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Large-Scale Ice Fracture Experiments
Phase 2

Field Program Report
April 17 - May 8, 1993

DRAFT

PARTICIPATING ORGANIZATIONS

AMOCO EURASIA PETROLEUM COMPANY
CANADIAN MARINE DRILLING LTD.
MINERALS MANAGEMENT SERVICE
MOBIL RESEARCH & DEVELOPMENT CORPORATION
NATIONAL ENERGY BOARD CANADA
OFFICE OF NAVAL RESEARCH

Prepared by

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Clarkson University
Jessco, Inc.
Sandwell, Inc.

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Contents

Introduction

In 1990, Canadian Marine Drilling Ltd. (Canmar), Amoco Canada Petroleum Company Ltd. and Mobil Research & Development Corporation joined efforts with Clarkson University, Sandwell, Inc. and Jessco Operations, Inc. to design an experimental program to investigate the fracture properties of ice. The joint-industry project "Large-Scale Ice Fracture Experiments" was conceived as a two-phase program. Phase 1 was completed in January, 1992 and consisted of freshwater ice fracture tests designed to test the feasibility of larger scale sea ice fracture experiments. Based on the success of that test program, Phase 2 was approved with the participation of the following organizations:

Project Participants

- ○ AMOCO EURASIA PETROLEUM COMPANY
- ○ CANADIAN MARINE DRILLING LTD. (CANMAR)
- ○ MINERALS MANAGEMENT SERVICE (U.S. DEPARTMENT OF THE INTERIOR)
- ○ MOBIL RESEARCH AND DEVELOPMENT CORPORATION
- ○ NATIONAL ENERGY BOARD (CANADA)
- ○ OFFICE OF NAVAL RESEARCH (U.S. DEPARTMENT OF THE NAVY)

Phase 2 of the project was conducted near Resolute, Northwest Territories, Canada over the period April 17 to May 8, 1993. As in Phase 1, project management and operation of the data acquisition system were duties assumed by Canmar. Loading systems were again designed, constructed and operated by Sandwell, Inc. of Calgary. All field logistics, accommodations and heavy equipment operations were the responsibility of Jessco Operations, Inc., also of Calgary. Planning of the experiments, data analysis and laboratory ice characterization studies were carried out by J.P. Dempsey et al. of Clarkson University, Potsdam, New York.

Additional Research

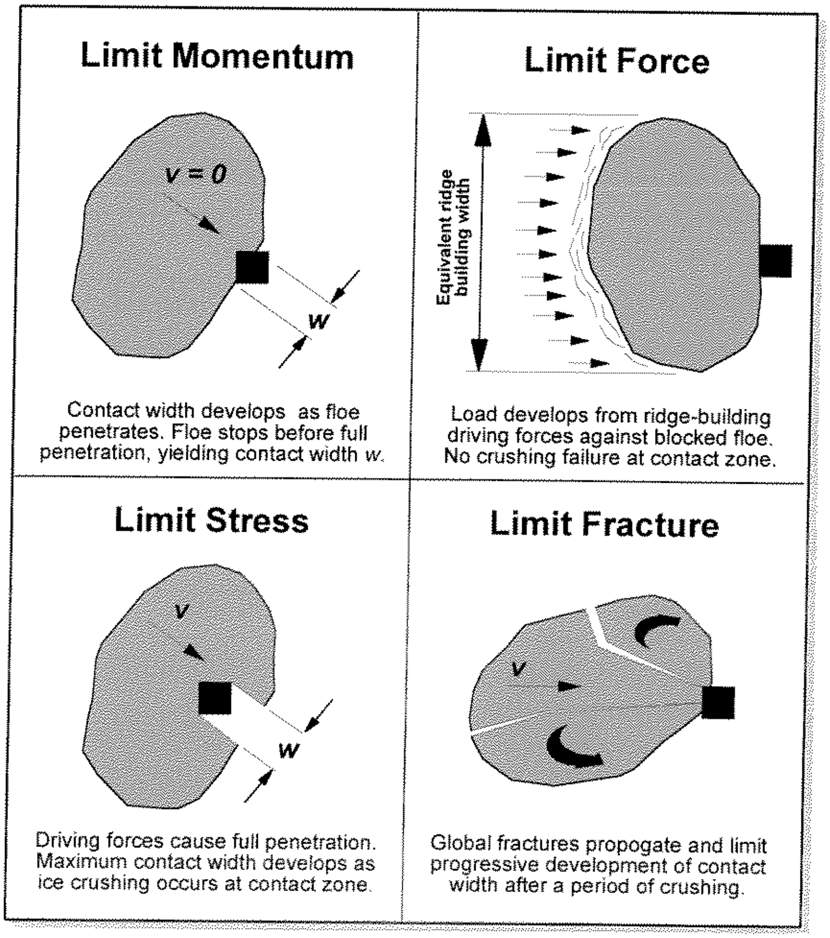
Three other research groups undertook additional work around the core experiments of Phase 2. Personnel from the INSTITUTE FOR MARINE DYNAMICS, National Research Council Canada, were contracted by the National Energy Board to perform crack speed measurements with high speed video and conduct small-scale beam fracture tests. NORTHWEST RESEARCH ASSOCIATES of Seattle, funded by the Office of Naval Research, monitored *in situ* ice stresses and performed shear stress tests with the assistance of the Phase 2 project team. Finally, the INSTITUTE OF OCEAN SCIENCES, Sidney, B.C., recorded the acoustic signatures of fracture events. Affiliations of all personnel involved in Phase 2 are summarized in Appendix A.

