Impact Analysis on the Coastal Erosion and Accretion due to Relocation of the Breakwaters

Seung-Chul Lee* · Joong-Woo Lee† · Kang-Min Kim** · Ki-Dam Kim***

*Sekwangeng Engineering co., Ltd., Seoul, Korea

† Division of Civil and Environmental Engineering, Professor, Busan, Korea

**Seileng Engineering Co., Ltd., Seoul, Korea

***Department of civil and Environmental Engineering, Master's course, Busan, Korea

Abstract : Recently it was known that the problems of nearshore processes and damage of berth and counter facilities frequently had appeared at the small fishery port, such as Daebang near Samcheonpo city, Korea. Here we try to analyze the impact of the rearrangement of counter facilities and berth layout adopted for tranquility of its inner harbor. Because this harbor is being connected to Daebang channel, the rearrangement of the structures might affect to the current speed and direction and wave height, so do to the sea bottom undulation. Therefore, we made model test for the several layouts of the berth and breakwater in this area. Numerical model result shows that the bottom was eroded by 1m by tidal currents and the speed of flow did not shrink, even after the construction work was completed. The direction of the sand movement was downdrift. Although the model study gave reasonable description of beach processes and approach channel sedimentation mechanism, it is necessary to compare with the field history, including the records of waves, tides and bottom materials, etc. for better prediction.

Key words : Breakwater, Erosion, Accretion, Tidal current, Sedimentation, Wind wave

1. Introduction

Harbor and fishery port facilities have been built in all over the country. As the number of fishing boat increases recently, It is necessary to expand the port facility, too. Therefore, a new function to the old harbor was introduced, and redevelopment plan was established so that it can include the function of recreational and convenient supports. Incoming and outgoing of large vessel were increased by trade increase between the countries, and then the development of harbor and construction of breakwater is being progressed attaining public attentions. However, scale of storm is being increased due to global warming phenomenon and significant wave height does. In order to protect the port facilities it is necessary to expand the counter facilities and to rearrange the plan form. Construction of breakwater for calmness of harbor causes change in fluid flow of ambit. And then, it breaks balance of erosion and accumulation ratio at the coast. Therefore, engineers need to analyze the change by fluid flow through the use of available scientific tools. Daebang fishery port is located at a mid of tidal basin near Samcheonpo city.

Samcheonpo harbor amending plan is shown in Fig. 1. Daebang breakwater at Samcheonpo harbor is going to be

extended 250m (total length 400m) to open sea direction. Although it might enhance the calmness against the wave attacks from the open sea, it brings some changes on current distributions in the vicinity area. We would analyze the variation of fluid flows, and compare the sand transport patterns between before and after renovation.

Fig. 1 Relocation area at the Samcheonpo

2. Governing Equations

2.1 Current and circulations

In this numerical study for the dynamics of coastal circulation the governing equations are the vertically

* Seung-Chul Lee, kmaritime99@nate.com 051)410-4981

** kikami@seileng.com 051)410-4981

*** allyesyon@hanmail.net 051)410-4981

† Corresponding Author : jwlee@hhu.ac.kr 051)410-4461

integrated two-dimensional equations as follows.

$$\frac{\partial h}{\partial t} + \frac{\partial h \bar{U}}{\partial x} + \frac{\partial h \bar{V}}{\partial y} = hS \quad (1)$$

$$\begin{aligned} \frac{\partial h \bar{U}}{\partial t} + \frac{\partial h \bar{U}^2}{\partial x} + \frac{\partial h \bar{U} \bar{V}}{\partial y} = & f \bar{V} h - gh \frac{\partial \eta}{\partial x} - \frac{h}{\rho_0} \frac{\partial p_a}{\partial x} \\ & - \frac{gh^2}{2\rho_0} \frac{\partial \rho}{\partial x} + \frac{\tau_{sx}}{\rho_0} - \frac{\tau_{bx}}{\rho_0} - \frac{1}{\rho_0} \left(\frac{\partial s_{xx}}{\partial x} + \frac{\partial s_{xy}}{\partial y} \right) \\ & + \frac{\partial}{\partial x} (h T_{xx}) + \frac{\partial}{\partial y} (h T_{xy}) + h U_s S \end{aligned} \quad (2)$$

