TRANSMISSION OF LONG-PERIOD WAVES THROUGH POROUS BREAKWATERS AND RESONANCE OSCILLATIONS IN HARBOURS

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INTRODUCTION: Long waves with periods of several minutes sometimes terminate the loading or unloading of cargoes in many major ports. The long waves with significant heights of only $10cm \sim 20cm$ can be detrimental to the cargo handling. It is therefore of great importance to develop an accurate prediction model for long waves in a harbour. Long waves induced by the groups of primary short wave components can be predicted by radiation-stress model as proposed by Kioka *et al.* (1999). Radiation-stress model requires short wave components as input and considers refraction, diffraction, reflection and breaking of short wave components to compute the radiation stresses as driving force for the long waves. The model also needs proper treatments of harbour boundaries and breakwaters for long waves in order to produce better results. The analytical solution for the transmission of long waves induced by wave groups through the porous harbour boundary may be incorporated to enhance the prediction of harbour oscillation by radiation stress model. In this study, we present the modified analytical solution and experiments for the transmission of long waves induced by wave groups through the porous breakwater and analytical solution is then implemented into the radiation stress model to investigate the harbour oscillations.

ANALYTICAL SOLUTION FOR LONG WAVES: A continuous vertical breakwater of infinite length with rectangular cross section, having a homogeneous, isotropic rubble base of width b and height $(h\text{-}d)$, and crowned with an impervious caisson of same width as shown in Fig.1 is considered in this study. Cartesian coordinates are employed with origin on the undisturbed free surface with z being positive vertically upwards. The water depth h, is assumed as constant at both sides of the breakwater. Characteristics of the porous rubble base are expressed by its porosity λ, linear friction factor f, and the inertial coefficient s. We assume that the excitations are provided by a group of two sinusoidal short-wave components with slightly different frequencies propagating towards the positive direction of x-axis as demonstrated in Fig.1. Central frequency and wave number of incident short waves are denoted by ω and k respectively. For an inviscid and incompressible fluid and for irrotational flow, the wave fields in the seaward and leeward sides as well as beneath the crown of the breakwater are represented by the velocity potentials (Sollitt and Cross 1972, Losada *et al.* 1993).

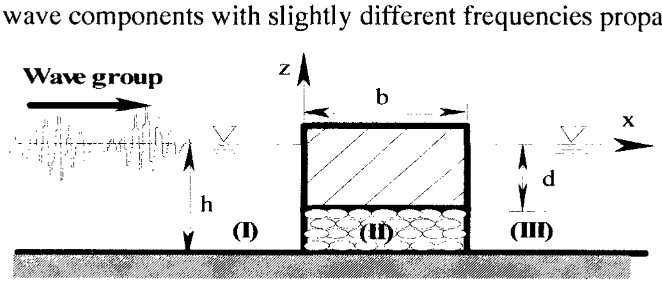

Fig.1 Definition Sketch

Introducing slow variables $(x_1, y_1, t_1) = (\varepsilon x, \varepsilon y, \varepsilon t)$, and denoting velocity potential by ϕ, we write a solution in terms of harmonics with respect to the fast time as:

$$\Phi = \sum_{n=1}^{\infty} \varepsilon^n \sum_{m=-n}^{n} \phi_{nm}(x, y, z, x_1, y_1, t_1) e^{-im\omega t} \tag{1}$$

in which $\phi_{n,-m} = \phi^*_{nm}$ and ε is the steepness of the carrier waves.

The short wave potential ϕ_{11}, can be evaluated by eigen-function expansion proposed by Losada et al. (1993). Long wave potential ϕ_{10}, can be determined both in porous and water region through the perturbation analysis. After determining the long wave potential in all the regions, the matching conditions at x_1=0 and x_1=b_1 are specified in terms of the pressure and mass flux to ensure the continuity of the solutions that leads to the following long wave equations:

$$E_R = A_{10}\left[\frac{KN}{i}\left(R_1R_2^* + T_1T_2^* - 1\right) + \frac{\Omega}{\sqrt{gh}}\left\{-2b_1KS\left(R_1R_2^* - 1\right) + \frac{N}{i}\left(R_1R_2^* - T_1T_2^* + 1\right)\right\}\right] \Big/ \left(\frac{2b_1S\Omega^2}{gh} - \frac{2N\Omega}{i\sqrt{gh}}\right) \tag{2}$$

$$E_T = A_{10}\left[-\frac{N}{i}\left\{\frac{\Omega}{\sqrt{gh}} + K + R_1R_2^*\left(\frac{\Omega}{\sqrt{gh}} - K\right)\right\} + T_1T_2^*\left\{\frac{N}{i}\left(\frac{\Omega}{\sqrt{gh}} + K\right) - \frac{2b_1KS\Omega}{\sqrt{gh}}\right\}\right] \Big/ \left(\frac{2b_1S\Omega^2}{gh} - \frac{2N\Omega}{i\sqrt{gh}}\right) \tag{3}$$

where $S = s - if, \quad N = \dfrac{\lambda(h-d)}{d}$

In equations (2) & (3), E_R is the amplitude of reflected free long wave, E_T is the amplitude of transmitted free long wave, R_1 and R_2 are the reflection coefficients and T_1 and T_2 are the transmission coefficients of two short wave components of the group, K and Ω are respectively the wave number and frequency of the group, and A_{10} is the amplitude of incident locked long wave.

