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Technical Report TR-AVR-07

Tests in ice of a 1:8 scale model of the CCG R-class hull

B. Colbourne

June 1987

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TESTS IN ICE OF A 1:8 SCALE MODEL OF THE CCG R-CLASS HULL

TR-AVR-07

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SUMMARY
A series of model tests was carried out on a 1:8 scale model of the CCG R-Class hull. The range of model velocities and ice parameters covered those suggested by the ITTC. The purpose of the tests was to provide relatively large scale ice resistance data for comparison with model tests on the same hull at 1:20 and 1:40 scale.

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TESTS IN ICE OF A 1:8 SCALE MODEL OF THE CCG R-CLASS HULL

1.0 INTRODUCTION

This report presents the results of a series of model tests in ice performed on a 1:8 scale model of the CCG R-Class hull. These tests were performed as part of an ongoing effort to verify scaling methods and ship-ice testing procedures using the R-Class hull. At the present time, work on 1:20 scale and 1:40 scale R-Class testing is continuing.

This test series was conducted in cooperation with Arctec Canada Inc. on behalf of Transport Canada Transport Development Centre.

2.0 MODEL

The 1:8 scale R-Class model, designated Model M 389 was milled to the R-Class lines shown in Figure 1. These are the same lines used to generate the 1:20 and 1:40 scale hull forms. The model consists of a wooden inner hull covered with polyurethane foam over coated with glass reinforced polyester resin. The moulded lines were cut in the foam layer followed by application of the fibreglass. This outside skin has a mean thickness of approximately 8 mm. Final surface coating was with a two component epoxy paint mixed with flattening agent to give the desired surface roughness. The model was not fitted with any appendages.

Test conditions for the model were as follows:

Forward Draft	846 mm (838 moulded)
Aft Draft	902 mm (894 moulded)
Mean Draft	876 mm (868 moulded)
Moulded Displacement (FW)	14,905 kg
Actual Displacement (Approx)(FW)	15,245 kg
KB	485 mm
KM	1096 mm
KG	969 mm
Roll Period	4.1 sec
Length BP	10.992 m
Length WL	11.625 m
Midship Beam (Max)	2.420 m
LCB Fwd of Midship	40 mm

3.0 EXPERIMENTAL PROCEDURE

The model was towed on a rigid towing system in the IMD refrigerated towing basin. This towing system allows model freedom in heave, pitch and roll and provides restraint in surge sway and yaw. For each test the following parameters were measured:

1	Model Speed	m/sec
2	Tow Force	N
3	Roll	deg.
4	Pitch	deg.
5	Heave	mm
6	Side Force at Yaw Restraint	N

In general, three speeds were run in each sheet of ice resulting in run length of approximately 20 m. This is slightly shorter than 2 ship lengths. A number of longer runs were done to confirm that the resistance reached steady state within this length. The measurement interval was taken as the last 8 m in each 20 m run.

Target ice properties were 56 mm 50 kPa, 56 mm 100 kPa, 88 mm 50 kPa, 88 mm 100 kPa and 125 mm 100 kPa. Three model speeds (.24 m/s, .48 m/s and .95 m/s) were run in each of these ice conditions with some repeat runs performed. In addition, presawn tests were performed for 56 mm and 88 mm ice at each of the three model speeds.

Ice strength was measured using cantilever beam tests at locations on either side of the model track in the middle area of the tank. Ice thickness was measured following each test at 2 m intervals on both sides of the model track. These results were averaged over the measurement intervals to give an icethickness for each run.

Periodically, ice friction measurements were carried out on a sample with a surface coating prepared at the same time and in the same way as the model surface.

The model tow point was located at the centre of gravity and the yaw restraint was located at a centre approximately 3088 mm aft of the tow post centre. Thus measured yaw loads should be multiplied by 3.088 to give yaw moments.

As part of the test program the broken piece size was photographed in the channel aft of the vessel. Piece size averages are given in the results section following. It is intended that a more in depth analysis of this data be performed at a later date.

