A Prediction Model of Sediment Transport Induced by Wind Waves and Their Associated Long Waves in Surf and Swash Zones

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1. Introduction

In a train of irregular wind waves, the high and low waves usually appear in groups. The existence of the wave groupings will induce secondary waves with a period corresponding to that of the groupings. During a storm of one or two days, beach erosion occurs rapidly with sand transport from the foreshore beach to the offshore. Formerly, wind waves were considered to be the main external force of beach erosion. Although the larger waves break further offshore making the surf zone wider, the wave heights in the inner surf zone remain the same as those during non-storm conditions because the wave heights after breaking are limited by the water depth. Therefore, it is difficult to attribute the abrupt beach erosion solely to the wind waves. In contrast, infragravity waves do not break in the surf zone and reach their maximum height at the shoreline. Katoh and Yanagishima [1990], based on their field measurements, reported that the infragravity waves induced by grouped wind waves play a significant role on the beach erosion.

As a first step, the present study investigates the coupling field of "grouped wind waves and infragravity waves" via integrating the surf and swash zones. Based on the calculated wave fields, the contributions of the wind waves and infragravity waves to the sediment mobility are discussed. The incident wave groups propagating over a plane slope are analyzed based on time-dependent mild slope equations including the after-breaking dissipation term. The long wave generation is analyzed according to Symonds' model based on linearized shallow water equations (LSWE). The forcing term is expressed in terms of the short wave radiation stress. To extend the prediction for landward swash motions, nonlinear depth-integrated shallow water equations (NSWE) are calculated based on Kobayashi et al. model [1987] with slight modification. Analyses are then made to show the sensitivity of sediment transport to input wave parameters. Finally, contributions of the infragravity waves to the sediment mobility in the surf and swash zone are discussed.

2. Wave groups

The surf and swash zone hydrodynamics of the wave groups are analyzed using the time-dependent mild slope equations proposed by Nishimura et al. [1983] (Eqs. 1, 2) in which, η is the water surface fluctuation of wind waves, c is the wave celerity, Q_x is the flow rate in the x direction, n is the ratio of the group velocity to the phase velocity. The dissipation coefficient after breaking, f_d, is added to Eq. (1) to include the after breaking attenuation.

$$\frac{\partial Q_x}{\partial t} + c^2 \frac{\partial \eta}{\partial x} + f_D Q_x = 0 \qquad (1)$$

$$\frac{\partial \eta}{\partial t} + \frac{1}{n}\frac{\partial}{\partial x}(nQ_x) = 0 \qquad (2)$$

3. Infragravity waves generation by a time-varying breakpoint

The generation model of infragravity waves proposed by Symonds et al. [1982] describes that the variation of the breaking points of grouped wind waves acts like a wave generator radiating low frequency waves in both seaward and shoreward directions. Depth-integrated, linearized shallow water equations (Eqs. 3, 4), are used to express the infragravity wave motion, in which, ζ is the water surface fluctuation of the infragravity waves, U is the depth averaged velocity in the x-direction, S_{xx} is the radiation stress term. The shoreward propagating waves will be totally reflected at the shoreline, which results in a standing wave pattern. After reflection at the shoreline, this wave will propagate seaward and superimpose itself on the directly seaward radiated wave depending on the relative phase.

$$\frac{\partial \zeta}{\partial t} + \frac{\partial (dU)}{\partial x} = 0 \qquad (3)$$

$$\frac{\partial U}{\partial t} + g\frac{\partial \zeta}{\partial x} = -\frac{1}{\rho d}\frac{\partial S_{xx}}{\partial x} \qquad (4)$$

Due to the limitation of the linear theory, a numerical model of Kobayashi et al. [1987] based on nonlinear shallow water equations (Eqs. 5, 6), is used to extend the solution towards the landward region, where, h is the total water depth ($h = d + \zeta$), $\tau_b = 0.5\rho f |u| u$ is the bottom shear stress and f is the bottom friction factor. In the present analysis, the LSWE, (Eqs. 3, 4) were firstly utilized to compute the infragravity waves up to the point of the minimum breakpoint of the grouped wind waves. Then, the temporal variations there were used as the boundary conditions, the nonlinear shallow water equations were solved.

$$\frac{\partial h}{\partial t} + \frac{\partial}{\partial x}(hu) = 0 \qquad (5)$$

$$\frac{\partial}{\partial t}(hu) + \frac{\partial}{\partial x}(hu^2) = -gh\frac{\partial \zeta}{\partial x} - \frac{\tau_b}{\rho} \qquad (6)$$

4. Results and discussions

Figure 1 shows the cross-shore propagation of grouped waves. The basic input conditions in Fig. 1 are as follows; the bottom slope is *S*=1/100, the components wave periods are $T_1 = 6\ s$ and $T_2 = 7\,s$, the incident wave height is $H = 2.4\,m$

and the modulation coefficient is $\alpha_1 = 1/2$. The domain length is 4200 m, and the horizontal axis is taken as positive in the onshore-ward direction with the origin at the offshore boundary. The minimum and maximum breaking point positions are $x'_{\min} = 221m$, $x'_{\max} = 385m$, respectively.

