The 2021 World Congress on
Advances in Structural Engineering and Mechanics (ASEM21)
GECE, Seoul, Korea, August 23-26, 2021

Non-matching mesh treatment in hydro-elastic analysis of floating structures

*Moonsu Park1), Phill-Seung Lee2)

1), 2) Department of Mechanical Engineering, Korea Advanced Institute of Science and Technology
1) uhsa00@kaist.ac.kr
2) plee@kaist.ac.kr

ABSTRACT

In this paper, we introduce an effective treatment method for non-matching meshes in hydro-elastic analysis of floating structures. A floating structure is modeled using the finite element method and the external fluid is modeled using the boundary element method. In general, the wet surface mesh of the floating structure should match with free surface and remeshing is inevitably required. If hydro-elastic analysis of floating bodies is performed with various loading conditions, it is necessary to modify the mesh for every loading condition. Of course, remeshing requires time and effort. To avoid this problem, a non-matching mesh treatment method is developed. Hydro-elastic analysis considering various loading conditions is possible without remeshing. The effectiveness of the proposed method is shown through numerical problems.

1. INTRODUCTION

For a long time, hydro dynamic analysis has been performed using the assumption that floating bodies are rigid. However, as the size of the floating body increases, the natural frequency of the floating body decreases, and accordingly, the probability of encountering the natural frequency with wave in water increases. Accordingly, interest in hydro-elasticity is increasing

Several researchers have developed a direct coupling method, which the structural and fluid equations are directly coupled with each other, and the coupled equations are solved simultaneously for beam and plate structures (Khabakhpasheva and Korobkin 2002, Wang and Meylan 2006, Eatock Taylor 2007). The direct coupling method was extended

---

1) Graduate Student
2) Professor

for 3D floating structures (Kim et. al. 2013, Kim et. al. 2014, Yoon et. al. 2014, Lee et. al. 2015, Yoon et. al. 2017), in which shell finite elements was employed to model the structures.

In a numerical model for hydro dynamic analysis, the wet surface mesh of the floating structure should match with free surface. Remeshing is required when loading conditions change. This study a numerical method than can consider various loading conditions without remeshing. A special numerical integration method is applied to treat the non-matching mesh between structural mesh and free surface.

2. Direct coupling method

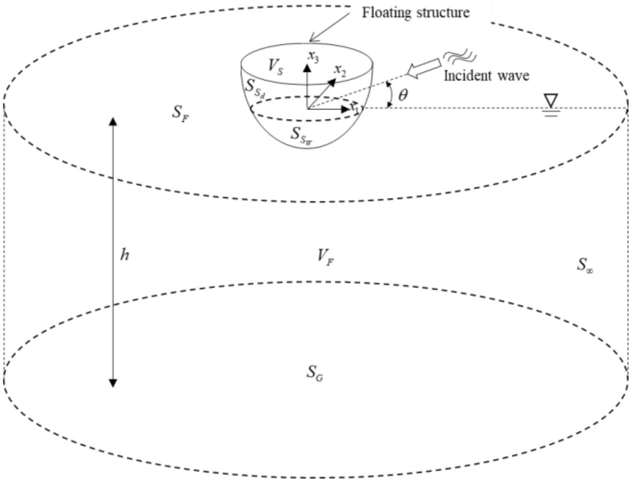


Fig. 1 Schematic of a floating structure

Fig. 1 represents the hydro dynamic problem considered in this study. It is assumed that the floating structure has a homogeneous, isotropic, and linear elastic material and the fluid flow is incompressible, inviscid, and irrotational. The potential flow theory is employed. An incident regular wave comes from the positive x_1 direction with an angle θ and the amplitude is assumed to be small enough to use the linear wave theory.

The volume of the floating structure is denoted by V_s, and V_F represents the volume occupied by external fluid. The surface of the floating structure S_s is divided into dry and wet surfaces, S_{Sd} and S_{Sw}, respectively. The fluid domain is surrounded by the wet surfaces, free surface, the bottom surface, and the surface which is a circular cylinder with a sufficiently large radius R denoted by S_{Sw}, S_F, S_G, and S_∞, respectively.

