A Prediction Model of Wind and Infragravity Waves Generated in Surf and Swash Zones

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1. Introduction

In a storm, a beach erodes rapidly within one or two days due to the sand transport from the beach to the offshore. Formerly, wind waves had been considered to be the main external forces of beach erosion in a storm. The larger waves in a storm break further offshore making the surf zone wider but leaving the wave height in the inner surf zone same. Therefore, it is basically difficult to attribute the abrupt beach erosion in a storm to the wind waves. In contrast to the wind waves, the infragravity waves of about 30 seconds to several minutes in a period will develop during a storm and do not break in the surf zone, being the largest at the shoreline. The results of field data also show that beach erodes in a storm due to not only the wind waves but also the infragravity waves (Katoh, 1990). Therefore, an integrated prediction model of wind waves and long period waves is needed for studying of the mechanism of beach profile change and take into account the infragravity waves as one of the important external forces. The existence of wave groups also gives rise to second order waves with periods corresponding to the period of the groups. Due to their long periods they are termed infragravity waves. When the short waves come into the surf zone and loose their height and energy due to the wave-breaking, they can no longer balance the bound long waves that have been following them, and the long waves are then released from the short waves.

In the present study, a numerical integrated prediction model has been developed for studying of wind waves and long period waves hydrodynamics in surf and swash zones.

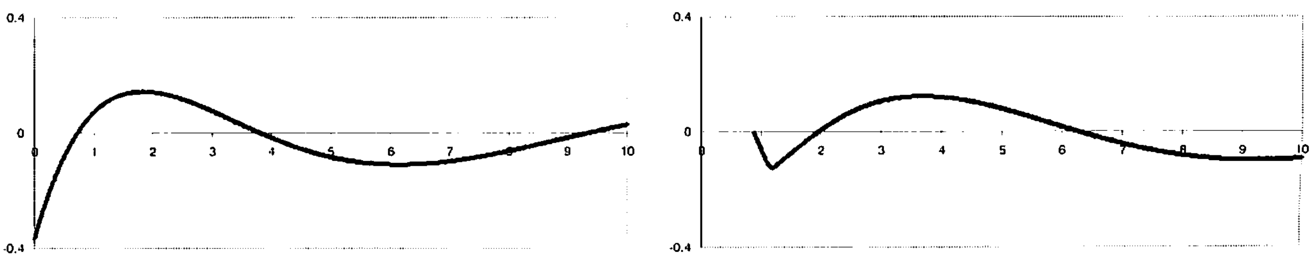
2. Infragravity waves generation by a time-varying breakpoint

A number of mechanisms for the generation of infragravity waves have been proposed (Longuet-Higgins and Stewart, 1962, 1964; Gallagher, 1971; Symonds et al., 1982, List, 1992; Schaffer, 1993), which may generate either leaky waves or edge waves. However, the mixture of wave modes on natural beaches complicates the comparison of field data with theoretical models for infragravity waves generation. Symonds et al. (1982) subsequently proposed a mechanism for the generation of infragravity waves which was directly due to the variability of wave breaking point positions. This model proposes that a time-varying breakpoint position (due to incident wave groupiness) radiates long waves at the group frequency both shorewards and seawards. The two-dimensional model adopted here provides a mechanism whereby energy is transferred to low frequency waves in the near-shore.

In the present study, Symonds' model with concerning of depth-integrated, linearized shallow water equations has been adopted for generation of infragravity waves (Eq. 1) where the primes denote dimensional variables, x' is the distance positive offshore with origin at the shoreline, U' is the depth integrated velocity in the x' direction, ζ' is the sea surface elevation, h' the water depth, ρ the density, g the gravitational acceleration and S_{xx} is the radiation stress term.(Fig. 1,2)

$$\frac{\partial U'}{\partial t'} + g\frac{\partial \zeta'}{\partial x'} = -\frac{1}{\rho h'}\frac{\partial S_{xx}}{\partial x'}$$
$$\frac{\partial \zeta'}{\partial t'} + \frac{\partial (h'U')}{\partial x'} = 0 \qquad (1)$$

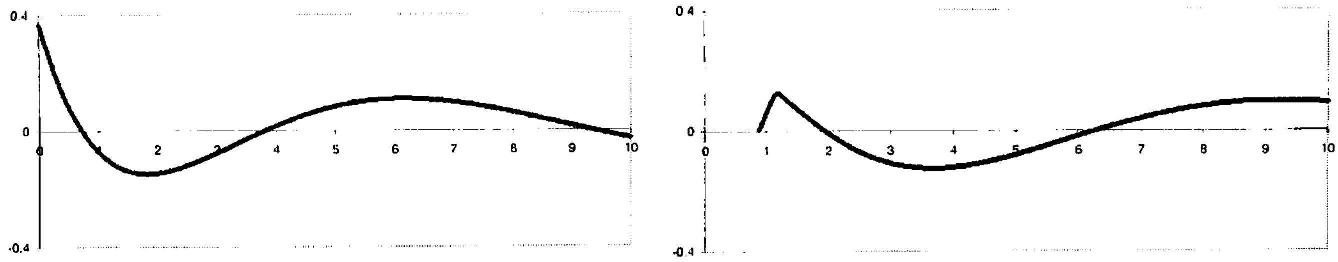
The field data of an entirely natural sandy beach (Hazaki-Japan) has been considered for studying of the ability of this integrated prediction model. The uniform slope, $\tan\beta = 1/140$, and significant wind waves height ($H_{1/3}$) and wave period ($T_{1/3}$), 3.7m and 8.5 sec. respectively have been considered for the representative wave condition in Hazaki beach in this study.