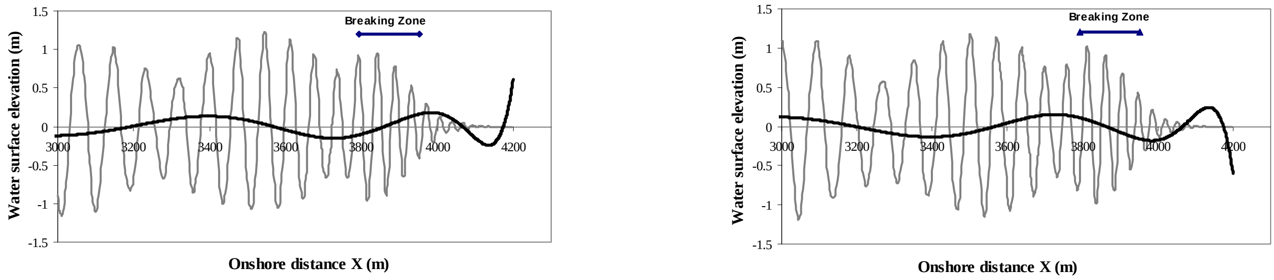

Fig. 1- *Water surface fluctuations of the grouped wind waves and infragravity waves at different stages of the grouped period*

Figure 2 shows the cross-shore distributions of the Shields parameters for the grouped wind waves (GWW), the infragravity waves (IGW) and the composite waves (GWW&IGW). The result of the combined Shields parameter, $\psi_{GWW\,\&\,IGW}$, shows a bimodal distribution representing two maxima at both the shoreline and the breaking zone. The figure also shows the contribution of the grouped wind waves and infragravity waves. The results indicate that the grouped wind waves govern the sediment mobility for the region where the water depth is greater than 2m.

Figure 3 illustrates the cross-shore distributions of the composite Shields parameter ψ ($=\psi_{GWW\,\&\,IGW}$) under different incident wave heights. As the incident wave height H increases, the peak locations of the Shields parameter curve in the surf zone shift offshore. Near the shoreline, the value of ψ increases again with the increase of H due to the growth of the infragravity waves. Figure 4 shows the cross-shore distribution of the time averaged Shields parameter $\overline{\psi}$ in the swash zone. The positive $\overline{\psi}$ regions are found in the up-rush region and the widths increase with the incident wave heights. The positive regions suggest the occurrence of a berm formation. Whereas, in the down rush regions around the water depth is around 0.1m, the negative regions of $\overline{\psi}$ exist, which suggests beach erosion would occur.

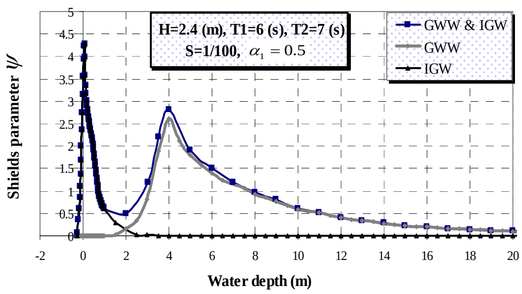

Fig. 2- *Contributions of the grouped wind waves (GWW), infragravity waves(IGW) and composite waves to the Shields parameter*

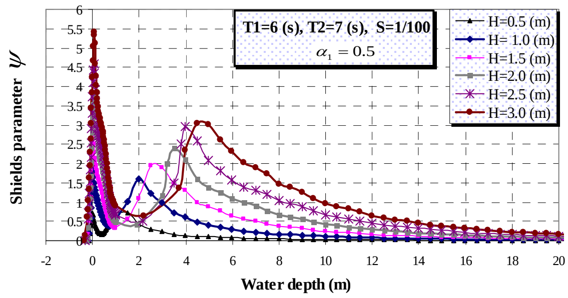

Fig. 3- *Effects of the incident wave heights on the Shields paremater*

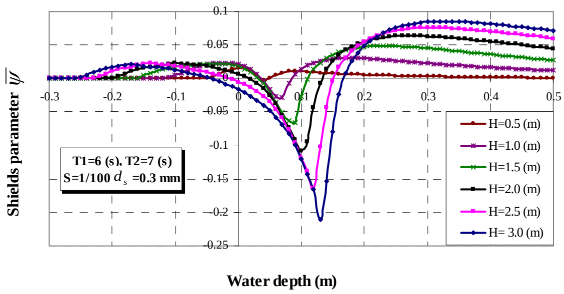

Fig. 4- *Effects of the incident wave heights on the time-averaged Shields parameter*

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