4.0 RESULTS

Results of the trials are given in Table 1 including ice properties and mean or RMS values of all recorded parameters. Tests showing zero ice strength are presawn ice sheets. In addition, open water runs were performed for the three test speeds with recorded results given in Table 2. Ice friction values are presented in Table 3. More detailed ice properties for each of the test sheets appear in the following section.

In general the quality of the recorded data is judged to be very good although there is considerable scatter around the target ice strength and thickness. This is particularly true of ice strength, however at the target values of 100 and 50 kPa there was some difficulty in predicting tempering time and in measuring the ice strength. These strengths are substantially higher than those normally used in model ice tests.

A measuring equipment problem resulted in the loss of some data in the 125 mm 100 kPa ice test. Thus the resistance value indicated for .95 m/s @ 111 kPa and 129.4mm is an estimate based on graphical reconstruction of the recoverable information in the resistance time series. The presawn results appear to show a slight strength effect in that the presawn tests conducted at .95 m/s were done in relatively low strength ice and these resistance results seem to be low when compared to tests conducted at lower speeds. This strength effect appears to manifest itself in local crushing between the sawn ice floes and the model. Alternately the strength of the ice may influence the degree of secondary breaking. For the purposes of these tests the presawn results were used to provide a means of correcting the data to target strength and thickness. Thus slight errors in these results are not judged to have a major effect on the overall ice resistance prediction.

In order to provide results at the desired strength and thickness of ice, a correction method was applied to the gathered data. The basic steps in this method are as follows:

a) The presawn resistances are plotted against test ice thickness and a fair curve drawn through the data for each speed. These curves are used to supply presawn resistances at thicknesses corresponding to each level ice test run and a presawn resistance at each target thickness. No attempt was made to separate the open water resistance because it is not clear how the ice sheet influences the hydrodynamic resistance of the model.

b) For each level ice run, the relevant presawn resistance is subtracted to yield a residual resistance for the given ice strength and thickness.

c) A linear correction for ice strength is applied to each residual resistance based on the percentage deviation from the target ice strength.

d) The resulting residual (or breaking) resistance values are plotted against ice thickness for each speed and target ice strength value. A fair curve is drawn through each set of points. These curves are used to determine a breaking resistance at the target thickness, strength, and speed.

e) The corrected breaking resistance values are added to the corrected presawn resistance values to yield a total icebreaking resistance for the target strength and thickness values. These results are given in Table 4 and shown in Figure 2.

Functionally this can be expressed as:

R_p = measured pre-sawn resistance
R_T = measured level ice resistance

a) $R_p = f\ (h)$

b) $R_B(h_o, \sigma_o) = R_T\ (h_o, \sigma_o) - f(h_o)$

c) $R_B(h_o, \sigma_o) = R_B\ (h_o, \sigma_o)\ (1 + \frac{\sigma_t - \sigma_o)}{\sigma_o}$

d) $R_B(h, \sigma_t) = g(h, \sigma = \text{const. } \sigma_t)$

e) $R_T(h_t, \sigma_t) = f(h_t) + g(h_t, \sigma_t)$

where R_B = breaking resistance
h = ice thickness
σ = ice strength
o = measured value
t = target value
f = arbitrary function
g = arbitrary function

Model motions, (roll, pitch and heave) were recorded at the towing gimbal referenced to the model centre of gravity. The predominant motion in an icebreaking situation is vertical motion at the bow which results in both heave and pitch in the model. However these motions are quasi-static in nature and thus the pitch centre is probably the centre of flotation which is some distance aft of the model c.g. This would result in a larger apparent heave and a smaller apparent pitch at the model c.g. Thus in the recorded results, the heave is the best indicator of the relative motion at the model bow.

