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Study on the Procedure to Obtain Attainable Speed in Pack Ice

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ABSTRACT

Cost evaluation for voyage route planning in ice covered sea is one of the major topics among ship owners. Information of ice properties, such as ice type, concentration of ice, ice thickness, flexural strength of ice and speed-power relation in given ice properties, are very important to decide optimum route in cost perspective.

To find procedure of attainable speed evaluation at any designated pack ice condition model test results of resistance, self-propulsion and overload test in ice and ice free water were used. Also calculation of net thrust and estimation of ice resistance by empirical formula were performed. All model tests were carried out in KRISO ice tank and towing tank.

Combination of model test results and careful observation of underwater videos shows physical phenomena of underwater situation and suitable buoyancy and clearing resistance of empirical formula. Detailed description of determination of attainable speed in certain power and pack ice condition will be presented in this paper.

KEY WORDS: Pack Ice; Pack ice resistance; Model test; Attainable speed;

INTRODUCTION

In available literature there are not so many published articles regarding safe speed in an operation prospective. John Dolny et al. (2013) presented good research about safe speed of structure prospective and Hyun Soo Kim et al. (2016) presented new approach for evaluation of attainable speed in pack ice. They separated clearing and buoyancy components in pack ice resistance and made a regression formula for the Araon vessel based on the model test results. Another approaching technique to know performance in pack ice is studied and will be described in this paper.

Attainable speed is one of speed features that are used for operation in ice covered sea. From an operational point of view several definitions of speed should be compared. First one is attainable speed in ice is defined as the speed which is possible to achieve in certain ice type and properties. To know attainable speed, relationships between thruster and resistance in ice and ice free water are compared carefully in propulsion performance prospective. Second speed definition is safe speed. Hull is not safe if vessel is passing through in heavy ice condition with critical speed. Hence, to know safe speed of structure hull stress and collision effect of ice should be evaluated. Third one is limitation speed in ice passport. The authorities permit limitation of operating speed in ice passport based on vessel's speed-power performance in ice, operating method, routes, season and ice thickness. Three different speeds effect voyage route system and the lowest one will be operating speed by authority.

PROCEDURE TO GET ATTAINABLE SPEED

Previous study, which was presented by first author in IAHR 2016, is based on precise observation of underwater video and finding coverage of vessel's underwater surface area. But separation of clearing and buoyancy resistance in pack ice resistance is not easy because relationship among ice concentration, velocity of vessel and pack ice resistance is complicated. Total pack ice resistance was used instead of separation of clearing and buoyancy resistance. The flow chart of attainable speed evaluation used in this study is shown in Figure 1.

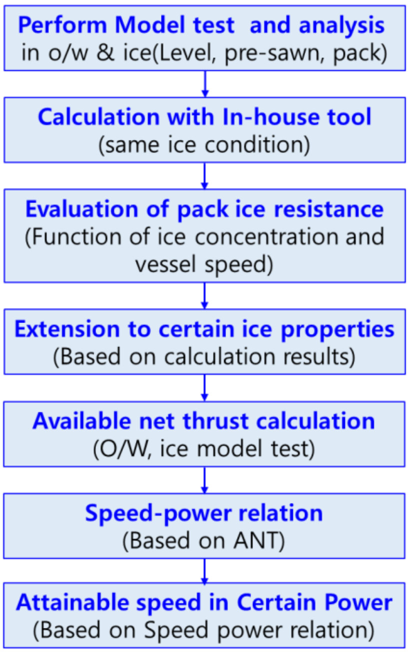

Figure 1. Flow chart to find attainable speed

First Korean ice breaking Research vessel Araon is used for the model test in this paper. Table 1 shows short information of Araon. Hyun Soo Kim (2011) presented more detailed information about Araon's specification in his paper.

Table 1. Principle dimension of Araon

Length, B. P. (m).	Length, B. P. (m)	Design Draft (m)	Propulsion Motors (kW)
95.0	19.0	6.8	2 set of 5,000

All model tests in ice and ice free water are carried out in KRISO's (Korea Research Institute of Ships and Ocean Engineering) ice tank and towing tank. Analysis software, which is explained in Cheol ho Ryu (2013) and Kyung Duk Park (2014)'s articles, is used for calculation of ice resistance.

