Open boundary conditions for forced wind waves in a coupled model of tide, surge and wave

S.Y. Kim*, Y. Matsumi *, T. Yasuda **, and H. Mase **
* Dept of Social Management, Tottori University, 4-101 Koyama-Minami, Tottori 680-8552, Japan.
sooyoul.kim@sse.tottori-u.ac.jp, +81-857-31-5311, ** Disaster Prevention Research Inst., Kyoto University, Gokasho, Uji, Kyoto, Japan.

1. Introduction

- To model a wind-driven long wave combined with tides, wind waves and surges under storm events in limited computational areas, variables at open boundaries are the tidal current, the tidal water level, the wind and pressure-induced water level and current.
- These can be obtained from the extrapolation or the interpolation from large-scale models or observations. At the open boundary, the tide-induced water level and current are usually estimated by the astronomical tidal components.
- The combined wind and pressure-induced water level at the open boundary has been computed by barotropic law.
- However, the combined wind and pressure-induced current is ignored in most cases of modeling the wind- driven long wave combined with the tide, the wind wave and the surge.
- In the study, the method is proposed to estimate the combined wind and pressure-induced current at the open boundary and is described for the performance in the simple case and the real case in comparison with the Orlanski scheme modified by Miller and Thorpe (OSMT) and the passive form of the Flather's condition (FLA).

3. SIMPLE TEST

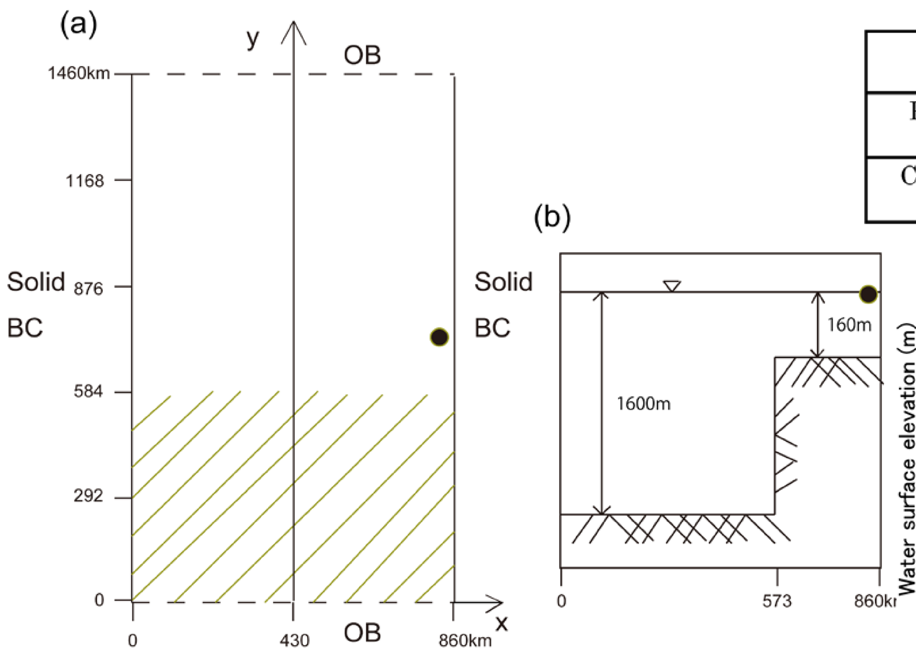

Fig. 1. (a) Sketch of channel and wind field with oblique line (●: the observed station) and (b) cross section.

Table. 1 Test case

	Wind Types	Open Channel	Closed Channel
PIC	Partially and impulsively (10h)	X	O
CWO	Constant (30d) on the whole basin	O	X