TABLE 1 1:8 R-CLASS TEST RESULTS, TEST DATA

Ice Sheet No.	Model Speed (m/s)	Ice Strength (kPa)	Ice Thickness (mm)	Mean Resistance (N)	Yaw Load (N rms)	RMS Roll Amplitude (deg)	Pitch Amplitude (deg)		Heave Amplitude (mm)	
							Steady	RMS	Steady	RMS
1	.48	0	55.1	404	507	0.1	0.1	0.1	2.1	2.4
1	.48	95	54.4	610	1046	0.2	0.1	0.1	1.9	2.2
1	.48	95	53.4	567	1241	0.1	0.1	0.1	1.7	1.9
2	.95	98	55.5	931	1908	0.2	0.2	0.0	0.1	1.3
2	.24	98	54.4	566	792	0.3	0.1	0.1	3.0	3.2
2	.24	63	56.3	471	600	0.3	0.1	0.1	2.9	1.8
3	.24	116	90.5	1380	1726	0.7	0.3	0.1	12.0	4.9
3	.48	116	90.6	1690	1654	0.6	0.4	0.1	11.0	2.8
3	.48	0	88.0	766	569	0.2	0.1	0.1	3.5	2.2
4	.95	90	88.6	1643	3053	0.3	0.4	0.1	6.3	4.3
4	.24	0	89.2	487	206	0.1	0.1	0.0	2.3	0.9
4	.24	48	88.7	813	864	0.5	0.2	0.1	6.0	2.3
5	.48	48	90.4	1098	1930	0.4	0.2	0.1	8.5	3.5
5	.95	48	88.3	1453	2979	0.3	0.2	0.0	1.1	4.6
5	.95	0	87.9	851	318	0.2	0.1	0.0	-.2	1.5
6	.48	56	57.4	587	1017	0.1	0.2	0.0	3.4	2.9
6	.95	56	58.0	842	1346	0.2	0.1	0.0	-3.5	2.6
6	.95	0	55.2	472	155	0.1	0.1	0.0	-5.0	2.4
7	.24	111	134.1	2850	2718	0.9	0.8	0.2	23.4	4.9
7	.48	111	134.6	3100	2834	0.8	0.9	0.3	23.3	6.5
7	.95	111	129.4	3400	3413	0.4	0.8	0.1	19.7	5.2
8	.95	90	55.9	990	1913	0.3	0.1	0.0	-.6	2.9
8	.24	0	54.0	193	130	0.1	0.0	0.0	0.8	1.0
9	.24	90	90.1	1149	1478	0.6	0.4	0.1	9.9	2.7
9	.95	90	88.8	1810	3046	0.6	0.4	0.1	6.1	4.2
10	.70	91	47.0	643	777	0.1	0.1	0.0	1.9	2.4
10	.95	91	47.3	721	1437	0.2	0.1	0.0	-4.2	2.2
10	.24	91	44.4	446	576	0.2	0.1	0.0	2.1	3.4

TABLE 2 1:8 R-CLASS TEST RESULTS

OPEN WATER RESISTANCE

Model Speed (m/s)	Mean Resistance (N)	Yaw Load (N)	RMS Roll Amplitude (deg)	RMS Pitch Amplitude (deg)	RMS Heave Amplitude (mm)	
.24	15	24	---	---	---	---
.48	45	24	0.0	0.0	-.80	2.0
.95	135	26	0.0	0.0	-4.3	2.4

TABLE 3 1:8 R-CLASS TEST RESULTS

FRICTION COEFFICIENTS

Ice sample dimensions 150 x 150 mm nominal

Ice Strength (kPa)	Condition (wet/dry)	Surface	Normal Force (N)	Tangential Force (N)	Friction Coefficient	slope	intercept
50	Dry	Top	19.6	1.1	.05		
50	"	"	49.1	5.2	.11		
50	"	"	98.1	12.9	.13	0.137	-1.25
50	"	"	147.2	19.8	.13		
50	"	"	196.2	24.9	.13		
50	Wet	Top	19.6	0.9	.04		
50	"	"	49.1	4.3	.09		
50	"	"	98.1	12.0	.12	0.143	-2.21
50	"	"	147.2	18.9	.13		
50	"	"	196.2	25.8	.13		
56	Dry	Top	19.6	1.6	.08		
56	"	"	49.1	4.5	.09		
56	"	"	98.1	11.1	.11	0.130	-1.52
56	"	"	147.2	17.2	.12		
56	"	"	196.2	24.6	.13		
56	Wet	Top	19.6	1.2	.06		
56	"	"	49.1	4.9	.10		
56	"	"	98.1	10.7	.11	0.122	-1.22
56	"	"	147.2	16.4	.11		
56	"	"	196.2	23.0	.12		

ave = 0.133

TABLE 3 (CONTINUED)

