MODELLING WAVE-INDUCED CURRENT AT HAEUNDAE BEACH ON ORTHOGONAL CURVILINEAR GRID BY USING CST3D

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Abstract. Haeundae Beach is sandy beach at Busan, Korea. Haeundae Beach is about 1.5 km-long enclosed by two headlands. The normal direction of the beach is between south and south-east. Tidal current at the site is not negligible, and waves are relatively high during monsoon and winter seasons. Currents were measured at nine points along Haeundae Beach on 4 June 2008 by using GPS-equipped drogues. Bathymetry around Haeundae Beach was surveyed on 7 August 2007 and 12 November 2007 by using an echo-sounder; wave, tide, and tidal current were measured between the two survey days, so that bathymetric change at the beach was obtained from the two surveys. The measured current vectors may include wave-induced current element, tidal current element, and wind-induced current. Seasonal sediment transport pattern at Haeundae Beach, Busan, Korea is known to be simple, according to previous observation. Typically sediment moves eastward, while sediment moves westward in winter. Tidal current contributes to long-term bathymetric change at the beach by transporting small-sized sediment.

1 INTRODUCTION

Haeundae beach is about 1.5 km-long, wide is 50 m, average depth 1 m, area 58,400 m³ and medium size sandy beach in Korea, see Figure 1. Bed material of the Haeundae beach is almost sand. Median diameter of the bed material varies between 270 and 604㎛, average median diameter is 300㎛. It is poorly sorted with average variation of 1.4Φ. Rocky bed is also found at shallow zones.

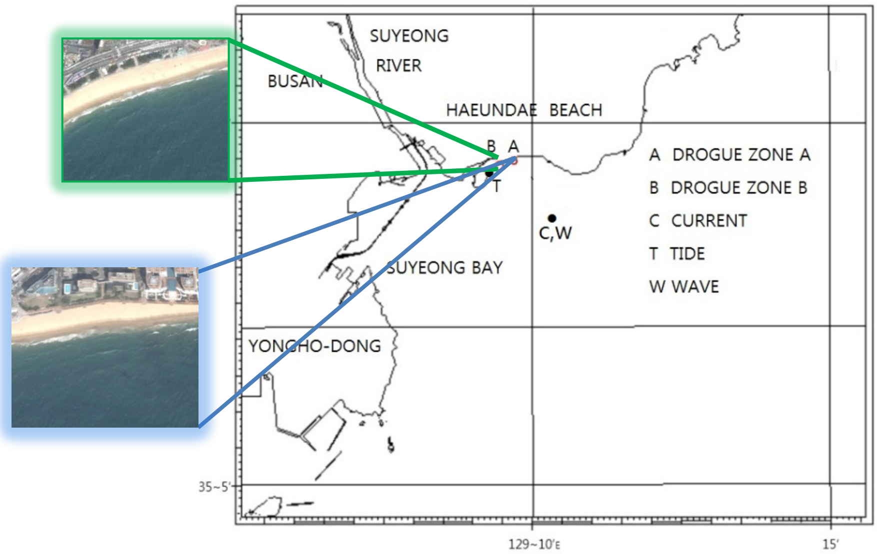


Figure 1: Map of Haeundae beach

Most waves come from S, and E. S waves are common in summer season, while SE waves common in winter. High wave generate strong wave-induced alongshore current, and have bigger impact on morphological change of the beach.

Mean tidal range at Haeundae Beach is 1.3 m , and the maximum tidal current speed during mean tide is about 20 cm/s at 20 m water depth during mean tidal range, see Busan City(2009) [1]. Even though tidal current near the beach is not strong, the tidal system affects movement of fine bed material, and contributes to formation of long-term equilibrium geography at the site.

Winds from N or NW are strong during winter, and don't much influence hydrodynamics at the beach, while winds from S during summer season take important roles on morphological change at the beach. Occasionally strong wind develops during typhoons at this area.

Normally the wave-induced current at the coast is expected in western direction for E incident waves, and eastward direction for S incident waves. The flow pattern around the beach sometimes exhibits complicated rip currents. The reasons for that may include asymmetric plane geography, and groin-like local non-erodible rocky bed around the beach.

