Water Waves Trapping by Poroelastic Finite Plate over Undulated Seabed

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1. Introduction

In the recent decade, poroelastic plates and membranes are widely used to trap and dissipate incoming ocean waves to create a tranquility zone in harbor and marinas. These clam zones are used for loading and unloading marine vehicles in terminals, safe anchorage of small boats and ferries, etc. The use of flexible plate as VLFS (very large floating structure) and temporary wave barriers started in the 1990s, and various technologies are used further to improve the working mechanisms of these flexible floating plates. Although model tests were conducted to investigate the effect of the poroelastic plate to dissipate incoming wave energy, there will form a calm region in the lee side of the plate. The wave reflection and dissipation coefficients associated with the wave scattering will be analyzed for a variety of wave and structural parameters. It is observed that the poroelastic plate can act as an effective wave energy dissipator.

2. Mathematical Formulation

2.1. Physical problem and boundary value problem formulation

The schematic diagram of the physical problem is provided in Fig. 1. The same figure was available in Koley (2020) [9] (See Fig. 12). The poroelastic plate is finitely extended and floating over the undulated seabed, which is also finitely extended. Further, the plate is placed at a finite distance apart from the existing vertical rigid seawall, as shown in Fig. 1. The governing equation and boundary conditions associated with the aforementioned physical problem are the same as provided in Koley (2020) [9] except for the plate boundary conditions. It is to be noted that in Koley et al. (2020) [8], the flexible porous plate is considered, whereas, in the present study, a poroelastic plate is considered. Due to the presence of the poroelastic plate, the following

Keywords
- Trapping
- Poroelasticity
- Flexible Plate
- Wave Scattering

Abstract
In this paper, oblique wave trapping by a poroelastic floating plate is analyzed. The poroelastic horizontal plate is floating over an uniform bottom bed, finitely extended and positioned at a finite distance away from an existing rigid seawall. Due to the presence of the poroelastic plate, a major amount of incoming wave energy will be dissipated, and there will form a calm region in the lee side of the plate. The wave reflection and dissipation coefficients associated with the wave scattering will be analyzed for a variety of wave and structural parameters. It is observed that the poroelastic plate can act as an effective wave energy dissipator.
dynamic boundary condition holds on the plate
\[
\mathcal{B} \left( \frac{d^2}{dx^2} - k_p^2 \right) \zeta + (\rho g - \bar{m}_p \omega^2) \zeta = i \rho \omega \phi,
\]
where \( \mathcal{B} = \left( 1 - \frac{2Ev}{2 - v} \right) EI \) is the modified flexural rigidity due to the effect of poroelasticity property with \( E \) being the Young’s modulus. Here, \( \varepsilon \) is the plate porosity and \( v \) is the Poisson’s ratio. Further, \( EI = Ed^3/\left(12(1 - v^2)\right) \) with \( d \) being the thickness of the poroelastic plate. Moreover, \( \bar{m}_p = (1 - \varepsilon) \rho_p d \) is the modified uniform mass of the plate per unit length with \( \rho_p \) being the plate density. Now, the linearized kinematic boundary condition on the poroelastic plate is given by
\[
\frac{\partial \phi}{\partial n} = -i \omega \zeta - i k_G \phi,
\]
where \( G_0 \) is the porous-effect parameter which is a complex number (see Koley and Sahoo (2017)[10] for detailed derivations). This complex porous-effect parameter \( G_0 \) consists of two parts: resistance component which corresponds to the real part of \( G_0 \) and inertia component which corresponds to the imaginary part of \( G_0 \).

Now, to solve the physical problem as stated above, a coupled eigenfunction expansion and boundary element method can be used. Further, for the plate boundary discretization, a finite difference formula is applicable. The details are available in Koley (2020)[9], and the same is deferred here to avoid mere repetitions.

\[\begin{align*}
\text{Figure 1. Schematic diagram of the vertical cross-section of the physical domain} \\
\end{align*}\]

3. Results

The main aim of this study is to analyze the effectiveness of floating poroelastic plates to create a tranquility zone in the lee side of the plate region. In this regard, the three physical parameters associated with the wave scattering, such as reflection coefficient, transmission coefficient, and dissipation coefficient, are important to analyze. The values of the parameters are taken as follows: time period of the incident wave \( T = 8 \) sec, water depth of the left side uniform region \( h_1 = 20 \) m, water depth of the right side uniform region \( h_2 = 10 \) m, angle of incidence \( \theta = 30^\circ \), gravitational acceleration \( g = 9.81 \) m/s², water density \( \rho = 1025 \) kg/m³, Plate Young’s modulus \( E = 5 \) GPA, \( \rho_p / \rho = 0.9 \), Poisson ratio \( v = 0.3 \), plate length \( l/h_1 = 2.5 \), plate porosity \( \varepsilon = 0.3 \), porous-effect parameter \( G_0 \) with \( k_0^0 \) being the incident wavenumber, \( f \) and \( s \) are the friction and inertial coefficients respectively. The bottom profile for the present study is taken as sinusoidal in nature with the bottom profile as

\[
z = -d(x) = h_2 + \left( h_1 - h_2 \right) \left( 1 + 2 \left( \frac{x}{L} \right)^3 - 3 \left( \frac{x}{L} \right)^5 - \frac{a}{h_1 - h_2} \sin \left( \frac{2 \pi x}{L} \right) \right)
\]

where \( m \) and \( a \) are the number of ripples and ripple amplitude respectively. This type of bed profile often formed due to sediment transport near the shoreline areas.
plate, a calm zone can be created at the lee side of the plate.

Figure 3. Variation of (a) $K_r$ vs $(L_1 - L)/\lambda$ for various $a$ with $m = 5$ and (b) $m$ with $a = 2$.

Figs. 3(a) and (b) depict the variation of the reflection coefficient $K_r$ versus $(L_1 - L)/\lambda$ for various values of (a) bottom bed ripple amplitude $a$ and (b) number of ripples $m$ for sinusoidally varying profile. It is seen in both the figures that the variation of $K_r$ is oscillatory and periodic in nature with the variation in $(L_1 - L)/\lambda$. It is further observed that $K_r$ is less for higher ripple amplitude. The reason behind this phenomena is that a part of the wave energy is reflected from the bottom bed and dissipated further in presence of the porous plate. Moreover, no significant variations in $K_r$ is observed for variation in number of ripples $m$ of the bottom bed profile.

4. Summary

The wave scattering due to the presence of floating poroelastic plate over undulated seabed is analyzed. The results demonstrate that with the appropriate positioning of the poroelastic plate, the wave reflection can be reduced drastically. Further, with proper values of the porous-effect parameter, the free surface elevation in the lee side of the poroelastic plate can be reduced significantly. Moreover, the variation in ripple amplitude and ripples number have a significant effect on the wave reflection. In summary, it can be concluded that proper positioning of the poroelastic plate with appropriate structural configuration can create a tranquility zone in the lee side of the plate region.

Declaration of Conflict of Interests

The author declares that there is no conflict of interest. They have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References