Ice Strength (kPa)	Condition (wet/dry)	Surface	Normal Force (N)	Tangential Force (N)	Friction Coefficient		
90	Dry	Top	19.6	6.5	.33		
90	"	"	49.1	10.5	.21		4.47
90	"	"	98.1	16.2	.17		
90	"	"	147.2	21.9	.15	0.118	
90	"	"	196.2	27.5	.14		
90	Wet	Top	19.6	4.9	.25		
90	"	"	49.1	8.5	.17		
90	"	"	98.1	14.6	.15		2.47
90	"	"	147.2	20.3	.14	0.123	
90	"	"	196.2	26.7	.14		
90	Wet	Top	19.6	0.9	.05		
90	"	"	49.1	3.4	.07		-1.71
90	"	"	98.1	9.4	.10		
90	"	"	147.2	15.0	.10	0.113	
90	"	"	196.2	20.6	.11		
111	Wet	Top	19.6	3.0	.15		
111	"	"	49.1	6.4	.13		1.33
111	"	"	98.1	12.8	.13		
111	"	"	147.2	17.3	.12	0.107	
111	"	"	196.2	21.8	.11		
111	Wet	Side	19.6	4.9	.25		
111	"	"	49.1	6.0	.12		
111	"	"	98.1	11.3	.11		1.57
111	"	"	147.2	17.6	.12	0.108	
111	"	"	196.2	23.3	.12		

ave = 0.114

TABLE 4 1:8 R-CLASS TEST RESULTS

CORRECTED ICE RESISTANCE

Model Speed (m/s)	Ice Thickness (mm)	Ice Strength (kPa)	Presawn Resistance (N)	Breaking Resistance (N)	Total Resistance (N)
.24	56	50	210	202	412
.48	56	50	415	135	550
.95	56	50	488	290	778
.24	56	100	210	390	600
.48	56	100	415	230	645
.95	56	100	488	470	958
.24	88	50	480	340	820
.48	88	50	760	300	1060
.95	88	50	850	620	1470
.24	88	100	480	710	1190
.48	88	100	760	675	1435
.95	88	100	850	980	1830
.24	125	100	907*	1420	2327
.48	125	100	1245*	1350	2595
.95	125	100	1330*	1750*	3080

* Based on Extrapolated Data

TABLE 5 1:8 R-CLASS TEST RESULTS

PIECE SIZE DISTRIBUTION

Test	Ice Thickness	Ice Strength	Model Speed	Av. Piece Length (m) +SD	Av. Piece Area (m²) ±SD
8R1	53.9	95	.48	.410 ± .368	.065 ± .106
8R2	55.5	98	.95	.384 ± .282	.060 ± .079
	54.4	98	.24	.306 ± .214	.037 ± .039
	56.3	63	.24	.287 ± .178	.036 ± .039
8R3	90.5	116	.24	.339 ± .272	.052 ± .072
	90.6	116	.48	.274 ± .200	.036 ± .039
8R4	88.6	90	.95	.384 ± .249	.066 ± .072
8R5	90.4	48	.48	.435 ± .285	.075 ± .070
	88.3	48	.95	.484 ± .307	.093 ± .102
8R8	134.1	111	.24	.480 ± .397	.110 ± .175
	134.6	111	.48	.406 ± .307	.076 ± .087
	129.4	111	.95	.404 ± .301	.102 ± .097
8R9	55.9	90	.95	.404 ± .201	.055 ± .050

Within the intervals selected for measurement, roll motions were consistently very low. However the model was observed to exhibit significant roll motions during transitional periods of the test (ie when first entering the ice sheet of shortly after changes in speed).