Project Background

To date, methods to estimate global ice loads on arctic structures generally assume that crushing is the primary ice failure mode. Field observations indicate that crushing occurs perhaps only 10% of the time, whereas global cracking and splitting of ice floes (at significantly lower loads) is much more frequent. Global splitting has been proposed as a fourth ice load limiting scenario (Blanchet, 1990), joining limit momentum, limit force and limit stress (Fig. 1). This has implications in the design of arctic offshore production structures against multi-year ice. By incorporating the statistics of full-scale splitting of ice floes, a reduction in probabilistic global design ice forces could be realized.

An overview of limit fracture and some general background information on fracture modelling is presented in Appendix B.

Fig. 1
Global ice load limiting scenarios



Limit Momentum: Contact width develops as floe penetrates. Floe stops before full penetration, yielding contact width *w*.

Limit Force: Load develops from ridge-building driving forces against blocked floe. No crushing failure at contact zone.

Limit Stress: Driving forces cause full penetration. Maximum contact width develops as ice crushing occurs at contact zone.

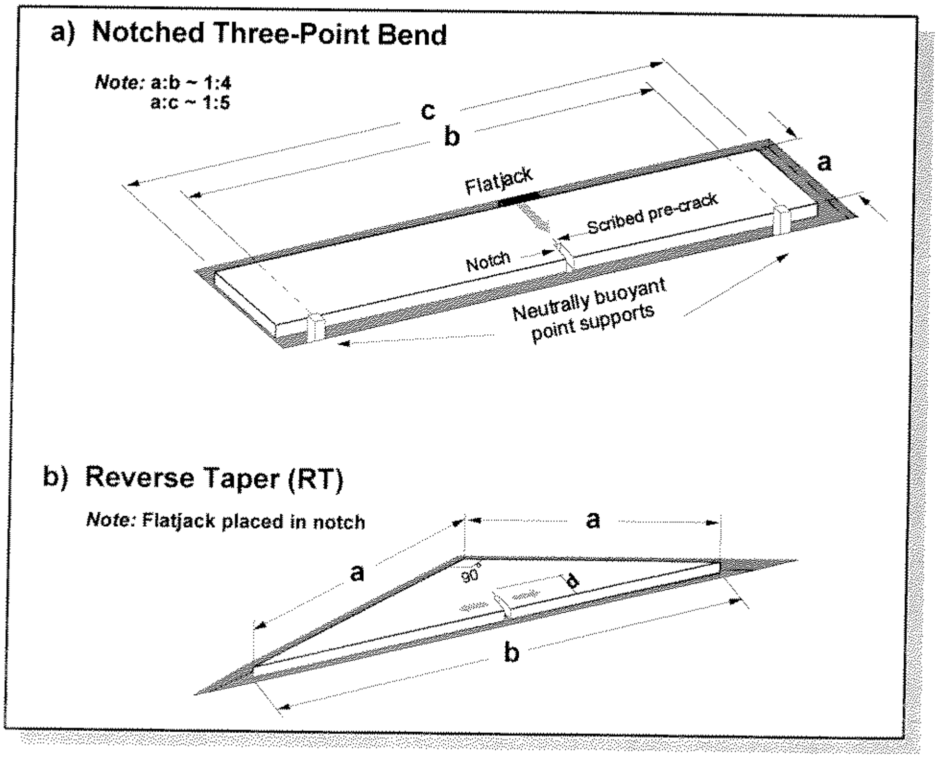
Limit Fracture: Global fractures propogate and limit progressive development of contact width after a period of crushing.

