PORT AND OCEAN ENGINEERING UNDER ARCTIC CONDITIONS
TECHNICAL UNIVERSITY OF NORWAY

SS MANHATTAN TESTS

A REVIEW OF THE ICE PROGRAM

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ABSTRACT

The U. S. Army Cold Regions Research and Engineering Laboratory was contracted by Humble Oil Company to plan and supervise the ice testing aspects of their arctic tanker tests aboard the SS Manhattan. Since the prime purpose of the entire test program was to derive thrust and resistance values for varying ice types, USACRREL's responsibility was to define the ice conditions encountered.

While the ship was underway in ice, a continuous description (log) of ice conditions, speed, propeller rpm, etc. was maintained. For formal tests ice thickness was measured at adequate intervals to define the sheet over the test section. Total channel width, size of cusps and other parameters were also noted.

The major effort for formal tests was to measure the ice strength to enable comparison of tests in floes of equal thickness. Temperature and salinity profiles of the ice sheet were taken which could be used indirectly to measure ice strength. Brazil tensile tests were made to measure the strength directly but, as with all small sample ice testing, there was a large scatter in the results. A least squares fit of the Brazil data vs brine volume as determined from the temperature salinity measurements gives the following relationship:

$$\sigma_B = 4.82 - 5.68\sqrt{\nu}$$

where σ_B = Brazil tensile strength in kg/cm^2 and ν = brine volume.

To compare the strength of one ice sheet to another for purposes of correlating ship tests it appears that brine volume measurements should be used rather than small sample tests. Although the relationship between brine volume and strength is not precisely known there is far less scatter in the brine volume measurements.

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INTRODUCTION

For nearly 500 years man has tried to navigate the Northwest Passage for a reason which is still viable. Ocean transportation is the most economical way of moving bulk cargo around the world and use of the Northwest Passage would drastically shorten many major shipping routes.

John Cabot in 1497, Martin Frobisher in 1577, and Henry Hudson in 1610 were some of the early explorers who attempted to find the short route to Cathay. After these men came whalers about whose exploits little is known except that their business was lucrative and their area of operation was the eastern Arctic. The end of the Napoleonic wars left England with a large fleet and serious exploration began again. The loss of Sir John Franklin's expedition with three ships led to an intensive series of search expeditions which failed in their primary mission but which completed much of the mapping of the northern Canadian islands. It was one of these search expeditions under Capt. R. McClure that first made the Northwest Passage although part of the trip was made on foot after it became necessary to abandon the ship.

Amundsen completed the first successful traverse of the passage in 1906 in a very small ship. Later, during the Second World War, Sgt. Larsen of the RCMP made two trips in the small schooner St. Roch. In 1954 the Canadian icebreaker Labrador with a displacement of 6,500 tons became the first large ship to complete the passage. In all, less than ten surface ships had completed the passage before the voyage of the 105,000 DWT (150,000 tons displacement) Manhattan in 1969. The Manhattan's size, over 15 times that of previous large ships in the passage, proved to be a great advantage.

The Prudhoe Bay oil discovery, which increased the world's known oil reserves by 5 to 10%, has been the impetus behind a renewed effort to make economic use of the Northwest Passage. The Humble Oil Co. elected to invest nearly 50 million dollars to determine the feasibility of using the Northwest

Passage to move oil from Prudhoe to the Atlantic Coast and to determine design criteria for new, specially designed icebreaking tankers.

There are alternative ways to ship the estimated 300,000 tons of oil per day. The Trans-Alaska Pipeline System (Alyeska) from Prudhoe to Valdez, an open water port in southern Alaska, is one which would get the oil to a year-round tanker port in the Pacific Ocean. However, the large oil-consuming markets are around the Atlantic Ocean and specifically the eastern United States. Another alternative is to pipe the oil into Canada and down the MacKenzie River Valley into the north central area of the United States. This is a very long line and it runs into international taxing and control problems. Initial estimates mentioned a saving of fifty cents per barrel or about 180 million dollars per year by using tankers! Little wonder, then, that Humble elected to research the tanker approach.

Now, in retrospect and with Humble's final decision to drop the tanker scheme well publicized,what has changed to redirect Humble's approach? I believe that large tankers are technically feasible, but with changing ice pressure their schedules cannot be precisely fixed. Thus large, costly storage facilities would have to be constructed on the permafrost of the North Slope. Also the docking and loading of these large tankers some 20 miles offshore in 100 ft of water is a problem which requires more expensive time and research. Apparently the Manhattan experiment indicated a low profit margin for they now support the pipeline solution.