$$\begin{aligned} \frac{\partial h \bar{V}}{\partial t} + \frac{\partial h \bar{V}^2}{\partial y} + \frac{\partial h \bar{U} \bar{V}}{\partial x} = & -f \bar{U} h - gh \frac{\partial \eta}{\partial y} - \frac{h}{\rho_0} \frac{\partial p_a}{\partial y} \\ & - \frac{gh^2}{2\rho_0} \frac{\partial \rho}{\partial y} + \frac{\tau_{sy}}{\rho_0} - \frac{\tau_{by}}{\rho_0} - \frac{1}{\rho_0} \left(\frac{\partial s_{yx}}{\partial x} + \frac{\partial s_{yy}}{\partial y} \right) \\ & + \frac{\partial}{\partial x} (h T_{xy}) + \frac{\partial}{\partial y} (h T_{yy}) + h V_s S \end{aligned} \quad (3)$$

where, D is the still water depth, η is the surface elevation, $h = D + \eta$ is the total water depth, U, V are the velocity components in the x, y direction, $\bar{U} = \frac{1}{h} \int_{-D}^{\eta} U dz$, $\bar{V} = \frac{1}{h} \int_{-D}^{\eta} V dz$ are the depth averaged velocities. $f = 2\Omega \sin \phi$ is the Coriolis parameter (Ω is the angular velocity of the Earth, ϕ is the latitude), g is the acceleration of gravity, ρ is the density of sea water, p_a is the atmospheric pressure, $\tau_{sx}, \tau_{bx}, \tau_{sy}, \tau_{by}$ are the x and y components of the surface wind and bottom stresses, $s_{xx}, s_{xy}, s_{yx}, s_{yy}$ are components of the radiation stress tensor. S is the magnitude of the discharge due to point sources and (U_s, V_s) is the velocity by which the water is discharged into the ambient water. The lateral stresses are given by

$$\begin{aligned} T_{xx} &= 2A \frac{\partial \bar{U}}{\partial x}, \quad T_{yy} = 2A \frac{\partial \bar{V}}{\partial y} \\ T_{xy}, T_{yx} &= A \left(\frac{\partial \bar{V}}{\partial x} + \frac{\partial \bar{U}}{\partial y} \right) \end{aligned} \quad (4)$$

The most basic of subgrid scale eddy viscosity models is proposed by Smagorinsky. (1963) $A = c_s^2 l^2 \sqrt{2S_{ij}S_{ij}}$, ($i, j = 1, 2$), c_s is a constant, l is a characteristic length and the deformation rate is given by

$$S_{ij} = \frac{1}{2} \left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} \right), \quad (i, j = 1, 2) \quad (5)$$

The bottom stress, $\vec{\tau}_b = (\vec{\tau}_{bx}, \vec{\tau}_{by})$ is determined by

quadratic friction law

$$\vec{\tau}_b = \rho_0 c_{fb} \vec{U}_b |\vec{U}_b| \quad (6)$$

where, c_{fb} is the bottom drag coefficient and $\vec{U}_b = (U_b, V_b)$ is the flow velocity above the bottom. The friction velocity associated with the bottom stress is given by

$$U_{\tau b} = \sqrt{c_{fb} |\vec{U}_b|^2}, \quad c_{fb} = g / (Mh^{1/6})^2 \quad (7)$$

where, U_b is the depth average velocity and the drag coefficient can be determined from the Manning number ($32m^{1/3}/s$)

The wind stress, $\vec{\tau}_s = (\vec{\tau}_{sx}, \vec{\tau}_{sy})$ is determined by the winds above the surface. The stress is given by empirical relation

$$\vec{\tau}_s = \rho_a c_d \vec{u}_w |\vec{u}_w| \quad (8)$$

where, ρ_a is the air density, c_d is the drag coefficient of air, and $\vec{u}_w = (U_w, V_w)$ is the wind velocity 10m above the sea surface. The friction velocity associated with the surface stress is given by

$$U_{\tau s} = \sqrt{\frac{\rho_a c_{fs} |\vec{u}_w|^2}{\rho_0}}, \quad c_{fs} = \begin{cases} c_a : u_w < w_a \\ c_a + \frac{c_b - c_a}{w_b - w_a} (u_w - w_a) : w_a \leq u_w < w_b \\ c_b : u_w \geq w_b \end{cases} \quad (9)$$

The drag coefficient can either be a constant value or depend on the wind speed. The empirical formula proposed by Wu (1980, 1994) is used for the parameterization of the drag coefficient. Where, $c_a = 1.255 \cdot 10^{-3}$, $c_b = 2.425 \cdot 10^{-3}$, $w_a = 7m/s$ and $w_b = 25m/s$ are empirical factors (Geernaert and Plant, 1990).