Though fracture is a very important global failure mechanism, it is not well understood. Scale effects in ice make it difficult to extrapolate small-scale studies such as laboratory fracture toughness tests to full-scale conditions. In 1990, a theoretical model of global floe splitting was developed for Canmar and Mobil by Dr. J.P. Dempsey of Clarkson University. A two-phase jointly funded experimental program was then conceived to calibrate the model.

Phase 1 was completed on a freshwater lake near Canmore, Alberta in January, 1992 and confirmed the feasibility of the larger experiments planned for Phase 2. Large-scale experiments were necessary in order to define the fracture parameters of saline ice under natural conditions, a requirement for proper calibration of the theoretical model.

Phase 1 Overview

The primary goal of Phase 1 was to assess the technical feasibility of large-scale, full-thickness ice fracture measurements. This objective was fulfilled. Additionally, fracture toughness and global elastic modulus were determined for 13 full-thickness freshwater ice test specimens. Specimens were originally rectangular (Fig. 2a), but warm temperatures caused melting at the bottom of the loading slots. The reverse taper (RT) geometry


a) Notched Three-Point Bend

Note: a:b ~ 1:4
a:c ~ 1:5

b) Reverse Taper (RT)

Note: Flatjack placed in notch

Fig. 2
Test configurations for Phase 1

was adopted to alleviate this problem since the flatjack loading system (essentially a thin, rectangular steel bladder inflated with either nitrogen gas or hydraulic oil) was placed in the scribed pre-crack (Fig. 2b).

A major accomplishment in Phase 1 was the success of the servo-controlled flatjack loading systems with crack tip opening displacement (CTOD) as the feedback variable. Controlled crack growth was consistently obtained, allowing multiple tests on a single specimen and investigation of the change in fracture resistance with crack growth.

Scale range of 1:85 achieved in Phase 1

The largest known fracture specimen at that time was also tested during Phase 1, an RT of plan dimensions 40.5 x 40.5 x 57 m and thickness 60 cm. This resulted in a scale range from smallest to largest specimen of 1:85. Fracture toughness of RT specimens exhibited significant scatter over this range, most likely due to the presence of a natural thermal crack density.

Additional information on Phase 1 is included in the proprietary field report of May 11, 1992 (Canmar, 1992). A more general summary of the experiments is presented in Kennedy et al. (1993) and details of the theoretical floe splitting model are included in Dempsey et al. (1993).

Objectives of Phase 2

Phase 2 was the opportunity to obtain the information necessary to properly calibrate the theoretical fracture model. Data collection was therefore the primary goal. In general terms, the objectives of Phase 2 were to:

- Plan, design and conduct large-scale sea ice fracture experiments based on the experience gained in Phase 1;
- Study the effects of loading rate, specimen size, crack length, scale range and other parameters on fracture load, toughness, energy and global modulus of full-thickness sea ice; and,
- Use the results of Phase 2 (and Phase 1) to calibrate the theoretical model of floe splitting for use in probabilistic design ice load models.

It was important to complete as many tests as possible over a wide range of loading rates and specimen sizes, but it was equally important to achieve some degree of test repeatability.

Site Description

Resolute, Northwest Territories, Canada was identified as the location which provided the best combination of accessibility, accommodations, equipment, logistics support and, most importantly, thick saline ice. Resolute is located on Cornwallis Island in the Canadian Arctic Archipelago and has for decades served as a base for Arctic research and polar expeditions. Resolute is also serviced by two Boeing 737 commercial flights per week from both Edmonton, Alberta and Montreal, Québec.

Weather Conditions

Phase 2 was carried out over the last two weeks of April and the first week of May. This timing was selected based on a study of close to 40 years of ice thickness, air temperature and storm frequency records for the region. Conditions in Resolute are generally consistent from year to year, but blowing snow can create severe working conditions and bring on-ice work to an abrupt halt.