The Manhattan was selected for a number of reasons. Built in 1961 as one of the early supertankers, she is extremely heavily built. During her early design, the U. S. Navy requested a speed of 17 knots, which dictated a relatively high power of 43,000 SHP. To get this power required two propellers. She also had two rudders which gave added maneuverability and safety in the ice. At about one-half the size of the ships Humble hoped to build for the Northwest Passage, the SS Manhattan was an ideal test ship.

However, much modification was needed. A new bow of a shape different from previous icebreakers was added. From the bow nearly to the stern a sloping ice belt some 9 ft wide and 16 ft high was added at the waterline. In the stern a second hull was built inside the ship to protect the machinery spaces. Shear couplings were added to protect the turbines from the anticipated high torque loadings caused by the propellers hitting ice.

ICE TESTING PROGRAM

A large ice testing program was conducted during the voyages under the direction of USACRREL. Personnel from the University of Alaska, Iowa State University, and the University of Minnesota assisted in the field measurements. Since the prime objective of the entire experiment was to obtain icebreaking tanker design data, all engineering data (power, turning, side friction, etc.) were related to ice thickness and strength as much as possible. Ice strength varies from floe to floe and from day to day in any one floe and so strength measurements were necessary to compare tests.

Basic to the entire experiment was the thickness of the ice that the ship broke. The ice encountered during the 1969 trip was extremely heterogeneous - primarily old multi-year floes, one-year ice and some thin new ice. Thicknesses sometimes doubled from 6 to 12 or more feet in distances of less than 100 feet. It was, therefore, impossible to relate the ship's data to ice thickness for the majority of the 1969 tests. During the 1970 tests ice thickness seldom varied by more than a few inches throughout entire 3000-ft test runs.

For each formal test, profiles were measured of ice temperature and salinity. These parameters are used to compute the brine volume, which is that fraction of the ice volume made up of liquid inclusions. Since the ice between these inclusions is essentially pure, ice strength can be directly related to brine volume.[1] Figure 1 shows this relationship for ring tensile tests.

Three-inch-diameter cores were taken with a USACRREL auger, cut into about 10-cm lengths and put into plastic freezer containers for subsequent melting and salinity (resistance) determination. This was done as rapidly as possible to minimize brine drainage losses. After the samples were placed in the containers,

