Diffraction and radiation problems of a floating barge in front of a partial reflecting wall

Bin Teng[*,a], Ziqi Li[b], Ying Gou[b], Hongyuan Shi[a], Yanni Li[a]

a) School of Hydraulic and Civil Engineering, Ludong University, China
b) State Key Laboratory of Coastal and Offshore Engineering, Dalian University of Technology, China
*Corresponding author e-mail address: bteng@dlut.edu.cn (B. Teng).

1 INTRODUCTION

Perforated structures are widely used coastal structures to provide protection for ports and docks for ship loading and unloading. The presence of a wharf or breakwater beside a body will makes the incident and scattered waves be reflected between the body and the wall continuously. Thus, the resonance phenomenon may occur at some special frequencies. Accordingly, the hydrodynamic problem is more complex to be computed. Teng et al. (2023) and Teng et al. (2025) proposed a reduction mirror image method to treat the partial reflection condition, and derived the diffraction and radiation solutions for a uniform cylinder in front of a partial reflecting vertical wall by eigenfunction expansion method.

In this work, the reduction mirror image method is extended for the diffraction and radiation problems of arbitrary 3D bodies in front of a partial reflecting vertical wall. The integral equation method is applied to solve the wave diffraction and radiation problems. Numerical examination is carried for a rectangular barge in front of a partial reflecting wall. The numerical results show that the exciting wave force and the hydrodynamic coefficients oscillate with the wave number, and the oscillation amplitudes decrease with decreasing the reflecting coefficient of the wall. For a solid wall the exciting force and the hydrodynamic coefficients have large peaks at the resonance frequency of the gap between the barge and the wall. With applying partial reflecting wall, the peaks of exciting wave force and hydrodynamic coefficients can be reduced greatly.

2 BOUNDARY ELEMENT METHODS FOR 3D BODIES IN FRONT OF A PARTIAL REFLECTION WALL

Consider the diffraction and radiation problems of an arbitrary 3D body arranged in front of an infinite-long vertical wall with a partial reflection coefficient $R = K_R e^{i\sigma}$. Without losing generality we assume the fluid domain and the body is on the left-hand side of the wall. A right-handed Cartesian coordinate systems *Oxyz* is established, with its origin at the intersection of the wall and the free surface. The *x*-axis directs rightward, the y-axis is along the wall and the positive *z*-axis is vertically upwards, as shown in Fig. 1. The body center is located at (-*B*, 0).

As usual, we divide the total complex wave potential into the incident potential ϕ_0 , the diffraction potential ϕ_7 and the radiation potentials $\phi_j\,(j = 1, 2, ..., 6)$. These velocity potentials must satisfy the free surface condition, the body surface condition, the far field condition, and the partially reflecting wall condition. At the nearby of the partial reflecting wall, we further divide the wave potential ϕ_j (j=0,1,…,7) into the incident component $\phi_j^{(R)}$ to the wall and the reflection component $\phi_j^{(L)}$ from the wall. The reflecting wave component and the incident component should satisfy the following relationships at the wall:

$$\begin{cases} \phi_j^{(L)}(x,y,z) = R\,\phi_j^{(R)}(x,y,z) \\ \dfrac{\partial\phi_j^{(L)}(x,y,z)}{\partial x} = -R\,\dfrac{\partial\phi_j^{(R)}(x,y,z)}{\partial x}, \end{cases} \quad j=0,1,2,...,7, \quad at\ x=0 \tag{1}$$

where R is the reflecting coefficient of the wall.

To satisfy the partial reflecting condition at the vertical wall (x=0), the total incident potential is defined in the fluid domain (x<0) as

$$\phi_0(x,y,z) = -\frac{\mathrm{igA}}{\omega}\frac{\cosh k(z+d)}{\cosh kd}\mathrm{e}^{\mathrm{i}k_y y}(\mathrm{e}^{\mathrm{i}k_x x} + R\mathrm{e}^{-\mathrm{i}k_x x}) \tag{2}$$

where d is the water depth, A the amplitude of the incident wave and k the wave number, which satisfies the dispersion equation $\omega^2 = gk\tanh kd$ with the wave frequency ω. $k_x = k\cos\beta$ and $k_y = k\sin\beta$ are the wave number components in the x and y directions, where β is the wave incident angle relative to the x-axil.