The data on piece size is presented in tabular form as averages and standard deviations for the tests during which this data was recorded.

Measured yaw loads were recorded at the yaw restraint only. This measurement was somewhat experimental in that this test series was the first time the yaw force was recorded at IMD. This measurement by itself does not give complete information on sideloads on the model but can be used to estimate side forces at the bow. In general the RMS value of the yaw load was on the order of one to two times the mean resistance of the model. This translates into average side loads at the bow of 50 to 100% of the average resistance.

5.0 PROPERTIES

Average ice properties are presented for each of the test ice sheets. In those cases where two sets of properties are shown for a single sheet, one portion of the sheet was used at the first strength and the remainder of the sheet used after tempering to the lower strength. With the exception of strength, all parameters were recorded either shortly before or shortly after the test. Strength has been interpolated to give a value at test time. In this and all cases in the report, strength is defined as Flexural Strength as measured by cantilever beam test.

TABLE 6 ICE PROPERTIES

Ice Sheet	Test	Average Thickness (mm)	Average Strength (kPa)	E/σ	Fracture Toughness kPa/√m	Comp. Strength (kPa)	Density Mg/m³
1	8R1	55.0	95	2840	NR	178	.928
2	8R2a	54.9	98	3570	NR	152	.927
	8R2b	56.2	63	3050	NR	168	NR
3	8R3	91.2	116	6640	NR	NR	.923
4	8R4a	87.6	90	2910	20.7	NR	.923
	8R4b	88.8	48	3110	7.1	NR	.927
5	8R5	88.7	48	3110	10.4	138	.928
6	8R7	57.1	56	1770	NR	NR	.931
7	8R8	133.1	111	3860	37.8	NR	NR
8	8R9	55.7	90	1960	NR	220	.924
9	8R10	88.7	90	3160	NR	178	.924
10	8R11	46.0	91	1910	17.1	172	.928

