PAPER FOR THE YOUNG SCIENTIST AWARD (Fluid Mechanics)

Wave Interactions with Submerged Porous Structure

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1. ABSTRACT

The purpose of this study is to investigate the scattering of oblique water waves by a thick porous structure immersed in a fluid of finite depth. The small amplitude water wave theory is used, and the Sollit and Cross model is used to describe the flow past porous structure. To solve the resulting boundary value problem, the matched eigenfunction expansion method utilizes and reduces it to a system of linear algebraic equations. The system is then numerically solved and the values of important quantities like water wave elevation, reflection, transmission and dissipation coefficients are obtained and plotted through different graphs. It has been found that as the porous structure's frictional coefficient grows, the water elevation, reflection and transmission coefficients decrease and the dissipation coefficient rises. This innovative structure could be helpful for creating unrestricted safe navigation channels or harbors in natural environments with unstable soil at the bottom and significant water depth, where the complete and partial porous structures may not be helpful.

2. INTRODUCTION

In recent times, there has been considerable enthusiasm for study on porous breakwaters. These structures are commonly employed to create a tranquil area in the sea to facilitate the movement of anchored or maneuvering ships, as well as safeguard cargo and passenger activities conducted in close proximity (see [1]-[3]). Many researchers study the interaction of water waves with rectangular porous structures (both complete and partial porous structures) with finite width, such as rubble-mound breakwaters, by using Sollit and Cross model (see [4]-[5]). In this study, we propose to investigate the efficacy of a fully submerged rectangular porous structure with a finite width that is neither bottom-standing nor surface-piercing. Such a structure would be a novel addition to the breakwater types and could provide solutions to various ocean engineering challenges.

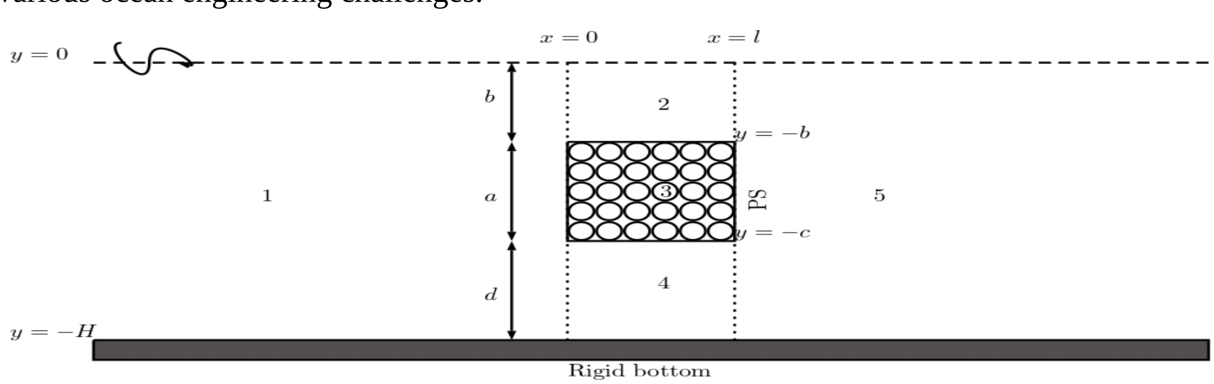

Figure-1 Schematic of the Problem

2. MATHEMATICAL FORMULATION

The porous structure is kept as in Figure-1. The fluid is assumed to be incompressible, inviscid and the flow is irrotational and simple harmonic in time with angular frequency ω. The incident wave is assumed to propagate along the x-axis with an angle θ. The potential function in the z-direction is selected to be harmonic throughout. Then in each region j there exists the velocity potential of the form $\Phi_j(x,\ y,\ z,\ t)\ =\ Re\{\varphi_j(x,\ y)e^{(i(\boldsymbol{\nu}z\ -\ \omega t))}\}$ satisfying