Applied the reduction mirror image method (Teng et al, 2023, 2025), the wave diffraction and radiation problems of a body in front of a partial reflecting wall can be substituted by the analogy of the diffraction and radiation problems of the body S_B and its image S_b about the Oyz plan in the infinite domain, as sketched in Fig. 2. The scattering potential $\phi_j(\mathbf{x})$ (j=1,2,…,7) and its normal derivation $\partial\phi_j(\mathbf{x})/\partial n$ on the image surface S_b are described as the R time reductions of the corresponding terms on the body surface S_B at the symmetric position, i.e.

$$\begin{cases} \phi_j(x,y,z)|_{S_b} = R\phi_j(-x,y,z)|_{S_B} \\ \dfrac{\partial\phi_j(x,y,z)}{\partial n}|_{S_b} = R\dfrac{\partial\phi_j(-x,y,z)}{\partial n}|_{S_B} \end{cases} \tag{3}$$

where R is the reflection coefficient of the partial reflecting wall.

With application of the wave Green function, the integral equations for the scattering potentials of the analogy problem can be derived as

$$\alpha\phi_j(\mathbf{x}_0) = \int_{S_B+S_b}\frac{\partial G(\mathbf{x};\mathbf{x}_0)}{\partial n}\phi_j(\mathbf{x})ds - \int_{S_B+S_b}G(\mathbf{x};\mathbf{x}_0)\frac{\partial\phi_j(\mathbf{x})}{\partial n}ds, \quad j=1,.2,..,7 \tag{4}$$

where α is the free term coefficient, which is a function of body geometry.

Taking the relationship between the scattering potentials and their normal derivatives on the imagery body surface S_b and the body surface S_B, as Eq. (3), the above integral equation can be written as

$$\begin{aligned} \alpha\phi_j(\mathbf{x}_0) = &\int_{S_B}\frac{\partial G(\mathbf{x};\mathbf{x}_0)}{\partial n}\phi_j(\mathbf{x})ds + R\int_{S_b}\frac{\partial G(\mathbf{x};\mathbf{x}_0)}{\partial n}\phi_j(\hat{\mathbf{x}})ds \\ &-\int_{S_B}G(\mathbf{x};\mathbf{x}_0)\frac{\partial\phi_j(\mathbf{x})}{\partial n}ds - R\int_{S_b}G(\mathbf{x};\mathbf{x}_0)\frac{\partial\phi_j(\hat{\mathbf{x}})}{\partial n}ds, \quad j=1,.2,..,7 \end{aligned} \tag{5}$$

where $\hat{\mathbf{x}} = (-x,y,z)$ represent the symmetric position of (x,y,z) about the plan Oyz.

As the image body S_b and the original body S_B are symmetrically arranged about the y axil, we discretized the image body surface S_b with the symmetric mesh of the original body S_B. Thus, only the potentials on the original body need to be determined. After solving the potentials on the body surface, the exciting wave force, added mass and radiation damping of the body can be obtained by integration of the potentials over the body surface.

NUMERICAL RESULTS FOR A FLOATING BARGE

To examine the influence of a partial reflection wall on the hydrodynamic property of a floating body in front of it, a floating rectangular barge with a width of $2a$, a length of $2L/a$=6 and a draft of T/a=1 is computed. The water depth is taken as d/a=2. The long side of the barge is parallel to the y-axis. The distances between the barge center and the wall are selected as B/a=2.0 and 1.2 (or the gap width between the barge and the wall is e/a=1.0 and 0.2), respectively.

Fig. 3 shows the variation of the sway forces, the force component in the x-direction, on the barges arranged at B/a=2.0 and 1.2 under the action of normal incident waves. It can be seen that the sway forces firstly increase with increasing dimensionless wave number ka and begain to decrease oscillatingly after reaching their maximums. The maximum and its occurring frequency increase with decreasing the gap width between the barge and the wall. With decreasing the reflection coefficient of the wall the peak and oscillation amplitude can be decreased quickly.

Fig. 4 shows the variation of the heave force on the barge, the force component in the z direction, under the action of normal incident waves with the dimensionless wave number ka. It can be seen that at low frequency the heave force increases with the reflection coefficient of the wall. When the reflection coefficient R=1.0, the heave force can be doubled. With increasing wave number, the heave force begain to deacrease oscillatingly. When the gap is narrow, the second peak can appear.

More results on wave force, added mass and radiation damping coefficients will be presented on the workshop.