LABORATORY EXPERIMENTS: Laboratory experiments were carried out for rough verification of the theoretical results, in a wave flume of 26 m long, 0.6 m wide and 1.2 m height. A composite breakwater with geometric parameters d/h=0.60 and b/h=0.80 was built in the wave flume in water depth of h=40 cm. The porous part of the breakwater was filled with gravel of mean diameter 2.0 cm and porosity $\lambda = 0.45$. Six capacitance type wave gauges were installed in the seaward and leeward sides of the breakwater to measure time series to be used in the analysis. Details of the experimental setups are demonstrated in Fig.2.

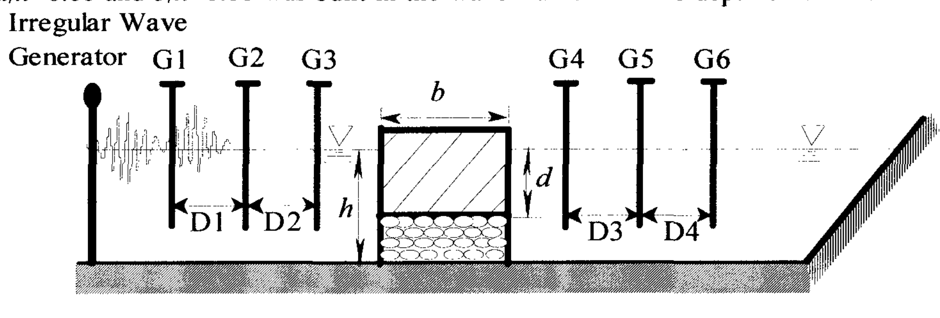

Fig.2 Experimental Setups

COMPARISON OF THE RESULTS: Separation of different long wave components is carried out using Fast Fourier Transform (FFT) from the time series measured in the seaward and leeward sides during experiments. A comparison of the transmitted free long wave is shown in Fig.3 plotting the apparent transmission coefficient $|E_T|/|A_{10}|$ against relative depth kh. To minimize the effects of the multiple reflections from the breakwater and wave generator, only first 2 to 3 waves of the wave groups are used in the analysis. A good agreement is found between theoretical and experimental results. The value of $|E_T|/|A_{10}|$, is found as 0.8 both in the experiments and the theoretical calculation, which indicates that significant part of the locked long wave energy associated with the incident wave groups transmitted to the leeward side of the breakwater as free waves.

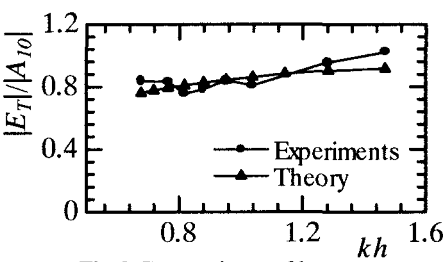

Fig.3 Comparison of long waves

RADIATION STRESS MODEL AND HARBOUR RESONANCE: The radiation stress model can further be enhanced to take into account the effect of porous harbour boundary by incorporating the analytical solutions for long waves described above. The higher values of apparent transmission coefficient presented above in Fig.3, indicate that major parts of the locked long wave energy associated with incident wave group is transmitted into the harbour basin as free waves. It indicates that for very low frequency wave, the porous breakwater can be treated as fully transparent boundary. In calculating the total long wave fields induced by short wave groups, the primary short-wave information is necessary both outside and inside the harbour that can be calculated using ray-tracing method from the incident short waves conditions. Radiation stress is then calculated after Kioka *et al.* (1999) as forcing terms to generate bound long waves. In calculating the bound long waves from the radiation stress, the porous harbour boundary is removed and the breakwater is represented by its centerline. Along the centerline of the breakwater, a sharp change of the radiation stress is occurred. Due to the sharp change in radiation stress, bound long wave is released and propagates as free long wave into the harbour. This modification however, gives slightly larger amplitude of the transmitted free long waves that can be adjusted using the apparent transmission coefficients from the analytical solution presented above. The free long waves transmitted into the barbour basin through the porous breakwaters may have some link with resonance oscillations in harbours. The details of the results will be discussed during the presentation of the paper.

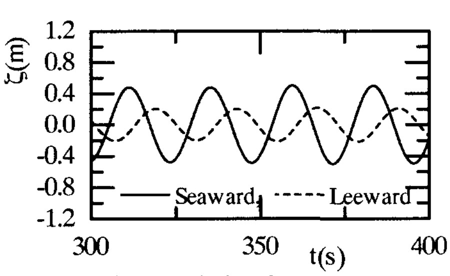

Fig.4 Radiation Stress Model

CONCLUSIONS: Many of the major ports in the world are of rubble mound construction. Through the porous rubble mound both the short and long waves are partially transmitted into the basin. Analytical and experimental results are obtained for the transmission of long waves induced by the short wave groups due to the porous breakwaters. A methodology to incorporate the analytical long wave solution with radiation stress model is discussed to investigate the effect of transmitted long waves on the resonance oscillations in harbours.

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