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Resistance and Seakeeping Performance Analysis of an Icebreaker Vessel in Oblique Bow Waves Using SNUFOAM

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ABSTRACT

The present study is concerned with computational fluid dynamics (CFD) analysis of resistance and seakeeping performance of an icebreaker vessel. SNUFOAM, a CFD code developed by Seoul National University towing tank laboratory and specialized in fluid dynamics problem in naval architecture and ocean engineering, was used for this study. In SNUFOAM, the dynamic interface compression method was applied to obtain precise and sharp free-surface behavior. A mesh deforming technique was used to enable six degrees-of-freedom motion. Resistance performance in calm water were analyzed first. By comparison with experimental data, it was confirmed that SNUFOAM accurately predicts the ship resistance. Using SNUFOAM, an analysis procedure on seakeeping performance in regular wave was established and applied to oblique bow wave conditions, to acquire the resistance and motion responses. Test conditions were selected based on Arctic Ocean condition. It was found that the icebreaker vessel satisfies required resistance and seakeeping performance at the design speed.

KEY WORDS :Computational Fluid dynamics; Arctic Region; Seakeeping; Icebreaker.

INTRODUCTION

Operation of vessels and offshore plants in polar region are exposed to harsh environments compared to ships operating on conventional routes. The sea ice, snow storm, and ice fog, due to low temperature below -10 ° C are present and there is a possibility of damages to the ship due to various ice conditions such as drift ice and flat ice. It contributes to increase the design costs of the ships.

These vessels for arctic region are experimentally studied in special facilities such as ice tanks that can reproduce the polar environment (Lee, et al., 2006), but it takes a lot of time and resources to conduct experiments with ice. Therefore, to reduce the design cost, it is essential to develop and utilize a simulation program specialized for polar environment conditions (Hansen and Loset, 1999; Lubbad and Loset, 2011).

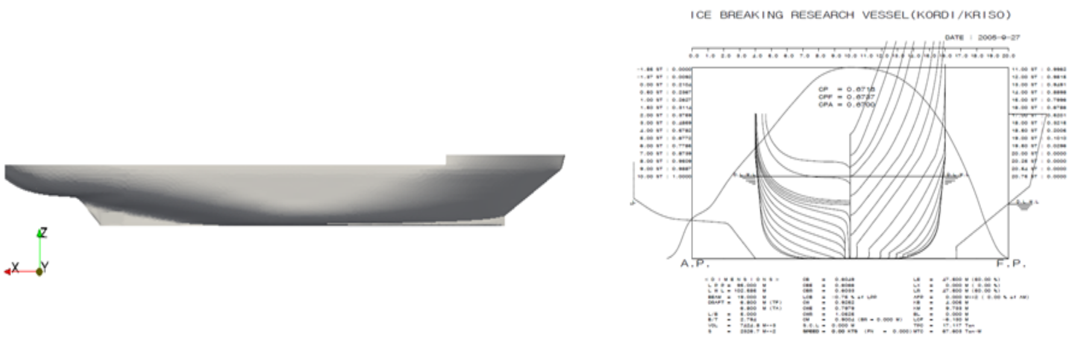
Computational fluid dynamics (CFD) analysis is a feasible and useful simulation method for designing polar region application. The CFD results can be combined with other computer aided engineering applications, such as structural analysis and design optimization. To utilize CFD analysis in polar environments case, simulation of ship motions coupled with external causes, such as ice behavior, is required.

In the present study, as preliminary study for estimating the ice load of a ship and offshore plant in the polar environment and carrying out the analysis of ice-fluid interaction, resistance and seakeeping performance of an icebreaker ship was analyzed using SNUFOAM, a CFD code developed by Seoul National University towing tank laboratory and specialized in fluid dynamics problem in naval architecture and ocean engineering. To perform the seakeeping analyses, a dynamic interface compression, grid morphing, and numerical towing tank technique were applied to SNUFOAM.

The resistance analysis results were compared with the experiments in the same condition, to validate the CFD code. In addition, by seakeeping analyses, six degrees-of-freedom (6DOF) motion response of the icebreaker in regular wave was obtained.

TEST MODEL, CONDITON AND COMPUTATIONAL METHODS

The test model is ARAON, an icebreaker designed and built in Korea. To be coherent with experiments, the scale ratio was 1/18.667 and corresponding model ship length between perpendiculars was 5.09 m. Figure 1 shows the design and principal dimensions of ARAON.



