

## Investigations on Wave Reflection Characteristics due to Composite Breakwater

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**This paper examines the reflection characteristics of normally incident waves acting on a composite breakwater, which is composed of an elastic membrane and a submerged breakwater. Based on the small amplitude wave theory, mathematical analysis procedures are developed by using the eigenfunction expansion method. Several factors of reflection characteristics, such as the width of the composite breakwater, the height of the submerged breakwater, and the membrane mass, are considered. Results of these analyses show that for long period waves, reflection effects from the mass of the elastic membrane are not significant. However, when the ratio of the membrane's half width to the water depth,  $l/h$ , is equal to 1.0, and the coefficient of the submerged breakwater height,  $q'$ , is equal to 0.9, the reflection effect of the composite breakwater is significant. As for the short period waves, when  $l/h = 1.0$ ,  $q' = 0.7$ , membrane pretension  $T' = 0.002$ , and membrane mass  $m' = 0.2$ , the reflection of the composite breakwater shows substantial effect. Since the present investigation is based on mathematical analysis, results in this study need further experimental verification.**

### INTRODUCTION

In recent years, there has been a gradual shift in design concept for coastal structures. Conventional coastal structures such as offshore or detached breakwaters and/or groins may provide prevention of coastal erosion or improve tranquility behind breakwaters. Yet they could reduce the water exchange between the breakwaters' two sides and significantly alter the coastal environment ecologically and aesthetically. Thus, preservation of coastal ecology and aesthetics are the new requirements for designing coastal structures, besides the requirement of providing safety for human activities and properties. One solution to the new requirements is the submerged breakwater. It not only preserves the view of the surrounding coastal area, since the structure is submerged, but also reduces toe scouring because its reflection coefficient is smaller than that of a conventional breakwater.

Concerning the design of a submerged breakwater, a number of studies has appeared in the literature, discussing wave deformations by the structures as well as the interaction between waves and the submerged structure. For example, based on the Boussinesq or KdV equation, Madsen et al. (1991) and Beji and Battjes (1993) analyzed the interaction between the waves and submerged breakwaters. Ohyama and Nadaoka (1994) investigated wave form deformation as the waves pass through submerged breakwaters by solving the Laplace equation with the nonlinear free surface boundary condition using the boundary element method (BEM). Huang and Dong (1999) used the Navier–Stokes equations with exact free-surface boundary conditions to simulate wave deformation and vortex generation in water waves propagating over a sub-

merged dike. Hsu et al. (2004) used a Reynolds Averaged Navier–Stokes (RANS) model to simulate the vortex generation and dissipation caused by progressive waves passing over impermeable submerged double breakwaters without wave breaking and they discussed wave energy dissipation. As for the application of the eigenfunction method, Losada et al. (1996) used a 3-dimensional nonbreaking regular wave model to simulate wave interaction with submerged breakwaters, and they compared it with the results of a 2-D model based on a mild-slope equation. Twu et al. (2001) presented a theoretical analysis by using the complex eigenfunction approach to deal with problems of wave reflection and transmission coefficients when the wave is passing through deep and multislice porous submerged breakwater. In addition, the harbor tranquility problems can be resolved by adopting a suitable porosity with the thickness-depth ratio of the breakwater.

Although the submerged breakwaters can dissipate the incident wave energy and reduce the impact on coastal structures, they are not easy to construct where there is a steep bottom slope. Further, the submerged breakwater is not as effective as the conventional detached breakwaters when the tranquility behind the breakwater is concerned (Losada et al., 1996; Requejo and Losada, 2000). To improve the tranquility behind the offshore breakwater, the submerged plate is an alternative. Most research works on the submerged plate focused on the calculation of the reflection coefficient using physical experiments or numerical models. For example, Patarapanich (1984a) investigated wave reflection and transmission characteristics from a submerged horizontal plate in shallow water by using the energy flux approach. Based on the potential theory, Patarapanich (1984b) also studied forces and moment on a horizontal plate due to wave scattering, and he presented a general solution for this wave scattering by using the finite element method. Variation of the wave parameters and the plate-width-to-depth ratio were also carefully discussed. For regular and irregular waves passing through a submerged plate, Patarapanich and Cheong (1989) conducted a series of physical experiments to investigate the reflection characteristics. More recently,

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