For the problem, the following coupled equations are obtained (Kim et. al. 2013)

$$P_D = -j\omega\rho_w\phi, \tag{1}$$

$$\omega^2 \int_{{}^0V_s} {}^0\rho_s u_i \bar{u}_i dV + \int_{{}^0V_s} C_{ijkl} e_{kl} {}^0e_{ij} dV + \int_{{}^0V_s} {}^0\sigma_{ij} \bar{\eta}_{ij} dV$$
$$-\int_{{}^0S_{S_w}} \rho_w g u_3 {}^0u_i \bar{u}_i dS - \int_{{}^0S_{S_w}} \rho_w g\, {}^0x_3\, {}^0n_j \mathrm{F}_{ij} \bar{u}_i dS - j\omega \int_{{}^0S_{S_w}} \rho_w \phi g\, {}^0n_j \bar{u}_i dS = 0 \tag{2}$$

$$\alpha \int_{{}^0S_{S_w}} \phi \bar{\phi} dS - \int_{{}^0S_{S_w}} \left(\frac{\partial G}{\partial n_\xi} \phi - j\omega G u_i n_i \right) dS_\xi \bar{\phi} dS_x = 4\pi \int_{{}^0S_{S_w}} \phi^I \bar{\phi} dS\,. \tag{3}$$

The finite element method is employed for the floating structure and the boundary element method is used for the external fluid. The discretized coupled equations for the steady state 3D hydro-elastic problems can be written as follow:

$$\begin{bmatrix} -\omega^2 \mathbf{S}_M + \mathbf{S}_K + \mathbf{S}_{KN} - \mathbf{S}_{HD} - \mathbf{S}_{HN} & j\omega \mathbf{S}_D \\ j\omega \mathbf{F}_G & \alpha \mathbf{F}_M - \mathbf{F}_{Gn} \end{bmatrix} \begin{bmatrix} \hat{\mathbf{u}} \\ \hat{\phi} \end{bmatrix} = \begin{bmatrix} 0 \\ 4\pi \mathbf{R}_I \end{bmatrix}. \tag{4}$$

2. Non-matching mesh treatment

Fig. 2 represents wet surface changes by loading conditions. When the mesh matches with the free-surface, as shown in Fig. 2(a), it is easy to discretize the structural wet and dry surfaces by locating all wet nodes at the free surface. However, as shown in Fig. 2(b), when the mesh and free-surface are not matched, remeshing is required in general.

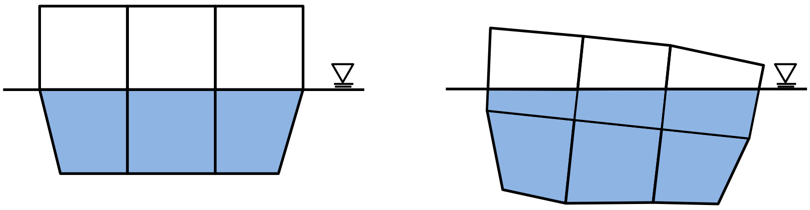


Fig. 2 Wet-surface change of the meshes:
(a) Matching mesh and (b) Non-matching mesh.

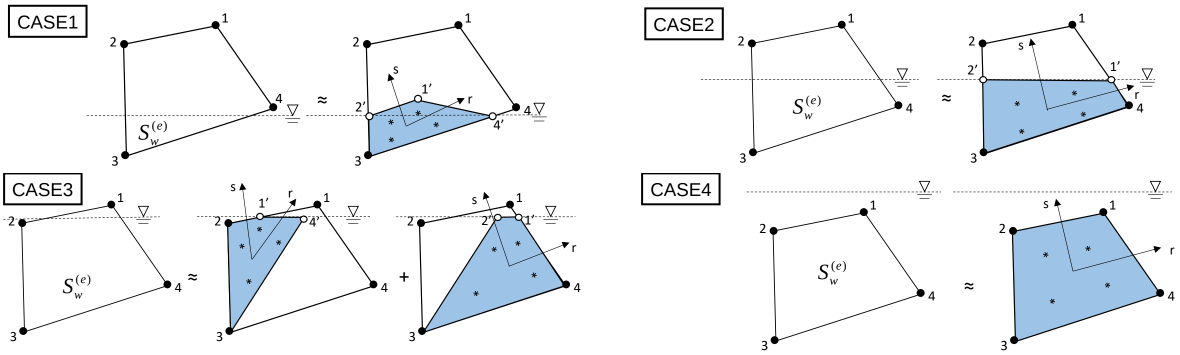


Fig. 3 Numerical integration method

To handle the non-matching mesh problem without remeshing process, an effective numerical integration technique is applied for 4-node elements s shown in Fig. 3 (Lee et. al. 2016). In this case, the terms $\mathbf{S}_{\mathbf{HD}}, \mathbf{S}_{\mathbf{HN}}$, $\mathbf{S}_{\mathbf{D}}$, $\mathbf{F}_G$, $\mathbf{F}_{Gn}$, $\mathbf{F}_M$, and $\mathbf{R}_I$ in Eq.(4) can be integrated over the wet-surfaces using the special numerical integration method.

3. Numerical example

The proposed method is applied to a whole ship model with 2 different loading conditions to verify the method. The ship structure is modeled using shell finite elements as shown in Fig. 4, and the loading conditions are represented in Fig. 5. The total number of elements used is 15,026 and the total degree of freedom is 57,585.

