this simulation was located at a distance of 3km, as the sand recycle area. The initial bathymetry is shown in Fig.9, and the wave condition and coefficients are shown in Table 2.

In order to evaluate the coefficients K_1, K_2 and A_d, the contour line changes during 5 years from 1981 to 1994, before the sand recycle project, was simulated using the proposed model without nourishment. Fig.10 shows comparison between computed and measured data at 5m water depth and shoreline. Also, the comparison of the volume of changes is shown in Fig.11. From these figures, the computed results agree well with the measured data.

By using the computed results mentioned above, the prediction of the contour line changes was calculated after nourishment with the sand recycle. In the sand recycle project, the sand at the deposition area was dredged, and then the sand was removed and injected at the erosion area. Therefore, the shoreline and 1m contour in the run-up region at the deposition area was retreated

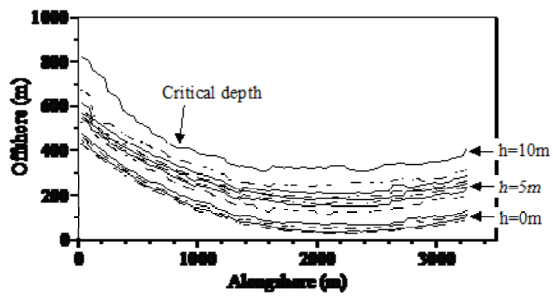

Figure 9. Initial depth contour in 1989

Table 2: Wave condition and coefficients used in sediment transport formulas

$H_{1/3}$(m)	$T_{1/3}$(s)	S_{max}	α	d_{50}(mm)
1.12	7.62	75	-10.0	0.25
K_1	K_2	Vs(m/s)	Kx(m^2/s)	Ky(m^2/s)
0.1	0.0	-0.001	0.00057	0.0023
C_{ld}(m$^{0.5}$)	A_d(m$^{0.5}$)	C_u(m/s)	dd_{50}(mm)	tan θ
0.014	0.016	-0.19	0.25	1/50

with the dredging.

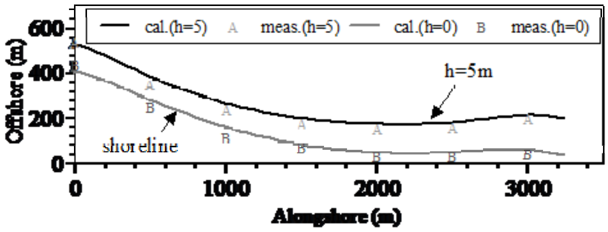

Figure 10. Computed contour lines at 5 years later

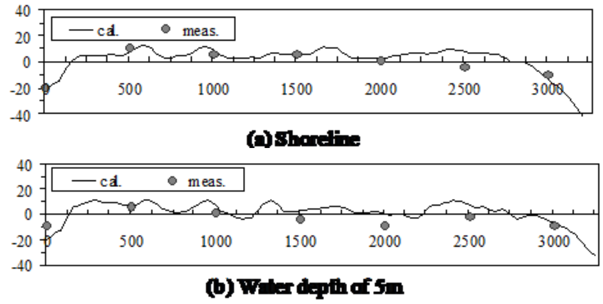

Figure 11. Comparison of the volume of contour line changes during 5 years

The amount of annual dredging bed material is 30,000m^3. And the bed material was injected at the shoreline at the erosion area. Fig.12 shows difference of the contour line changes between nourishment and non-nourishment. It was found the shoreline and the contour lines at water depth of 2m, 6m and 10m advanced after nourishment. Moreover, comparison of the volume of changes is shown in Fig.13. The proposed model is found to estimate the measured contour line changes.