Wind correct, the following simple estimate for geostrophic winds is made from low-level wind observations (cgs units)

$$V_g = \frac{U_*}{\sqrt{C_{Dland}}} \quad (10)$$

where, $U_* = k U_{obs} / \ln(z_{obs}/z_0)$ is the friction velocity, k is von Karman constant ($k \approx 0.4$), z_{obs} is the elevation of wind observation, z_0 is the surface roughness length (assumed $\approx 30cm$) and $C_{Dland} \approx 0.00255 z_0^{0.1639}$ is a drag

coefficient over the land. The wind profile within the constant stress region(10~60m) is described by the following modified logarithmic form,

$$U_z = \frac{U_*}{k} \left[\ln\left(\frac{z}{z_0}\right) - \psi\left(\frac{z}{L}\right) \right] \quad (11)$$

where, U_z is the wind velocity at elevation z , $z_0 = C_1/U_* + C_2U_*^2 + C_3$ ($C_1=0.1525$, $C_2=0.019/980$, $C_3=-0.00371$) is the surface roughness length, Ψ is a universal similarity function KEYPS formula (Lumley and Panofsky, 1964), ΔT is the air-sea temperature gradient, L is Obukov stability length.

$$L = 1.79 \frac{U_*^2}{\Delta T} \left[\ln\left(\frac{z}{z_0}\right) - \psi\left(\frac{z}{L}\right) \right] \quad (12)$$

$$\begin{cases} \Psi = 0 & |\Delta T = 0 \\ \Psi = Cz/L & |z/L > 0 \\ \Psi = 1 - \phi_u - 3\ln\phi_u + 2\ln\left(\frac{1+\phi_u}{2}\right) & \\ + 2\tan^{-1}\phi_u - \frac{\pi}{2} + \ln\left(\frac{1+\phi_u^2}{2}\right) & |z/L \leq 0 \end{cases} \quad (13)$$

where, $\phi_u = 1/(1-18R_i^{1/4})$, $R_i = z/L(1-18R_i)^{1/4}$.

For the shallow water and transport equations in Cartesian coordinates the Courant-Friedrich-Lévy (CFL) number is defined as

$$\begin{aligned} CFL &= (\sqrt{gh} + |U|) \Delta t / \Delta x + (\sqrt{gh} + |V|) \Delta t / \Delta y, \\ CFL &= |U| \Delta t / \Delta x + |V| \Delta t / \Delta y \end{aligned} \quad (14)$$

The time step interval Δt is the range from 0.1sec to 5sec.

The MIKE21 used here simulates the water level variations and flows assumed vertically well-mixed in response to a variety of forcing functions.

2.2 Sand transport

Bed load, a bed load factor k_b can be applied to the selected transport formula. The default value is 1, and values can vary between 0.5 and 2.0. Beyond this range the validity of the chosen formula could be questioned. Suspended load, a suspended load factor k_s can be applied to the selected transport formula. As for bed load the default value is 1, and values can vary between 0.5 and 2.0. Again, beyond this range the validity of the chosen formula could be questioned.

The Engelund and Hansen (1967) formula only predict total load, whereas information about both bed load and suspended load is required. The total load formula can still be applied by using the calibration factors k_b and k_s for bed load and suspended load, respectively, in order to differentiate between the two modes of transport. By specifying $k_b = 0.1$ and $k_s = 0.9$, it is understood that 10% of the transport takes place as bed load. The transport rates are obtained from the relations:

$$S_{bl} = k_b \cdot S_{tl}, \quad S_{sl} = k_s \cdot S_{tl} \quad (11)$$

Where the total sediment transport is obtained by:

$$S_{tl} = 0.05 \frac{C^2}{g} \theta^{\frac{5}{2}} \sqrt{(s-1)gd_{50}^3} \quad (12)$$

The equilibrium concentration c_e is simply specified as the suspended load divided by the water flux and converted from volumetric concentration to mass concentration:

$$c_e = k_s \frac{S_{sl}}{V \cdot h} \cdot s \cdot 10^6 \quad (13)$$

where, S_{bl} is bed load(m^2/s), k_b is bed load calibration factor, S_{sl} is suspended load(m^2/s), k_s suspended load calibration factor, S is relative density of the sediment, S_{tl} is total load(m^2/s), c_e is equilibrium mass concentration (g/m^3), V is the flow velocity(m/s).

The shields parameter θ is defined as:

$$\theta = \frac{\tau}{\rho g (s-1) d_{50}} \quad (14)$$

where, $\tau = \rho g V^2 / C^2$ is flow shear stress (C is the local Chezy number), ρ is the density of water, ρ_s the is density of sediment, for quartz sand $2650 kg/m^3$, and s is the relative density of the sediment(ρ/ρ_s).

