PREDICTION MODEL OF THE MORPHODYNAMICS AROUND COASTAL STRUCTURES CONSIDERING WAVE-CURRENT INTERACTION

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This study develops a 3D morphodynamic model around coastal structures considering wave-current interaction. In the wave model, the current effects on wave breaking and energy dissipation are taken into account as well as the wave diffraction effect. Furthermore, the nearshore current model is modified in association with the surface roller effect. Several model tests against detached breakwaters were carried out to investigate the performance of the model. Then, the model was applied to Kunnui fishing port for the prediction of the bathymetry after 1 year, and to calibrate and verify the morphodynamics around the coastal structures. For the model tests, the performance of the model was investigated; and for Kunnui fishing port, the model result shows a good agreement with the field observation. It was found that the wave-current interaction with the surface roller was significantly playing an important role in the prediction of the 3D morphodynamics computation.

Key Words: *3D morphodynamic model, Quasi-3D, wave-current interaction, coastal structures, detached breakwater*

1. INTRODUCTION

An accurate prediction of waves and nearshore currents is a key role in solving coastal engineering problems, especially of those related to beach morphological evolution. Previously, some three dimensional (3D) morphodynamic models using a quasi three dimensional (Q-3D) model around coastal structures have been proposed (e.g. De Vried et al., 1988; and Bos et al., 1996). However, the model prediction was not accurate, and the major reason is due to the nearshore waves and current fields were independently determined without considering the wave-current interaction. Therefore, in order to predict the morphodynamics around the coastal structures with better accuracy, 3D morphodynamic model that considering the wave-current interaction is needed. Recently, we have proposed a new Q-3D model with considering the wave-current interaction and the surface roller, Khaled Seif et al. (2010).

The main objective of this study is to develop a reliable numerical model for predicting the morphodynamics around the coastal structures taking into account the wave-current interaction.

2. NUMERICAL MODEL

The numerical model consists of four modules, as shown in **Fig.1**. The wave module is based on the wave action balance equation with energy dissipation terms for the wave breaking and the wave diffraction under multi-directional random waves, Mase et al. (2004). The nearshore current module is based on the Q-3D nearshore current model, Kuroiwa et al (2002). The Q-3D is considering the stresses due to the surface roller. The wave and nearshore current field are dependently determined with the consideration of wave-current interaction. An iterative feed-back process between the wave module and nearshore current module was carried out to obtain the steady state condition. The total sediment transport rate module was defined as the sum of the bed load due to the wave orbital velocity, the bed load due to the steady current velocity at the sea bottom, and the

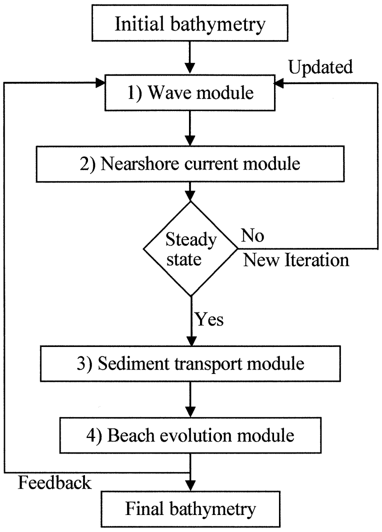

Fig.1 Flowchart of the numerical model.

suspended load due to the nearshore currents with undertow in the surf zone (Kuroiwa et al., 2000). The changes in bottom elevation were calculated using the continuity equation of sediment transport that was proposed by Watanabe et al. (1986). The shoreline was treated as a moving boundary. In order to predict the final bathymetry, the new bottom topography at each step was fed-back into the hydrodynamic and sediment transport computations.

3. MODEL TESTS

Several model tests associated with detached breakwaters with and without the wave-current interaction were carried out to investigate the performance of the model, and the planform development behind a single detached breakwater.

(1) Model setup

The computations were performed in an area of 0.6km alongshore and 0.6km cross-shore. The initial bathymetry with a gradient of 1:50 was set. The grid size was 10m $(\Delta x=\Delta y)$. The significant wave height at the offshore boundary was 1.5m, and the significant wave period was 7.0s. According to Johnson et al. (1994), the equilibrium planform that develops behind a single detached breakwater is mainly governed by its length and the distance to the initial shoreline. Therefore, the length W_B of the breakwater and its distance to the initial shoreline X_B are systematically varied in the tests. The computation conditions are summarized in **Table 1**.

