

Effects of a current on waves sheltered lee side of a vertical-wall breakwater
 (直立式防波堤背後の遮蔽域における波に対する流れの影響)

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1. Introduction

Study on a breakwater is a very important topic in coastal engineering. But most of the previous studies are related to the effective breakwater design to reduce wave activities behind it. There are a very few studies available for investigations into a current effect on waves that propagated into the lee side of a breakwater. This study is limited to the current effects on wave characteristics behind a vertical-wall breakwater. For numerical simulations, a two-dimensional numerical model based on Madsen type extended Boussinesq equations is used to find current effects on sheltered waves. During the simulations, a steady current field is defined either partially or in a very limited area (jet current) of the domain. For simplicity, it is assumed that jet current is confined within a constant width and is uniform along the depth.

2. Governing equations and numerical computations

The governing equations (Madsen and Sørensen, 1992) for the numerical model are as follows:

$$S_t + P_x + Q_y = 0 ; \quad P = \int_{-h}^{\xi} u dz, \quad Q = \int_{-h}^{\xi} v dz \tag{1}$$

$$P_t + (P^2/d)_x + (PQ/d)_y + gdS_x - h^2(B + 1/3)(P_{xx} + Q_{yy}) - Bgh^3(S_{xxx} + S_{yyy}) - hh_x(P_x/3 + Q_x/6 + 2BghS_{xx} + BghS_{yy}) - hh_y(Q_x/6 + BghS_{yy}) = 0 \tag{2}$$

$$Q_t + (PQ/d)_x + (Q^2/d)_y + gdS_y - h^2(B + 1/3)(Q_{xx} + P_{yy}) - Bgh^3(S_{xxx} + S_{yyy}) - hh_x(P_x/6 + BghS_{yy}) - hh_y(Q_y/3 + P_x/6 + BghS_{xx} + 2BghS_{yy}) = 0 \tag{3}$$

In Eqs. (1) to (3) u and v are water particle velocities in x - and y -direction respectively, d is the total water depth, h is the water depth, S is the surface fluctuation, g is the acceleration due to gravity, P and Q are depth-integrated velocity components in x - and y -direction respectively, and $B (=1/15)$ is a curve fitting parameter.

For the application of the above equations in a wave-current coexistence field the following wave-current dispersion relation is considered (Mohiuddin *et al.* 2000):

$$-\omega^3 \{1 + k^2 h^2 (B + 1/3)\} + \omega^2 U k \{1 - k^2 h^2 (B + 1/3)\} + \omega k^2 \{U^2 + gh(1 + Bk^2 h^2)\} - U k^3 \{U^2 - gh(1 + Bk^2 h^2)\} = 0 \tag{4}$$

In Eq. (4) ω is the absolute wave angular frequency, k is the wave number, and U is a current velocity component in the wave propagation direction (equivalent uniform current).

Governing equations are solved by a semi-implicit finite difference method. The solution to the above Eq. (4) gives the wave number k in the wave propagation direction.

3. Simulation conditions and computational parameters

Layout of the computational fields is shown in Fig. 1. As shown in Fig. 1(a) parallel to the x -axis a partial current field is defined from the tip of the breakwater and in Fig 1(b) a jet current field is defined with in a very confined area of the domain for a fixed distance, J_d , from the breakwater tip. The still water depth in the domain is 0.6m and the length of the infinitely thin breakwater is 8.5m. The size of the computational domain is 26m×26m. For a 3s incident wave period H/h (wave height/water depth) ratio is equal to 0.33. In this paper, comparative results of 5 cases are presented. Case 1 is defined when there is no current field in the domain and case 2 is for an adverse current field as Fig. 1(a) with a current magnitude of $U=-0.25$ m/s. Case 3 is a jet current field (adverse current, $U=-$

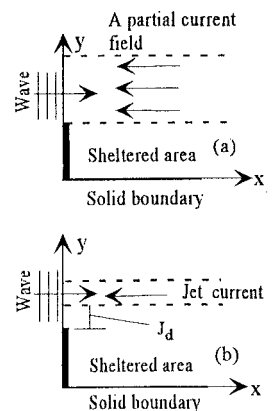


Fig. 1: Layout of computational fields.

0.25m/s) close to the tip of the structure ($J_d=0$) and case 4 is also a jet current field (adverse current, $U=-0.25$ m/s) but the distance of the jet current field, J_d , is equal to 3m from the tip of the vertical-wall breakwater (Fig. 1b). Case 5 is similar to the case 4 but the current direction and the wave direction are similar to each other (following current, $U=0.25$ m/s).