	Lpp (m)	B (m)	T (m)	Disp. (m^3)	Scale Ratio
Prototype	95	19	6.8	7424.8	18.667
Model	5.09	1.017	0.364	1.1414	

Figure 1. Design and principal dimensions of ARAON

Resistance and seakeeping tests were performed using SNUFOAM (Lee, 2015). The continuity and Reynolds-averaged Navier Stokes equations were used as the governing equations. In addition, a volume of fluid (VOF) method was used to enable free-surface behavior. The ship motion in waves was reproduced by mesh deformation, which was used for performing body motions with considerable boundary deformation. (Jasak, H., 2009).

The resistance test was conducted in the calm water condition, with advance speed variations, as shown in Table 1. Seven ship speeds in the full scale were chosen and corresponding advance speeds in the model scale were derived, following Froude's scaling law. Seakeeping simulation were conducted in regular wave condition, considering the wave condition in Arctic Ocean. The period and wave height in the model scale were 1.80 s and 0.1 m, respectively. In the wave condition, wave length was equivalent to the ship length. The wave has encounter angle of 170°, thus the model ship was in the oblique bow wave condition. Three Froude number conditions were selected: 0, 0.067, and 0.202.

Table 1. Resistance test condition

Vs (knots)	Froude number	Vm (m/s)
4	0.067	0.476
8	0.134	0.953
10	0.168	1.191
12	0.202	1.429
14	0.236	1.667
15	0.253	1.786
16	0.270	1.905

A right-handed coordinate system was used. The origin located at the intersection of station 10 and calm water surface. The size of the computational domain was $-2.36L < X < 2.36L$, $0 < Y < 1.2L$, $-1.3L < Z < 0.52L$. The computational mesh consisted of hexagonal cells and was generated by snappyHexMesh. The number of cells were around 1,300,000. Dirichlet boundary condition was applied to the inlet and hull surface. Neumann boundary condition was used to the outlet. Time and space were differentiated by second order scheme.

RESULTS AND DISCUSSIONS

Figure 2 shows resistance analysis results of ARAON and comparisons with experiments. By the comparison, it was shown that SNUFOAM has error under 3% and is feasible for analyzing resistance performance. The total resistance increased in high Froude number conditions, but in terms of total resistance coefficient, the ship showed good resistance performance around the design speed with low resistance coefficient.

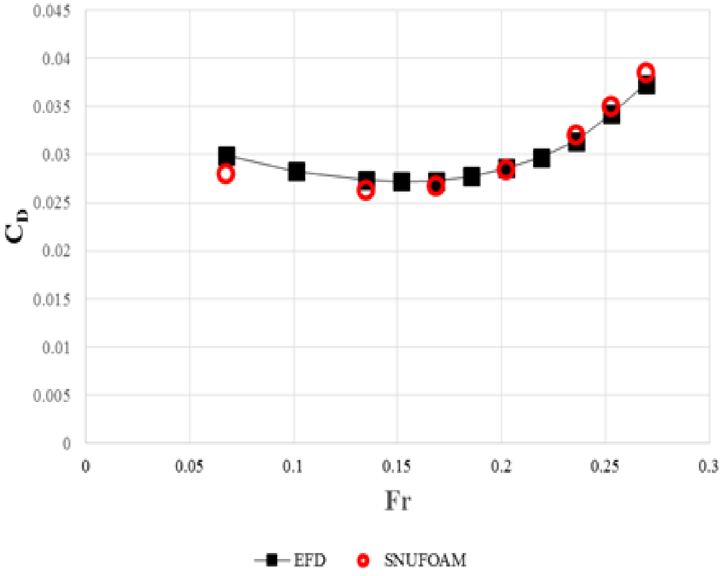


Figure 2. Resistance coefficient of ARAON model in calm water condition

Figure 3 shows surface pressure distribution in waves. In oblique bow waves, the pressure distribution developed with wave profile, but 6DOF motion of the ship also affected the surface pressure. Maximum local pressure was found when the bow impact water surface.