Until, recently sophisticated and comprehensive measurements have not yet been undertaken at the site to understand characteristics of the wave-induced current. Accurate prediction of the bathymetric change of the beach is important for prediction of the wave-induced current and sediment transport.

Many external forces may drive the current at a specific time at Haeundae Beach. The forces include tidal force, wave-induced force, wind-induced force, and storm surge-induced force. Tidal current field is more or less regular, and predictable with high accuracy. On the other hand, wave-induced current and wind-induced current are non-periodic. Wave-induced current speed depends on wave power, and wind-induced current speed depends on wave power, and wind-induced current speed depends on wind speed. Strictly speaking, separation of measured current vectors into individual components, i.e. tidal, wave-induced, wind-induced components, and ocean currents may not be possible due to nonlinearity. However, we assume zero interaction between the current components for convenience.

Some research works on rip current and its danger at Haeundae Beach have been carried out. (Kim et al. [2], Chun et al. [3], Lee et al. [4]) Kim et al. [5] conducted a wide range of research work on Haeundae Beach problems. They carried out laboratory experiments and numerical modelling on the wave-induced current and bathymetric change at the beach. They also proposed countermeasures to mitigate serious erosion problem of the beach.

In the present study previous measurements are used to verify computations. Drogues were deployed at several near-shore points along the beach at 15:00, 4 April 2008 during a high wave period to measure strength and direction of the wave-induced current along the beach. [1] A numerical model system is then used to reproduce the measured alongshore current field composed of wave-induced current and tidal current. The model results also describe the wave-induced current field at the beach of the survey time.

A numerical modelling system, CST3D, was adopted to simulate the wave-induced current at Haeundae Beach. An orthogonal-curvilinear grid is used to lead small numerical error, i.e. the computed current vectors are more-or-loss parallel with grid lines. CST3D is thought to effectively describe overall seasonal wave-induced current field at Haeundae Beach. Computed current field result agrees well measured current vectors with regard to speed and direction. The model results could be used as input date for simulation of bathymetric change at the beach.

2 MEASURING CURRENTS AT HAEUNDAE BEACH BY USING DROGUES

Drogues are often used to measure sub-surface current. They are affected by wind to some extent because of drag force of the floating buoy. Drogues were composed of a small buoy, GPS, vein, and weight. They were deployed at several positions in two zones (Figure 1) along Haeundae Beach at 15:00, 4 June 2008 during a low air pressure period to measure near-shore currents, see Figure. 2 and 3. Wave and wind were measured simultaneously at the time so that measured currents could be explained with driving external forces. Tidal current at 20 m deep water and tidal level were measured in 2007 by using ADCP.

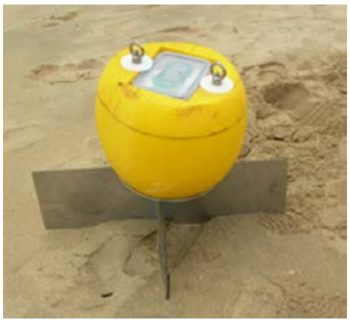


Figure 2: GPS-equipped drogue manufactured for present survey

Drogues were deployed at 9 positions of about 4 m water depth, and all of them landed onshore after some time. GPS date show time-series Lagrangian positions, and were convert into average current vectors, see Figure 3. Then the average current vectors were split into the alongshore and cross-shore components (Table 1). The magnitude of the alongshore components of near-shore currents was between 11 to 26 cm/s, which is significant.

Table 1: Measured field current at Haeundae at 15:00, 4 June 2008

Zone		A				B			
Position	1	2	3	4	5	6	7	8	9
Speed (cm/s)	12	17	17	15	15	11	26	21	15
Average (cm/s)		15				17			

Waves were continuously measured at St. W including the drogue survey time, 15:00 of 4 June 2008, see Figure 1. The significant wave height from 12:00 to 15:00 4 June 2008 of was 2.0 m, the peak wave period was 6.0 s, and the main deep offshore wave direction was from SE, i.e. heading towards 135 degree counterclockwise from East. The offshore SE waves become SSE at 20 m water depth by retraction [1].

