

A parabolic equation for wave propagation over porous structures

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Porous structures such as seawalls, detached breakwaters, or submerged breakwaters are frequently used to protect shorelines from the effects of waves. The effectiveness of these structures is due to the fact that they are able to reflect, absorb, and dissipate wave energy. Wave energy reduction on the leeside of porous structures increases so that only a small part of the wave energy is transmitted to the nearshore. Consequently, the wave field on the leeside of such structures becomes quiet and the intensity of the wave action on the shoreline decreases; as a result, coastal erosion and the corresponding coastal disasters are mitigated. Wave transformation over porous structures must be understood in order to determine the stability of these porous structures and to evaluate their usefulness with regard to wave energy reduction.



The main purpose of this paper is to extend the parabolic equation for waves propagating over submerged permeable structures in the surf zone. The governing equation is a parabolic formulation of the MSE including the breaking and energy dissipation effect of porous structures. The approximate MSE enables a more accurate description of combined wave refraction and diffraction in the computational domain. An implicit finite-difference approximation scheme is implemented in the numerical solution. Several numerical cases were computed and compared through experiments to examine the validity of the present model. This model was also applied to practical cases of wave-height evolution in the vicinity of the submerged permeable structures over a complicated bathymetry. The definition sketch for linear periodic waves propagating over a submerged permeable structure in the surf zone is shown in Fig. 1.

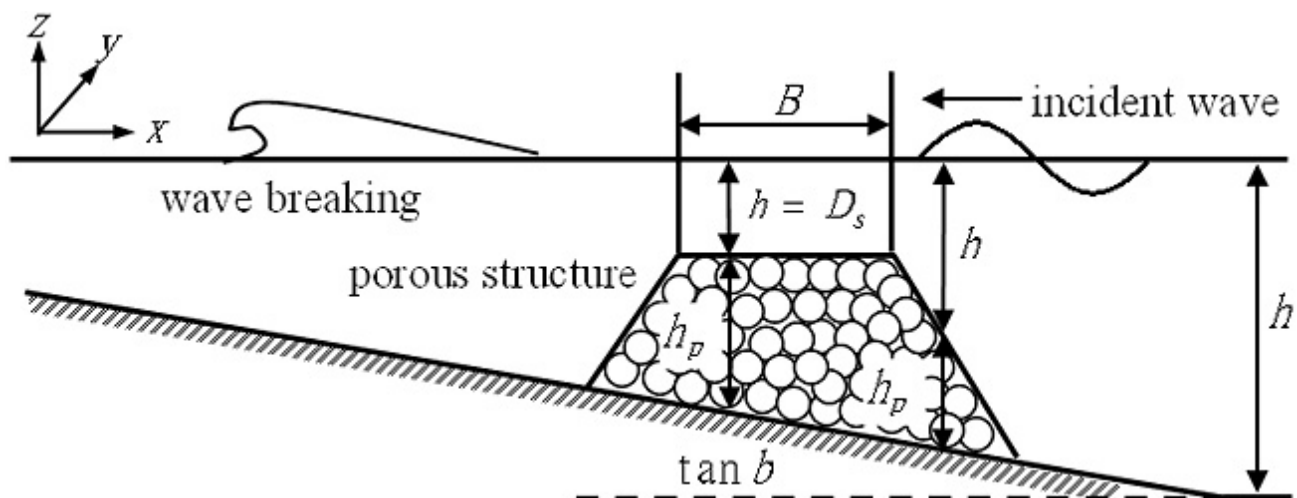


Fig. 1 Waves propagating over a submerged permeable structure.

The applicability and validity of the present model were verified through experiments in which waves propagated over permeable sloping beaches. Numerical simulations of the wave-breaking processes over a gravel sloping bottom were performed and compared with the experimental data provided by Lara et al. (2006). Fig. 2 shows the spatial variations of the wave heights from a shoaling zone to still water level. The numerical results of the present model can reproduce the wave transformation over a permeable sloping bottom. Notably, under incident wave conditions, the breaking wave height, location of the breaking point, and wave decay caused by energy dissipation against breaking and porous gravel slopes were accurately predicted.