Mean ice thickness in Resolute Bay for the testing period is historically 180 cm (6 feet) with on-ice snow cover averaging 25 cm (10 inches) deep. Air temperatures were expected to be in the range of -25 C to -15 C, quite comfortable for work.

All heavy equipment was shipped in advance and checked on-site prior to the arrival of most personnel. The tests could then be postponed if some equipment was damaged in transit or if the weather forecast near the proposed start date was unfavourable.

Fortunately, 1993 conditions were quite favourable and ice thickness, snow cover and air temperature were as expected. However, two successive days of severe blowing snow (April 28 and 29) filled the access road to the site and testing was impossible. This was the only downtime experienced over the 21-day test period and was again fortunate, as historical records indicate a mean of 8 to 10 days of blowing snow over that time period.

Site Selection

The specific site chosen for the tests was Allen Bay, a relatively large sheltered area with a consistently level first-year ice sheet around 180 cm thick. Snow cover on the ice varied from 5 to 40 cm thick, and air temperatures remained around -15 C to -20 C over the three- week period. A road was plowed from the Resolute Airport base camp to the shoreline of Allen Bay prior to the arrival of the project team so that ice thickness, crystal structure and other properties could be verified before any heavy equipment was mobilized to site.

A road was then plowed from the shore to the selected test area, about 800 metres out into Allen Bay. Additional plowing and backfilling was required near the shoreline to smooth out some rough spots caused by rafting and a minor tidal hinge, but beyond 30 m from shore the ice sheet was undeformed. Ice and snow conditions in the test area were generally uniform.

The site was fully accessible on Day 2 of the test program and was a 10-minute drive from the base camp (see Fig. 3). While road work was underway, several days were spent preparing the data acquisition shack and assembling and testing the loading system in workshops at the base camp.

Once a specific area for testing had been identified, a long straight road was plowed to allow equipment and trailers to be quickly and easily moved from test to test. General views of the test site are presented in Fig. 4 and Fig. 5 and a brief daily log summary is included as Appendix C.