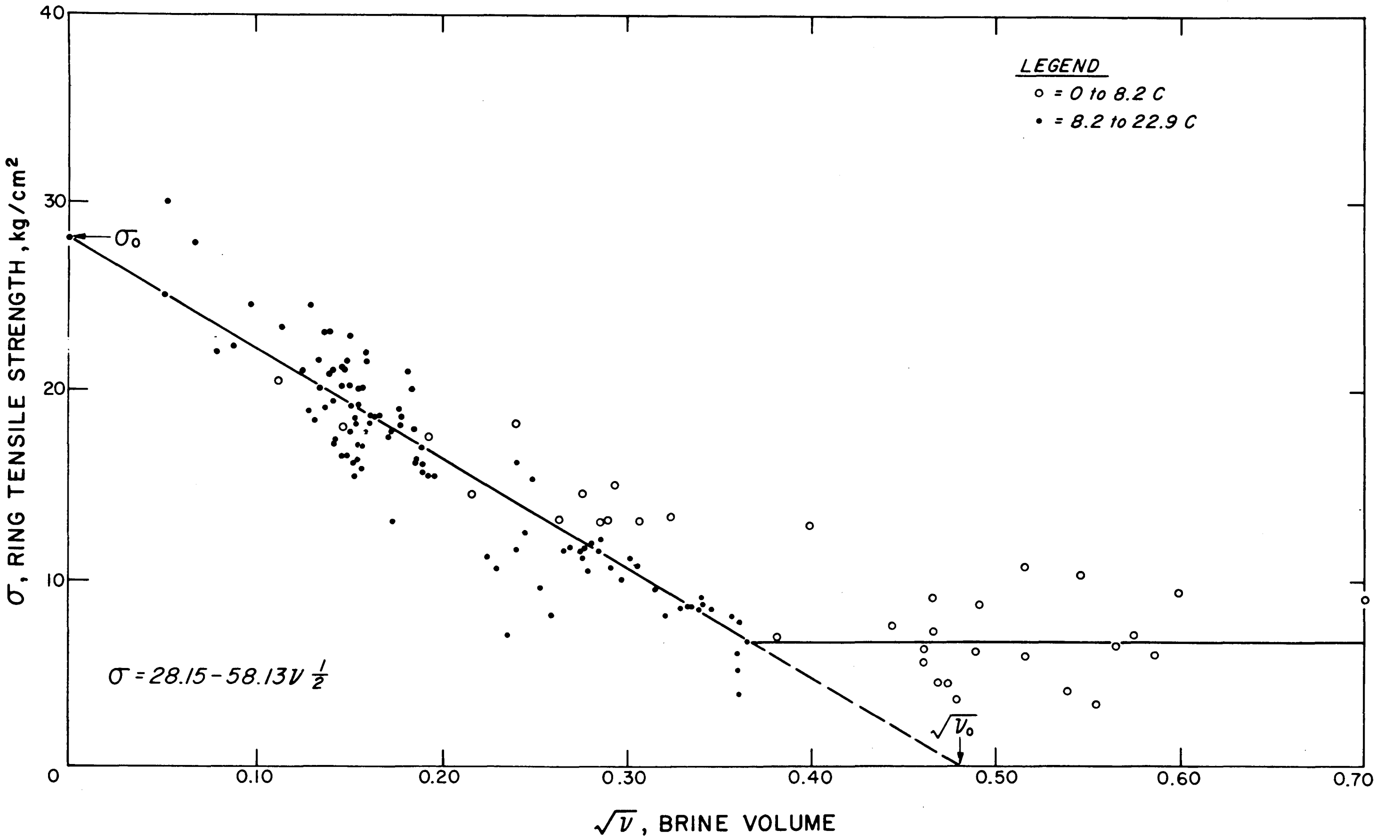

FIGURE 1. RING TENSILE STRENGTH VS. BRINE VOLUME

small holes were drilled into them and their temperatures were measured by either mercury thermometers or a thermistor. On cold, windy days a second core was taken nearby to measure temperature, for the samples cooled too rapidly.

Lastly, another core was taken on which Brazil tensile strength tests were run. This test has been used recently in preference to the ring tensile test because the sample preparation is easier and the test is therefore probably more consistent as it does not create stress concentrations. For this test a cylinder about 3 inches long and 3 inches in diameter is pressed on a diameter and the load at failure noted. Using the formula from Nevel[2]

$$\sigma = \frac{P}{\pi r L} \qquad 1$$

where P is the load, r the radius of the sample, and σ the Brazil tensile strength. Since these tests require so little preparation they can be run rapidly with the ice near its in-place temperature, and complete profiles can easily be run. Measuring the strength along the diameter of a vertical core is also desirable since it is along this axis that the anisotropic ice fails under most natural conditions. During the SS Manhattan tests all the ice was broken by downwards bending by the sloping bow. The average of the Brazil values over the top third of the ice sheet was used for comparing the ice strength of the different floes in which the ship was tested.

Like the ring tensile test and all other tests on small ice samples, the Brazil tests showed a large scatter when compared to the calculated brine volume. To get a better view of the relationship the strength determinations were averaged for small brine volume ranges and these are plotted in Figure 2. Table I shows the data as averaged over 0.005 brine volume increments. The empirical equation for Brazil strength based on a least squares fit from 270 samples is

$$\sigma_B = 4.82 - 5.68\sqrt{\nu} \qquad 2$$

for ν less than 0.13 and where σ_B = tensile strength as determined from a Brazil test, ν = brine volume.

It appears that one should use strength values computed from brine volume measurements to compare the ice from individual ship tests since these data show

