INTEGRATED NONLINEAR INTERACTIONS AMONG SOLITARY WAVE, COMPOSITE BREAKWATER AND SEABED

Nagoya University, member, ○ Ayman M. Mostafa
Nagoya University, member, Norimi Mizutani

1. Introduction:

Composite breakwaters are very popular along the Japanese coast. The performance and stability of composite breakwaters are of major concern to the engineering profession. Oumeraci (1994) reported on the failure mechanism of some vertical breakwaters all over the world. The occurrence of seabed instability and the development of scour trenches at the offshore toe were found to be detrimental for the stability of the breakwater. Early research considered the interaction between linear/nonlinear waves and a composite breakwater (e.g., Mizutani and Mostafa, 1998), but less interest has been given to solitary waves. However, solitary waves can be utilised to provide good model for the extreme design wave conditions because they have the largest energy, impulse and run-up (Fenton and Rienecker, 1982).

In this work, a coupled BEM-FEM model and a poro-elastic FEM model are adapted to simulate the nonlinear interactions among a solitary wave, composite breakwater and seabed. The deformations of the wave and the porous media are presented at various wave phases and, finally, the possibility of seabed failure is examined. It has been found that solitary waves have the potential to cause a seabed failure in the vicinity of a composite breakwater.

2. Numerical Models:

The BEM-FEM model employs fully nonlinear potential and modified Navier-Stokes equations for the wave field and porous media, respectively. The numerical wave source has been adapted from previous work by the authors (Mostafa and Mizutani, 1997) to generate solitary waves. The water surface levels (η) and the horizontal velocity (U) at the wave-maker are computed using a second-order analytical solution. Small values of the time increment ($\Delta T<T/72$) and node spacing ($\Delta L<L/25$) are adopted to reproduce accurately the water surface along the wave tank, where T and L are the wave period and length, respectively. The model provides the wave deformations and the porous flow in a time marching scheme. The poro-elastic FEM model is based on Biot's equations and adopts an equivalent non-Darcy coefficient of permeability. It also uses the nonlinear wave pressure computed by the BEM-FEM model as a boundary condition along the interfaces between the wave and the porous media. The poro-elastic model outputs the displacement of solids, pore pressure and the dynamic stresses.

3. A Case Study

Computations have been made for a solitary wave of 3.0m incident height (H) and 20.0s period (T) in a water depth (h) of 15.0m. The composite breakwater is considered to have a rubble base of 8.0m height (d) over the sand seabed and 34.0m length (b). The breakwater has an infinite extent normal to the direction of wave propagation and, hence, the problem becomes a two dimensional one. The base has side slopes of 2:1 and is constructed of rubble stones having 50.0cm average diameter (D) and 45% porosity. To simplify the problem, the caisson has been considered to be high enough to reflect the waves without overtopping it. The sand bed is 16.0m thick (ds) and has porosity (m) and permeability (K) of 35% and 0.22cm/s, respectively. Values of the shear modulus (Gs and Gf) of the rubble base and seabed are considered as $10^8 N/m^2$ and $10^7 N/m^2$, respectively. The porewater is assumed to have air bubbles that produce a degree of saturation (Sr) ranging from 95% to 100% and the porewater compressibility is computed consequently.

4. Numerical Analysis:

The solitary wave interacts with the breakwater and deforms as it passes over the rubble base and again on its way back to the wave source. The solitary wave reaches a maximum elevation (η) over the SWL of 6.7m (2.23H) at the offshore face of the caisson, while the transmitted wave goes up to 0.64m (0.21H) at the onshore face (Fig.1), where t is the time. The water surface levels on both faces of the caisson are drown down after the solitary wave is reflected back to the offshore side due to nonlinear interactions with the breakwater.