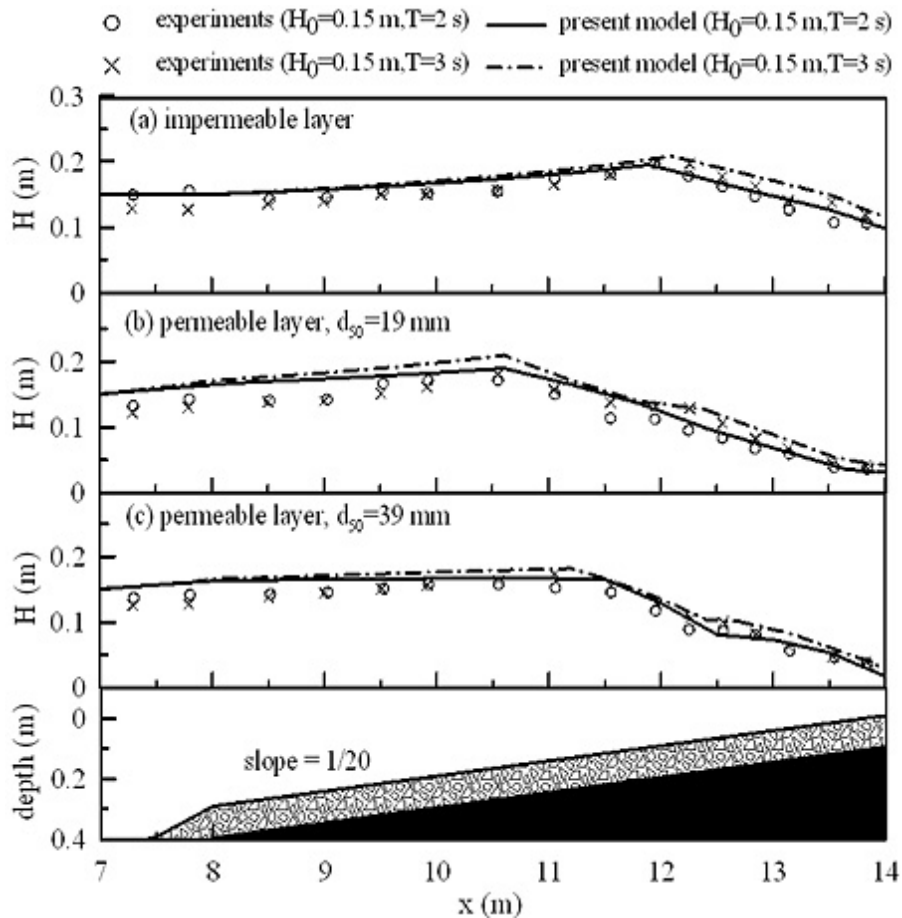


Fig. 2 Wave height evolution on permeable gravel slopes. (a) impermeable layer; (b) permeable layer ($d_{50}=19$ mm); and (c) permeable layer ($d_{50}=39$ mm). The thickness of the porous layer is 11 cm.

In order to examine the validity of the present model, a large-scale experiment was conducted in a three-dimensional wave basin to create waves propagating over a permeable submerged circular pile that is rested on a gravel sloping bottom with normal incidence. This model test was carried out in a laboratory of the National Cheng Kung University, Taiwan. As shown in Fig. 3, the wave basin had a length, width, and depth of 40 m, 40 m, and 1.2 m. Fig. 4(a) and Fig. 4(b) shows the results of relative wave heights of experimental data and numerical data in a planar wave pattern. The comparison between experimental data and numerical data demonstrates that the model is capable of describing the combined effect of wave refraction, diffraction, and porosity. Note that the present model predicts a favorable focusing wave pattern. The relative error $\varepsilon = |(H_m - H_c)/H_m|$ between the numerical calculations and experiments as shown in Fig. 4(c) may be caused by wave reflection from the side walls in the wave basin. Wave reflection is neglected in the present model.