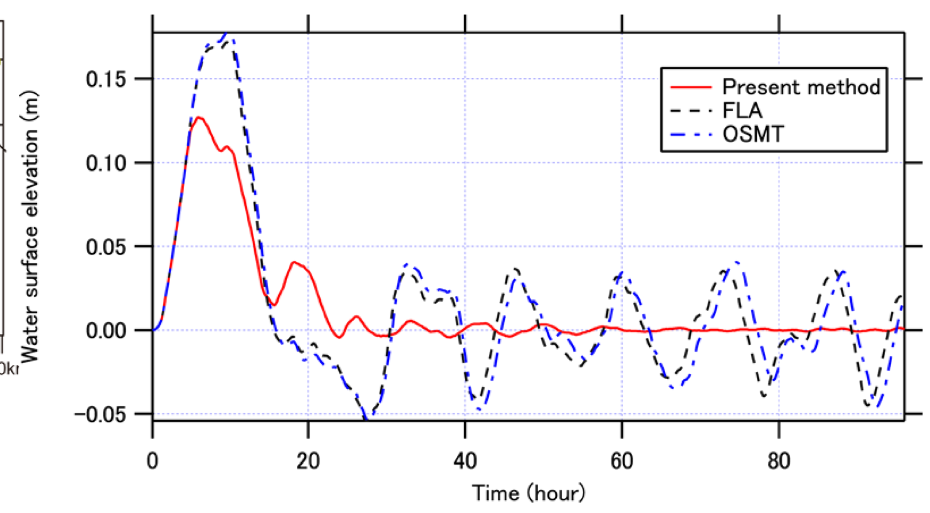

Fig. 2. Comparisons of calculated water levels for different OBCs at the grid point B in the case of PIC.

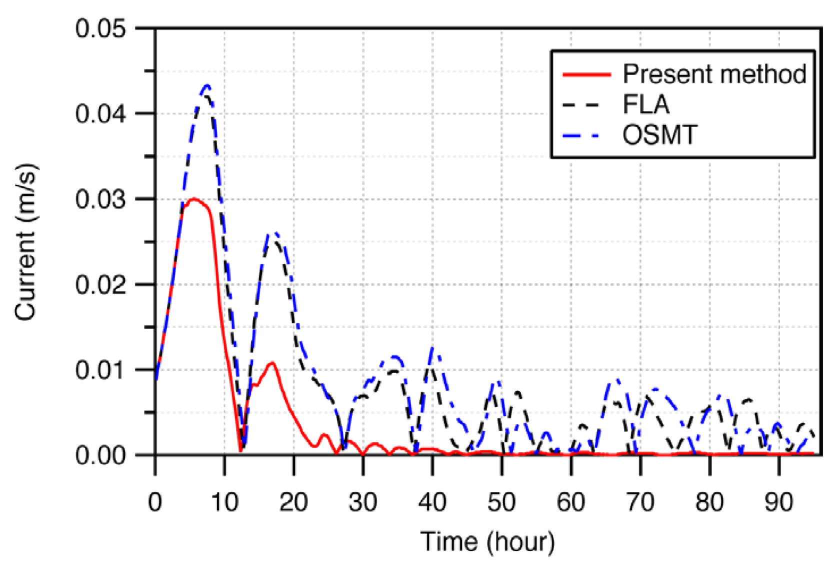

Fig. 3. Comparisons of calculated currents for different OBCs at the grid point B in the case of PIC.

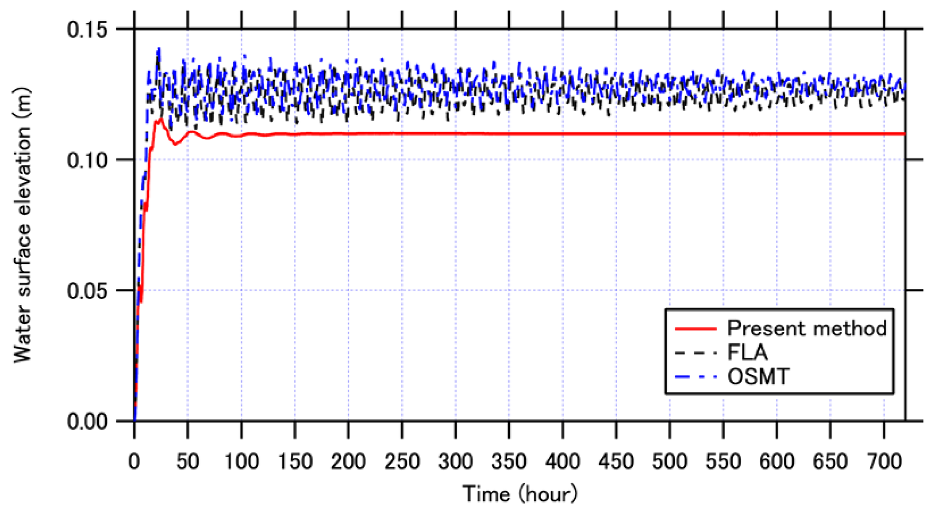

Fig. 4. Comparisons of calculated sea surface level for different OBCs at the grid point B in the case of CWO.

