Wave Interaction with Moored Sloping Breakwater

S. Kharaghani*and J.J. Lee**

1. ABSTRACT

Interaction of periodic waves with a moored inclined floating breakwater has been studied theoretically and numerically. The floating breakwater is inclined at a well defined angle with the sea bottom; its seaward end in protruding above the water surface. In static equilibrium, without incoming waves, the body weight, the buoyance force, and the restoring forces from the mooring lines which are modeled using linear springs keep the breakwater at a fixed angle. The theoretical formulation is based on a suitable variational principle. For the numerical solution a combination of finite element approximation as well as eigen function expansion technique is used.

The result is obtained in terms of wave transmission and reflection coefficient as well as the sway, heave and roll motion of the breakwater. The sensitivity of the solution on the parameters such as the bottom gap size, angle of inclination, and the mooring line stiffness are investigated over a range of incident wave transmission coefficient for dimensionless wave number $hk > 0.60$ (k is wave number, h is the water depth). The results suggest that a certain degree of sheltering effect can be realized by employing this type of sloping breakwater.

2. INTRODUCTION

Many marine structures are built in the coastal region to withstand the attack of the ocean waves and to proide a sheltered environment. Rubble mound breakwaters are examples for such applications. For certain applications this type of permanent structure might not be the most efficient. For example, during the construction of certain harbor facilities when only temporary protection is needed for a certain period, and when such protection is no longer needed after the construction it would be reasonable to assume that a permanent breakwater would not be necessary. Portable breakwaters could provide the need for such applications. Among many types of portable breakwater, one possible type is the moored inclined floating breakwater which consists of a pontoon structure whose density is so designed that the structure would be neutrally buoyant and

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it is placed such that the pontoon is oriented as a well defined angle with the bottom; the seaward side of the pontoon is above the water surface. In static equilibrium, without incoming waves, the body weight, the buoyancy force, and restoring forces from the mooring lines which are modeled using linear springs keep the floating breakwater at a fixed angle. The effectiveness of the floating breakwater described above under the attack of periodic incident waves is studied theoretically and numerically. The bottom edge of the pontoon maintains a varying height of clearance so that it is not necessarily resting directly on the bottom. This clearance would extend the use of the same structure even for a deeper water depth. Of course, the effectiveness of these breakwaters deployed at such water depth must be carefully studied.

3. MATHEMATICAL AND NUMERICAL FORMULATION

For the analysis, the fluid is considered inviscid, incompressible and irrotational. Therefore, the governing equation is the Laplace equation with a mixed boundary condition on the free surface, the homogeneous Neumann condition at the sea bottom, as well as appropriate radiation conditions at infinity which require that the scattered waves are outgoing from the body. An additional boundary condition which requires that the normal velocity of the fluid and the body to be equal of the floating breakwater is also necessary. The boundary conditions are linearlized, the radiation boundary conditions are replaced by a suitable matching boundary condition in the associated functional.

The equivalence of the variational principle and the differential formulations allows for us an adoption of a well known variational form to be applied for the solution of Laplace's equation and its boundary conditions. The associated functional based on the suitable variable variational principle for the present study can be expressed as follows:

$$F(\phi_1, \phi_2, \phi_3) = \int\int_{R_1} \frac{1}{2}(\nabla\phi_1)^2 dxdy - \frac{\sigma^2}{2g}\int_{S_F} \phi_1^2 dx - \int_{S_R} (\phi_1 - \frac{1}{2}\phi_2)\phi_{2,n} dy -$$

$$\int_{S_L} (\phi_1 - \frac{1}{2}\phi_3)\phi_{3,n} dy - \int_{S_0} V_n \phi_1 ds \qquad (1)$$

where V_n is the normal velocity of floating object, and $\phi_1(x,y)$, $\phi_2(x,y)$, and $\phi_3(x,y)$ are the complex velocity potential describing the flow field in the regions 1, 2 and 3, respectively.