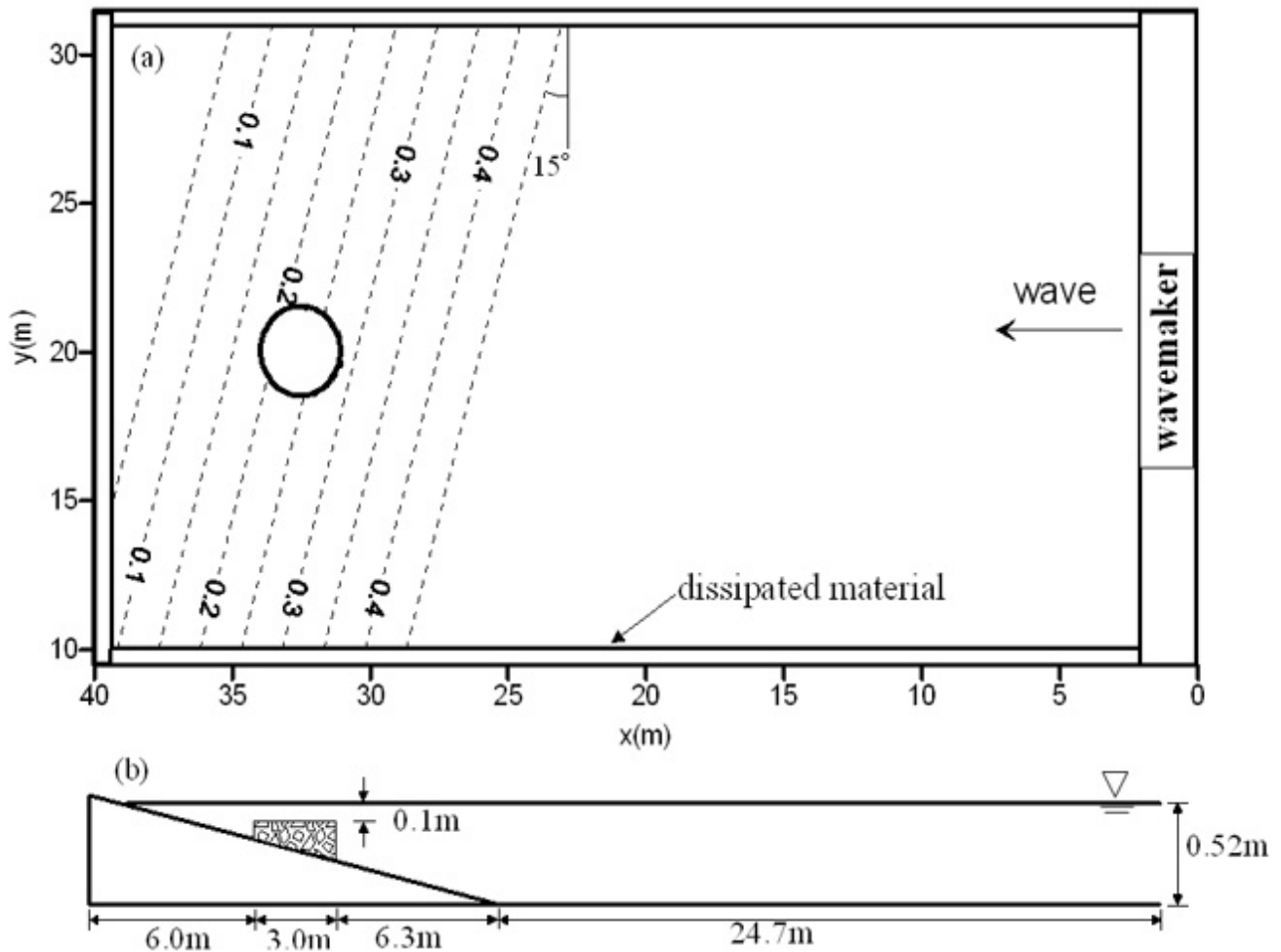


Fig. 3 Laboratory experiment in a wave basin with a submerged permeable circular pile placed on a sloping bottom. (a) plane view; (b) section view.

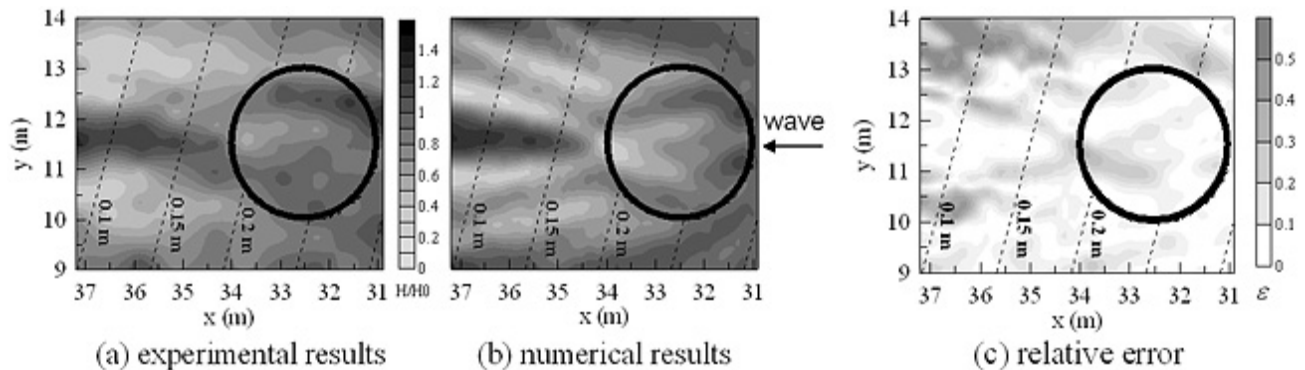


Fig. 4 A comparison of wave patterns around a submerged permeable cylinder. $H_0=0.04$ m, $T=0.9$ s.