3. REALISTIC TEST

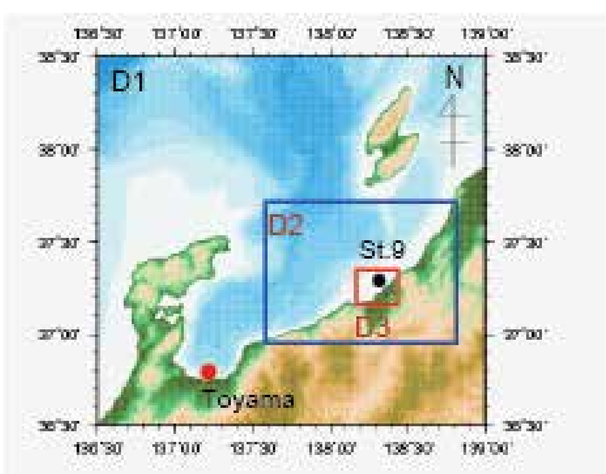

Fig. 5. Geophysical regions of 3 level grid domain for the realistic case (●: the observed station, Toyama).

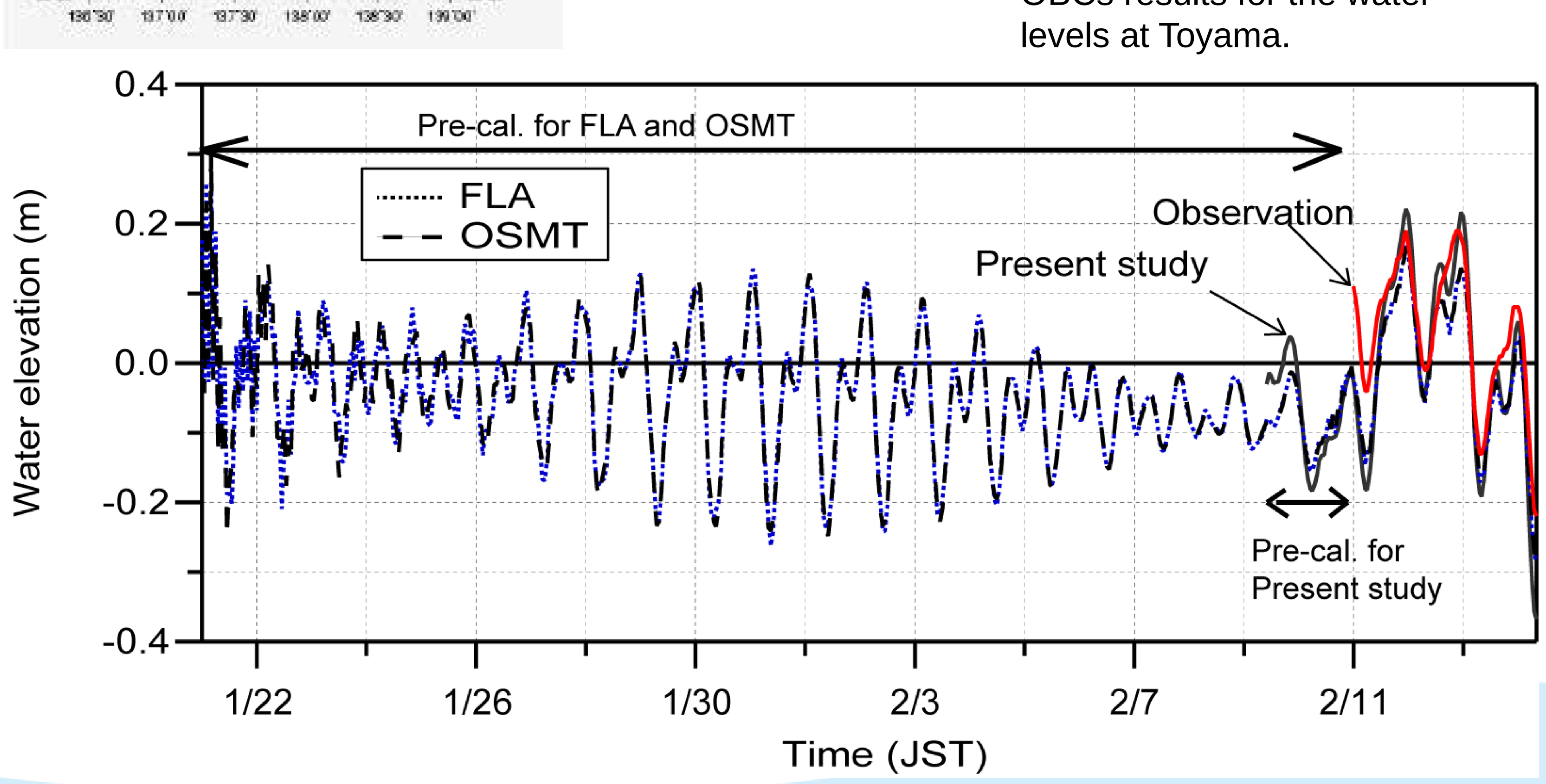

Fig. 6. Comparisons between observations and different OBCs results for the water levels at Toyama.