A definition sketch of a moored inclined floating breakwater with its designated boundaries for regions 1, 2, 3 is shown in Fig.1. For the numerical

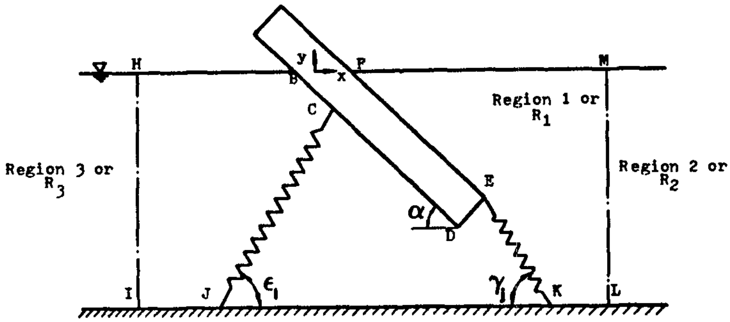

Figure 1. Definition sketch of a moored inclined floating breakwater with its designated boundaries.

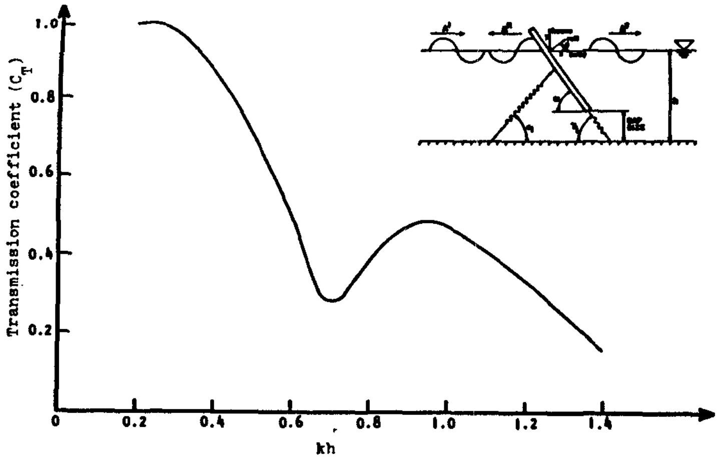

Figure 2. Transmission coefficient for 30% gap size and α=18.43 degree angle of inclination as a function of dimensionless wave number (kh).

computation, the entire fluid region for the present study has been subdivided into regions 1, 2, 3 by drawing two auxilliary vertical lines on both sides of the floating breakwater such that an inner region 1 enclosing the breakwater is formed. This inner region indicates the finite domain of direct computational interest where the functional equation 1 is integrated over with its boundaries. Regions 2 refers to the region to the right of the imaginary boundary line, thus wave would propagate in positive x-direction toward infinity. Region 3 refers to the region to the left imaginary boundary line, thus the scattered waves propagate toward negative x-direction. As a result of impact of an incident wave in the presence of the moored floating body, the total velocity potential can be decomposed as the sum of three components

$$\phi = \phi^I + \phi^D + \phi^R \tag{2}$$

where ϕ^I, ϕ^D and ϕ^R are the velocity potential of the incident wave, diffracted wave, and the radiated wave, respectively. The two dimensional plane motion of the moored inclined floating breakwater can also be decomposed in terms of three unknown modes of motion. These modes of motion are expressed in terms of translation in x-direction (sway), translation in y-direction (heave) and rotation about z-axis (roll motion) so that V_n can be expressed in terms of these three components.

For the numerical implementation the finite element approximation is used near the body and eigenfunction expansions are used to express the solutions away from the floating object. It should be mentioned that the finite element approximation is used to estimate ϕ_1 in region 1 near the breakwater while ϕ_2 and ϕ_3 are approximated by a finite number of the eigenfunction expansions with unknown coefficients in regions 2 and 3, respectively. Then the solution near the body is matched with the eigenfunction expansions along the common boundaries between regions to obtain the final solution. Thus the solution to the system of simultaneous algebraic equations for the unknown node velocity potential, coupled with the three unknown amplitudes of motion of the floating breakwater are sought numerically.

