Determination of performance limitations for ships navigating to and from Voisey's Bay, part 3: resistance of bulk carrier in rubble ice

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Publisher's version / Version de l'éditeur:
https://doi.org/10.4224/40003168
Technical Report (National Research Council of Canada. Institute for Marine Dynamics); no. TR-1998-05, 1998-12

National Research Council Canada
Conseil national de recherches Canada

Institute for Marine Dynamics
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DETERMINATION OF PERFORMANCE LIMITATIONS FOR SHIPS NAVIGATING TO AND FROM VOISEY'S BAY PART 3;

RESISTANCE OF BULK CARRIER IN RUBBLE ICE

TR-1998-05

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December 1998

DOCUMENTATION PAGE

REPORT NUMBER TR-1998-05	NRC REPORT NUMBER	DATE December 1998
REPORT SECURITY CLASSIFICATION Unclassified		DISTRIBUTION Unlimited

TITLE

Determination of Performance Limitations for Ships Navigating to and from Voisey's Bay Part 3; Resistance of Bulk Carrier in Rubble Ice

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PUBLICATION

SPONSORING AGENCY(S)

Canadian Coast Guard

IMD PROJECT NUMBER 802	NRC FILE NUMBER		
KEY WORDS icebreaker, bulk carrier, resistance, propulsion	PAGES 17	FIGS. 6	TABLES 8

SUMMARY

This report presents the results of model experiments carried out to support CCG's evaluations of shipping related to the proposed Voisey's Bay nickel mine. The tests included resistance experiments rubble ice on a model of a bulk carrier. The width of the rubble varied from a channel just wider than the ship to a wide channel, the width of the model basin. The results are used to predict the performance of the ship over a range of ice conditions, likely to be encountered on the coast of Labrador.

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Evaluation of Performance Limitations for Ships Navigating to and from Voisey's Bay Part 3; Resistance of Bulk Carrier in Rubble Ice

1.0 INTRODUCTION

In March and April 1997, the Canadian Coast Guard (CCG) sponsored an expedition into the approaches of the proposed site for a shipping terminal for the Voisey's Bay nickel mine. The voyage provided essential data on the ice conditions and the performance of the ship 'C.C.G.S. Henry Larsen'. However, whilst this single voyage was useful in providing benchmark data for ships operating in these conditions, it did not give sufficient information for evaluating the same ship in other ice conditions or other ships in the same conditions.

In May 1997, the Institute for Marine Dynamics (IMD) proposed a series of scale model experiments to CCG. There were two objectives for this proposal. The first was to correlate the observed performance of the 'C.C.G.S. Henry Larsen' with a model in the scaled conditions equivalent to those found on the probe. This would give confidence to the techniques used for modeling the ice conditions. The second objective was to use model experiments to predict the performance of a typical bulk carrier in the ice conditions found on the ship probe.

To meet the project objectives a series of physical model tests was carried out to predict the performance of the bulk carrier in the different types of rubble ice expected to be encountered during operation of the ship. For the purposes of this report, rubble is defined as multiple layers of ice blocks. It is expected that the bulk carrier will encounter two major types of rubble ice. The first type is effectively an infinitely wide rubble field, created by the highly dynamic ice conditions in the shear zone, away from the land fast ice. The second type corresponds a previously broken, but relatively narrow channel. This approximates the ship moving in level, land fast ice, following the track made by another ship, where the channel is full of several layers of ice, but there is uniform ice on either side of it.

The experiments described in this report were conducted using an existing model of the M.V. Arctic. The objective was to determine if there was any change in resistance between the ship in an infinitely wide rubble field and the ship in a narrow channel, filled with rubble. These experiments were carried out in order to expand on the data collected in an earlier series of experiments on the same model (described in Reference 1). These experiments had not given firm conclusions on the extent of any resistance variation between the two types of rubble. The effect of different amounts of consolidation (re-freezing) on the resistance of the ship in the wide rubble field were also studied.

The results of experiments comparing the performance of the bulk carrier with an icebreaker are given in Reference 1 and the effect of changing from a load draft to a light ballast draft are described in Reference 2.

2.0 SUMMARY OF ICE PROBE DATA

Rubble dimensions used in this report were based on the approximate geometric scaling of piece size and total thickness measured during the Voisey's Bay probe of March and April 1997. Based on these data, pack ice thicknesses varied between 1.2 and 1.5 m. These correspond well with other historical data for the Nain/Hopedale area. Flexural strength averaged approximately 420 kPa. This gave two target thicknesses of 1.0 and 1.5 metres, which could be modeled to cover the range of observed data.