MODEL TEST IN KRISO ICE TANK AND TOWING TANK

Model tests were carried out with three ice thicknesses which is categorized case 1 (41cm), case 2 (56cm) and case 3 (90cm). Figure 2 and 3 are shown the photos of model at level ice and pre-sawn ice (underwater view) respectively.

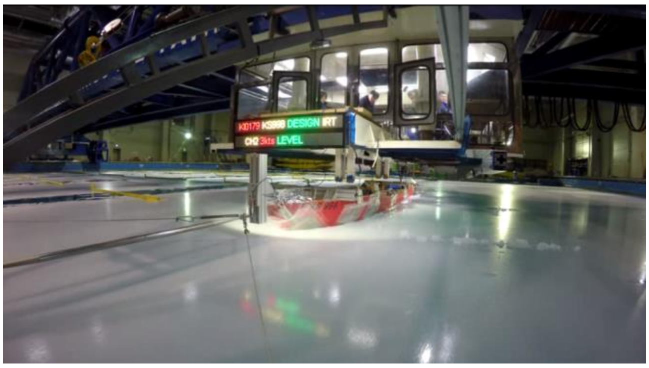

Figure 2. Photo of level ice test

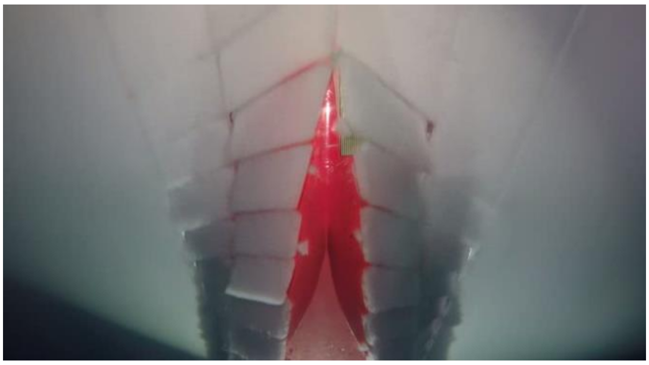

Figure 3. Photo of Pre-sawn ice (underwater view)

Model test for pack ice condition were performed in three different ice thickness (0.5m, 1.0m, 1.5m) and three different concentration of pack ice (60%, 80%, 90%) per each ice thickness.

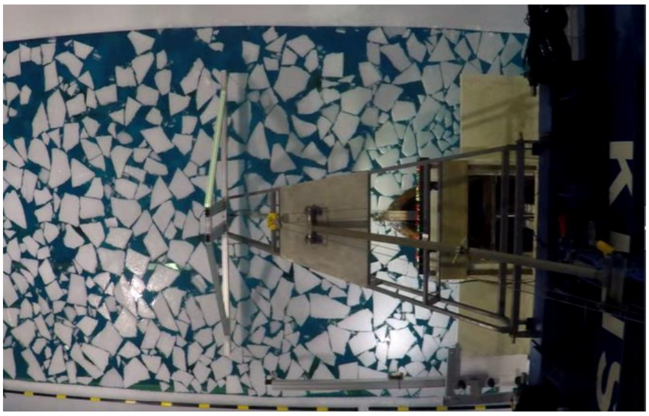

Figure 4. Photo of pack ice at 6/10 concentration

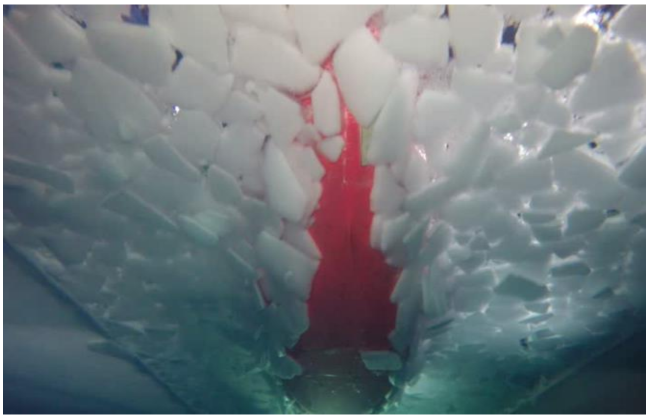

Figure 5. Photo of pack ice at 8/10 concentration (under water view)