a) Zone A b) Zone B

Figure 3: Maesured drogue tracks at Haeundae Beach at 15 :00 of 4 June 2008

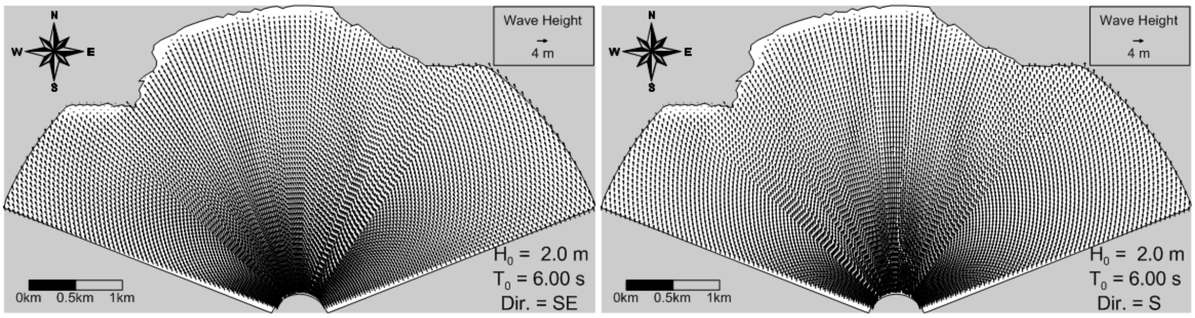
The major driving force of the currents near shoreline where drogues were dropped is believed to be the wave-induced force. Tide-induced force may be a minor driving force of the field current for the measured period at the site.

3 NUMERICAL MODELING OF BATHYMETRIC CHANGE AT HAEUNDAE BEACH

In this study a recently-developed, free-downloadable numerical model system, CST3D [6], is adopted to reproduce the measured field currents, and to understand characteristics of the wave-induced current at Haeundae Beach. The system can use orthogonal curvilinear grid, which can express circular shoreline effectively. The model system is composed of a wave module, an external driving force module, a flow module, and a sediment transport module. The system uses sigma grid in vertical direction.

3.1 Computation of wave fields

In order to obtain the driving force field we need wave field, i.e. wave height, period, are direction fields. The wave module of the system is an open source SWAN v40.91ABC (The SWAN Team, 2013 [7]). The SWAN solves wave field on frequency domain, and incorporates wave-current interaction. The two representative wave settings of the previous section are supplied to the module as input conditions. The two wave vectors are computed and shown in Figure 4. The field wave conditions at the survey period were: the significant wave height was 2.0 m, the peak wave period was 6.0 s, and the main wave direction at offshore deep water was S, SE. Waves refract as they approach shallow water, and the wave direction of the incident waves at the survey time at the station of 20 m depth was SSE. Computed wave vectors for the conditions corresponding to the field survey time are shown in Figure. 4. The wave transformations due to non-even bottom geometry like submerged rocks, shoals, and shallow water depth are well observed as in Figure 4. Then, spatial gradient of wave energy constitutes the driving forces of the wave-induced current. In SE wave field contain higher waves than S wave field due to boundary condition.



a) SE wave b) S wave

Figure 4: Computed wave fields for two representative wave settings

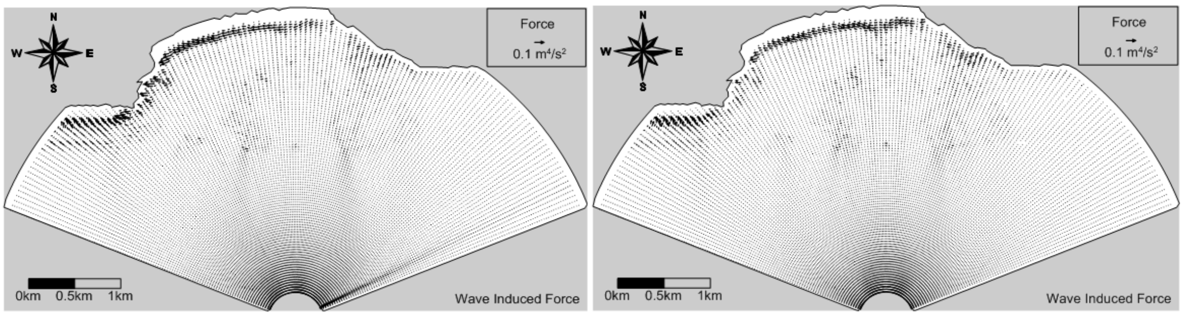
3.2 Computation of wave-induced driving forces

