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Load-Varying Methods for Ship Power Estimation in Brash Ice Channel by Ice Tank Model Test

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ABSTRACT

A series of ice tank tests of a bulk carrier was conducted at National Maritime Research Institute. According to the Finnish-Swedish Ice Class Rules, 1m thick brash ice channel was assumed as actual condition for ice class IA vessel and simulated in the ice tank. For the propulsion tests, two kinds of load-varying methods i.e. in brash ice and in open water, were employed. The difference in thrust at self propulsion point between these two methods was 8.1% at most, while RMSE of measurement in brash ice was 15.1%. The power required for 5knots in brash ice were estimated and compared with the rule-based calculation.

KEY WORDS: Ice tank test; Brash ice channel; Load-varying method

NOMENCLATURE

R	Resistance
V	Ship speed
F	Towing force
T	Thrust
Q	Torque
N	Propeller revolution
ρ	Density
g	Gravity acceleration
h_B	Mean thickness of brash ice

Subscriptions I and W represent ice and water, respectively.

INTRODUCTION

New buildings of ice-strengthen vessel seem to be increasing as a consequence of recent positive use of the Arctic Ocean. As for large vessels such as tankers and bulkers, the main engine power is facing a paradox as needs to reduce power for energy-saving and at the same time needs to fulfill the power required for navigability in ice. The fair estimation of propulsion power of ice-strengthen vessels is thus important to meet all requirements by such as ice class rules and the authority's regulations. Ice tank model test is a major tool for power estimation of ice-strengthen vessels. The Finnish-Swedish Ice Class Rules (FSICR) allows to prove sufficiency of main engine power by ice tank tests instead of provided formulae calculation (Trafi, 2010).

ITTC Recommended Procedures gives standards of general propulsion tests in ice (ITTC, 2011) which is similar way to that of in open water. However, obtaining propulsion factors and self propulsion point in the ice tank test needs to correct many parameters due to non-uniform nature of ice condition. Load-varying method is a convenient way to determine required thrust regardless of detail propulsion factors.

A series of resistance tests and towing propulsion tests in ice tank was conducted to estimate power in ice. The ice condition was assumed as brash ice channel of 1m thick, which corresponds to the thickness for ice class IA of FSICR. As applying load-varying method, two procedures for testing and analysis to obtain required thrust were considered such as by towed propulsion tests in ice; by a set of resistance tests in ice and towed propulsion tests in open water. The thrusts and the power derived from these two methods were compared to each other in order to evaluate the differences.

METHODS

Load-Varying Method

The procedures of load-varying method for open water test is briefly introduced in ITTC Recommended Procedures. When towed propulsion test is performed, the parameters such as *F*, *T*, *Q* and *N* are measured. These parameters can be obtained normally in brash ice directly (Method-1). As a replacement, another method that does not require towed propulsion test is proposed (Method-2). The overall flow of test and analysis is shown in Figure 1.

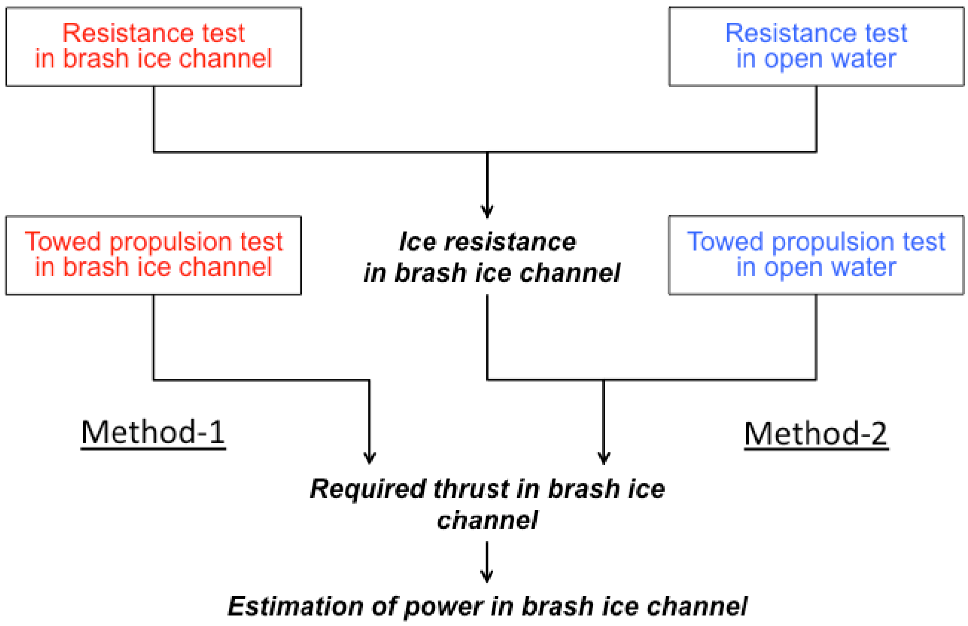


Figure 1. Flow chart of the test program and analysis for load-varying methods.