COMPARISON BETWEEN MODEL TEST RESULTS AND CALCULATION RESULTS

Accuracy of In-house code for ice resistance calculation was verified by comparison of code results with model test ones and published in several papers, for example Woo jin Kim(2015), Cheol ho Ryu (2013) and Kyung Duk Park (2014). This comparison showed that difference of ice resistance evaluated by code and measured by experiment is less than 10%. The accuracy of In-house code is checked one more time in this study and Figure 6 shows the comparison of in-house code results with model test results. It's less than ±8% but case 2 has 13% difference when speed is 5 knots

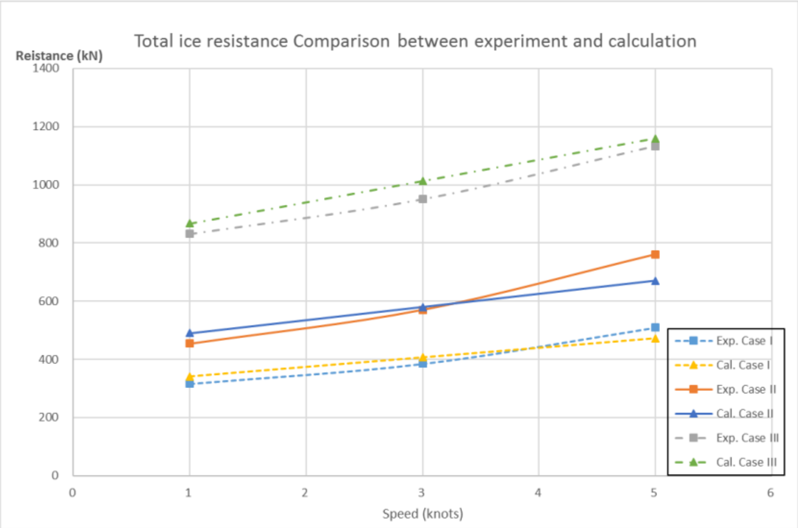

Figure 6. Total ice resistance comparison between experiment and calculation

In In-house code pre-sawn ice resistance is calculated by following formula.

$$R_{pre-sawn} = R_{Buoyancy} + R_{Clearing} + R_{open\ water} \quad (1)$$

$$R_{pre-sawn} = R_{pack\ ice\ at\ 100\%\ concentration} \quad (2)$$

Where R means Resistance and all subscripts are the meanings of resistance

Open water resistance is come from open water model test results.

Figure 7 shows pre-sawn ice resistance comparison between experiment and calculation. The difference is less than ±8% but in case 1 difference reaches 9.7% when speed is 5 knots. Figure 7 shows that in Case 2 coincidence of calculated result and experimental one is the best among three cases.

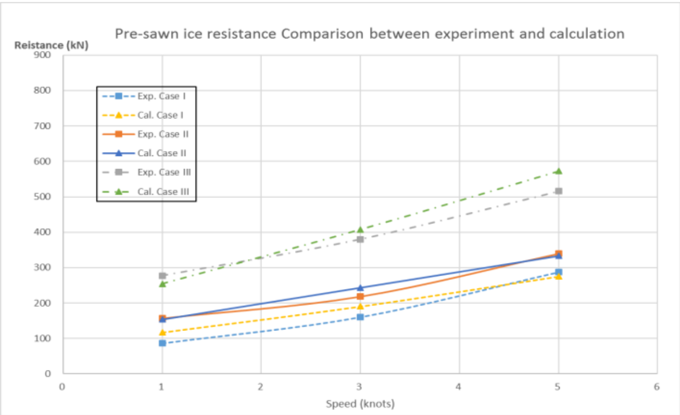

Figure 7. Pre-sawn ice resistance comparison between experiment and calculation

Figure 8 shows model test results of pack ice (three kinds of ice concentration) and pre-sawn (100% concentration) results when ice thickness is 1.06m. The relation according to variation of speed, ice concentration and pack ice resistance show reasonable tendency.