(2) Model test results

Fig.2 and **Fig.3** show examples of the computed wave height distribution and depth-average current velocities around the detached breakwater for Test 2 without and with the wave-current interaction, respectively. From these Figures, it was found that by considering the wave-current interaction, the wave height distribution behind the detached breakwater, and the magunitude of the current velocities were changed. Fig. 5 shows the computed final bathymetry for Test 2, and it was found that the bathymetry behind the brakwater with the interaction was deeper than without the interaction. This is due to the model run reached the steady state condition only with the wave-current interaction consideration. Similar comparisons were conducted on the rest of model tests (Test 1, Test 3, Test 4, and Test 5), and the obtained results gave an assurance to the results above. In order to investigate the planform development behind a single detached breakwater, comparisons between the computed bathymetries of the model tests were done. From these comparisons it was found that a deposition occur behind the detached breakwater whereas the current decreases, and erosion occur on both side of it due to the accelerated current towards the lee of the breakwater. These results are the same as frequently observed in the field.

Table 1 Computation conditions of model tests

Model test	Parameters		
	Breakwater length, W_B, m	Distance from shoreline, X_B, m	W_B / X_B
Test(1)	210	300	0.7
Test(2)	210	210	1.0
Test(3)	210	150	1.4
Test(4)	330	300	1.1
Test(5)	330	150	2.2

As shown in the figures (**Fig.4** to **Fig.8**) the type of the planform development behind a single detached breakwater depends on the dimensions of the breakwater (W_B and X_B), in addition weather the wave-current interaction was considered or not. It was concluded that by increasing the length of the detached breakwater, the bathymetry behind it was slightly shallower. Also, by decreasing the breakwater distance to the shoreline, the bathymetry is less effected overall the area.

As a conclusion of the model tests, it was found that the wave-current interaction with the surface roller was significantly playing an important role in the prediction of the morphodynamic computation around the coastal structures.

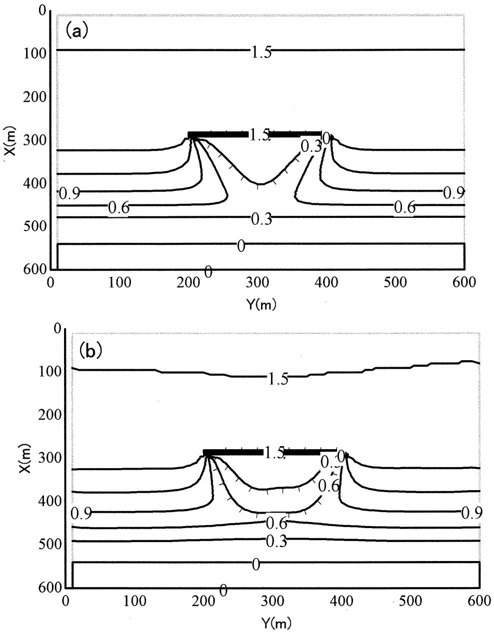

Fig.2 Computed wave height distribution (a) without and (b) with interaction for Test 2.

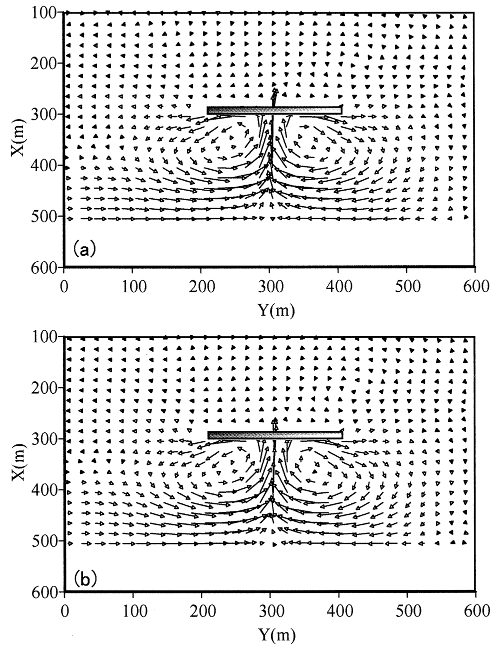

Fig.3 Computed depth-average current velocity (a) without and (b) with interaction for Test 2.