4. Results and discussions

Figure 2 (case 1) shows computed wave height contours for perpendicular wave propagation into the domain. Sheltered wave heights greatly reduce due to the breakwater.

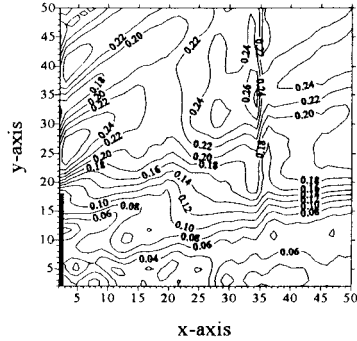


Fig. 3: Computed wave height (case 2).

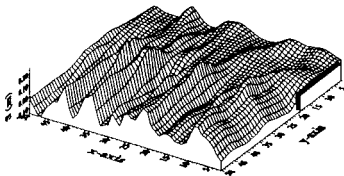


Fig. 5: A perspective view of developed wave field at $t=37.5$ s (case 4).

(case 5) the maximum wave height is greater than that of without a current field but in comparing with wave propagation on an adverse jet current field magnitude of the maximum wave height is smaller (0.12m) for case 5. Fig. 5 shows a wave field at $t=37.5$ s for the case study 4. Fig. 6 explains that a jet current field ($U=-0.25$ m/s) whether close to the tip of the breakwater or not produces similar effects at section $y=10$ irrespective of its location.

5. Concluding remarks

Numerical study has been carried out to find effects of a current field on waves sheltered lee side of a vertical-wall breakwater. Study shows that existence of a current field, especially jet current, produces large impact on sheltered waves. Experimental investigations need to be carried out for the verification of the model results. Further investigations will be required to find out relation between the distance of a jet current field from the tip of the breakwater and the wave heights in the sheltered region of the breakwater.

References

Madsen, P. A. and O. R. Sørensen (1992): A New Form of the Boussinesq Equations with Improved Linear Dispersion Characteristics. Part 2. A Slowly-Varying Bathymetry, *Coastal Engineering*, Vol. 18, pp. 183-204.
 Mohiuddin, M., H. Togashi and Y. Hirayama (2000): Modeling Effects of Currents on Wave Deformation, *Proceedings of Coastal Engineering*, JSCE, Vol. 47, pp. 16-20 (in Japanese).

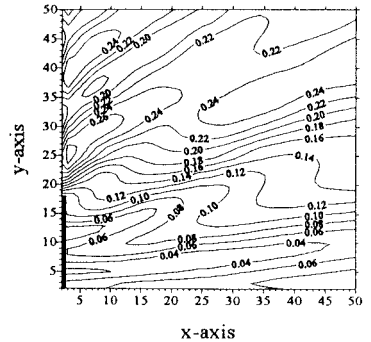


Fig. 2: Computed wave height (case 1).

The maximum wave height along a section $y=10$ is equal to 0.08m (Fig. 6). For the similar wave propagation on an adverse current field (case 2, $U=-0.25$ m/s) computed wave height contours are presented in Fig. 3. At several locations of a section $y=10$ (Fig. 6) computed wave height exceeds the wave height without a current field (case 1). Comparing Fig. 2 and Fig. 3 it is also understood that a current field modifies wave height distribution patterns in the whole domain. Wave propagation in presence of a jet current (case 3) is simulated and computed wave height contours are presented in Fig. 4. Comparing Fig. 4 with Fig. 2 it is found that wave height in the sheltered region has sharply increased. For case 3 and case 4 computed wave heights along a section $y=10$ (Fig. 6) show two times larger wave heights (0.17m) than the case 1 (no current field). Although in presence of a following current

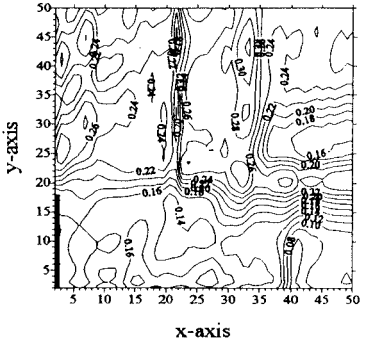


Fig. 4: Computed wave height (case 3).

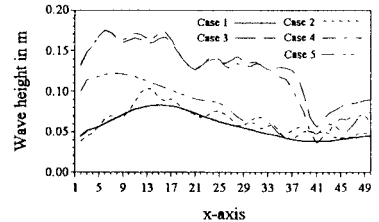


Fig. 6: Comparative wave heights along a section $y=10$.