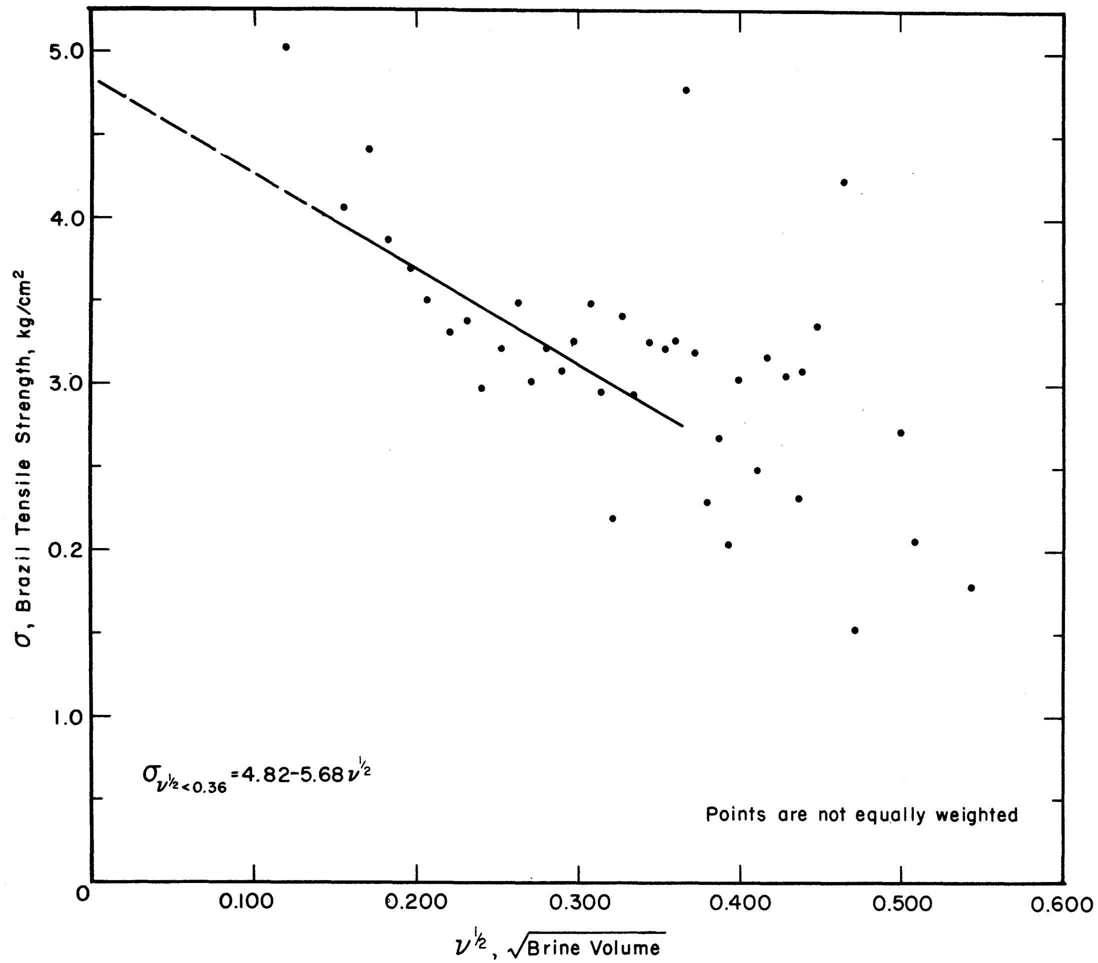

FIGURE 2. BRAZIL TENSILE STRENGTH VS. BRINE VOLUME

much less scatter. Of course, an in-place cantilever beam test is the best way to measure strength directly. However, in polar ice this test is so time-consuming that it is mentioned only in passing.

ICE LOG PROGRAM

An "ice watch" was maintained during the record voyage whenever the ship was moving through ice-covered waters. The purpose of the watch was to observe and describe in a log the variations in the ice conditions through which the ship passed and thus, hopefully, to be able to compare the Manhattan's performance with regional ice observations and forecasts.

A form was made that called for the following information: Date, time, position, total ice concentration, concentration and estimated thickness in three age categories (old ice, first-year ice and young ice), concentration and estimated height of surface features of the old ice and first-year ice, size of floes, snow depth, propeller RPM, cracks formed by the ship, ship's speed, and other remarks.

The first problem encountered was the training of observers. Our ice party personnel were the logical ones to perform these duties but only two of the nine-man party had ever seen sea ice before. Mr. A. Lavinski of the Canadian DOT who was on board to supply liaison between the ship's crew and the DOT ice observation flights was a tremendous help in setting up the forms and training the observers. Training was not completed before we entered the ice and the ice log reflects this fact by being more complete and probably more accurate later on during the voyage.

Estimating ice thickness while underway was also a difficult and subjective problem. To partially alleviate this problem we hung over the side rods which were painted alternate colors at 1-ft intervals. These were located near the bow where the ice often turned on edge. However, these rods were well above the ice surface and above the broken pieces so that they would not be carried away as a large piece of ice slid past the ship's side. After some experience and a few actual measurements on the ice our estimates were within 10 to 20%. Snow depth was estimated in the same fashion.