$(\frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} - \nu^2)\varphi_j = 0$ in each region j=1,2,3,4 and 5 (1)

$\varphi_{jy} = 0$ at y=-H for j=1,4 and 5 (2)

$\varphi_{jy} - K\varphi_j = 0$ at y=0 for j=1,2 and 5 (3)

$\varphi_1 = \varphi_2$ and $\varphi_{1x} = \varphi_{2x}$ at x=0, -b<y<0 (4)

$\varphi_1 = (m + if)\varphi_3$ and $\varphi_{1x} = \epsilon\varphi_{3x}$ at x=0, -c<y<-b (5)

$\varphi_1 = \varphi_4$ and $\varphi_{1x} = \varphi_{4x}$ at x=0, -b<y<-H (6)

$\varphi_5 = \varphi_2$ and $\varphi_{1x} = \varphi_{2x}$ at x=l, -b<y<0 (7)

$\varphi_5 = (m + if)\varphi_3$ and $\varphi_{5x} = \epsilon\varphi_{3x}$ at x=l, -c<y<-b (8)

$\varphi_5 = \varphi_3$ and $\varphi_{5x} = \varphi_{4x}$ at x=l, -b<y<-H (9)

$\varphi_2 = (m + if)\varphi_3$ and $\varphi_{2x} = \epsilon\varphi_{3x}$ at y=-b, 0<x<l (10)

$\varphi_4 = (m + if)\varphi_3$ and $\varphi_{4x} = \epsilon\varphi_{3x}$ at y=-c, 0<x<l (11)

$\varphi_1(x,y) = \frac{\cosh k_0(y+H)}{\cosh k_0 H}\{e^{ik_{0x}x} + R_0 e^{-ik_{0x}x}\}$ as $x \to -\infty$ (12)

$\varphi_5(x,y) = \frac{\cosh k_0(y+H)}{\cosh k_0 H}\ T_0 e^{ik_{0x}(x-l)}$ as $x \to \infty$ (13)

where ν is the z -component of the wave number k_0, $\sqrt{k_0^{\ 2} - \nu^2}$, $\nu = k_0 sin\theta$, $K = \frac{\omega^2}{g}$, and m, f and ϵ are the inertial coefficient, frictional coefficient and porosity of the porous structure, respectively. $R_0$and $T_0$are corresponding to the reflection and transmission coefficient to be determined.

3. METHOD OF SOLUTION

To get the solution of the problem, the method of separation of variables followed by eigenfunction expansion in each region is applied. By using the matching conditions (4) to (11) and the orthogonality of eigenfunction gives rise to a system of equations, which is solved numerically to determine unknown constants.

3. RESULTS AND CONCLUSIONS

From Figure-2, it is observed that when the porosity and frictional factor of the porous structure grow, water elevation decreases. Figure-3 depicts that when the frictional factor of the porous structure grows, wave reflection and transmission decrease and the wave energy dissipation rises. The effects of additional factors such as the length, width and position of the porous structure have been studied and will be presented at the conference.

