Response to Reviewer 2

The authors would like to thank the reviewer for the carefully reading of this manuscript and for the constructive comments which help to improve the quality of this manuscript. The corrections are marked in green in the Revised Manuscript. Please see below for our responses to the reviewer's comments.

Reviewer #2: Comments and Suggestions for Authors

The authors have tried to understand the ice forces acting on a submarine when it is operating at the surface. The paper is generally well written, and uses commercial computer code combining ice elements with CFD to calculate the interactions with the ship's hull. The reviewer thinks the paper can be improved in the following areas;

1.The paper is clearly about the hull of a submarine ship operating at the surface. As a result, the title of the paper is somewhat misleading. Underwater structures is a term that can mean equipment on the sea bed, such as the type of equipment that is common in offshore energy projects.

Thanks for your comments

Considering that submarines are more sensitive, underwater structures were used instead in the previous manuscript. All underwater structures have been replaced with submarines in the revised manuscript.

2. The authors should check the context for their use of Colbourne's method. It is primarily a way for non-dimensionalizing the results of model experiments, in order to make accurate predictions of full scale forces. The approach taken was to reflect that contact forces between a ship and pack ice (at low concentrations) or icebergs was impulsive in nature, and more difficult to understand, compared to more steady state forces, such as level ice or open water forces, where a mean force is a suitable measure. The method allows for the consistent presentation of forces, and allows for a the size and shape of the floe sizes. It's primary function is to smooth out the uncertainties in model experiments, and to allow for the fact that ice density and water density at model scale are different from the full scale values.

Colbourne's method also does not include any shape factors for the hull. While this might not be important for a single impact, it does become more important as ice concentrations increase, and ice pieces jam on each other rather than just coming into contact with the hull.

While the use of the method to normalize the results is valid, the approach does not really contain any predictive properties beyond the original data. Therefore using it to estimate a maximum force might be beyond its capability. As a result, the prediction of maximum load might be suspect.

Also, in Colbourne's method, B is the beam of the ship at the waterline. In the case of a submarine ship, is beam at the waterline used, or maximum beam for the ship?

Thanks for your comments.

Based on extensive experiments, it has been found by Colbourne that there is a linear relationship between the natural logarithm of C_p and the natural logarithm of Fr_p.

This method is frequently employed for the verification of ice floe tests. Initially, the test data is utilized to compute C_p and Fr_p, and then $\ln C_p$-$\ln Fr_p$ curve can be plotted.

Subsequently, a linear equation is fitted to this curve. In this manner, the relationship between C_p and Fr_p can be established, then the ice resistance can be deduced inversely.

In the existing studies, both the scale relationship between the model and the actual ship is considered, and the resistance of the actual ship is directly computed from the model test.

For example, Jeong S Y [1]considered the scaling relationship and defined C_p as:

$$C_{pack} = 10^{a}(F_h)^{b}\left(\frac{d_{floe}}{B}\right)^{c}(C_{conc})^{d}\left(\frac{W_{ch}}{B}\right)^{e}$$

Where d_{floe}/B and C_{conc} denote the normalized ice floe size and ice concentration and W_{ch}/B denotes the normalized channel width for the model tests. If it is assumed that the W_{ch} is over 8 times the ship's beam, the value of W_{ch}/B is 8 in the equation. In addition, a is the intercept of the regression analysis and b, c, d, and e are the regression coefficients for the four variables, respectively.

The linear regression equation is calculated through the test data, and finally the ice resistance prediction formula is determined as:

$$R_{pack} = 10^{2.651}(F_h)^{-1.665}\left(\frac{d_{floe}}{B}\right)^{1.019}(C_{conc})^{5.196}\left(\frac{W_{ch}}{B}\right)^{-1.211}\frac{1}{2}\rho Bhv^2$$

The ice resistance is calculated using the above equation, and a one-to-one correspondence curve is plotted by comparing the test ice resistance with the calculated ice resistance, as depicted in the figure.