The linearized equations of motion of the floating breakwater can be written as follows:

$$M\ddot{x} = F_{dx} + F_{sx} + \sum_{j=1}^{n} (F_{Mx})_j$$

$$M\ddot{y} = F_{dy} + F_{sy} + \sum_{j=1}^{n} (F_{My})_j \quad (3)$$

$$I\ddot{\theta} = M_{d\theta} + M_{s\theta} + \sum_{j=1}^{n} (F_{M\theta})_j$$

where M is the mass, and I is the mass moment of inertia of the floating body about its center of gravity. The terms $(F_{dx}, F_{dy}, M_{d\theta})$, $(F_{sx}, F_{sy}, M_{s\theta})$ and $(F_{Mx}, F_{My}, F_{M\theta})$ are forces and moments associated with hydrodynamic effects, hydrostatic effects and that due to moorings respectively.

To obtain, for example, the force and moment terms due to the hydrodynamic effect, integrations of hydrodynamic pressure and the moments due to this force must be performed. The pressures are related to the velocity potential function by the well known Bernoulli's equations.

A detailed presentation of the mathematical formulation and the numerical implementation using the finite element approximation is presented in Kharaghani (1986).

4. NUMERICAL RESULTS

A series of numerical calculations using the developed computed model of the theory is carried out to investigate the response of the inclined floating pontoon breakwater. The computed results are expressed in terms of wave transmission and reflection coefficients as well as sway, heave and roll modes of motion. The sensitivity of the solution on the parameters such as bottom gap size, angle of inclination, and mooring line stiffness are inestigated over a range of incident wave periods (see Kharagani,1986).

Fig.2 and 3 show the wave transmission and reflection coefficients as a function of the dimensionless wave number (kh) for a pontoon breakwater inclined at an angle of 18.43 degree with a bottom gap size of 30% as shown in the inserts of the figures. It is seen from Fig.2 that a substantial reduction in the wave transmission coefficient can be achieved for those wave frequency in the range of dimensionless wave number $kh > 0.6$. The wave numver k is defined as 2π/wave length and the water depth, h, is used as a characteristic

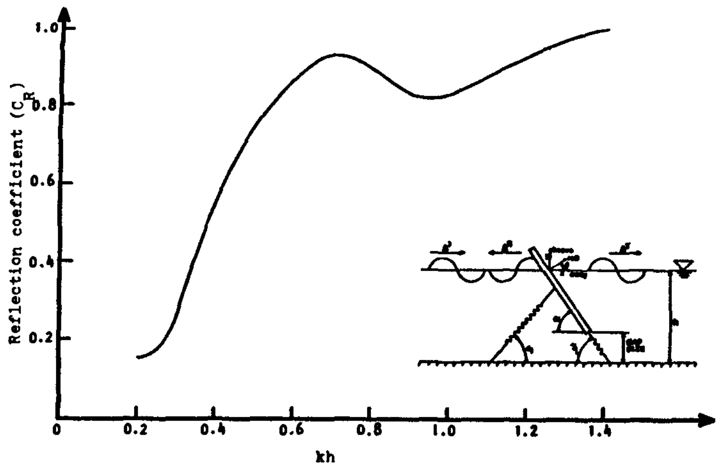

Figure 3. Reflection coefficient for 30% gap size and α= 18.43 degree angle of inclination as a function of dimensionless wave number (kh).