3. Investigation of Field Environment

3.1 Tides

According to the data of NORI, the mean sea level is 164.8cm at Samcheonpo. The level of App. HHW, HWOST and HWONT are 329.6cm, 300.8cm, and 217.4, respectively. The tide shape factor for the near of Samcheonpo Old port is 0.21 and the mixed tide is dominant in this area. Mean high water interval is 8h-39m and mean lower water

interval is 14h–51m after meridian passage of the moon at Samcheonpo.

3.2 Tidal currents

The simulation domain and flexible mesh appears in Fig. 2. Flood current (northwest direction) passes about 50 minutes longer than ebb current (southeast direction) at Samcheonpo channel. The maximum current speed was appeared at 2 hours 50 minutes after high and low water level. Flood current speed is 1.08m/s and ebb current speed is 1.49m/s.

Fig. 2 Bathymetric chart, flexible mash and comparison points

As flood current flows Daebang channel to northwest direction, ebb current shows its reverse pattern. The maximum current speed was appeared at 3hours after high and low water level at Daebang channel. Flood current speed is 2.93m/s and ebb current speed is 3.34m/s at spring tide. In terms of the observed data, ebb current indicates dominated in this domain.

3.3 Waves

Waves from S direction may cause a big impaction at Daebang wharf. The design wave height for south breakwater, east breakwater, and west breakwater are 1.5m, 1.0m, and 2.0m, respectively. The wave period is 13.0sec (Masan Regional Maritime Affairs, 2002). At revetment and wharf of Samcheonpo New port the design wave heights are 1.5m and 1.0m (Masan Regional Maritime Affairs, 2005). The direction, height, and period of the deep water design wave are S, 9.6m, and 13.0sec, respectively (Masan Regional Maritime Affairs, 2002).

3.4 Bottom materials

Range of grain diameter is 0.524858 ~ 0.915099mm and the mean grain diameter is 0.702222mm, at the center of Samcheonpo channel. The coarse sand was dominated in this domain. Range of general grain diameter in Samcheonpo New harbor was 0.004465 (very fine silt) ~ 0.497925mm (coarse sand), and the general value of mean grain diameter for the whole domain of study showed about 0.204983mm (fine sand) as per Masan Regional Maritime Affairs' survey report (2001). In this study, in order to analyze the sand transfer pattern in this area, we introduced the mean grain diameter down to 0.2mm to the numerical model.

4. Numerical Simulation

4.1 Model formulation

In order to simulate the tidal circulation and sand transport of the bottom materials we set the coastal waters into the numerical model including the eastern part of Tongyeong and southern part of east Namhae island for the coastal boundaries and the open boundary is located 17.5km away from the Samcheonpo, intending to reduce the impact of the open boundary. We adopted meshes of 20m interval near the Daebang and Samcheonpo wharf areas to get high resolution and conducted model simulation for 30days which includes the spring, neap, and medium tides. Table 1 shows the summary of model simulation set up. The FEM mesh within the simulation area was shown in Fig. 2. Stations PT-1 and PT-2 are selected for the verification of the surface elevations. Also, stations S1(C1) through S4(C4) are selected for the tidal current. In the model, we did consider the effect of the wind stress (Fig. 3) and applied cold start for the coastal circulation simulation.

Table 1 Summary of model simulation set up

Items	Simulation conditions(Before/After construction)	
Tidal circulation	Cal. area	45km×30km △S (along the coastal line): 20, 40, 60, 90, 125, 150m
	Mesh scheme	Element:22052 Node:13116 /Element:22051 Node:13146
	Cal. Time	30days ($M_2+S_2+K_1+O_1$)
Sand transport	Grain diameter : 0.2mm Porosity : 0.4 Relative density :2.65

Fig. 3 Wind data at Tongyeong(August, 2007)

4.2 Model verification

In order to verify the numerical model we made comparisons with the observed tides at PT-1 and PT-2. Furthermore, the calculated maximum tidal currents were compared with the field measurements at the Daebang and Samcheonpo channel (Fig. 2). The tide elevation results agreed generally fairly well. The interrelation coefficient of tide elevation, R squared at Samcheonpo Old wharf were 0.973(With wind : 0.974) before and 0.972(0.973) after the relocation of the structures. At Mackjeonpo wharf, they were 0.988(0.989) and 0.988(0.989), respectively. These are shown in Fig. 5 and 1.0 indicates the highest agreement between prediction and observation.