The density of the external fluid ρ_w is 1,000 kg/m^3 and the water depth h is assumed to be infinite. The gravitational acceleration g is 9.8 m/s^2. Wave periods from 8.0 to 26.0 s with a constant increment (ΔT = 1s) are considered. Using elastic modulus E = 210GPa, and Poisson's ratio ν = 0.3, the hydro-elastic analysis is carried out. Fig. 6 shows the numerical results. To investigate the effect of hydro-elasticity, we also plot the numerical results of the proposed formulation for the rigid body case.

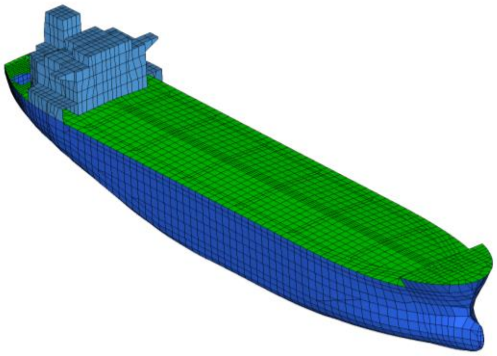
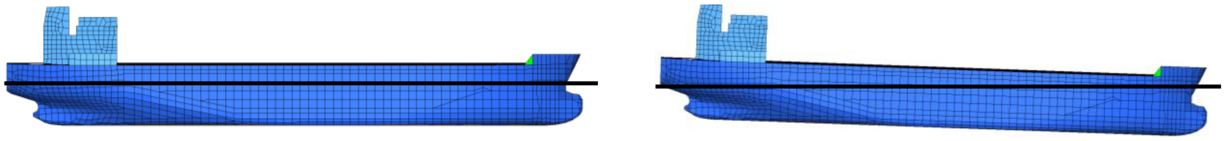