Method-1 is a direct method to obtain propulsion parameters in ice. Measured *T* and *F* are plotted in *F*-*T* diagram like Figure 2. Their regression line should cross with the *F* axis at all resistance in ice (R_I+R_W), and should cross with the *T* axis at the thrust required in ice, respectively.

Method-2 requires towed propulsion test only in open water. This can reduce both of the number of ice sheet to be used and the parameters to be measured in ice. The resistance of ice is analytically added after the measurement so that the *T* at self propulsion point balances in ice. Resistance tests in both of ice and open water must separately be performed to determine R_I to calculate required *T*.

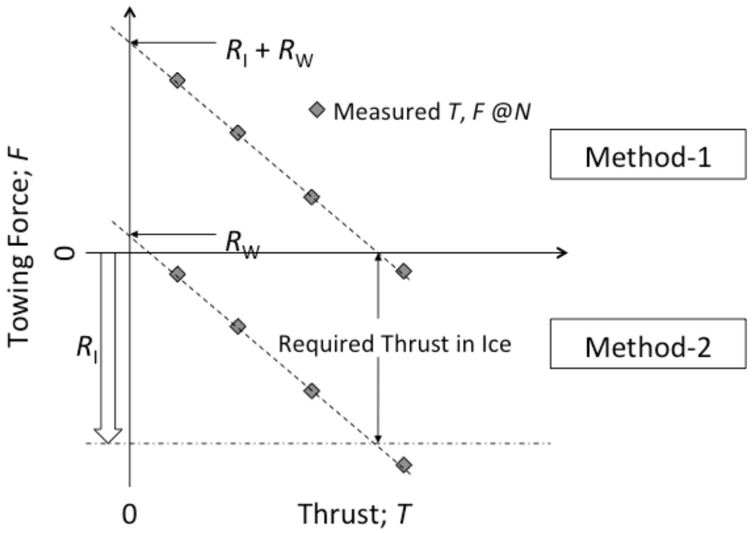


Figure 2. Supposed *F*-*T* diagram of towed propulsion tests.

Model Ship

The tested ship is a Panamax bulk carrier of 75,000DWT with 1 propeller designed by Oshima Shipbuilding Co., Ltd. (OSY) as shown in Figure 3. It is considered as one of the typical ships in the NSR having ice-strengthen hull. Ice breaking ability is not important for those ships; therefore they have rather normal shape to keep open water performance and cargo capacity.

The model length *L* was 5.7m and the width *B* was 0.84m. The main body of the model was made of wood and coated by FRP. The surface was painted by a fine-grained epoxy paint to control hull-ice friction coefficient to 0.1 which was confirmed by the measurement using model ice and painted test specimen, according to ITTC Recommended Procedures.

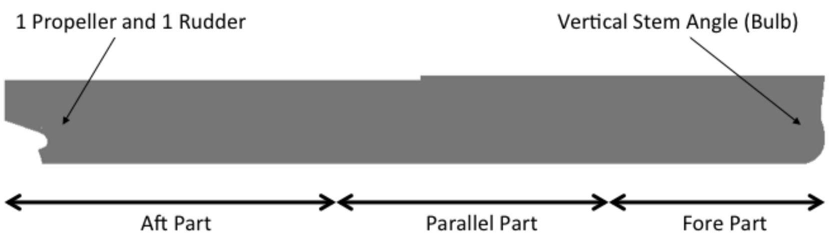


Figure 3. Side view of the model ship.

