A Prediction of Cohesive Sediment Transport in Young-Kwang Area

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1. INTRODUCTION

There are a multitude of problems related to the transport of cohesive sediments and the absorbed pollutants along the west and south coast of Korea, which is abundant in fine-grained cohesive sediments. Harbours and navigation channels in such area are affected by the severe accumulation of mud which makes expensive dredging operations and if heavily polluted requires disposal expenses of dredged material. In this situation, many large-scale coastal development projects are also planned along the west coast of Korea. Therefore, a sediment transport model is urgently required to handle such complicated coastal issues.

Various types of cohesive sediment transport models have been developed since early eighties (Sheng, 1983; Hayter and Mehta, 1986; Odd, 1988; Le Hir, 1994; Hamm et al., 1996). In order to develop the predictive methods for the cohesive sedements for extended period of time, the environmental conditions should be properly modeled and interfaced with sediment transport model and numerous empirical parameters of the model need to be tested and calibrated with available information.

The west coast of Korea is characterized by macro-tides resulting in wide tidal flats and strong tidal currents combined with severe waves and storm surges during the winter monsoon and frequent passage of typhoons. These high-energy coastal environments provide complexities and difficulties in predicting the cohesive sediment transport using numerical models.

The coastal flow and wave conditions are produced at each time step and grid point of the sediment transport model by means of systematic interfacing of hydrodynamic and wave models. In shallow water, the interactions between tides, storm surges and waves and local effects of wind forcing need to be considered for the accurate calculation of sediment transport especially during the extreme sea states. In order to generate coastal environmental conditions, the basic information has been prepared for all the coastal waters of Korea. The depth grid system are ready for the coastal waters of Korea and for the area of interest nested by interpolating the depth data retrieved from the data base comprizing of 90 electronic charts.

The flow velocity and water level due to tide and storm induced combined-flow are determined by solving the depth-integrated equation of mass and motion. The hydrodynamic equations are solved by a fractional step method in conjunction with the approximate factorization techniques leading to the implicit finite difference scheme, NESWAM(NEsted Shallow WAter Model). The system was tested for the Young-Kwang area, south-western coastal waters of Korea. The site location and bathymetry of the study area is shown in Fig.1. Water level and velocity fields simulated by combined effects of M_2, S_2, O_1 and K_1 at 18/12/1991 03:00 are also presented in Fig. 2. Along the open boundary of this fine grid(grid resolution of 500 m), tide- and surge-combined water levels and currents were obtained by the area weighting interpolation.

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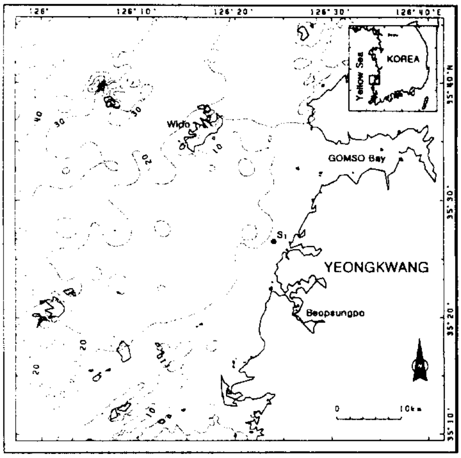

Figure 1. Site location and bathymetry of the study area.

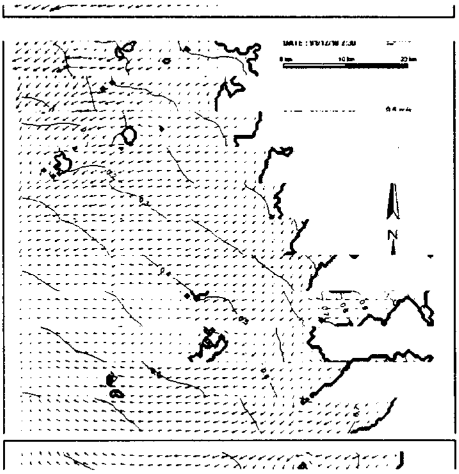

Figure 2. Water level and velocity fields at 18/12/1991 03:00.

High waves of 3-6 meters occur during the winter monsoon and passage of typhoon in summer. The wind-wave prediction is carried out using SWAN shallow water wave model based on the wave energy conservation equation. Fig. 3 shows the temporal variation of significant wave height and wave period predicted at location S1 in Fig. 1.