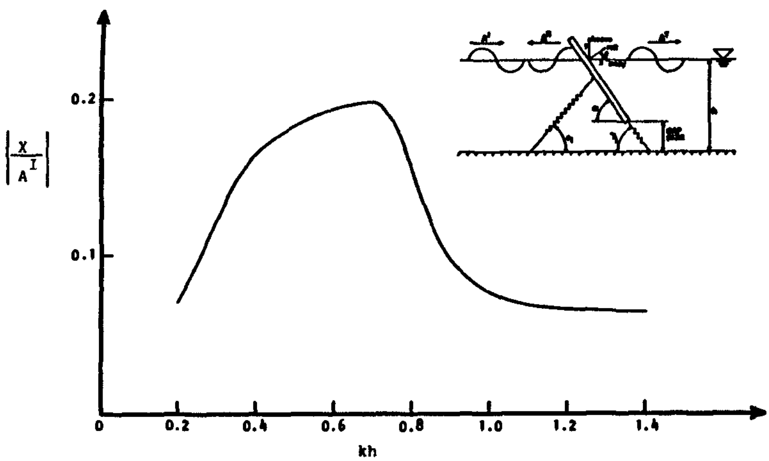

Figure 4. Sway mode of motion for 30% gap size and angle of inclination α=18.43 degree.

depth. It is noted that the transmission coefficient is defined as the transmitted wave amplitude divided by the incident wave amplitude which the reflection coefficient is defined as the reflected wave amplitude divided by incident wave amplitude. The computed amplitude for sway, heave and roll motion of the same sloping potoon breakwater are shown in Fig. 4, 5, and 6. These results indicated the relative dynamical response of the wave-structure interaction in the wave frequency range presented.

As extensive sensitivity analysis for the similar results for different gap size, inclination angle and mooring line stiffness has been conducted by Kharaghani (1986). The interested reader is referred to this for more detail presentation of the results. Similar trend has also been obtained by other investigators using different numerical technique. A comparison of the previous available theorectical results and experiments is given in Fig. 7. This shows a comparison of transmission coefficient for 30% gap size and 18.43 degree inclination angle for two different model thickness of the breakwater. A comparison with prior experimental data and the theoretical result indicates that the major trend is preserved. The result indicates if one could design the structure strong enough to withstand the wave forces a substantial large reduction in wave transmission can be achieved for a fairly large wave frequency range.

5. CONCLUSIONS

A numerical method has been developed to solve the two dimensional problem of the response of a moored inclined floating breakwater subjected to a sinusoidal incident wave. The present method is based on a suitable variational method using the hybrid finite element approximation to a fluid region near the body and the linear equations of motion of the floating breakwater. The body motions, transmitted wave and reflected wave are solved simultaneously. The investigation of the performance of the floating breakwater has been examined by studying the curves of the transmission, reflection, and the three modes of motion with respect to a large range of wave period (kh) that simulate the situation in an idealized incident wave condition from shallow water to deeper water. The results suggest that it is possible to design a moored inclined floating breakwater to be used as a temporary portable wave barrier in providing a sheltered environment against the incident waves in a certain frequency range.

6 ACKNOWLEDGMENTS

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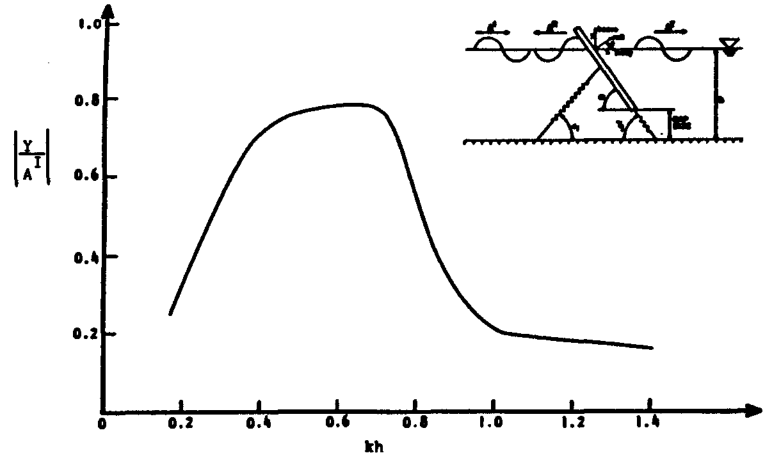

Figure 5. Heave mode of motion for 30% gap size and angle of inclination α=18.43 degree.