(1) (2)

Fig. 1- Variations of water surface elevation at (1): $t = \pi/2$, *(2):* $t = \pi$, $\chi = 2$ ($\chi = \sigma^2 X / g \tan\beta$) *and* $\Delta a = 0.2$

-The ordinate is non-dimensional surface elevation, $\zeta = \zeta / (\frac{3}{2}\gamma^2 X \tan\beta)$ *and the abscissa is on-offshore distance,* $x = X'/X$



(3) (4)

Fig. 2- Variations of water surface elevation
At (3): $t = 3\pi/2$ *, (4):* $t = 2\pi$, $\chi = 2$ *and* $\Delta a = 0.2$

3. Grouped wind waves modeling

The surf and swash hydrodynamics under grouped wind waves has been analyzed using time-dependent mild slope equations with concerning grouped wave propagation by two component sinusoid waves (Fig. 3) and energy dissipation terms due to wave breaking in the surf zone (Eq. 2). The staggered leap-frog finite difference scheme was adopted for the numerical analysis.

$$\frac{\partial Q'_x}{\partial t} + c^2 \frac{\partial \zeta}{\partial x} + f_D Q'_x = 0 \qquad (2)$$
$$\frac{\partial \zeta}{\partial t} + \frac{1}{n}\frac{\partial}{\partial x}(nQ'_x) = 0$$

in which, the dissipation coefficient after breaking, f_d, has been evaluated according to the Dibajnia and Watanabe (1987) formula; $f_D = \alpha_D \tan\beta \sqrt{\frac{g}{d}} \sqrt{\frac{\hat{Q} - Q_r}{Q_s - Q_r}}$, where α_D is a coefficient which becomes 2.5 in the surf zone and $\hat{Q}$ is the amplitude of the flow rate, Q_s and Q_r are given by the following equations;

$$Q_s = \gamma_s cd \quad , Q_r = \gamma_r cd \qquad (3)$$
$$\gamma_s = 0.4(0.57 + 5.3\tan\beta) \quad , \gamma_r = 0.4(\frac{a}{d})_b$$

where, $(\frac{a}{d})_b$ is a ratio of wave amplitude to water depth at the breaking point.

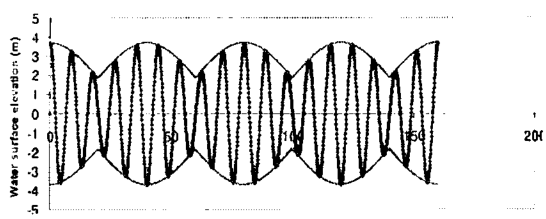


Fig. 3- Grouped wave maker at offshore boundary (x=0)

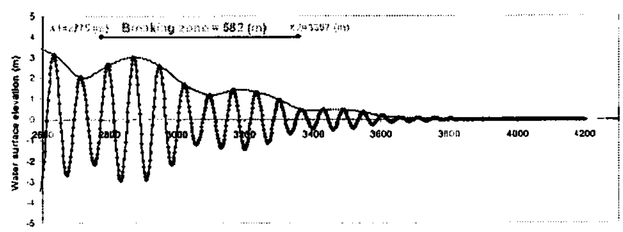


Fig.4- Grouped wave deformation in surf and swash zones

3. Results

The results show that the amplitude of outgoing progressive infragravity waves at the maximum position of the breakpoint ($x=x_2$). The value is going to be maximum and minimum at about χ =1.2 and χ =3.7 respectively (Fig. 5).

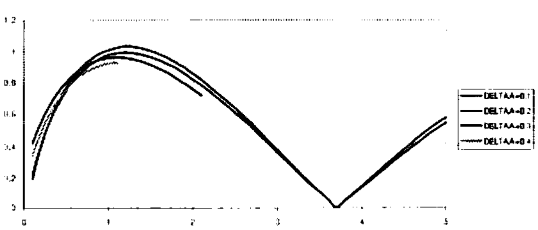


Fig. 5- Amplitude at $x=x_2$*, normalized by* $\Delta\zeta$*, as a function of* $\chi = \sigma^2 X / g \tan\beta$ *at the group frequency*

References

[1] Symonds G., D. A. Huntley and A. J. Bowen, "Two-Dimensional Surf Beat: Long wave generation by a time-varying breakpoint". Journal of Geophysical Research, Vol. 87, p. 492-498, Jan. 20, 1982.

[2] Katoh K. and S. I. Yanagishima, "Berm erosion due to long period waves". Coastal Engineering, 1990