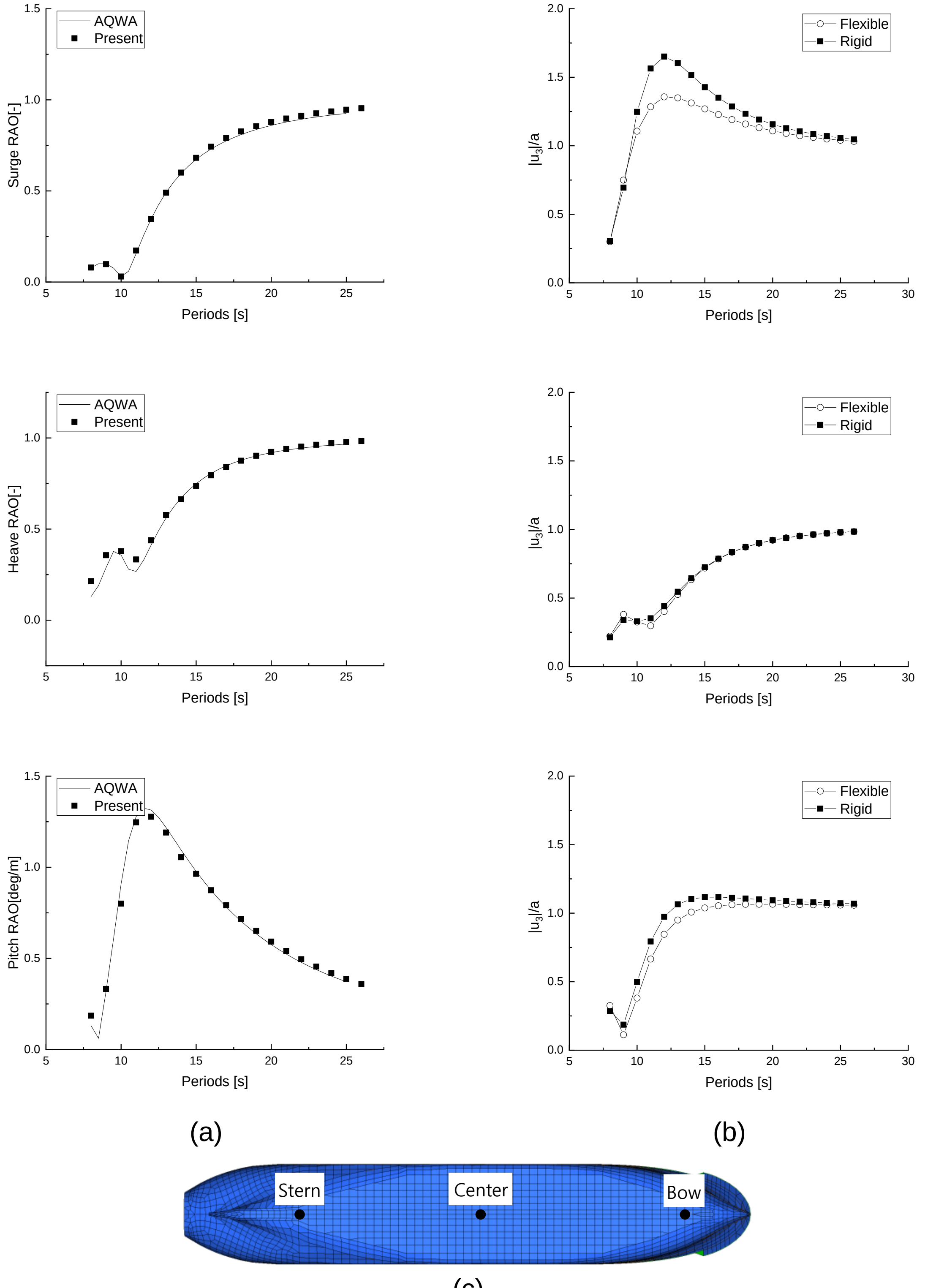
Fig. 4 Whole ship FE model



(a) (b)

Fig. 5 Loading conditions: (a) Even trim (LC01) and (b) bow trim (LC02).

All the results obtained from the present formulation and ANSYS AQWA are in good agreement. However, unlike the higher-order method used in ANSYS AQWA, a bilinear interpolation is employed in the present discretization. Small differences can be observed.



(a) (b)

(c)

Fig. 6 RAOs of the rigid motion: (a) surge, heave, and pitch motion, (b) vertical displacements at the bottom of the whole ship located at (c) stern, center and bow

4. Conclusions

We proposed a method for the hydro-elastic analysis considering various loading conditions without remeshing. The special numerical integration method is adopted to treat the non-matching mesh problem. The proposed method is verified through numerical examples. It can be applied to the hydro-elastic analysis using whole ship models. In the future, we will extend this study to 3-node elements (Lee et. al. 2004, Lee et. al. 2012, Jeon et. al. 2014, Lee et. al. 2014, Jeon et. al. 2015).

Acknowledgments

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIT) (No. NRF- 2018R1A2B300532814) and was also supported by “Human Resources Program in Energy Technology” of the Korea Institute of Energy Technology Evaluation and Planning (KETEP), granted financial resource from the Ministry of Trade, Industry & Energy, Republic of Korea (No. 20204030200050).

REFERENCES

Kim KT, Lee PS, Park KC, A direct coupling method for 3D hydroelastic analysis of floating structures. Int J Numer Methods Eng. 2013, 842-866.

Lee KH, Lee PS, Nonlinear hydrostatic analysis of flexible floating structures. Appl Ocean Res. 59 (2016), 165-182.

Lee KH, Cho S, Kim KT, Kim JG, Lee PS, Hydroelastic analysis of floating structures with liquid tanks and comparison with experimental tests. Appl Ocean Res. 52(2015), 167-187.

Yoon JS, Lee PS, Towards hydro-elastoplastic analysis of floating plate structures. J Fluids Struct. 71(2017), 164-182.

Kim JG, Cho SP, Kim KT, Lee PS, Hydroelastic design contour for the preliminary design of very large floating structures. Ocean Eng.,78 (2014), 112-123.

Yoon, J. S., Cho, S. P., Jiwinangun, R. G., Lee, P. S., Hydroelastic analysis of floating plates with multiple hinge connections in regular waves. Marine structures, 36 (2014), 65-87.

Khabakhpasheva TI, Korobkin AA. Hydroelastic behaviour of compound floating plate in waves. Journal of Engineering Mathematics 2002; 44:21–40.

Wang CD, Meylan MH. A higer-order-coupled boundary element and finite element method for the wave forcing of a floating elastic plate. Journal ofFluids and Structures 2004; 19(4):557–572.

Eatock Taylor R. Hydroelastic analysis of plates and some approximations. Journal of Engineering Mathematics 2007; 58:267–278

Lee PS, Bathe KJ. Development of MITC isotropic triangular shell finite elements, Computers and Structures, 82(11-12), (2004), 945-962.

Lee YG, Yoon KH, Lee PS. Improving the MITC3 shell finite element by using the Hellinger-Reissner principle, Computers and Structures (2012), 110-111, 93-106.

Jeon HM, Lee Y, Lee PS, Bathe KJ. The MITC3+ shell element in geometric nonlinear analysis, Computers and Structures, 146 (2015), 91-104.

Lee Y, Lee PS, Bathe KJ. The MITC3+ shell finite element and its performance, Computers and Structures, 138 (2014), 12-23.

Jeon HM, Lee PS, Bathe KJ. The MITC3 shell finite element enriched by interpolation covers, Computers and Structures, 134(2014), 128-142.