Fig. 3
Resolute area and location of test site

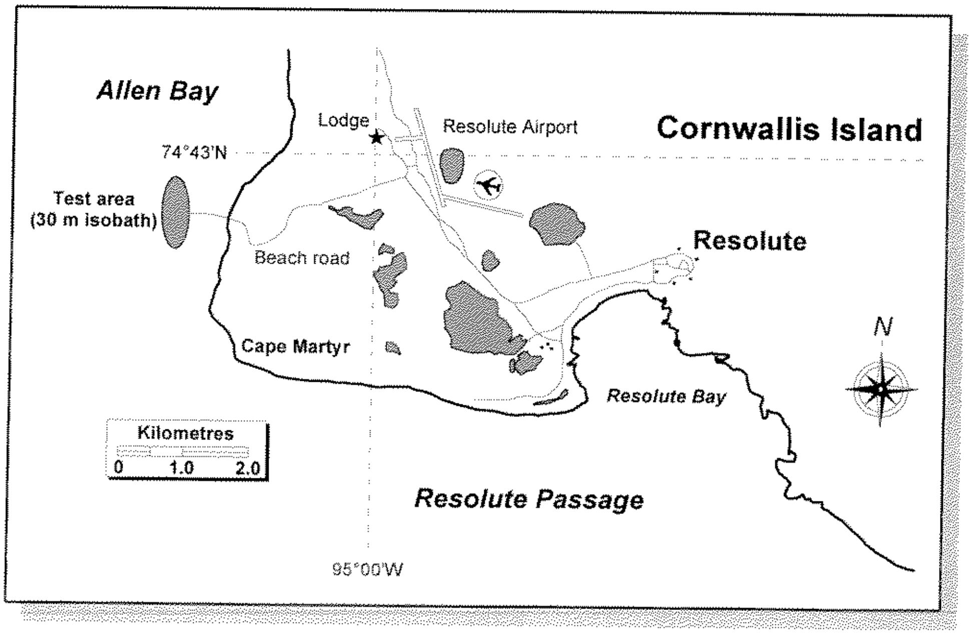


Fig. 4
General view of Allen Bay test site

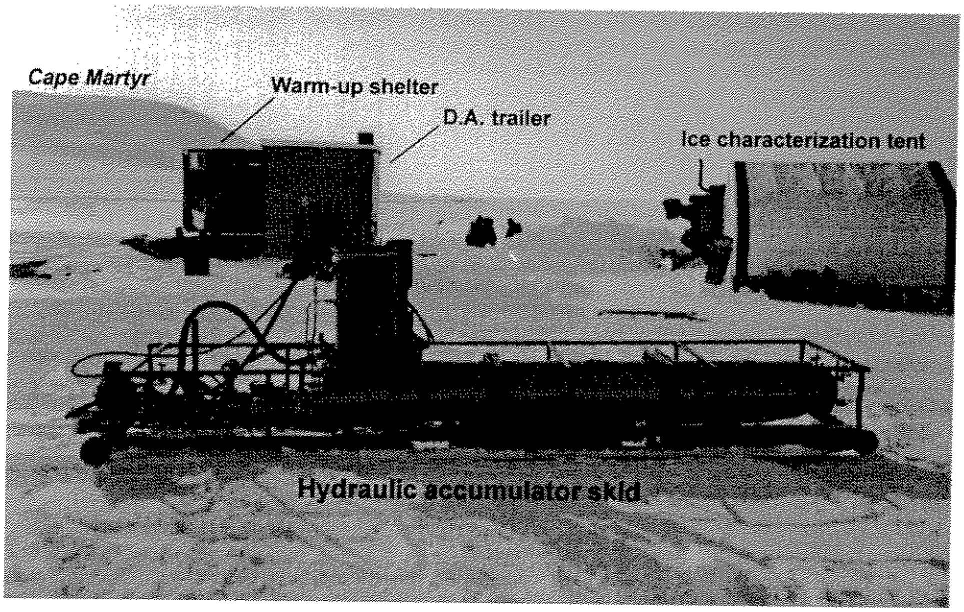
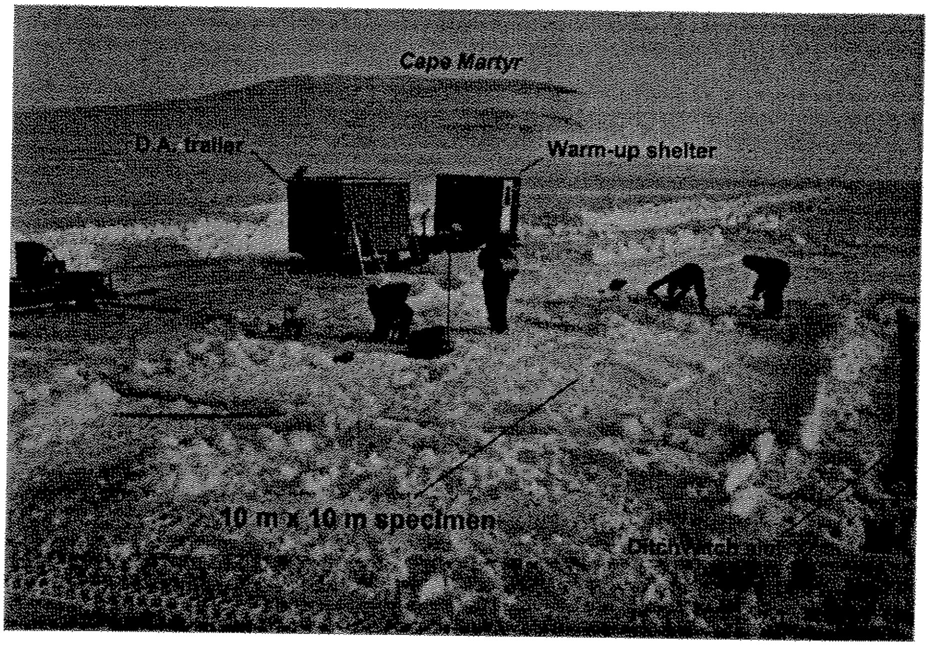


Fig. 5
General view of test site and typical test specimen



Snow Cover

A hardpacked snow cover was present on the ice at Allen Bay. A region representative of the snow conditions in the test area was selected and a series of thickness and snow/ice interface temperature measurements carried out. Snow thickness measurements were taken along a straight line at 4 m intervals over a total survey length of 120 m. As shown in Fig. 6, the snow cover was undulating, producing the rippled effect typical of the Arctic, and varied in thickness from 5 or 6 cm to almost 40 cm. Spot measurements of the snow/ice interface temperature are presented in Fig. 7.