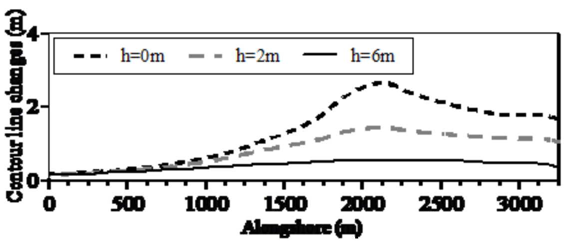

Figure 12. Difference of contour lines between nourishment and non-nourishment

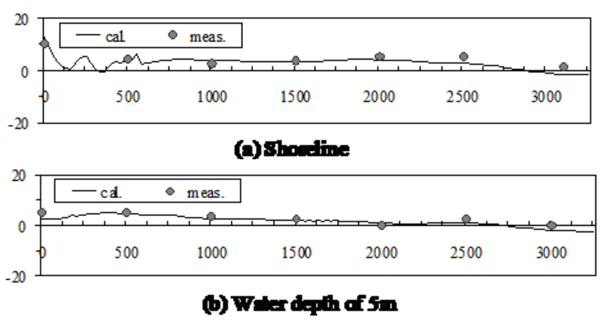

Figure 13. Comparison of the volume of contour line changes

CONCLUSIONS

In this study, a new n-line model, which can predict the changes of depth contour line and shoreline after beach nourishment for various grain sizes of bed materials, was proposed. The behavior of the nourished materials was demonstrated by two-dimensional advection diffusion equation.

From model test with beach nourishment, it was confirmed that the presented model could reproduce qualitatively contour line changes after nourishment. Although in case of injecting in the offshore area, shoreline was not advanced remarkably, the case of injecting near shoreline gave an effective of beach nourishment.

From model tests with grain size effects, it was confirmed that the injecting of the bed material of large grain size was effective for beach nourishment.

From field verification, it was confirmed that the contour lines at the injection point was advanced, and the presented model reproduced the quantity of contour line changes of the measured data.

LITERATURE CITED

DABEES, M.A. and KAMPHUIS, J.W., 2000. NLINE; Efficient modeling of 3-D beach change, *Proceedings of the 25th International Conference on Coastal Engineering,* Sydney, Australia, ASCE, pp.2700-2713.

INMAN, D.L., and QUINN W.H., 1951, Currents in the surf zone, *Proceedings of 2nd Conference on Coastal Engineering.*

KAMPHUIS, J.W.; DEVIES,M.H.; NARIN, R. B.; and SYAO, O. J., 1986. Calculation of littoral sand transport rate, *Coastal Engineering*, 10, pp1-12.

KUROIWA, M., and NODA, H., 1994. Field investigation of sand drift using Fluorescent tracer, *Proceedings of the International Symposium : Waves physical and numerical modeling*, pp.1483-1490.

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

NADAOKA, K.; TANAKA, N., and KATO, K., 1981. Field measurements of local sediment transport in surf zone using the fluorescent sand tracer, *Report of the Port and Harbour Research Institute*, Vol.20 No2, pp.75-126.(in Japanese)

OZASA, H., and BRAMPTON, A. H., 1980. Mathematical modeling of beaches backed by seawalls, *Coastal Engineering*, 4(1), pp.47-63.

SHIBUTANI, Y.; KUROIWA, M.; and MATSUBARA, Y., 2007. One-line Model for Predicting Shoreline Changes due to Beach Nourishments, *Journal of Coastal Research, Special Issue*, 50, pp.511-515.

SHIBUTANI, Y.; KUROIWA, M.; and MATSUBARA, Y., 2008. N-line Beach Evolution Considering Advection Diffusion Effects of Nourished Sand, *Proceedings of the 18th International Offshore and Polar Engineering Conference*, pp. 713-720.

SUNAMURA, T., and HORIKAWA, K., 1974. Two-dimensional beach transformation due to waves, *Proc. 14th Int. Conf. on Coastal Eng.*, pp.920-938

UDA, T., and KAWANO, S., 1996. Development of a Predictive Model of Contourline Change due to Waves, *Journal of hydraulic, coastal and environmental engineering*, No.539/II-35, 121-139.

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