6.0 DISCUSSION AND CONCLUSION

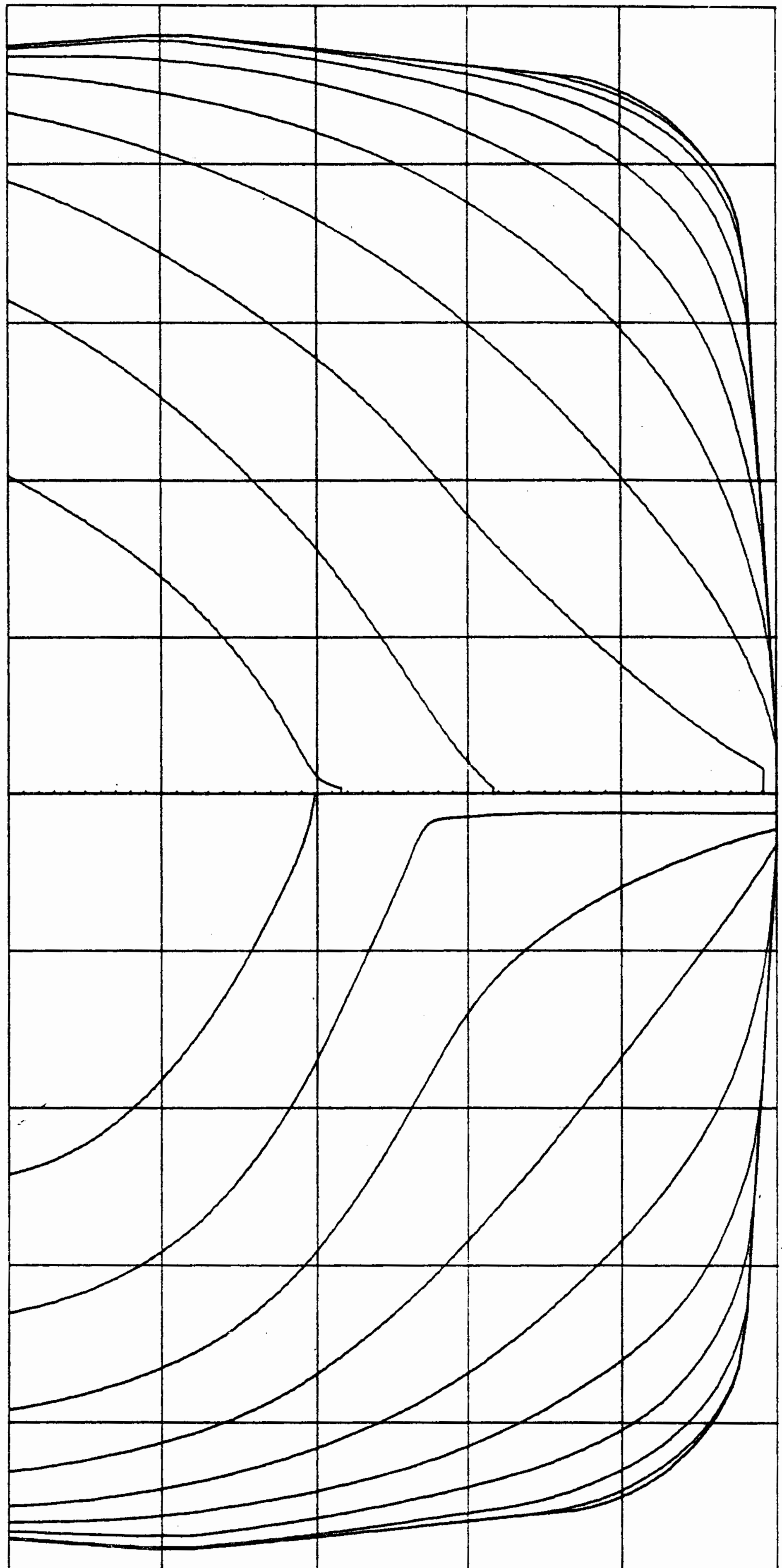
The data gathered during this test series showed features not easily discernable in smaller scale tests. The most important of these is the effect of ice strength. Although only two strengths were tested, the trend of increasing resistance with increasing flexural strength is clearly demonstrated, both in the raw data and in the final predictions.

Vessel motions also appear to play some part in ice resistance. As model speeds increase, the oscillating vertical motion in the bow tends to decrease. The pattern of the model bow riding up onto the ice sheet and then breaking the ice is only evident at lower speeds. At higher speeds, icebreaking becomes more of a continuous process with reduced bow motions as the ice is pushed more smoothly under the model. This difference in motions may indicate two modes of icebreaking related to model speed and overall ice strength. The low speed mode would consist of the model riding up on the ice and forcing it down in discrete steps with the accompanying higher vertical oscillation at the bow. The higher speed mode on the other hand would not involve appreciable oscillation of the bow with the ice being forced down and broken at a faster rate than the model is able to react.

Other than these two features, the recorded resistances appear to be in keeping with both smaller scale results and available full scale data. As the remaining R-Class data is gathered it is expected that differences in prediction at various scales will be explored and discussed in more detail.

In conclusion although testing a 1:8 scale model presents a number of practical problems related to model size and ice strength, the results are judged to be worth the effort. Studies of this type add considerably to the reliability of ice-model testing by enlarging the data base and providing data for the development of improved scaling methods.