Rafted and rubble ice was between 3 and 5 metres thick. These observations suggest that the rubble ice was between two and three ice thicknesses deep.

References 3 and 4 give a summary of the ice data encountered on the Voisey's Bay probe and the associated ship performance.

3.0 TEST PLAN

In order to obtain the basic resistance data for the different rubble conditions, the test program given in Table 1 was carried out, in addition to the experiments described in Reference 1.

The results were combined into a single data base, and plotted as resistance against rubble ice thickness, for nominal speeds of 0.02, 0.094 and 0.188 m/s. These are shown in Figures 1 to 3. The three nominal rubble field widths (wide, medium and narrow) are identified with different symbols.

Based on the expanded data set, it was found that there was no significant difference between the results for the different rubble widths. On the basis of the results obtained, the width of the rubble field does not effect the resistance of the ship. A single line of resistance against ice thickness can be drawn for all rubble widths at each speed. The resulting linear regression equations are given in Table 6 below. Note that these results are slightly different from the equations given in Reference 1. However, they have the advantage of being derived from a bigger data set. The biggest change has been in the formulation of the low speed equation (0.02m/s) which is now a first order relationship, instead of the second order relationship postulated in Reference 1.

Speed	Equation for Resistance as a Function of Rubble Depth
0.020 m/s	Ri = 456.84 * Hi
0.092 m/s	Ri = 560.256 * Hi
0.186 m/s	Ri =580.365 * Hi

Table 6
Equations for M.V. Arctic Model,
Resistance against rubble depth, all widths

One thing that must be noted is the relatively high degree of scatter in the resistance data for the rubble ice. When a smaller sub-set of the data is used, based on Phase 2 only, it does appear that there is a small reduction in resistance, as the channel width is reduced. However, there was no noticeable difference in the amount of ice left in track behind the ship between any of the different widths of rubble ice. This would indicate that in the case of the narrow channel, the rubble is not being deflected under level ice by the passing of the ship.