EXPERIMENTS

Ice Tank and Model Ice

The ice tank of National Maritime Research Institute (NMRI) was used in this study (Figure 4 left). The length of the tank is 35m and the width is 6m. The capacity of the towing carriage is 50kN and the speed can be varied in the range of 5 to 1500mm/s. The water contains Propylene Glycol as a dopant. Model ice with columnar crystal structure, shown in Figure 4 right, is produced for normal model test. Wet seeding is performed at the first stage of each model ice production. Density of the ice can be adjusted to a value required for the test by controlling air bubble concentration in the ice.

Figure 4. NMRI ice tank and model ice.

Left: ice chamber and model ice. Right: typical crystal structure of the model ice.

Preparation of Brash Ice Channel

According to FSICR Guidelines (Trafi, 2010), brash ice channel for ice tank test should be filled by broken ice pieces. In each brash ice test, mother ice sheet was crashed by ice chisels as shown in Figure 5 left, and compressed to control ice concentration and to obtain desired thickness.

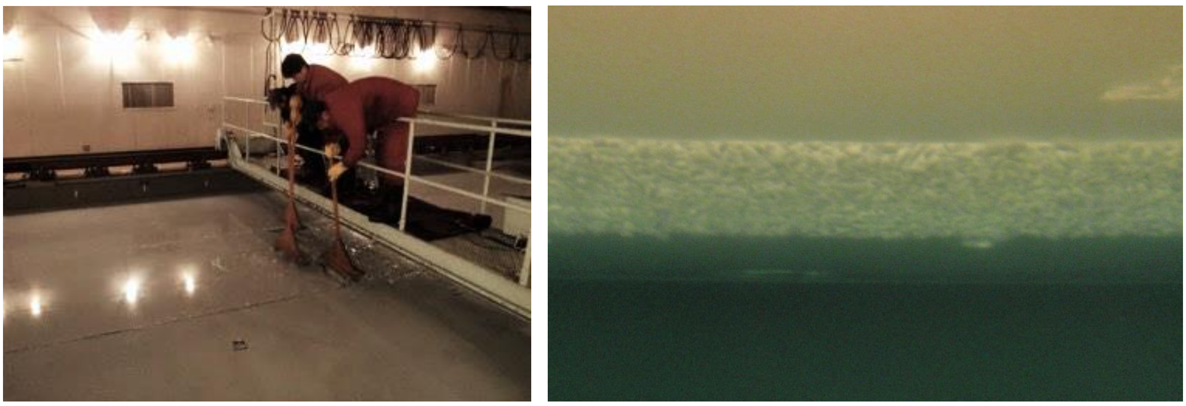


Figure 5. Making brash ice channel.

Ice Tank Test

The model ship was connected to the carriage via a resistance dynamometer to measure towing force F. During towed propulsion test, it equipped with a model propeller so that thrust T, torque Q and propeller revolution N were measured. The system of measurement was shown in Figure 6.

The propeller rotates at a rate of N while the carriage tows the model at a constant speed in each run. The test was repeated varying N to obtain several set of F, T, Q and N. The speed was set to model scaled value equivalent to 5 knots for ship.

For Method-2, resistance tests were also conducted in both conditions of ice and open water respectively to distinguish between the channel ice resistance R_I and water resistance R_W. The system of measurement was almost the same as towed propulsion test except for dismounting the model propeller.

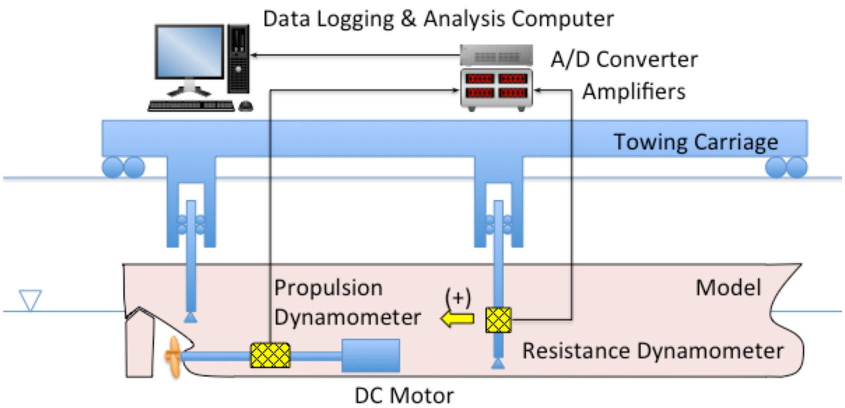


Figure 6. Measurement system for towed propulsion test.