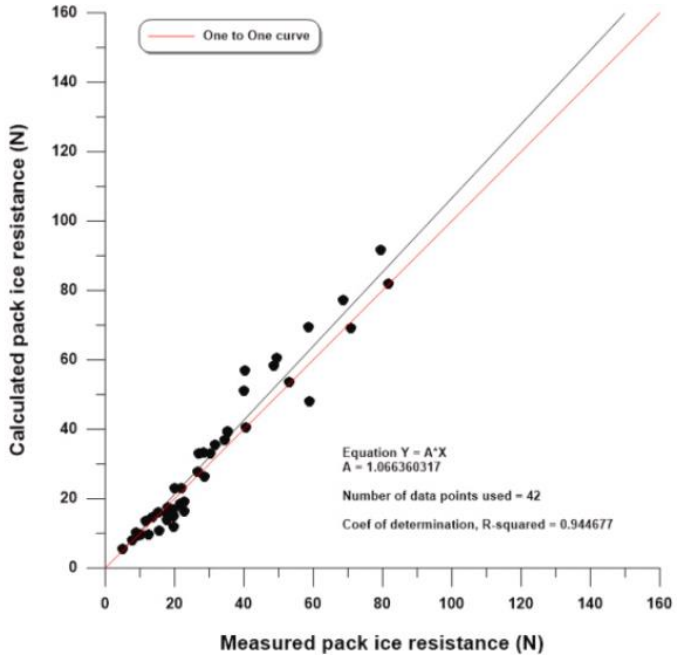

Figure 1 one-to-one correspondence curve[1]

Among them, y=x represents the blue straight line, while the red straight line denotes the fitting curve derived from the one-to-one corresponding data. It is observable that the straight line extends beyond the scope of the original data, serving a predictive function.

In another example, Guo C.Y.[2] neglects the scale effect and directly utilizes experimental data to establish the lnC_p-lnFr_p relationship. The following equation is then employed to validate the rationality of the experimental data and predict the ice resistance results for an ice thickness of 2.0m.

$$R_T = 6.917\,1V^2 + 4.4Fr_p^{-0.826\,7} r_i B h_i V^2 C^2$$

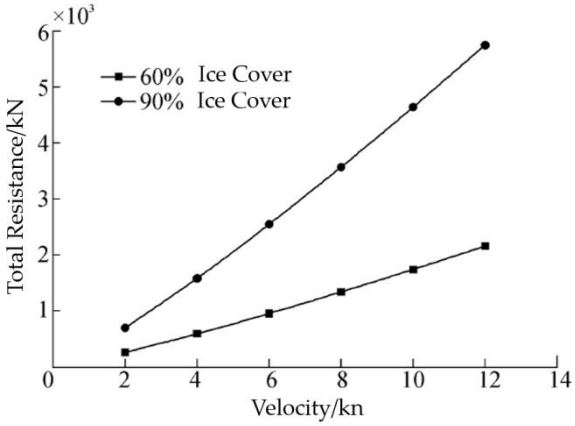

Figure 2 the ice resistance results for an ice thickness of 2.0m[2]

In summary, the application of this method involves predicting ice resistance. If there are alterations in the test conditions leading to variations in F_r, and consequently, modifications in the C_p of the final ice resistance data, the point (lnFr_p, lnC_p) obtained from this specific test condition should still lie on the same line. The collision between submarines and ice floes remains inadequately studied, lacking pertinent test data and empirical formulas. Therefore, this paper employs the simulation ratio as an experimental approach, utilizes the lnC_p-lnFr_p curve to validate the simulation results, and applies the curve to predict results for other working conditions.

In the original method, operating condition parameters, such as speed, density of ice floes, ice thickness, etc., are represented by Fr_p. Perhaps due to the substantial size difference between the icebreaker and the ice floes, the impact of the ice floes' size is not taken into account in this formula. Nevertheless, in this study, the size of the submarine and the ice floes are close, prompting an attempt to incorporate the ice floe size into the definition of Fr_p.

The definition of F_{rp} does not include shape factors for the hull; only the width B is incorporated into the definition of C_p. It is recognized that shape factors may become more significant as ice concentrations increase, and ice pieces jamming together rather than merely making contact with the hull. However, due to the close size between the submarine and the ice floes, the submarine only collides with the first ice floe, and the remaining floes are pushed aside without accumulating. Therefore, the research in this paper can neglect the influence of the almost shape factors.

In Colbourne's method, B represents the beam of the ship at the waterline. However, upon comparison, it is observed that when the maximum width B is employed in this paper, the relative error is smaller.

In general, Colbourne's method has been employed by other researchers to predict ice resistance, and it can be adapted to the specific working conditions of this study.

Assuming the simulation is considered an experiment, this method is utilized for testing and predicting the results, which demonstrate that the error falls within an acceptable range.

1 Jeong S Y, Choi K, Kim H S. Investigation of ship resistance characteristics under pack ice conditions. *Ocean Eng*, **2021**, *219*: 108264.

2 GUO C Y, XIE C, WANG S. Resistance of ships in pack ice conditions. *J. Harbin Eng. Univ*, **2016,** *37(4)*: 481-486.

Reviewer #2: Comments on the Quality of English Language

Overall the paper is well written. Some paragraphs are a bit long, and could be broken into smaller parts.

Thanks for your comments.

The introduction section in the original manuscript has been divided into multiple smaller paragraphs.