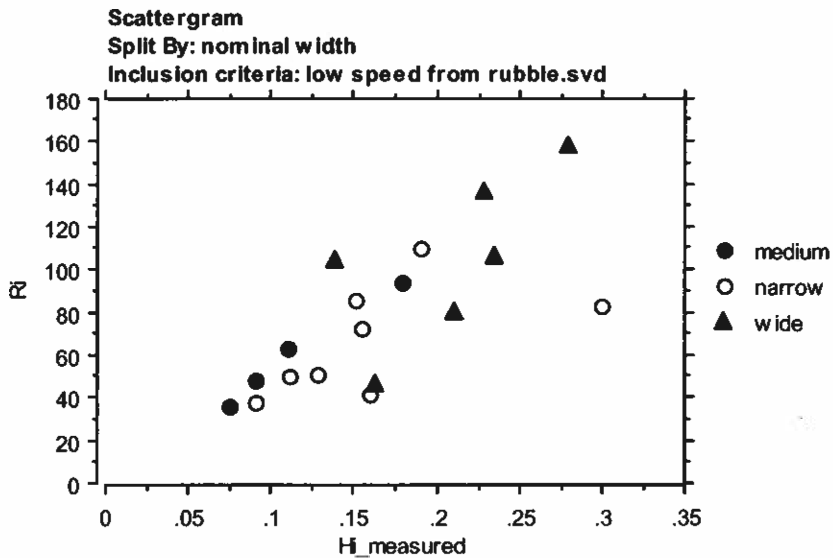

Figure 1
Resistance of bulk carrier model, V = 0.019 m/s

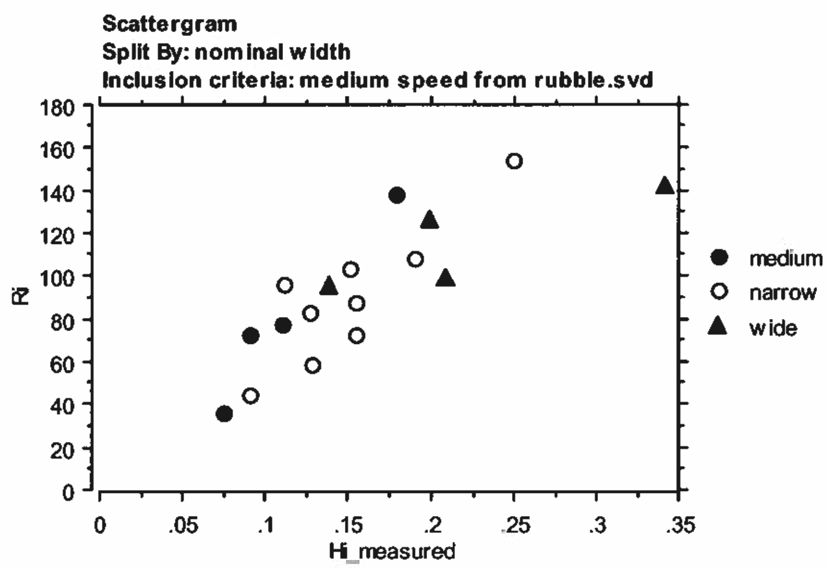

Figure 2
Resistance of bulk carrier model, V = 0.093 m/s

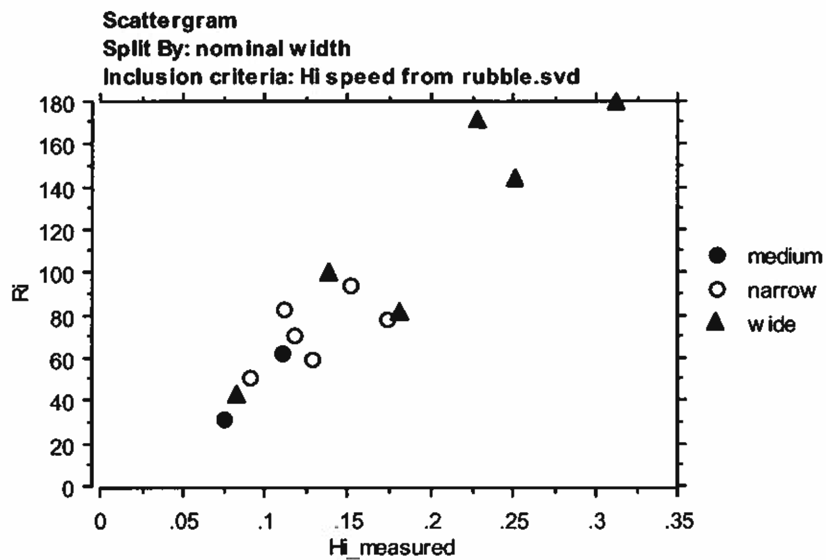

Figure 3
Resistance of bulk carrier model, V = 0.187 m/s

5.2 Resistance in Consolidated Rubble

All of the resistance and propulsion performance of the ship in rubble discussed so far has referred to unconsolidated rubble. In this type of rubble, there was no re-freezing of the ice, and so the rubble field consisted of a nominally uniform ice condition. In practice, if the ice field is stationary for some time, and the temperature is below freezing, then a hard crust will form on the top of the broken ice. The depth of the crust will depend on the number of freeze degree hours that the ice field is stationary and the amount of time between transits of the ship.

This factor was simulated in the ice tank after the experiments in unconsolidated ice for ice sheet VB13. The nominal 30/10 wide rubble field was left to freeze overnight for a total of 131 freeze-degree-hours. The resistance experiments were repeated at the same model speeds, equivalent to 2, 1 and 0.2 knots. Since the unconsolidated experiment had been carried out on the centreline, the south quarter point was used for these experiments.

A third degree of consolidation was obtained by continuing to freeze the ice sheet for a further 72 freeze-degree-hours, for a total of approximately 213 freeze-degree-hours. The experiment in this degree of consolidation was carried out on the north quarter point.

Total resistance and speed for the three degrees of consolidation are given in Table 7. They are also plotted in Figure 4.

It can be seen from Figure 4 that consolidation has a very important influence on the resistance. The ice thickness measurements are given in Table 8 below. Table 8 also gives the equivalent thickness of uniform ice that would have grown in the same time.

speed, m/s	Level of consolidation zero	131 f-d-h	213 f-d-h
0.188	170.5		
0.020	136.2		
0.094	125.6		
0.094		304.9	
0.020		339.6	
0.188		346.9	
0.094			740.0
0.020			765.3
0.188			715.4

Table 7
Effect of Consolidation on Total Resistance in Rubble Ice M.V. Arctic

The depth of consolidation was obtained by cutting a sample (200mm square) out of the ice sheet and measuring the thickness at approximately 50 mm intervals along each side, as well as along the centreline. The crust could be easily lifted out of the sheet. Any unconsolidated pieces which had not frozen to the crust were left behind. It was interesting to note that at the lower level of consolidation, the ice piece removed was much more uniform than the higher degree of consolidation. At the higher level, the large ice blocks had become frozen into the crust, giving the underside a very irregular pattern.

It can be seen from Figure 4 that the effect of consolidation can be approximated by considering an additional constant resistance value, based on the amount of consolidation. Figure 5 shows the increase in resistance, above the basic unconsolidated value, as a function of the thickness of the consolidated ice raised to the power two. This relationship is approximated as a linear function and the equation is given in Figure 5.