RESULTS AND DISCUSSION

Results of Towed Propulsion Tests

Towed propulsion tests were carried out for both of full and ballast conditions. Derived from measured towing force F and thrust T through all test runs, F-T diagrams were made as shown in Figure 7. The values were extrapolated to full scale, taking into account skin friction correction. Brash ice thickness and density of ice were also corrected using regression formula as following:

$$\frac{R_I}{\rho_I g B_I h_B^2} = a_0 + a_1 \frac{V}{\sqrt{g h_B}} \qquad (1)$$

where a_0 and a_1 are regression coefficients obtained from measurement data.

Towing force at no thrust means resistance, thus the intercept of each regression line was set to $R_I + R_W$ which were obtained from resistance tests. Note that measured thrust by Method-2 was raised by R_I because it was obtained in open water. In the figure, thrust is normalized by T_{SP} which means thrust at ship self propulsion point in brash ice. Towing force is also normalized by R_I.

Plots of thrust and torque on the basis of propeller revolution are shown in Figure 8.

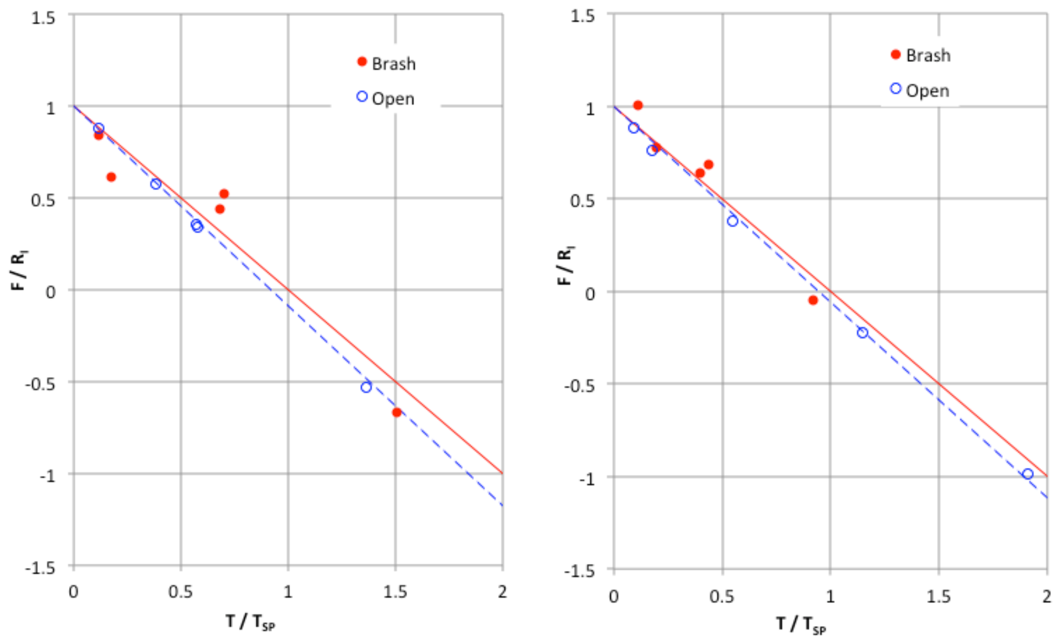
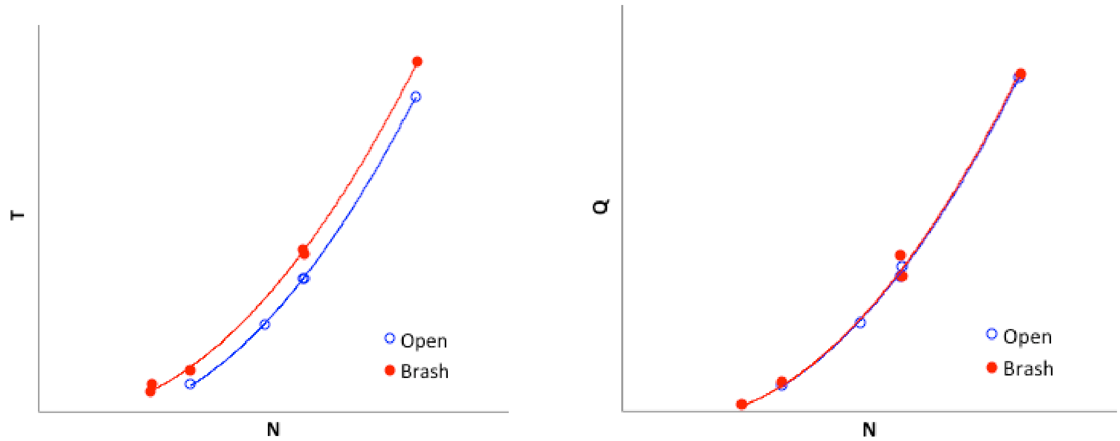
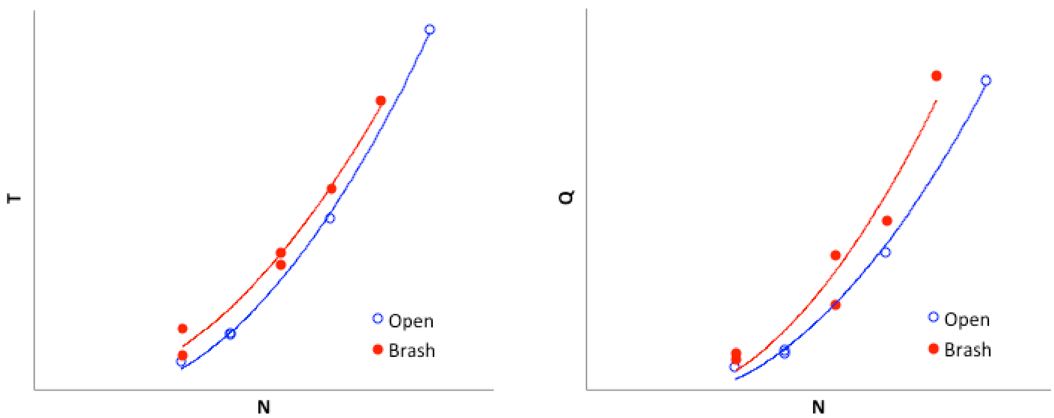