Figure 1



R-Class Lines

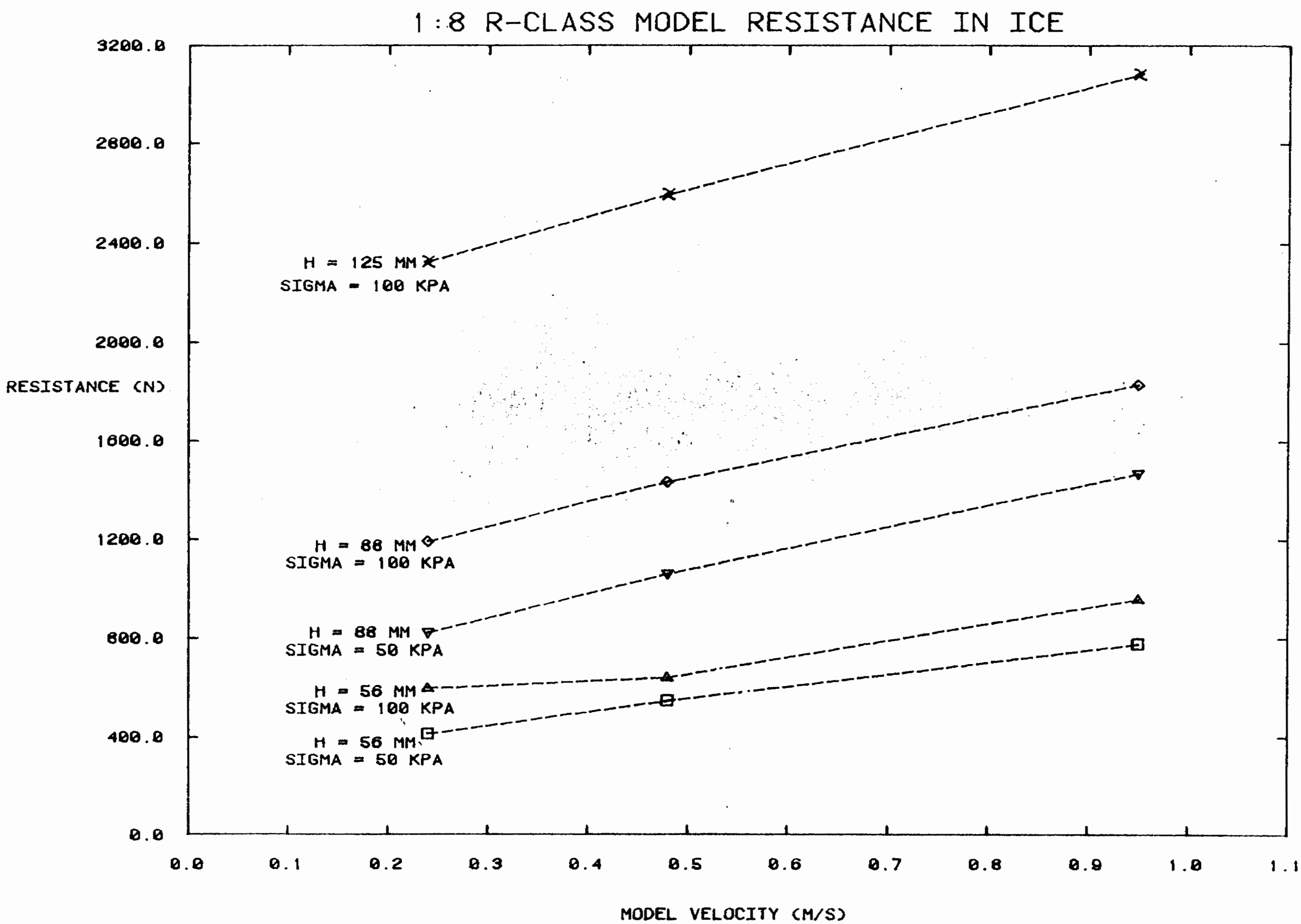

1:8 R-CLASS MODEL RESISTANCE IN ICE
RESISTANCE (N)
MODEL VELOCITY (M/S)
3200.0
2800.0
2400.0
2000.0
1600.0
1200.0
800.0
400.0
0.0
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
H = 125 MM
SIGMA = 100 KPA
H = 88 MM
SIGMA = 100 KPA
H = 88 MM
SIGMA = 50 KPA
H = 56 MM
SIGMA = 100 KPA
H = 56 MM
SIGMA = 50 KPA

Figure 2