Care should be used when interpreting the data for the increase in resistance due to consolidation of the rubble. The testing was carried out with no tempering of the ice sheet. It is not clear how a second tempering period effects the mechanical properties of the ice. The test plan was prepared on the basis of minimizing the practical problems for operation of the ice tank. The clear observation is that the unconsolidated rubble in the most optimistic prediction of ship performance, and that a relatively small degree of consolidation can increase the resistance significantly.

To truly understand the performance of ships in consolidated rubble, we recommend a detailed study of the mechanical properties of the ice, including measurements made in the field. So far, we only have a very crude understanding of the different resistance components for consolidated rubble ice and how they scale to ship values.

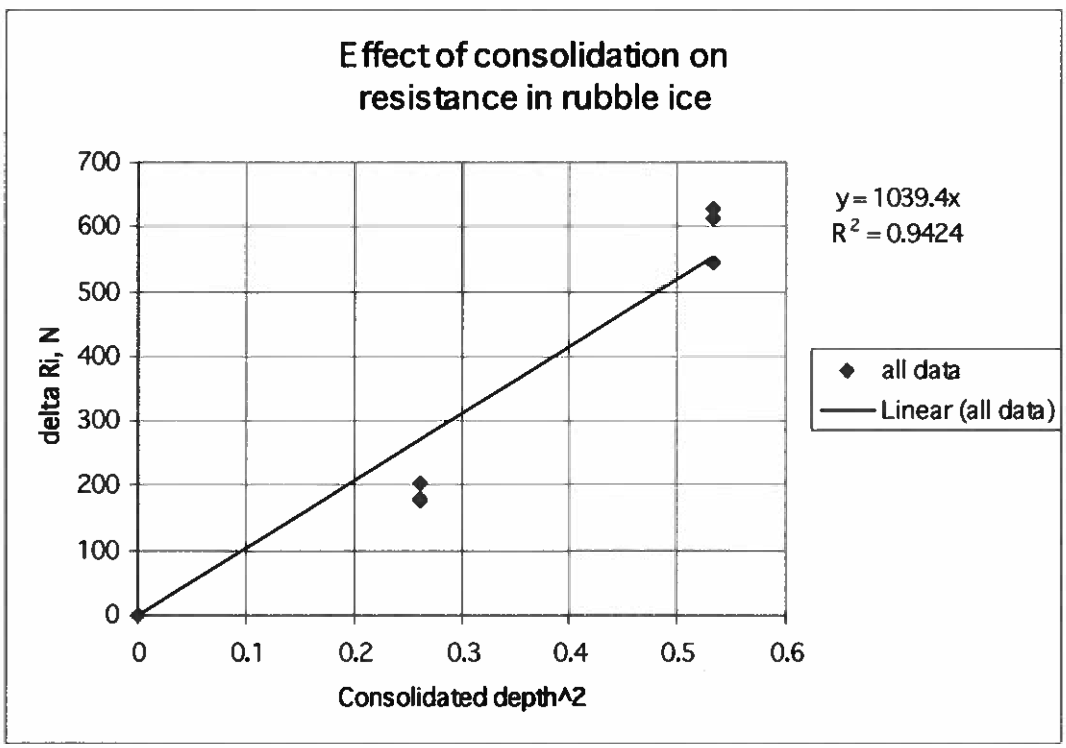

Figure 5
Increase in resistance due to consolidation of rubble ice

6.0 PREDICTION OF SHIP PERFORMANCE

Reference 1 gave a performance estimate for the bulk carrier model in unconsolidated rubble. Since the equations for resistance against rubble thickness have changed slightly as a result of the additional data, a revised version of this figure is given below.

The reanalysis of the rubble ice resistance data has resulted in an increase in the resistance values at low speeds and low ice thicknesses. However, the prediction is based on considerably more data, especially in thinner rubble thicknesses, and as a result it should be more reliable.

The conclusion is that 10MW of power is not sufficient for the ship to move forward at a steady speed in more than 2.4 metres of rubble. This rubble thickness is less than the average value encountered on the probe. Based on the model experiments, 20 MW should propel the ship in 3 metres of rubble ice at a speed of 0.7 knots, and 30 MW should propel the ship at 0.3 knots in 4.5 metres of rubble ice.

