RADIATION STRESS MODEL TO INVESTIGATE SURF BEATS IN A HARBOUR

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INTRODUCTION: Excessive long-period oscillations are often observed in relatively small-sized harbours when typhoons or low pressure pass by the sites. Such oscillations may be responsible for flooding on the wharf and for sediment transports in the navigation channel. Akabane fishery harbour experienced excessive long-period oscillations during past typhoons. Field data measured under several typhoons are available on the Internet (http://hydromac.tutrp.tut.ac.jp/coconut.html) maintained by the Coastal Cooperative study by researchers in Nagoya, Gifu and Toyohashi. Significant wave breaking was observed in front of the mouth of Aakabane harbour during the high waves, and induced severe long-period oscillations inside the harbour. In other words, the long-period oscillations inside the Akabane harbour are characterized by the wave-breakings induced surf beats. Previous studies indicate that the surf beats associated with the wave breaking can be explained better by radiation stress concept. So far the linear model is failed to predict the long-period oscilllation in Akanbane harbour (Fuji et al. 1997, Yamamura & Aoki 1998) under multidirectional irregular wave fields. The Boussinesq equation model can be applied to predict such harbour oscillations, but it can be applied only to the relatively small computational regions because of bulk of required computational memory. Besides, for long simulation time the accumulated effect of numerical errors becomes significant to cause numerical instability. In this paper, an alternative numerical model based on the radiation stress is applied to Akabane harbour to simulate long-period oscillations inside the harbour under typhoon that passed the harbour on September 22, 1996. Comparisons are made between measured and predicted results and the agreement is found as satisfactory.

MODEL EQUATIONS: The model equations are based on the commonly used long-wave equations with the spatial gradient of radiation stress as driving force and the additional absorbing terms in the momentum equations (Kioka et al. 1999):

$$\frac{\partial \zeta}{\partial t}+h\left(\frac{\partial U}{\partial x}+\frac{\partial V}{\partial y}\right)=0\ ;\ \frac{\partial U}{\partial t}+g\frac{\partial \zeta}{\partial x}=-\frac{1}{\rho h}\left(\frac{\partial S_{xx}}{\partial x}+\frac{\partial S_{xy}}{\partial y}\right)-f_s U\ ;\ \frac{\partial V}{\partial t}+g\frac{\partial \zeta}{\partial y}=-\frac{1}{\rho h}\left(\frac{\partial S_{yx}}{\partial x}+\frac{\partial S_{yy}}{\partial y}\right)-f_s V \tag{1}$$

where ζ is the long-period water surface displacement, U and V are the long-period horizontal velocity components in x and y-directions respectively, h is the still water depth, ρ is the density of water, S_{xx}, S_{xy} $(=S_{yx})$ and S_{yy} are the radiation stress components, and f_s is the distribution function of a sponge layer. For the breakwaters of rubble mound construction, partial transmission of long waves is possible. Forchheimer's resistance law is applied to describe the reflection characteristics of the permeable boundaries. The computation of the radiation stress is the important part of the proposed numerical model. In this model, the following expressions for the radiation stresses derived by Kioka & Ishihara (1993) for the directional irregular wave fields are used:

$$S_{xx}=\frac{1}{4}\rho g\sum_{n=1}^{N}a_n^{\ 2}+\frac{1}{4}\rho\sum_{n=1}^{N}\frac{a_n^{\ 2}\omega_n^{\ 2}h}{\sinh^2 k_n h}\cdot\left[\left(\cos^2\theta_n+1\right)+\frac{\sinh 2k_n h}{2k_n h}\left(\cos^2\theta_n-1\right)\right]+\frac{1}{2}\rho g\sum_{m=1}^{N-1}\sum_{n=m+1}^{N}a_m a_n\cos(\varphi_m-\varphi_n)$$
$$+\frac{1}{2}\rho\sum_{m=1}^{N-1}\sum_{n=m+1}^{N}\frac{a_m a_n\omega_m\omega_n h}{\sinh k_m h\sinh k_n h}\cdot\left[\frac{\sinh(k_m-k_n)h}{(k_m-k_n)h}(\cos\theta_m\cos\theta_n+1)+\frac{\sinh(k_m+k_n)h}{(k_m+k_n)h}(\cos\theta_m\cos\theta_n-1)\right]\cos(\varphi_m-\varphi_n) \tag{2}$$

$$S_{xy}=\frac{1}{4}\rho\sum_{n=1}^{N}\frac{a_n^{\ 2}\omega_n^{\ 2}h\cos\theta_n\sin\theta_n}{\sinh^2 k_n h}\cdot\left[1+\frac{\sinh 2k_n h}{2k_n h}\right]+\frac{1}{2}\rho\sum_{m=1}^{N-1}\sum_{n=m+1}^{N}\frac{a_m a_n\omega_m\omega_n h\cos\theta_m\sin\theta_n}{\sinh k_m h\sinh k_n h}\cdot$$
$$\left[\frac{\sinh(k_m-k_n)h}{(k_m-k_n)h}+\frac{\sinh(k_m+k_n)h}{(k_m+k_n)h}\right]\cos(\varphi_m-\varphi_n) \tag{3}$$

where a_n, k_n, ω_n and θ_n are the amplitude, wave number, angular frequency and angle of propagation of primary short-wave components respectively, and φ_n stands for the phase of primary short-wave components.