Figure 7. *F-T* diagrams in full scale derived from towed propulsion tests.
Left: Full. Right: Ballast.



(a) Full



(b) Ballast

Figure 8. Thrust and torque measured in towed propulsion tests.

Discussion

The RMSEs of measured data against the regression lines from the *F*-*T* diagrams are shown in Table 1. Although the deviation of towing force (or thrust) of Method-1 are significant, those of Method-2 agree well with the lines. Differences between thrusts at T_{SP} of each method were 8.1% for full and 5.5% for ballast which are less than RMSEs of Method-1. Therefore, in this case, Method-2 was reliable enough as a replacement of Method-1.

Table 1. RMSEs of thrust against regression lines.

Condition	Method-1	Method-2
Full (UIWL)	0.151	0.033
Ballast (LIWL)	0.085	0.030

In order to estimate power from towed propulsion tests, T_{SP} should be obtained from *F*-*T* diagram at first. Then *N* must be determined by *T*-*N* curve, and *Q* at *N* is derived. As shown in Figure 8, some differences of these parameters clearly exist between two methods and they should be accumulated in calculation of power. Estimated powers normalized by the value calculated by FSICR formulae are shown in Table 2. The powers of full-load condition agreed with each other well, however in ballast condition power of Method-1 are greater than that of Method-2. Torque in ice possibly increases due to propeller-ice interaction and it happens with more frequency when the draft is small. Therefore Method-2 should be used with care for ballast condition.

Table 2. Estimated power of each method against required value by FSICR formulae.

Condition	FSICR	Method-1	Method-2
Full (UIWL)	1	0.46	0.48
Ballast (LIWL)	1	0.37	0.28

CONCLUSION

Towed propulsion tests in ice tank were carried out to estimate power in brash ice channel. The tests in brash ice could obtain thrust at self propulsion point; T_{SP} directly, however the data showed large deviation. As for the tests in open water, in spite of separately requires resistance test in brash ice, the data was robust and reasonable. The difference of T_{SP} between two methods were 8.1% for full-load condition and 5.5% in ballast condition. Both were within RMSE of measurement in brash ice channel.

Thrust, torque and propeller revolution were measured in the tests and used for estimation of required power. The powers of full-load condition agreed with each other well. However, in ballast condition, power in brash ice are greater than that derived from open water tests. Higher torque in brash ice tests due to propeller-ice interaction possibly resulted in greater power, thus care should be paid for applying open water load-varying method to small draft condition.

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