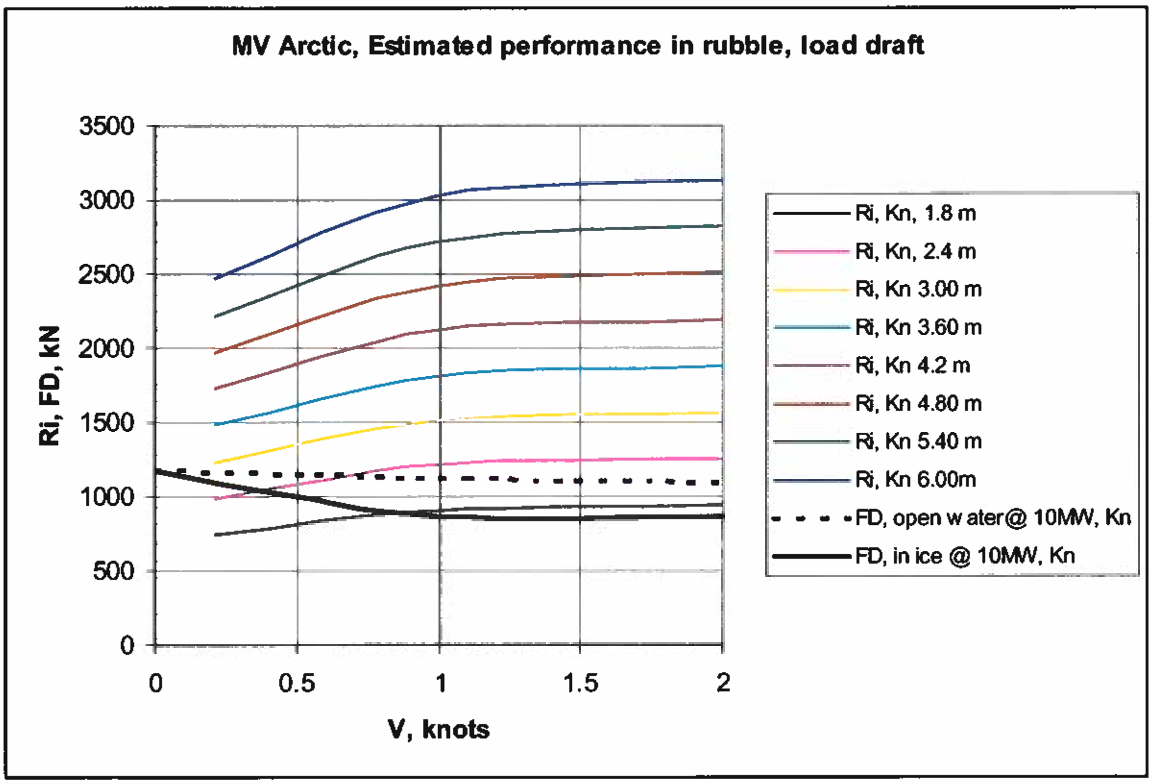

Figure 6
Estimate of Ship Propulsive Performance
in Rubble Ice, M.V. Arctic, Load Draft

All of these estimates are made assuming that the hull-ice friction coefficient is 0.065 and there is no icebreaker assistance for the ship. Bubbler systems, which inject air into the water close to the hull are well known for improving the performance of ships in ice. A bubbler system would reduce the resistance of the ship. Another factor which has not been considered in the analysis described in this report is assistance to the bulk carrier provided by an icebreaker. Based on the installed power for the M.V. Arctic, both of these extra factors would be required for navigating to and from Voisey's Bay in winter.

7.0 CONCLUSIONS & RECOMMENDATIONS

Based on the results of the model experiments given in this report, the M.V. Arctic should proceed at a steady speed through 2.4 m of unconsolidated, non pressurized rubble. Any increase in speed will require more installed power, a bubbler system or icebreaker support. Based on the data given in Reference 2, the ship should always be operated at a draft close to the design load draft, in heavy ice conditions. Operation in a light ballast draft should be avoided.

The effect of consolidating the rubble is to increase the resistance significantly, and very large increases were seen on the model results. However, care should be taken in interpreting these results, since the mechanical properties and scale effects of consolidated rubble ice are not well understood. Further research is required in this area as well as more data on the mechanical properties of rubble ice in its natural environment. However, we can be sure that consolidation will act to increase the resistance of the hull, and the limiting ice thickness will decrease with increased levels of consolidation.

Based on the model experiments described in this report, there does not seem to be any change in resistance in rubble between a wide rubble field, typical of the shear zone, and a narrow channel, filled with rubble, typical of the ship following a previously broken channel.

8.0 ACKNOWLEDGMENTS

The authors would like to thank the many other people who worked on this project, in particular the staff in the ice tank without whom the experiments could not have been carried out and the staff in the model fabrication and outfit shop who prepared the models for the experiments.

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