The ship's speed was constantly monitored by Doppler sonar; however, often while operating in the ice the sonar transducers were blocked by pieces of ice, rendering this system unreliable. During formal testing Raydist was used with some success. This is an electronic system that can measure changing distance to an accuracy of about 10 ft. The ice observers made remarkably accurate measurements of the ship's speed by simply noting the time it took for a known portion of the ship's length to pass a wood chip or recognizable piece of ice. Two sighting triangles were used from the bridge; the forward triangle had a base about twice as long as that of the after triangle and thus was to be used at higher speeds. With a base length of 60 ft for the after triangle, repeated observations could be used to determine acceleration.

As on most large ships, the 20-ft-diameter propellers of the Manhattan are fixed pitch. Thus the power required to drive the ship through the water and ice can be closely approximated from the ship's speed and its propeller RPM.

The ice log data were used primarily for engineering data to augment those gained during the formal testing program. Rough power-required versus ice thickness ratios can be gleaned from it. Coverage and thickness data are available for close prediction of ship transit times.

OTHER OBSERVATIONS

Many ancillary tests and observations were made throughout the trip which should be mentioned and which, I hope, will elicit ideas for future tests and comments on our present attempts.

Mr. Douglas Bradford of the Canadian DOT was on board the L. St. Laurent which escorted the Manhattan on the 1970 voyage. By use of a simple, somewhat subjective set of criteria he reported on ice pressure. "Light" pressure meant that the track behind the ship was closed no more than 50%. "Heavy" pressure meant that the ship's track was closed. "Very heavy" pressure meant that ice was piling on and under the ship. This is a start on a very difficult but very germane problem. If year-round shipping is to be economical, areas of ice pressure must be recognized and predicted so that they can be avoided or, at least, planned for.

Prof. R. L. Handy of Iowa State University performed tests on the snow cover with a bore-hole shear soil testing device. This showed that the dense polar snow had a cohesion similar to dense, structural silt, but that the snow was really too weak to be considered part of the ice beam when breaking. This device showed the maximum value for sliding friction to be 0.69, but, of course, this does not tell us about the actual friction of snow-covered ice on steel along the sides of a long cargo ship or tanker.

CONCLUSIONS

Enough good data were acquired from the two Arctic voyages of the SS Manhattan to make a preliminary design for a bulk carrier capable of navigating the Northwest Passage. But before the economic picture is crystal clear more knowledge is needed about ice movement and pressure. For future icebreaker testing the ice strength testing procedures should be refined; work on this is presently being carried out at USACRREL.

ACKNOWLEDGMENTS

The Humble Oil Company was directly responsible for the entire test, providing all the impetus, most of the money and a fine ship's company. The aid and direction of my colleagues at USACRREL, Dr. Assur, Dr. Weeks, and Messrs. Frankenstein, Nevel and Wuori were invaluable. My deep thanks to the gentlemen from the Universities of Alaska, Minnesota and Iowa State who collected most of the data, often under rather unpleasant conditions.

BIBLIOGRAPHY

1. Weeks, W. and A. Assur (1967) Mechanical Properties of Ice, USACRREL Monograph II-C3.

2. Nevel, D. E. (1969) The Ring Test, Brazil Test and Strength of Sea Ice, USACRREL Technical Note.

TABLE I

NUMBER OF SAMPLES	BRINE VOLUME Average	STRENGTH Average (Kg/cm^2)	STRENGTH Standard Deviation
3	.019	5.040	.184
5	.024	4.060	.815
13	.029	4.406	.580
32	.033	3.867	1.008
21	.038	3.692	.805
11	.042	3.491	.949
21	.048	3.333	.708
16	.053	3.379	.614
14	.057	2.976	.660
20	.063	3.249	.412
12	.068	3.458	.916
15	.073	3.094	.647
17	.078	3.212	.807
14	.083	3.076	1.065
11	.088	3.265	1.039
5	.094	3.480	1.698
9	.098	2.958	1.045
4	.103	2.200	.634
6	.107	3.407	.764
3	.112	2.943	.332
6	.118	3.255	.472
5	.124	3.210	.402
7	.129	3.252	.374
2	.135	4.780	.960
2	.138	3.190	1.250
1	.143	2.300	.000
2	.150	2.685	.105
1	.154	2.030	.000
2	.159	3.030	.330
4	.168	2.486	.667
2	.173	3.167	.253
1	.183	3.050	.000
2	.190	2.320	.150
2	.192	3.070	.390
1	.200	3.360	.000
1	.215	4.230	.000
1	.222	1.530	.000
2	.250	2.720	.870
1	.258	2.060	.000
1	.296	1.790	.000