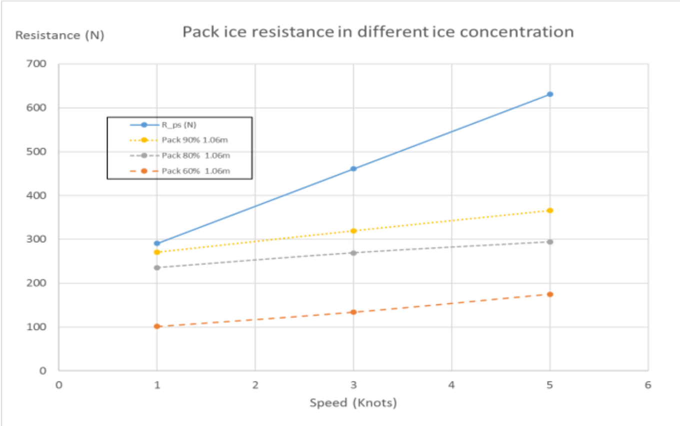

Figure 8. Pack ice resistance in different ice concentration

Based on above results authors tried to figure out relationship among ice concentration, ice resistance and ship speed. MATLAB was used to find plane of those relationship. MATLAB result is depicted in Figure 9. The merit of MATLAB is ability to generate relation formula and find RMS (Root Mean Square) value among the variables. RMS was 0.9359 and formula is shown in equation (3).

$$f(x,y) = a + bx + cy + dx\hat{}2 + exy \tag{3}$$

Where, a, b, c, d, e are constant value and x, y are ice concentration and velocity respectively.

The ranges of speed in formula (3) are applied between zero and maximum speed of the vessel from the open water results. This formula can calculate ice resistance in given ice properties using correlation factor.

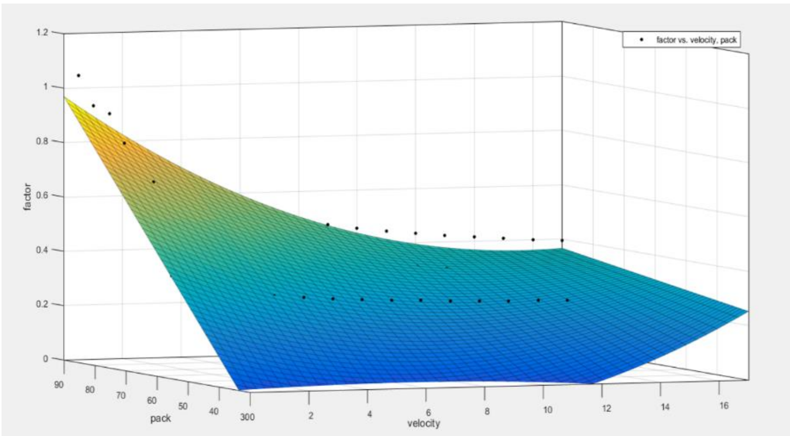

Figure 9. 3D plane of velocity, ice concentration and ice resistance

ANALYSIS OF ATTAINABLE SPEED

Bollard pull test results and available net thrust are shown in Figure 10 & 11. Detailed procedure for available net thrust is explained in Finnish Maritime Administration (FMA) and Hyun soo Kim (2015).