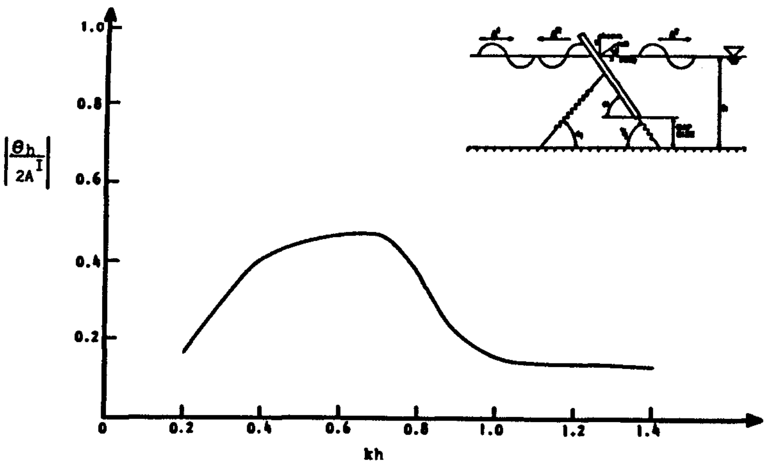

Figure 6. Roll mode of motion for 30% gap size and angle of inclination α=18.43 degree.

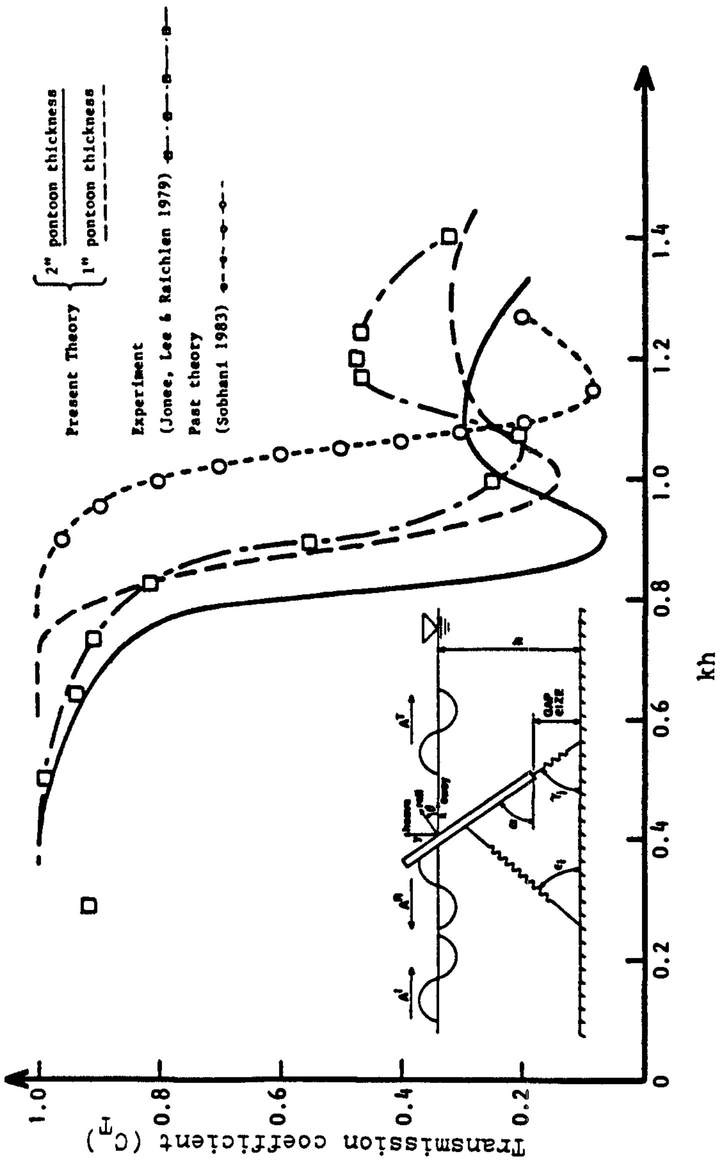

Figure 7. Comparison of wave transmission coefficient for gap size 30%, α=18.43 for two different breakwater thickness and with available theoretical and experimental results.

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