In a simple simulation of shallow water waves(Lee et al., 1997), the coastal wave conditions have been pre-calculated for about 100 cases of combinations of offshore boundary conditions(wave directions, periods and heights) using transformation conversion coefficients from offshore boundary wave condition to those at each grid point are calculated. The coefficients for a sample case are shown in Fig. 4, in which it is shown that the offshore waves are reduced to about half in wave heights at location S1. For a given offshore wave condition, the shallow water wave condition at each grid point of the sediment transport model is produced by means of interpolation of these conversion coefficients.

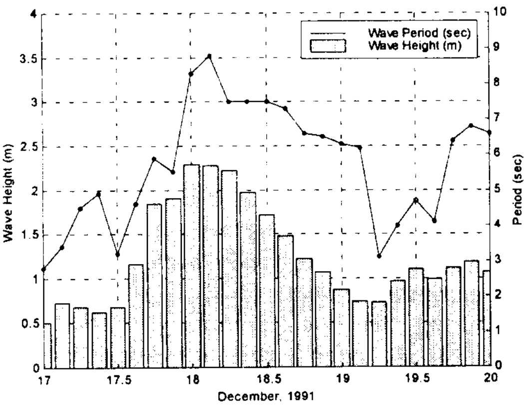

Figure 3. Temporal variations of wave height and period predicted by SWAN shallow water wave model.

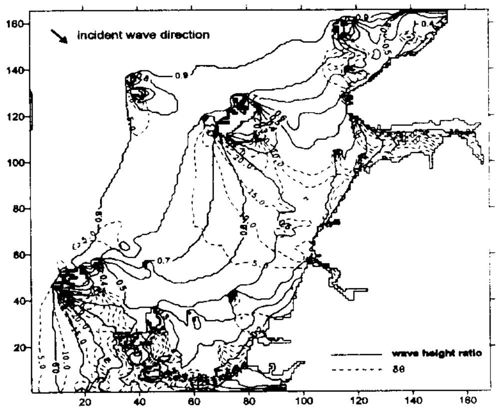

Figure 4. Example of shallow water wave conversion coefficients retrieved from data base for Yeongkwang area.

2. TWO DIMENSIONAL MODELLING OF COHESIVE SEDIMENT TRANSPORT

Suspended-load transport is described by an advection-diffusion equation for the sediment concentration. Two-dimensional horizontal models are derived by basic depth-integration under the assumption of vertical similarity in the advection terms:

$$\begin{aligned}&\frac{\partial}{\partial t}(dC)+u\frac{\partial}{\partial x}(dC)+v\frac{\partial}{\partial y}(dC)=\\&\frac{\partial}{\partial x}\left(dD_{xx}\frac{\partial C}{\partial x}+dD_{xy}\frac{\partial C}{\partial y}\right)+\\&\frac{\partial}{\partial y}\left(dD_{yx}\frac{\partial C}{\partial x}+dD_{yy}\frac{\partial C}{\partial y}\right)+S_T\end{aligned}\qquad(1)$$

where, C is the mass of sediment per unit volume of water and sediment mixture, D_{ij} is the effective sediment dispersion tensor, S_T is the source/sink term, and d is the flow depth. The source/sink term can be expressed as

$$S_T = Q_e + Q_d \qquad (2)$$

where Q_e is the rate of sediment addition due to erosion from the bed, Q_d is the rate of sediment removal due to deposition. To solve Equation (1), the source and sink in Equation (2), Q_e and Q_d, must be properly estimated and flow velocity components u, v determined from a circulation model.

The model domain geometry consists of a fluid domain and a sediment bed domain separated into several layers according to the shear strength profile. The calculation of the bottom shear stress is accomplished for the wave and current combined condition, from which deposition and erosion rates are calculated for the pre-assigned bottom bed profile as described in Hayter and Mehta(1986).

The rate of mud erosion depends on bed properties and bed shear stress, and simple functional relationships have been derived using such variables (Partheniades, 1965). Once all bottom shear stress values are calculated, the re-suspension rate is determined through an empirical formula as a function of the bed shear stress due to combined wave- and current-induced motions and the shear strength of the top bed layer. The erosion threshold shear stress beyond which erosion begins is estimated by empirical relations given as a function of bed density (Migniot, 1968). Bed dry density and shear strength profiles are specified initially for each grid point. For newly deposited materials, the erosion properties of bed change with time due to consolidation. For more detailed description of this routine see Hayter and Mehta (1986). Several studies proposed formula for the deposition rate (Krone, 1962: Mehta and Partheiades, 1975). The settling velocity needs to be estimated through available parameters such as bed shear stress, suspended concentration, salinity, and shear stress (Dyer, 1989; Le Hir et al. 1993).