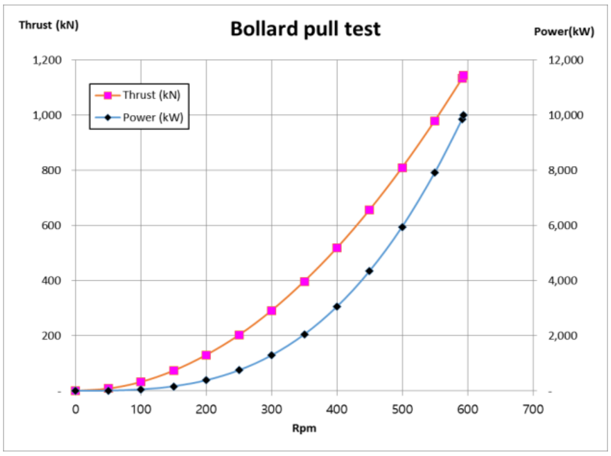

Figure 10. Bollard Pull test results

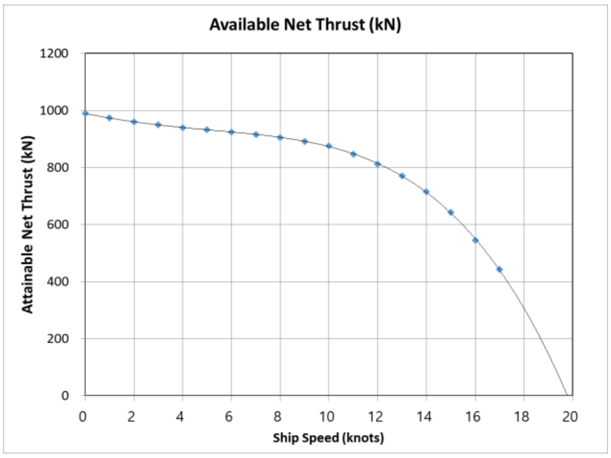

Figure 11. Available net thrust for two thrust

Based on pack ice model test results which are performed with different ice properties (concentration, thickness and flexural strength), analysis results of available net thrust and bollard pull test results, so called over-thrust, can be calculated. Over-thrust means it still have available thrust after overcome in certain ice resistance at maximum engine power of 10MW. It is possible to calculate pack ice resistance in variable pack ice properties (concentration: 6 to 9, thickness, strength and velocity) using In-house code. Ice thickness is changed from 0.5 to 1.4m, flexural strength is varied from 540kPa to 800kPa and velocity of vessel is varied from 1 knot to 16 knots. Figure 12 shows ice thickness and over-thrust relation when speed is at 5 knots pack ice and flexural ice strength of 540kPa. It's plotted with different pack ice concentration. The results show that over-thrust at 1.4m pack ice is about 350kN at 90% concentration. It means that 10MW powered vessel can operate of 5 knots at 1.4m, 90% pack ice and have a margin of 350kN thrust and 4.5MW power.

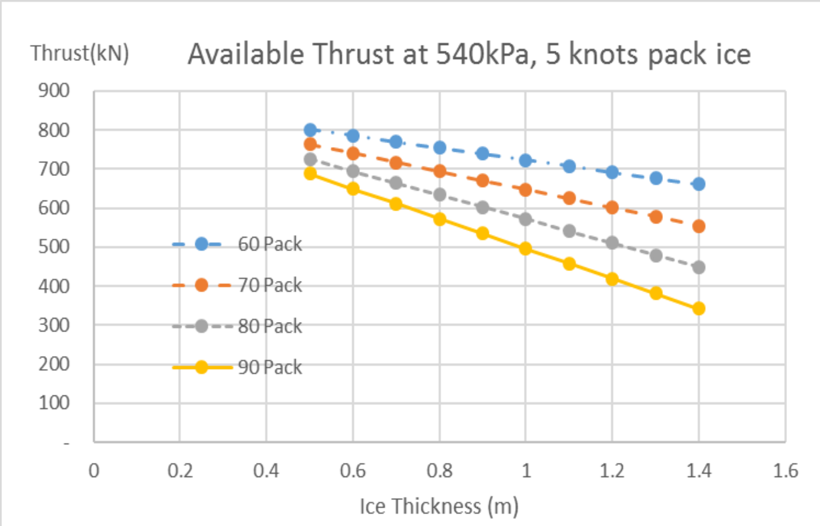

Figure 12. Ice thickness vs thrust relation

Attainable speed can obtain from Figure 13 & 14. This figures show residual thrust after overcome of pack ice resistance including open water resistance. Different ice concentrations are considered in calculation and it is found out the attainable speed in Figure 13 and 14 at 0.5m and 1.0m ice thickness respectively.