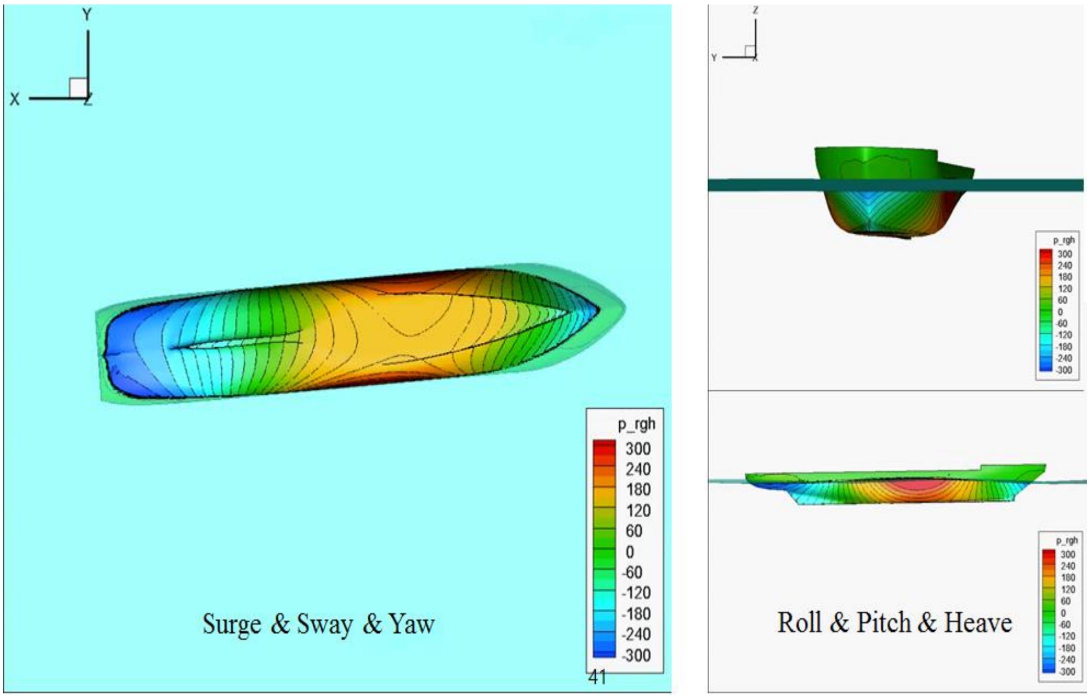


Figure 3. Surface pressure distribution of ARAON model in oblique bow wave condition

Figure 4 shows time-history of 6DOF motion of ARAON model in oblique bow waves and zero advance speed. Surge and sway motion oscillated with wave encounter. The model drifted in waves, thus the wave encounter frequency increased. Like surge motion, the yaw angle also increased while pitch and roll have regular response.

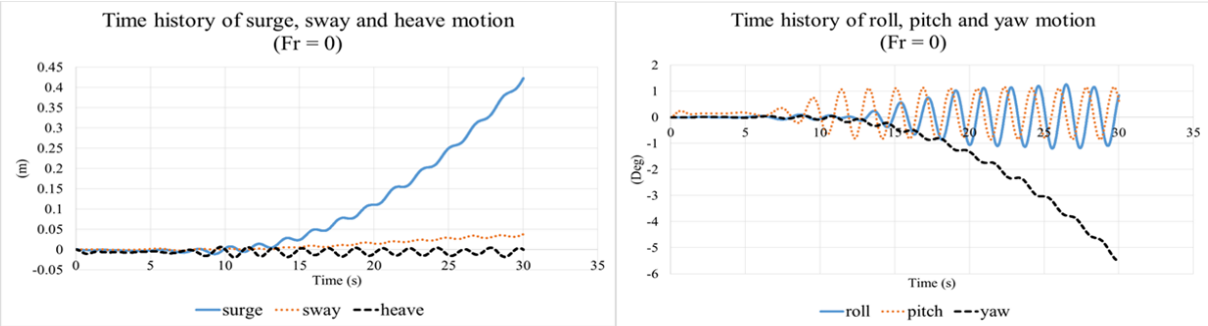


Figure 4. Time history of 6DOF motion of ARAON model in zero advance speed

CONCLUSIONS

In the present study, resistance and seakeeping performance of ARAON was analyzed using SNUFOAM, to analyze resistance and 6DOF motion. The calm water resistance showed error under 3%, compared with experiments. A 6DOF motion analysis process was established and applied to oblique bow waves. By the CFD analyses, it was shown that ARAON has reasonable resistance and seakeeping performance.

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