The advection-dispersion equation for suspended sediment transport is solved using split-operator approach, which is based on the recognition that the physical phenomena of pollutant transport are represented by superimposing two individual operations, advection and diffusion. Therefore, equation can be decoupled into the two elementary operations and solved separately and alternately for each minor increment.

This hybrid method employed here is useful for flow-dominated transport problems. This method takes the switching approach between advection and diffusion processes, keeping the concentration particles continuously moving forward rather than a single-reverse particle tracking(Lee, 1998). In this procedure, an assumption is involved that the variation of concentration within a grid cell is negligible in estimation diffusive effect as similar as the basic concept of finite discrete schemes. However, the results are quite satisfactory since the assumption is adopted in the diffusive process, which works the values for smoothing.

3. SIMULATION TEST OF ESTABLISHED SYSTEM

The system was tested for the Young-Kwang area, south-western coastal waters of Korea as shown in Fig. 4. The bottom surface sediment distribution is shown in Fig. 5. The suspended sediment concentration was measured at 1.6 m from sea bottom using bottom mounted water quality sensors at location S1 in Fig. 4(Lee et al., 1992).

The concentration varied slowly around 200-300 mg/l with the tidal current when the sea state was mild. However, the concentrations increased considerably with the advent of high waves, and reached high concentration of more than 3000 mg/l. The results of simulation test are also shown in Fig. 6. The bottom shear stress due to the combined action of tide and wave was estimated by using formula given by Tanaka and Shuto(1981). It was shown that the system provided a useful tool in the study of cohesive sediment transport modeling for engineering application in the wave-tide combined zone like the Yellow Sea. The comparison indicates that the simulation system of the sediment transport provides satisfactory results even for storm event where effects of wave and tide are combined.

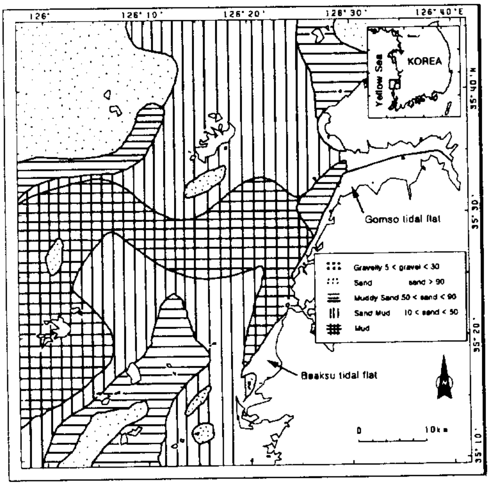

Figure 5. Bottom surface sediment distribution of the study area.

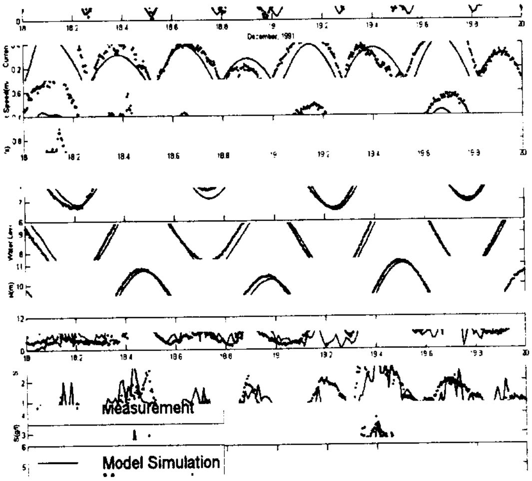

Figure 6. Comparison between simulation results and measurements of concentration, water level and current speed(dotted line: measurement, solid line: model simulation).

4. DISCUSSION AND CONCLUSION

Modelling of the cohesive sediment transport has been established by integrating various components of coastal models with intensive data base, which requires least effort in calibration and long-term simulation of the cohesive sediment transport. The system would be served as an efficient tool for the studies of sediment transport modeling for engineering applications in the future. When using a nested finer resolution, the velocity field was better represented.

The simulation test of the system provided overall trend of suspended sediment concentration when compared with the measurement. Further intensive work is necessary to make the developed simulation system applicable for engineering application. The lack of information on the deposition and erosion processes due to wave-current combined action need to be improved by field and laboratory experiment and simulation test. The problem in handling three dimensional processes with 2-D is considered as a cause of the discrepancy, which should be improved by expanding the system to cover 3-D features of sedimentation processes, especially to include transport of fluid mud near the bottom.

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