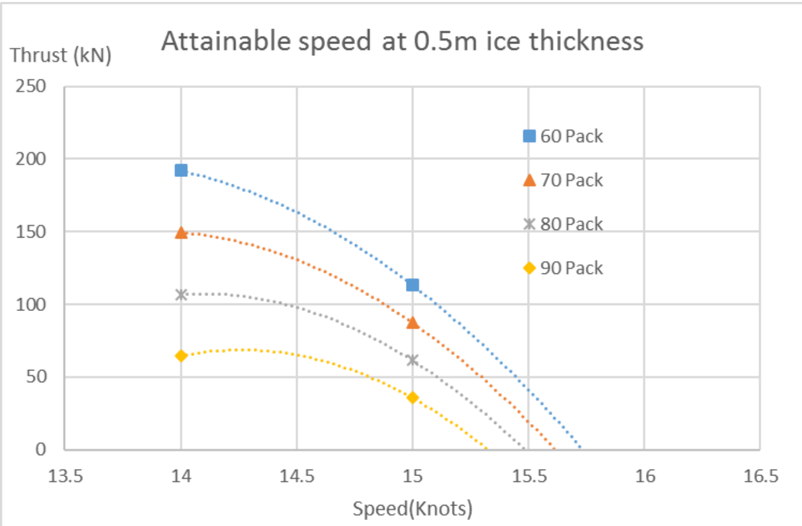

Figure 13 Attainable speed calculation at 0.5m ice thickness

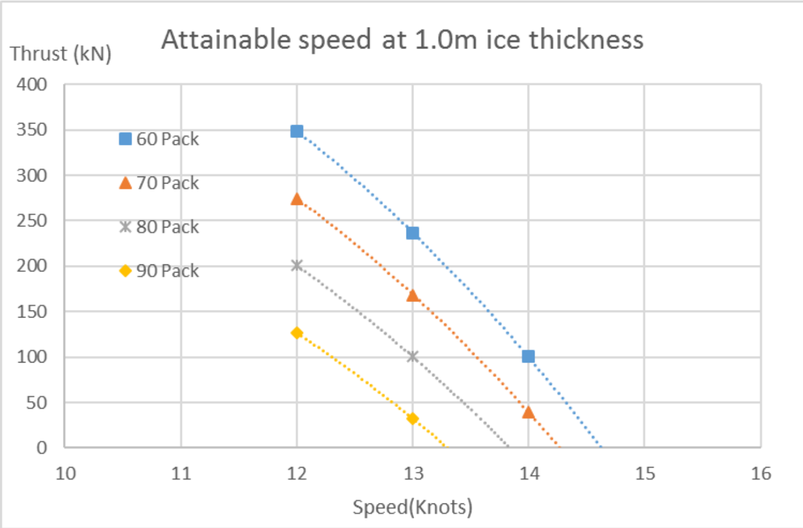

Figure 14. Attainable speed calculation at 1.0m ice thickness

Final attainable speed at 0.5m and 1.0m ice thickness, 540kPa ice strength and 10MW power is same as Table 2. It was calculated along different ice concentration.

Table 2. Attainable speed at 0.5 & 1.0m depend on ice concentration

Pack ice concentration (%)	60	70	80	90
Attainable speed (knots) at 0.5m	15.73	15.61	15.49	15.32
Attainable speed (knots) at 1.0m	14.63	14.27	13.84	13.30

Attainable speed in any pack ice condition can be obtained using interpolation method if ice properties (flexural strength, thickness, concentration) are given but real ice field is not categorized by ice properties (concentration, strength, strength). In natural ice field it's mixed with different ice properties (type, thickness, strength, concentration).

Anyway, this procedure is very useful to know speed and estimated arrival time based on pack ice condition and these results are also helpful to make voyage route planning. The merit of this procedure is possibility to calculate attainable speed if operator decides certain power level.

CONCLUSIONS

This paper is focused on attainable speed calculation. For this open water resistance and self-propulsion performance, characteristic of propulsion system, performance in different pack ice concentration and calculation of In-house code were used. The procedure is developed and will be useful in voyage route planning system.

Araon's performance in pack ice is evaluated in this paper. Based on the model test and analysis results it can be concluded that Araon is able to operate at 13.3 knots in pack ice with full power in next conditions: ice thickness is 1.0m, ice strength is 540kPa and ice concentration is 90%. This attainable speed should be not final operating speed. Operator must check safe speed in structure prospective and limitation of ice passport carefully. Lowest speed among these three kinds of speed will be operating speed.

For the future work, brash ice performance will be checked again and attainable speed in brash ice will be studied using similar approach that was presented in this research.

ACKNOWLEDGEMENTS

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