In addition to the laboratory verification, the present model was also applied using a typical real case. The case tested waves propagating over a permeable submerged breakwater using field data obtained during a field experiment at the CERC Field Research Facility (FRF) in Duck, North Carolina, U.S.A. Fig. 5(a) depicts the wave height along distribution the pier without a structure. For the construction of the submerged breakwater, Fig. 5(b) demonstrates that the model reproduces the general wave height variation due to wave refraction, diffraction, wave-breaking, and energy dissipation. The results show that the present model accurately predicts wave propagation for these types of wave conditions over a complicated bathymetry. It is also noted that the model does decay the wave

height on account of refraction, diffraction, wave-breaking, and porosity behind the submerged detached breakwater.

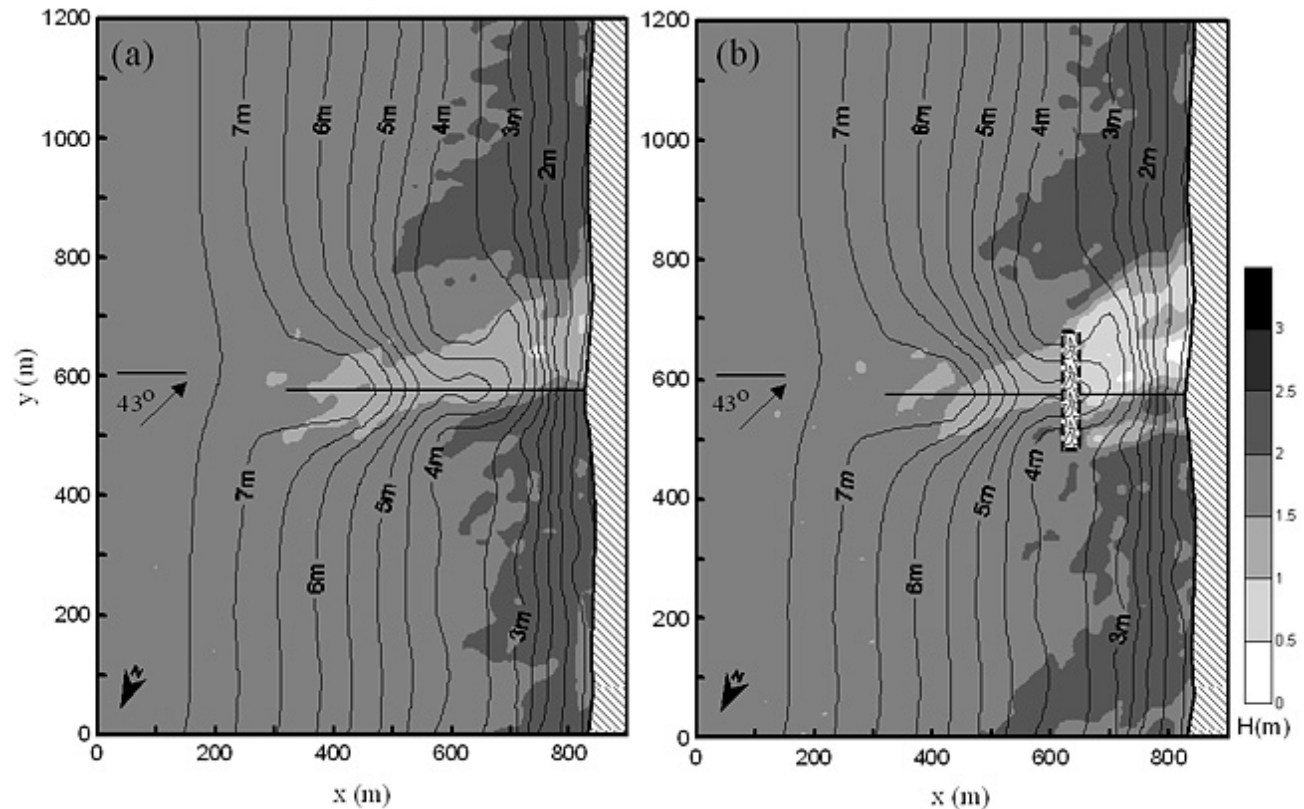


Fig. 5 Planar wave patterns (a) with and (b) without a permeable submerged breakwater on a complicated bathymetry at FRF coastal area, Duck, North Carolina, U.S.A. The line at the center represents the FRF pier.

In this paper, a numerical wave model has been developed for wave propagation over porous structures on the basis of a parabolic mild-slope equation, including wave-breaking and energy dissipation. The model is simple and it incurs a lower computational cost even when modeling large coastal areas. The validity of the present model is verified through comparisons with the experimental data for waves propagating over porous structures. The model is further applied to the real case of a submerged permeable breakwater on a complicated bathymetry.