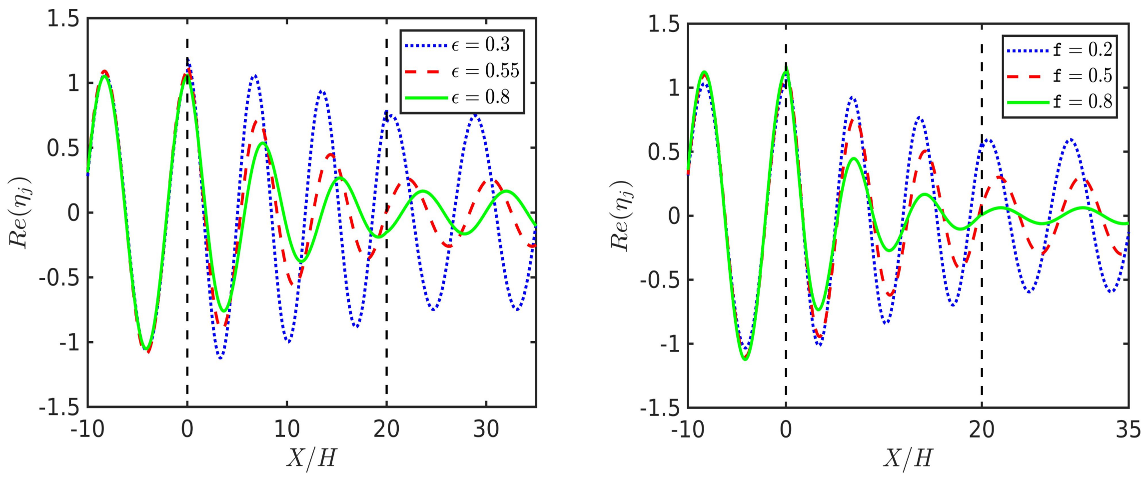

Figure-2: water elevation Re(η_j) for (a) f = 0.2, 0.5, 0.8 and (b) ε = 0.3, 0.55, 0.8.

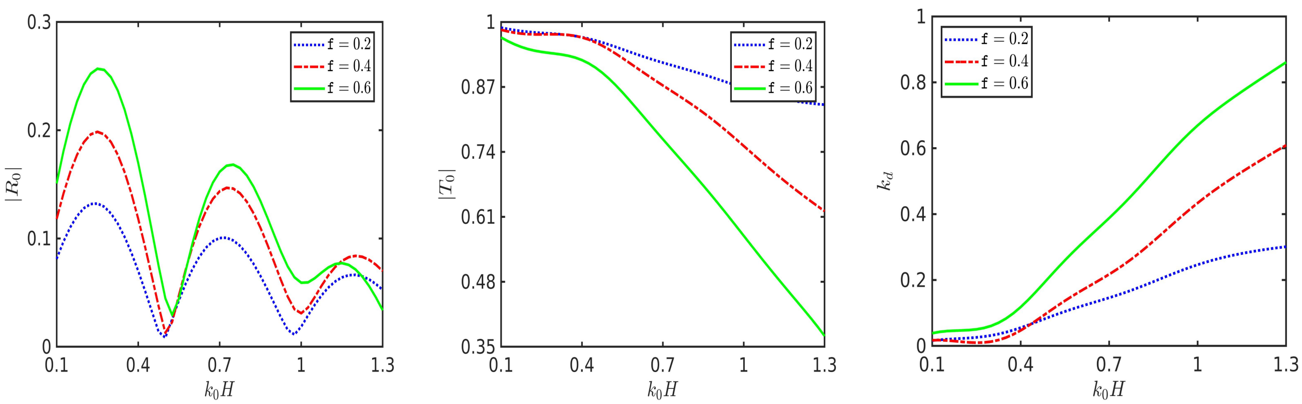

Figure-3: $|R_0|$, $|T_0|$ and k_d vs k_0H for f = 0.2, 0.5, 0.8.

REFERENCES

1. A. T. Chwang, A porous-wavemaker theory. Journal of Fluid Mechanics, 132:395–303 406,1983.
2. T. Sahoo, M. Lee and A. T. Chwang, Trapping and generation of waves by vertical343 porous structures. Journal of engineering mechanics, 126(10):1074–1082, 2000.
3. S. Neelamani, and R. Rajendran, Wave interaction with 'T'-type breakwaters. Ocean333 Engineering, 29(5):561–589,2002.
4. C. K. Sollitt, and R. H. Cross, Wave transmission through permeable breakwaters.356 In Proceedings of 13th international conference on Coastal engineering, ASCE, New York, pages 1827–1846, 1972.
5. G. Sahoo, S. Singla and S. C. Martha, Scattering of oblique water waves by thick porous structure and thin elastic plate. Ocean Engineering, 248:110526, 2022.