SEA ICE MECHANICS RESEARCH

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LONG TERM GOALS

The ultimate goal of our research is the development of a complete ice dynamics model that will include ice stress, lead direction, and ice thickness distribution in refrozen leads.

OBJECTIVES

The NorthWest Research Associates, Inc. (NWRA) objective during this past year was to conduct the necessary data reduction, data analysis, modeling, and code development to write and submit for publication three papers in the *Journal of Geophysical Research Special Issue for SIMI*, the three papers discussed in the technical approach section. These papers all derive from ONR's CEAREX, LEADEX, and SIMI field programs.

APPROACH

Our Approach is to use measured sea ice stress and motion to guide our model development.

ACCOMPLISHMENTS

Three papers were submitted for publication in the *Journal of Geophysical Research Special Issue for SIMI*. They are listed under Publications below.

SCIENTIFIC/TECHNICAL RESULTS

We have shown that the lead direction is aligned with the principal stress direction at the time of lead creation. This finding has been verified by use of SIMI data from stress buoys, GPS buoys, and SAR. The lead direction is not a material property but results from the stress state at the time the lead is created. Also, the principal directions of stress and strain rate do not coincide when lead systems are active.

- Technical results of stress in resultant space are shown in Figure 1.
- A yield surface for the isotropic part of pack ice behavior can be obtained from measured stress data.
- NWRA collected stress data from four rosette sites consisting of four sensors (a paper was submitted to the JGR Special Issue).
- NWRA has developed a new sea-ice stress data-processing procedure which considers numerous factors to convert sensor oil pressure to geophysical stress:
    1. Sensor response calibrated using in-situ calibration tests.
    2. Ice thickness data at the rosette sites.

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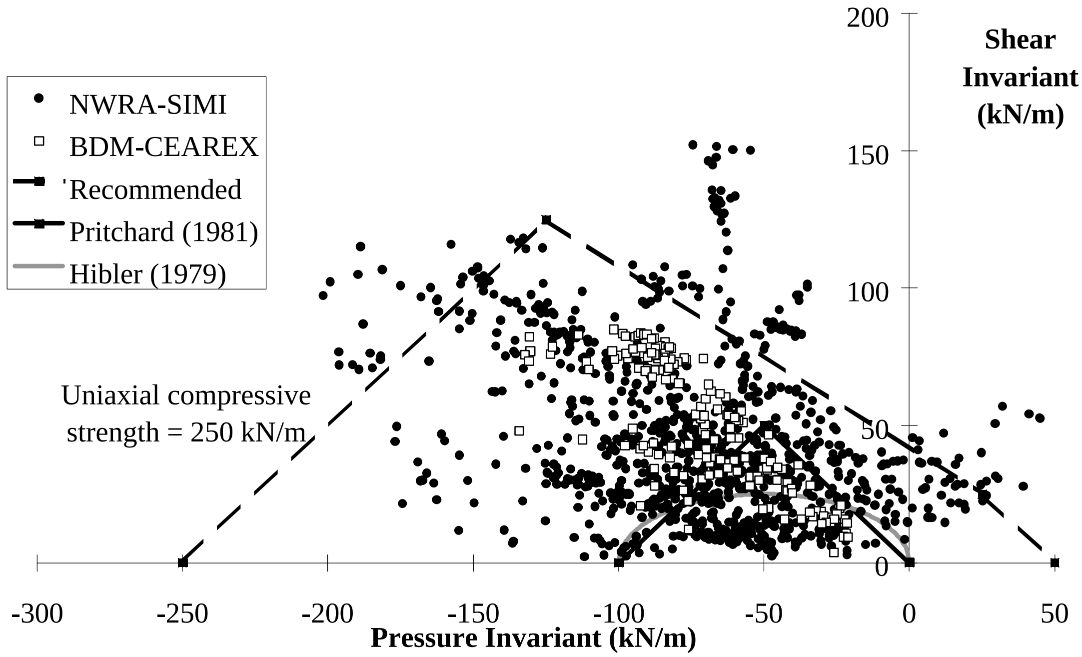

Figure 1. Stress-resultant invariants (hourly averages) with suggested failure surfaces

3. Distribution of the elastic modulus through the thickness.
4. Slow changes in stress sensor oil pressure resulting from sensor pressurization cycles.
5. Long-term trends in ice temperature data (creep in thermal stress).
6. Sensor temperature effects.
7. Time-dependent model to find ice stress from sensor oil pressure.
8. Thermal stress at stress sensor depth using the de-trended temperature data at all depths.
9. Stress at the depth of the stress sensor due to the bending moment caused by the large-scale stress and the variation in the elastic modulus with depth.

- Figure 1 shows SIMI and CEAREX geophysical stress data as invariants of the stress resultant (the integral of the stress through the ice thickness) with typical isotropic failure surfaces from Pritchard (1981) and Hibler (1979), and a recommended failure surface specifically for the *isotropic ice* in an anisotropic model. Note that measured stresses are clearly outside of the modeler's failure surfaces.
- Maximum compressive principal stress is unconfined compressive strength (250 kN/m).