The water velocity (Vs) at the seabed level offshore toe of the breakwater, X=0 at the offshore toe, is demonstrated to be very high and can wash away a great amount of sand particles (Fig.2). The water velocity is larger in the direction of the incident wave than in the opposite direction due to wave transmission to the onshore side. The formation of solitons is evident in the reflected wave profile and influences the velocity at the seabed for t/T>3.0. The pore pressure along the caisson base is high at the offshore side and is greatly damped towards the onshore side (Fig.3). Negative pressure is developed for t/T>3.0 because of draw down in water surface at the offshore face of the caisson.
The wave deformation and its induced pore pressure in the breakwater are presented at t/T=2.75 (Fig.4), where P is the pore pressure. The pressure gradient in the vertical direction inside the seabed is high at the offshore side while the pore pressure on the onshore side of the breakwater has a less gradient. The pore pressures on the onshore boundaries of the breakwater and seabed have significant magnitude.
Investigations have been conducted to test the possibility of seabed liquefaction/slip failure. It has been found that the dynamic stresses in the seabed may not cause liquefaction for the examined case, but slip failure may occur in the vicinity of the offshore toe. The solitary wave may cause a weak zone of nearly 3.1m depth ($Z_f/H \fallingdotseq 1.05$) at the offshore toe of the breakwater as shown in Fig.5. On the other hand, the seabed under the rubble base and at the onshore side may not suffer from tensile stresses for the tested wave conditions. Thus, it can be said that the sand bed at the offshore zone of the breakwater may be subject to slip failure due to tensile stresses or to suffer from scour by the high water velocity during the wave attack.

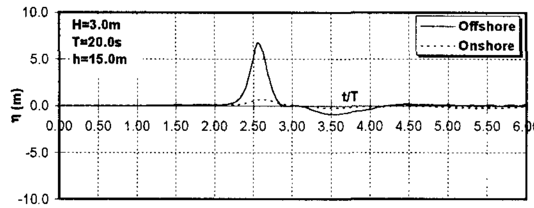

Fig.1 Water surface levels on both sides of a caisson

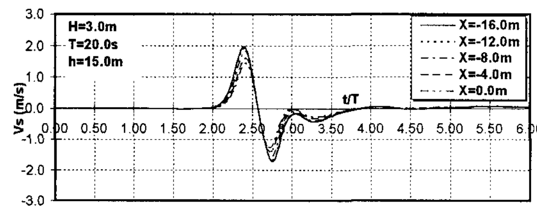

Fig.2 Water velocity at the seabed level offshore a caisson

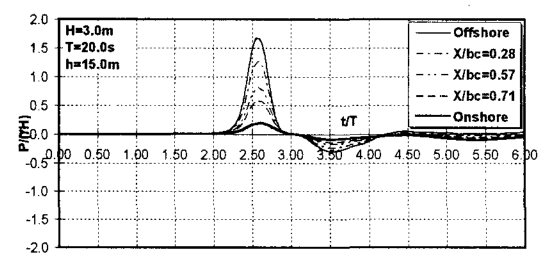

Fig.3 Pore pressure along the caisson base

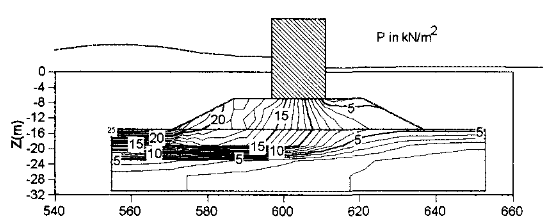

Fig.4 Wave field and pore pressure in the breakwater at t/T=2.75

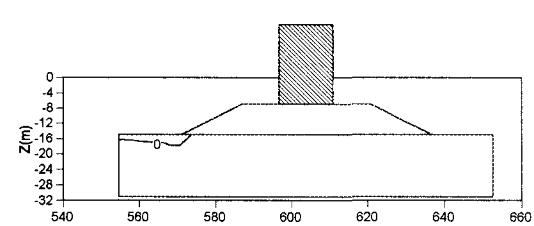

Fig.5 Maximum depth of tensile stresses (Z_f) at the offshore toe of a composite breakwater

5. References

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