2. OPEN BOUNDARY CONDTIONS

Variable *C*

- The Orlanski expressions modified by Miller and Thorpe (1981) are given by (referred to as OSMT).

(1) $$\eta_n^{t+1} = r\eta_{n\pm1}^{t} + (1-r)\eta_n^{pres}$$

(2) $$r = \begin{cases} 1 & if \quad C \ge 1 \\ C & if \quad 0 < C < 1 \\ 0 & if \quad C \le 0 \end{cases}$$

(3) $$C = \frac{\eta_{n\pm1}^{t} - \eta_{n\pm1}^{t-1}}{\eta_{n\pm2}^{t-1} - \eta_{n\pm1}^{t-1}}$$

(4) $$\eta_n^{pres} = -(P_0 - \tau_s / D)/\rho g$$

η : the sea surface level,
t : the time step,
n : the grid number at the boundary,
η_n^{pres} : the prescribed sea surface level.

The phase speed C is estimated by Eq. (3) with the variables in the interior grids.

The prescribed sea surface level, η_n^{pres} in Eq. (1) is given by Eq. (4)

Fixed *C*

- The blended radiation condition of one dimensional Sommerfeld`s Eq. suggested by Flather (1976).

(5) $$U_n^{t+1} = U_n^{pres} \pm \sqrt{gh}\left(\eta \pm \eta_n^{pres}\right)$$

U_n^{pres} : the prescribed normal current,
η_n^{pres} : the sea surface level calculated by Eq. (4),
η : the sea surface level on the nearest grid within the domain.

- The Flather's Method (referred to as FLA)
Originally suggested by Flather (1976) to calculate U_n^{pres} in Eq. (5) using the interior solutions. In the initial stage, t = 0 sets to $U_n^{pres} = 0$. As $t = t + 1$, $U_n^{pres} = U_n^{t-1}$. This iteration method continues during the storm surge calculation.

- The present Method (referred to as Present Method)

Two modes:

- First: generation of sea surface levels due to winds and pressure

(6) $$gD\frac{\partial \eta}{\partial x} = -\frac{d}{\rho}\frac{\partial P}{\partial x} + \frac{1}{\rho}\tau_s^x$$

P : the atmospheric pressure on the sea surface.

After integrating Eq. (3) and ignoring the initial values and the integration coefficient, so the sea surface level on the first mode is given by the same form with Eq. (4).

- Second: generation of currents winds and pressures

(7) $$\frac{\partial U}{\partial t} + gD\frac{\partial \eta_n^t}{\partial x} = 0$$

Through the similar procedures with obtaining Eq. (4), the following equation is obtained

(8) $$U_n^t = -gD\eta_n^t / \sqrt{gh}$$

U_n^t is the normal current and substituted with U_n^{pres} on the right-hand side of Eq. (5). The two-dimensional normal current in the *y* direction may be estimated with the same procedure.

6. RESULTS AND DISCUSSIONS

- A long wave was generated by forcing a wind of 14 m/s impulsively for 10 hours along the y direction over the lower portion in the closed basin.
- In the open basin, the constant wind of 14 m/s was forced for 30 days over the whole resion.
- While the oscillations with the range of ± 5 cm keeps on appearing in sea surface levels (SSLs) after forcing the wind from the results of OSMT and FLA conditions in the closed basin, the SSL becomes stable after 20 hours from those of the present method. The calculated current shows the same tendency with those of the SSL. From the results of the constant wind forcing, the similar trends are examined.
- For the real case, the numerical simulations were conducted from 10:00 10th ~ 08:00 14th in Feb. 1999 Japanese Standard Time (JST) at the Toyama coast in Japan with three open boundary conditions. It can be seen from Fig. 6 that the present method acquires the stable SSL after even 1 day for the spin-up, while the OSMT and FLA conditions need at least 6 days for the spin-up calculations to be stable in SLL at Toyama.
- From the results in the simple and real cases, it was found that the present method for the open boundary condition results in the more stable sea level and current. In addition, it showed that the duration of the spin-up calculation in implementing the present method is dramatically reduced compared to those in applying the OSMT and FLA conditions.