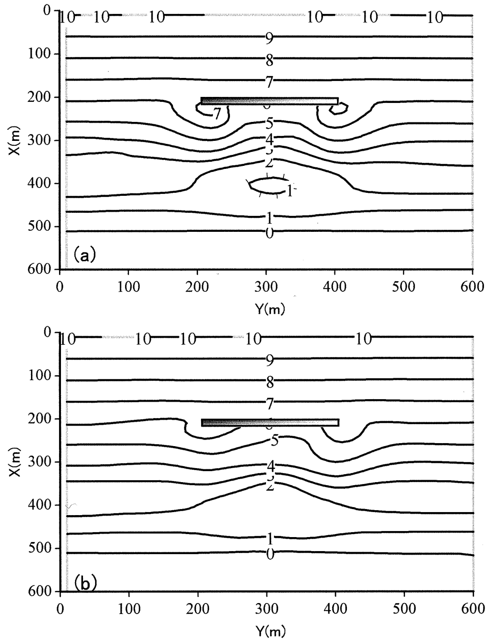

Fig.4 Computed bathymetry (a) without and (b) with interaction for Test 1.

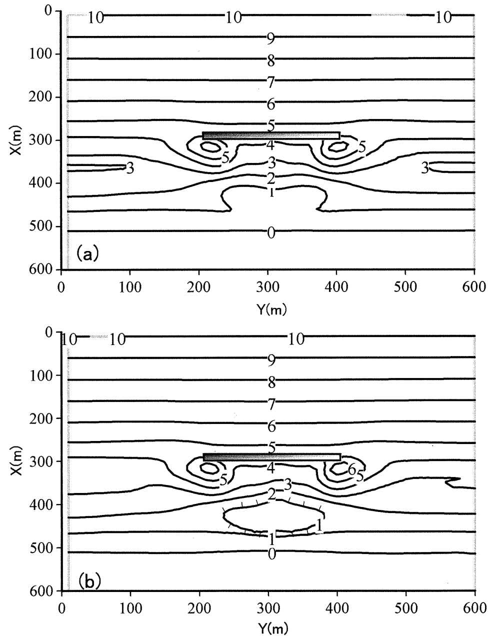

Fig.5 Computed bathymetry (a) without and (b) with interaction for Test 2.

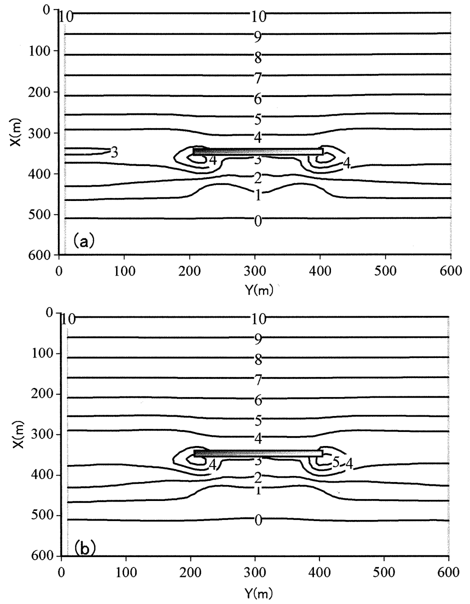

Fig.6 Computed bathymetry (a) without and (b) with interaction for Test 3.

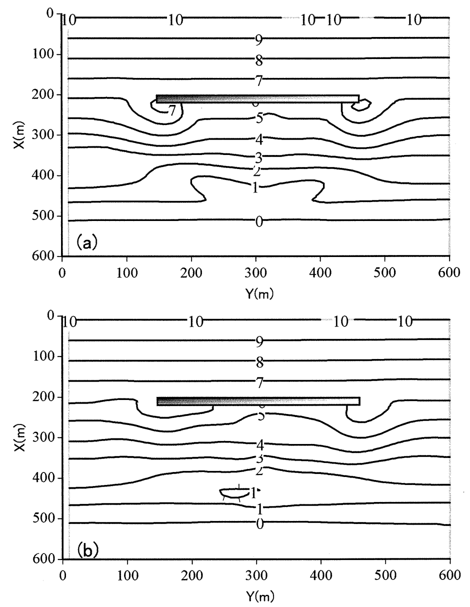

Fig.7 Computed bathymetry (a) without and (b) with interaction for Test 4.

4. Model Verification

The presented model was further verified and applied for 1 year tombolo formation behind Kunnui fishing port at Hokkaido, Japan. Kunnui fishing port was planned in 1985 and the construction was completed in 1994. Before completion of the port,