Technical results for pack ice stress data fit a scale-dependent strength curve, from Sanderson (1988) as seen in Figure 2.

- If properly installed, a stress rosette provides the average stress in the whole floe (1 to 3 km).
- Proof:

1. CEAREX – during the Day 281 ridge-building event, a sea-ice stress rosette found that the stress normal to the ridge direction was the only significant stress component (Coon et al., 1989).

2. SIMI – during the Day 35 lead creation event recorded by satellite SAR images and GPS/Argos drifting buoys, a sea-ice stress rosette found that the stress normal to the lead and the shear stress on the lead dropped to zero just before the lead opened and remained that way for over a week (Coon et al., 1995). The stress component parallel to the lead was variable but remained large throughout the event.
3. SIMI – Various combinations of eight stress sensors installed at four locations in "Lake Andy" were used to form rosette combinations with diameters of 3, 10, 50, and 100 meters. The oil pressure data from these four rosettes give essentially the same envelope.

- The instrumented floe can be considered an indentor pushing into the ice pack.
- Indentor has high aspect ratio (width of 1 to 3 km over floe thickness of 1 to 3 m).
- For high aspect ratio, indentation pressure is essentially the compressive strength.
- For the stated ranges of floe size and ice thickness, and a compressive strength of 250 kN/m from the SIMI and CEAREX stress data, these data are plotted as a rectangular area on the indentation pressure-area curves used in calculating ice loads on structures [see figure below, adapted from Sanderson (1988)].
- The new data are consistent and show a marked change of indentation pressure over scale.

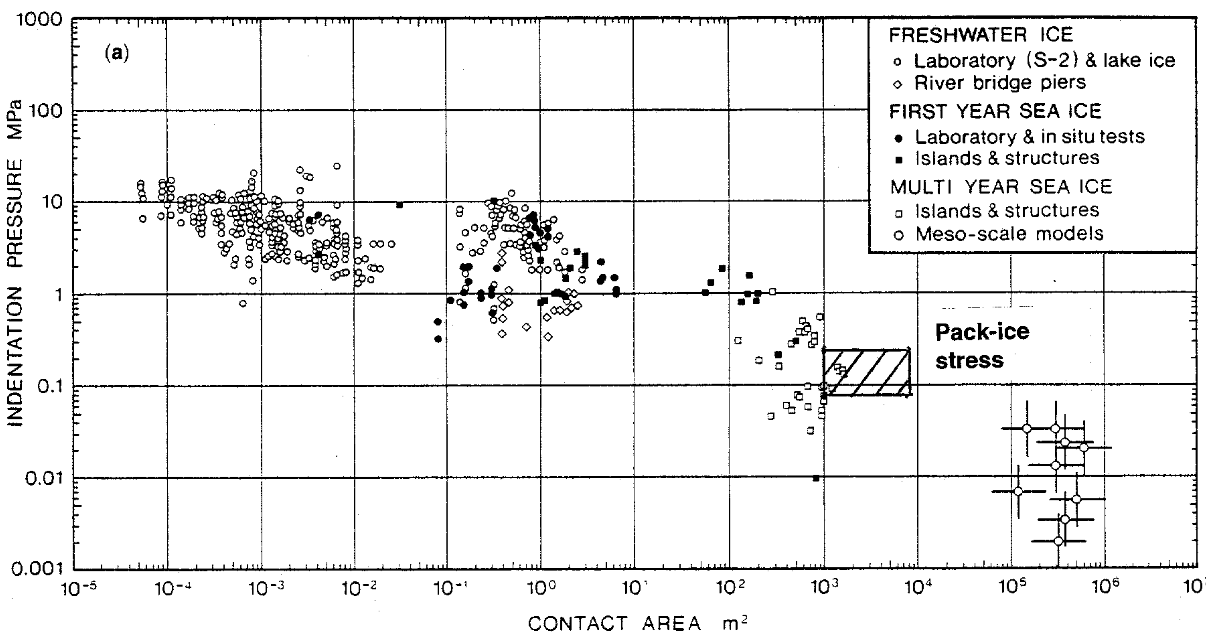

Figure 2. Indentation Pressure Found from Stress Data - after Sanderson (1988).

IMPACT FOR SCIENCE (and/or) SYSTEMS APPLICATIONS

The anisotropic sea-ice mechanics model can be developed for application to a range of problems, such as assisting in the interpretation of SAR data, forecasting ice conditions using current SAR data, forecasts of ice-generated noise, studies of climate dynamics, ice loads for offshore platform design, and environmental hazard analysis.

TRANSITIONS

At present, NWRA is using the sea ice stress data collected and interpreted under ONR programs for evaluating ice loads on offshore structures.

RELATED PROJECTS

Under NASA sponsorship, NWRA found that accounting for lead orientation allows a clear analysis of the effect of the weekly time step on calculations of open-water production, but that it is difficult to obtain a good estimate of open-water production in a single cell without accounting for lead orientation and location.

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