Fig. 4 Time series of surface elevation

Fig. 5 Coefficient of determination at PT-1 and PT-2

Table 3 Survey data of tidal currents by NORI

Survey point N34.93°E128.06° /Survey date	Strongest year Flood /Ebb current(m/s) (Simulation result: Before, After)	Spring tide Flood/Ebb current (m/s)
S1 : 05NH06 /2005.04.24 N34.92 E128.04°	2.02 (1.70,1.70)/ 2.30(2.24,2.24)	1.67 / 1.90
S2 : 01SR09 /2001.06.22 N34.93°E128.05°	1.51(1.40,1.39) / 1.25(2.08,2.02)	1.25 / 1.03
S3 : 01SR14 /2001.06.22 N34.92°E128.07°	1.06 (0.99,1.01)/ 1.56(1.66,1.63)	0.87 / 1.29
S4 : 05NH05 /2005.04.24 N34.92°E128.05°	1.93 (1.85,1.88)/ 2.14(2.11,2.08)	1.60 / 1.77

Past tidal current records by NORI were analyzed for the model verifications shown in Table 2 and Fig. 6. Generally the ebb current is dominant in the study area but one discrepancy is shown at S2, where the observed flood current is stronger. However this is doubt that a mistake might be caused by the analytic procedure. The simulation

Fig. 6 Result of tidal current at C1, C2, C3 and C4

result shows that the ebb currents are stronger at the whole domain, too as shown in Fig. 7 and Fig. 8. If we follow this result, we might imagine that the transfer of bottom materials in this area would be occurred in the direction of ebb currents. Flood currents were accelerated more at Samcheonpo harbor after passing Sinsu Island and absolute maximums were in Daebang channel. However, it disappeared in Jinju bay. Opposite patterns were shown for the Ebb currents. Fig. 8 shows the difference of ebb currents after relocation of Daebang breakwater. The speed of ebb currents were increased after relocation of Daebang breakwater which might impact on the sand movement to downdrift.

4.3 Simulation on sand transport

Bottom profile change is appeared dominant in front of Daebang breakwater. It was accelerated by current changes caused by the relocation of Daebang breakwater and the construction of Samcheonpo breakwaters. We have to notice on the progressing erosion together with the downdrift accretion. We analyzed the bottom profiles across several sections as shown in Fig. 9 through Fig. 11. Sections t1-t2 part in Fig. 9 and Fig. 10 are located at the Daebang channel. In Fig. 11, before the construction, 3.8m (0.9m) of erosion occurred at the landside of the channel and more after had 5m (1.2m) of erosion by applying the mean grain diameter 0.2mm (with wind data) to the model. More sands moved downward after construction. The sands were accretion in Section t3-t4 but erosion was increased at station 160 for the case of with wind data.

Erosion occurred at the station 100 of Section t5-t6 and accretion occurred at the center of the channel for without wind. There shows some differences at the relocation of breakwater. However, case with wind shows no significant difference in relation to the relocation of breakwater. It

seems to be because the north direction wind is strong. Accumulation of sand in the Section t7-t8 was appeared due to the sand swept from the updrift. Sand transport in the Section t21-t22 was complicated by wind and new breakwater. The increased ebb currents impacted on sand movement to downwards more (refer to Section t9-t10 thorough Section t17-t18 in Fig. 11). Although more analyses for other sections were made but the difference was found within 0.5m.

Fig. 7 Maximum flood and ebb currents(Without wind)

Fig. 8 Maximum flood and ebb currents at Daebang and Samcheonpo channel (Without wind) Jinju Bay

Fig. 9 Bottom level change (Without wind)

Fig. 10 Bottom level change (With wind)

5. Conclusion

We made numerical simulation on the variation of sediment transport due to the relocation of breakwaters at Daebang wharf, based on the result of 30 days tidal current simulations considering major four tidal components of M2, S2, K1 and O1 at the Samcheonpo channel. Grain diameter of bottom sand was decided by 0.2mm for analysis of sand transport pattern. We did not consider the wave induced current because the tidal current is dominant in this area. Flow velocity near the region of interest was about 1.5 ~ 2.3m/s and the ebb current suppressed the flood current. Flow velocities were not decreased at out side of the domain embraced by breakwaters of Daebang harbor and were widened and fast. Bottom was eroded by 1m by tidal currents and the speed of flow did not shrink, even after the construction work was completed. The direction of the sand movement was downdrift. Therefore, if we hope to build or expand the harbor and coastal structures, we have to consider the calmness of harbor and change of current flow. Specially, the case of breakwaters extended to open sea direction in the inner waterway, the waterway become narrower such as Daebang channel. As a result, the flow

Fig. 11 Change of bottom profiles

velocity was being increased and erosion was being accelerated. Therefore, we might find an ideal arrangement of breakwaters through the numerical simulation before construction.

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