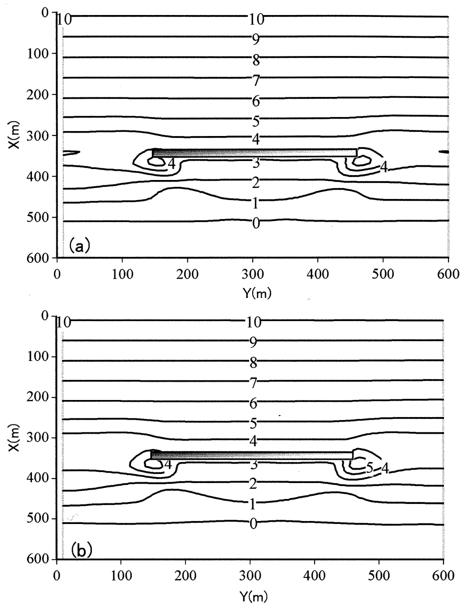

Fig.8 Computed bathymetry (a) without and (b) with interaction for Test 5.

the bottom contours were almost parallel, and after one year, a tombolo was rapidly formed behind the port in the period between 1989 ~ 1990, as shown in **Fig.9** and **Fig.10**. In this study, the beach evolutions from 1989 to 1990 were simulated to verify the present model.

(1) Model setup

The computation was performed in an area of 1.0km in the alongshore direction and 0.8km in the cross-shore direction. The initial bathymetry with the gradient of 1:90 was set. The grid size was 10m. According to Shimizu et al. (1996), the significant wave height of less than 0.5m is omitted, because the waves can not contribute against the beach evolution around the Kunnui fishing port. Therefore, the duration of which the beach evolution was generated in 1 year was 120 days. The time variation of wave data input at the offshore boundary was taken into account. The computations of the wave and current modules were repeated 10 times to reach 1 year beach evolution, as shown in **Table 2**. The principal wave direction was perpendicular to the shoreline. The median diameter of sand particle was 0.20mm.

Table 2 Computational conditions of the model.

Wave Condition	Period, day	H_s	T_s
1,5,6,10	28	0.75	7.0
2,4,7,9	1.9	1.25	8.0
3,8	0.2	2.0	10.0

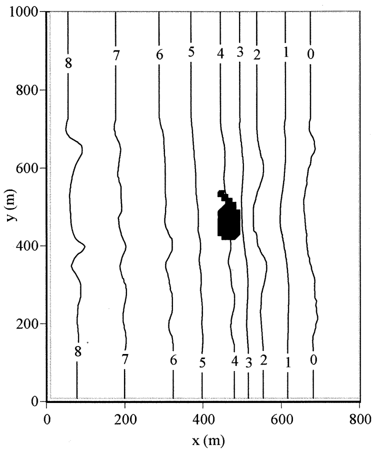

Fig.9 Observed bathymetry in 1989.

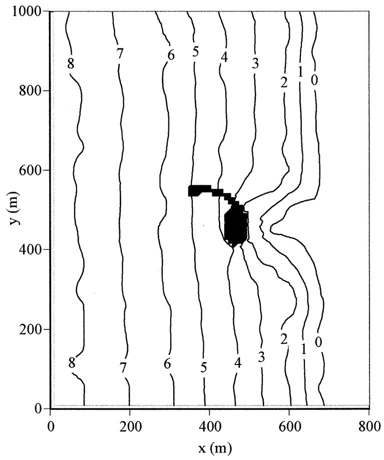

Fig.10 Observed bathymetry in 1990.

(2) Results and discussion

Fig.11 illustrates the computed bathymetry after 1 year (1989-1990) with considering the wave-current interaction. Comparing with the measured bathymetry in 1990, it was found that the tombolo was formed behind the Kunnui fishing port. Although the predicted tombolo was different from the measured one, the shoreline and the depth of contour lines of 1m, 2m, and 3m were advanced to the offshore direction due to the circulation behind the port. The shoreline and bottom topography changes such as the formation of tombolo behind the port could be qualitatively computed.

5. CONCLUSION

In this study, the morphodynamic model around coastal structures was described. The applicability

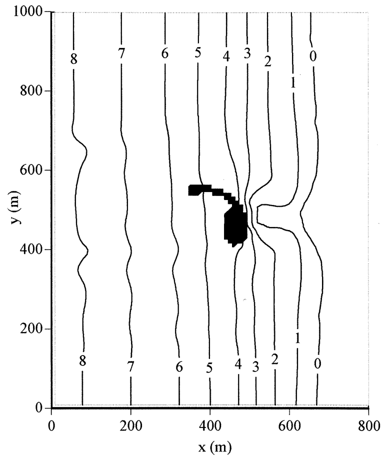

Fig.11 Computed bathymetry with interaction.

of the model was demostrated through several numerical tests and compared against field observations. The new proposed morphodynamic model shows reasonable agreement with the observations. Furthermore, it was found that the wave-current interaction with the surface roller was significantly playing an important role for the prediction of the 3D morphodynamics computation. The computed results of the rest of model tests will be presented in the conference.

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