CONCLUSIONS

From the examination, the following conclusions can be obtained:

1. The exciting wave force and the hydrodynamic coefficients on a body in front of a partial reflecting wall usually oscillate with the wave number, and the oscillation amplitude decreases with decreasing the reflection coefficient. For a rectangular barge, the exciting wave force and the hydrodynamic coefficients change quickly at the wave number corresponding to the gap resonance frequency.
2. With decreasing the reflection coefficient of the wall, the gap resonance influence on the exciting wave force and hydrodynamic coefficient can be reduced quickly. It is an effective measure to keep ships steady by applying a partial reflecting wall as the wharf.

ACKNOWLEDGMENTS

The work was supported by National Natural Science Foundation of China (No. 52271261, 52371266).

REFERENCES

[1] *Teng, B., Su, G., Gou, Y., Chen, L., 2023. Eigenfunction expansion solution for wave diffraction from a uniform cylinder in front of a partially reflective wall. Ocean Eng. 287, 115924.*

[2] *Teng, B., Li, Z.Q., Gou, Y., 2025. Eigenfunction expansion solution for the radiation problem of a uniform cylinder in front of a partially reflective wall. Ocean Eng. 315, 119854.*

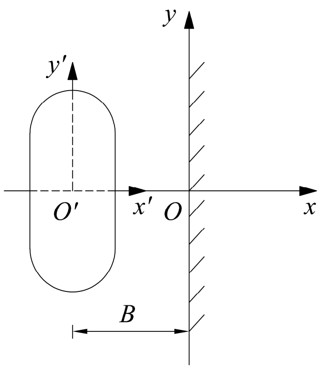


Fig. 1 Sketch of a body in front of a partial reflecting wall.

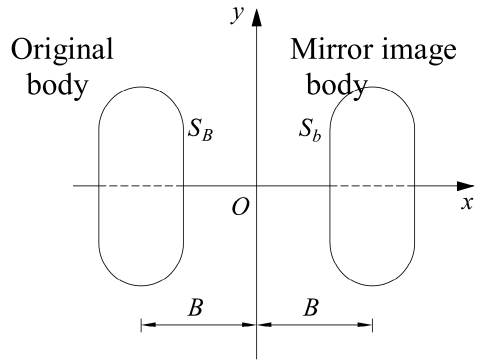
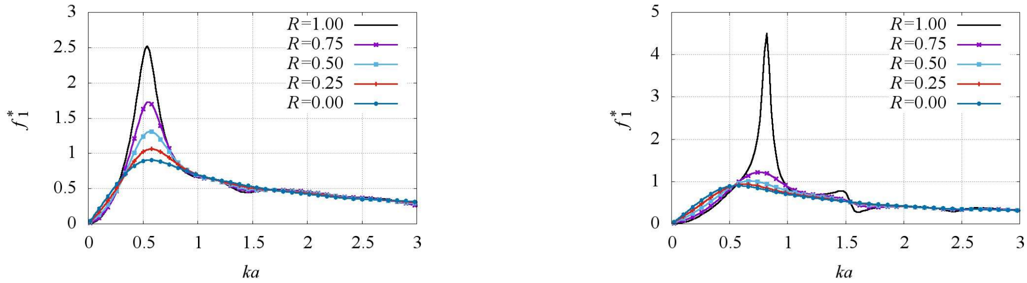


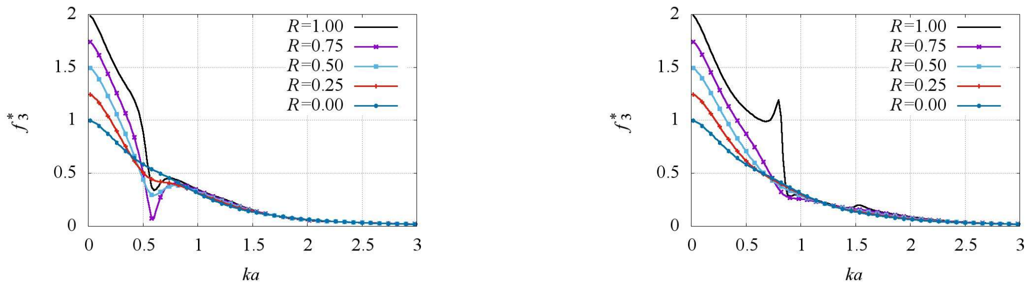
Fig. 2 Analogy to the wave diffraction and radiation from the body and its image in open water



(a) B/a=2.0

(b) *B/a*=1.2

Fig. 3 The *x*-direction wave force $f_x / 4\rho gAaL$ on a floating barge in front of a partial reflecting wall.



(a) B/a=2.0

(b) *B/a*=1.2

Fig. 4 The *z*-direction wave force $f_z / 4\rho gAaL$ on a floating barge in front of a partial reflecting wall.