OBLIQUE WATER WAVES IMPACTING ON A THIN POROUS WALL WITH PARTIAL-SLIPPING BOUNDARY CONDITION

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The problem of water wave interacting with porous media has been studied by many investigators. For oblique water waves impacting on a porous structure, Dalrymple et al. (1991) used the slipping condition of potential theory. However, it is found that when the incoming water wave is parallel to a porous breakwater, no matter how large the porosity of the porous wall is, the water wave permeates through completely. This phenomenon can also be found in all the other earlier studies, like Sahoo et al. (2000).

In order to eliminate the paradoxical phenomenon of waves obliquely impacting on the porous wall, we therefore do not follow the slipping boundary condition strictly, but to derive a new partial-slipping boundary condition similar to that in Beavers and Joseph (1967). According to this concept, obliquely incoming wave does not always permeate through the porous wall in normal direction, but propagates with a certain degree of angle.

Since the porous wall is extremely thin, we don't need to be concerned about the refractive angle and may regard the wave direction as unchanged when it permeats into the thin porous wall. In the present study, a new partial-slipping boundary condition which can remedy the above mentioned paradoxical phenomenon as $\theta = 90^\circ$ is proposed based on the concept that θ remains unchanged if the water wave permeates through the thin porous wall.

For the oblique incoming wave, the partial-slipping boundary condition is derived and obtained as follows:

$$\left.\frac{\partial \phi_1}{\partial x}\right|_{\left(-\frac{d}{2},y,z+\frac{d}{2}\tan\theta\right)} = \left.\frac{\partial \phi_2}{\partial x}\right|_{\left(\frac{d}{2},y,z-\frac{d}{2}\tan\theta\right)} = \frac{n_0}{d}\frac{iR}{1-iR}\left(\phi_1\Big|_{\left(-\frac{d}{2},y,z+\frac{d}{2}\tan\theta\right)} - \phi_2\Big|_{\left(\frac{d}{2},y,z-\frac{d}{2}\tan\theta\right)}\right)\cos^2\theta. \tag{1}$$

It is observed that when $\theta = 90^\circ$, there will be no normal velocity on each side of the porous wall.

And it can also be shown by figures that with the increase of θ, the reflection coefficient C_r smoothly approaches to 1, while the transmission coefficient C_t approaches to 0. It is clearly concluded that as water wave is parallel to a thin porous wall, the transmitted wave side remains quiescent, i.e. the transmitted wave side does not have wave energy ($C_t = 0$), while the energy is all captured in the incoming wave side ($C_r = 1$).

Therefore, when applying our new boundary condition, the paradoxical phenomenon has disappeared and the transmitted wave is more reasonable than the one following potential theory strictly.

It is interesting to see the viscous boundary layer effect by investigating the rotational parts of solutions near the thin porous wall. Song & Huang (2000) proposed eight physical quantities that should be continuous at porous interfaces. Only four of those are used here to construct proper boundary conditions. They are normal fluid stress, normal fluid flux, tangential fluid stress, and tangential fluid velocity.

The viscous boundary layer effect is also investigated, which provides proper boundary conditions on the thin porous wall for viscous flow and gives more detailed flow information.

Furthermore, since our proposed partial-slipping condition, instead of slipping condition of potential theory, is applied on wall surfaces for potential flow analysis, the viscous effect can be confined within the extremely thin boundary layer on the porous wall.

By using figures of vertical distribution of normal and tangential velocity amplitudes on the thin porous wall for demonstration, it is thus obtained that when one side of a thin porous wall is affected by a parallel water wave, there is no wave penetrating into the other side, which agrees with physical expectation.

In conclusion, based on the reason similar to that in Beavers and Joseph (1967), the present study derives a new partial-slipping boundary condition on the interfaces of the porous wall. And it is found that by applying our partial-slipping boundary condition, the present study indeed eliminates the unreasonable phenomenon that the water wave permeates completely into the original quiescent water field when its incoming direction is parallel to the porous wall. Moreover, the viscous boundary layer effect is also investigated in this study, which provides proper boundary conditions for viscous flow and provides more detailed flow information.

Since the thickness of porous structures are extremely small compared to the wavelength, a more reasonable wave trapping analysis of harbor structure with wave direction taken into account can be expected by applying the concept of this study.

Keywords: Oblique linear water wave; Thin porous wall; Partial-slipping boundary condition; Boundary layer.