RESULTS AND DISCUSSIONS: The model equations are numerically solved using a finite difference scheme with staggered mesh. Forward difference for time derivatives and centered difference for space derivatives are used, and a cold start technique is introduced for the initial condition. About 2 km alongshore and 2 km cross-shore region including the entire area of Akabane fishery harbour is reproduced in the model. Water depth at each grid points is derived from the bottom contour measured in the field. The Bretschneider-Mitsuyasu type frequency spectrum with Mitsuyasu directional distribution function is used to give incident primary short-wave components along the incident boundary. The value of directional spreading parameter S_{max} is estimated using the method of Goda and Suzuki (1975). The significant wave height $H_{1/3}$=3.2 m and significant wave period $T_{1/3}$=14.0s that were measured at the field during the typhoon (Spt.22, 1996) are used to derive the incident short-wave spectrum. Refraction and shoaling of the primary short-wave components are calculated using the method presented by Dalrymple (1988). The short-period waves that propagate into the harbour are determined from the directional spreading method. Ray tracing method (Larsen 1978) is employed to determine first-order short waves inside the harbour. Radiation stress is then calculated from equations (2) and (3). Reflection coefficient of 0.9 is used for the impermeable harbour boundary during ray-tracing process. The scattering waves of evanescent mode are not accurately reproduced by the angular spreading and ray method, but these scattering modes do not contribute to the forcing for long waves at the second order. Short waves are assumed to breakdown when the composite height of primary short-wave components reaches to $0.78h$ and the wave height after breaking is assumed to be $0.78h$. The reflection coefficient for long-wave components on the coastal boundaries is assumed to be 1.

Field measurement data are available for Akabane harbour, especially during several typhoons occurred in 1996. As for comparison purpose we select the typhoon that passed the Akabane harbour on September 22, 1996. Locations of measurement stations inside the harbour are shown in Fig.1.

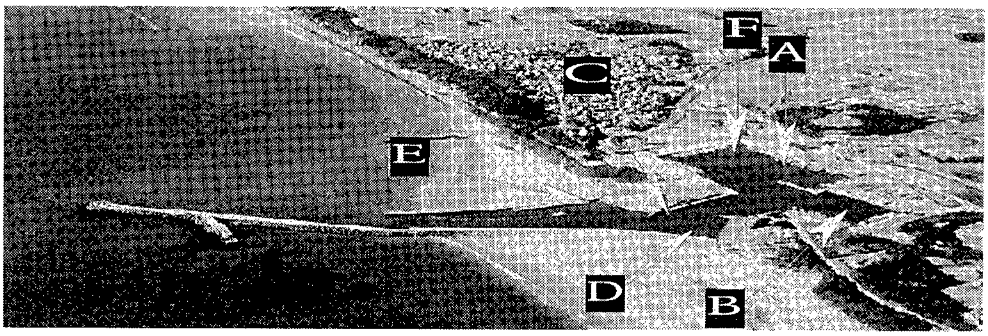

Fig.1 Location of measurement stations inside Akabane harbour

Computations are carried out matching the conditions of the typhoon and the comparisons are made at St.B and St.C Spectral analysis is carried out for the comparison. The analysis shows that the agreement between the measured and computed results is satisfactory and the radiation stress model can sufficiently predict the long-period excitations in Akabane harbour.

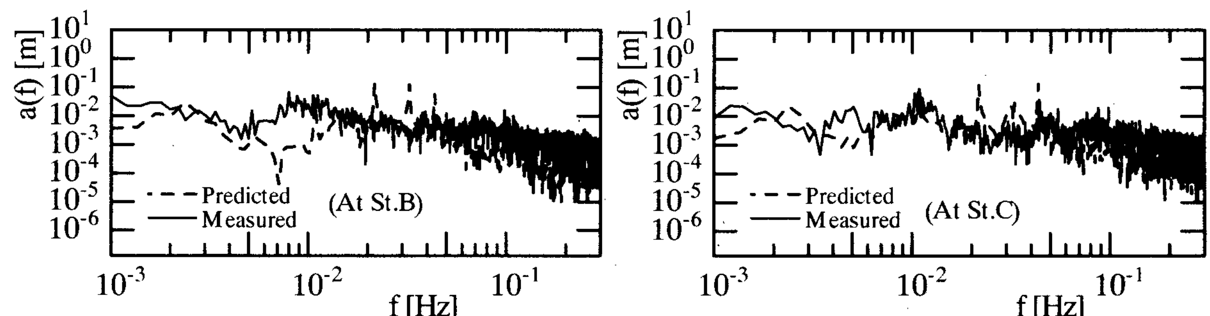

Fig.3 Computed and measured wave amplitudes at St.B and St.C

CONCLUSIONS: Radiation stress model is applied to the Akabane fishery harbour in the prototype conditions. The long-period oscillation under typhoon is investigated. Field measurement and predicted result show good agreement particularly in the long wave range. It is concluded that the radiation stress model can be a powerful alternative tool to predict long period oscillations in the harbour.

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