The depth-integrated wave-induced driving force components for monochromatic waves are obtained from the following equations:

$$F_x = -\rho\left(\frac{\partial S_{xx}}{\partial x} + \frac{\partial S_{xy}}{\partial y}\right) \qquad (1)$$
$$F_y = -\rho\left(\frac{\partial S_{xy}}{\partial x} + \frac{\partial S_{yy}}{\partial y}\right)$$

Where F_x, F_y are the wave-induced driving force component in the x and y directions, respectively; ρ is the water density, S_{xx}, S_{yy}, S_{xy} are the depth-integrated radiation thrust components acting normally in the x or y direction, cating normally in the y direction, acting tangentially in the x or y direction, respectively [8-11]. The driving forces for random waves can be computed by summation of forces for each wave component from the wave-induced force in the CST3D system, if needed. In the present study a monochromatic wave condition with the significant wave height and the peak wave period is alternatively used for ease of computation. Lateral mixing or turbulent mixing due to wave breaking influences the spatial distribution of the driving forces (Longuet-Higgins [9]). Horizontal turbulent mixing is often expressed as horizontal dispersion terms with large dispersion coefficients, which may cause difficulties in numerical computation. Instead the spatial distributions of the diving forces are obtained by a spreading process of Kim [12] in this module. The above driving forces may not be uniformly distributed in the water column [7]. However, the vertical distribution of the forces is close to uniform, if waves are shallow water waves. Wave-induced current was obtained after 60 minutes of real time with steady wave-induced force, when bay-size oscillation almost decayed. The computed wave-induced driving force vector field in the domain at the survey time is shown in Figure 5. The wave-induced driving forces push water body towards onshore within and near the surf zone.

Waves are used instead of the two settings with the significant wave height, peak wave period and main wave direction is used for ease of computation.



a) SE wave b) S wave

Figure 5: Computed wave-induced force for two representative wave settings

3.3 Computation of wave-induced current fields

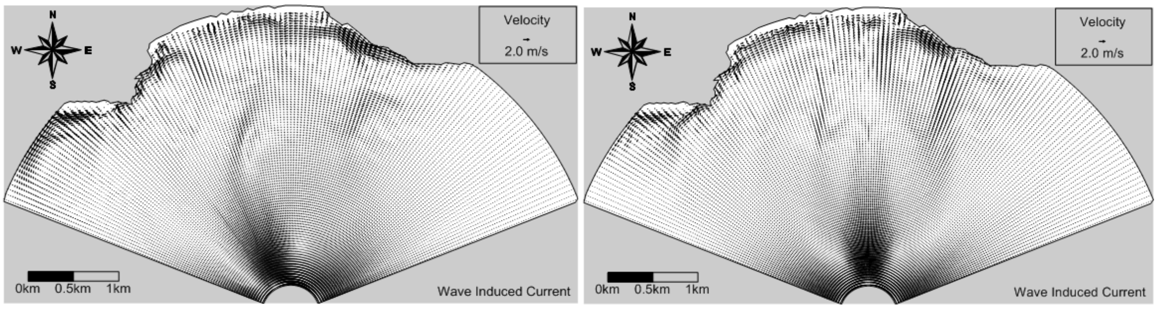
Costal flow model has common aspects, e.g. free surface exists, bed slope is mild, and flow is turbulent. Coastal flow model is specified by dimensions of governing equation, grid type, numerical schemes adopted, parallelism type, program language, application area, physics included, and driving forces of interest.

Wave-induced current is computed by using the flow module, FS, in CST3D. The flow module solves depth-average equation for preliminary solutions during the external mode, and solves continuity equation and three momentum equations to obtain final solutions during the internal mode:

$$\frac{\partial \eta}{\partial t} = -\frac{\partial HU}{\partial x} - \frac{\partial HV}{\partial y}$$
$$\frac{\partial HU}{\partial t} + A_x = B_x + Q_x$$
$$\frac{\partial HV}{\partial t} + A_y = B_y + Q_y \tag{2}$$

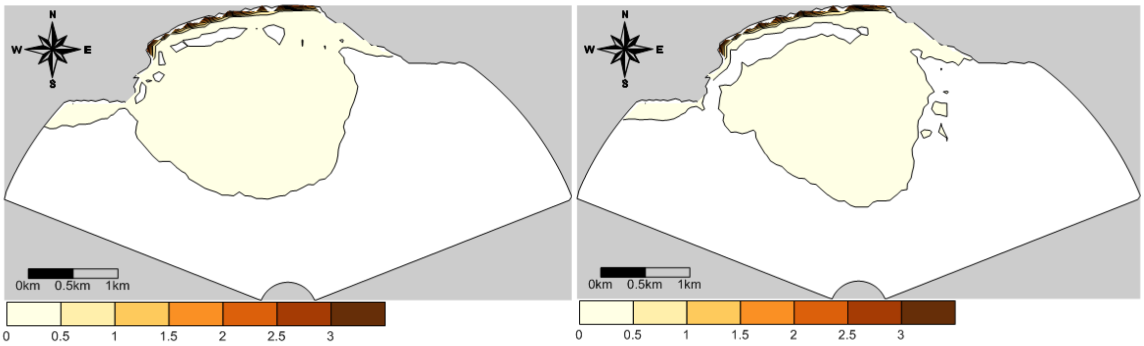
Where η is the water level, H is the water depth; U, V are the depth-average velocity in the x and y directions, respectively; A_x, A_y are the spatial advection terms in the x and y directions, respectively; B_x, B_y are the forces including Coriolis force, gradient of water level, pressure gradient, and horizontal dispersion in the x and y directions, respectively.

One layer is chosen for the present simulation. An option of the model system to consider interaction between the wave module and the flow module with repeated exchange of information was not turned on for this study.



a) SE wave b) S wave

Figure 6: Computed wave-induced current field for two representative wave settings



a) SE wave b) S wave

Figure 7: Computed wave-induced set-up contours

Computed wave-induced current vector fields in the domain for the two representative wave settings are shown in Figure 6. The overall computed wave-induced current direction along the shoreline for the representative wave setting SE is mostly westward along shoreline. The other computed flow field for the representative wave setting S shows complicated flow direction of the wave-induced currents to bathymetric change for the two representative waves may not be simply opposite. The computed wave-induced current speeds at several measurement points in both Zones A and B also agree reasonably well with measurements with a bit large magnitude, see Table 2. The magnitudes of the computed wave-induced current speeds are similar to the measured current speeds at the field, which was generated by not only the wave-induced forces, but also tide-induced forces. Thus, we need to examine the magnitude of tidal current component. The computed water level contours at the same time is shown in Figure 7. The computed set-up level is high along shoreline where waves break.

Table 2: Measured field current at Haeundae at 15:00, 4 June 2008

Zone	A	B
Average measured speed	15	17
Average computed speed	30	25

The model system is applied to the same conditions as the above application except the wave direction of S for examination of a different wave direction. The computed wave field, wave-induced driving force field, wave-induced current field, and wave-induced set-up contours are shown in Figure 7. Differently from the previous case, rip currents of maximum 50 cm/s develop for S waves at a location in front of the Busan Aquarium situated on the western part of the beach. The computed rip current proceeds by several hundred meters until it encounters the model land boundary. Appearance of rip current for different wave direction may demonstrate that the wave-induced current field is sensitive to the wave direction. The present study results could also be used an input for prediction of morphological change at Haeundae Beach.

4 CONCLUSIONS

Existing current data along the west part of Haeundae Beach in Lagrangian way using drogues was simulated by using a numerical modelling system. Time-series wave data are represented by two representative waves setting which could reproduce similar bathymetric change at Haeundae beach. Numerical modelling provided the wave, the wave-induced current field, and bathymetric change for two wave settings, and final bathymetric change.

The littoral drift at Haeundae may also be westward for incident waves of SE direction following the wave-induced current direction. The balance of the shoreline shape could be simulated by using the present wave and flow model results. The present model system could be applied to other similar geographies and physical environments for simulation of wave-induced current fields.

5 ACKNOWLEDGEMENTS

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