Fig. 6
Snow thickness,
Allen Bay

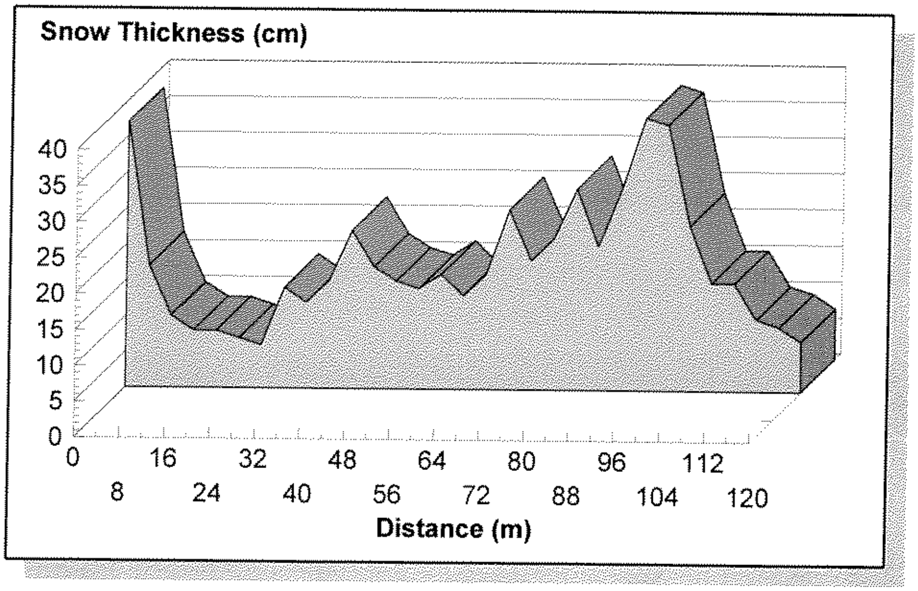
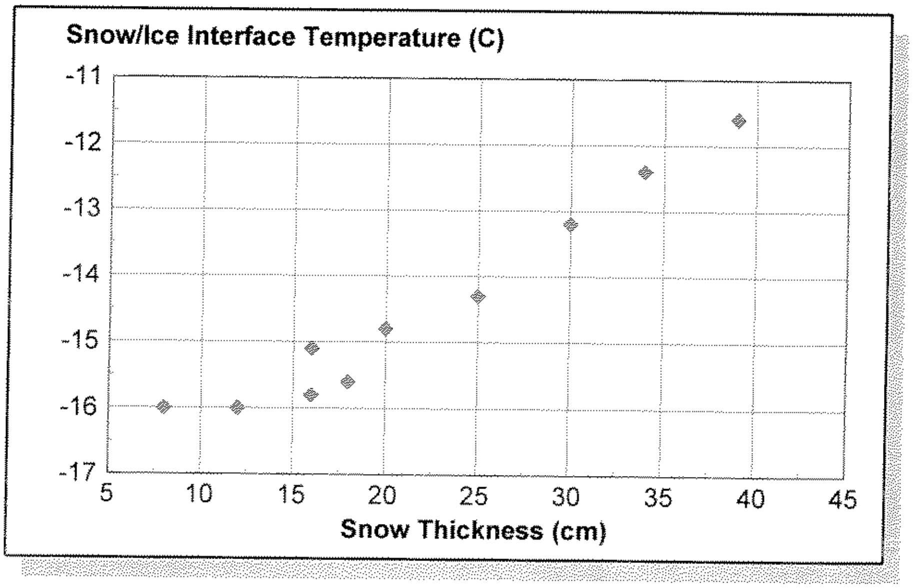


Fig. 7
Snow/ice interface
temperature,
Allen Bay



Specimen Preparation

Cutting a free-floating beam from an almost 6 foot thick sheet of ice required considerable planning. First of all, the specimens must be cut safely and with little risk to personnel and the environment. Secondly, it was essential that specimens be prepared quickly to maximize the number of large-scale tests over as broad a size range as possible. A DitchWitch trenching machine with specialized ice cutting teeth was identified as the best possible means of preparing test specimens.

Site Preparation

Access to the shoreline of Allen Bay was by way of a graded road which was cleared of snow in preparation for the experiments. Blowing snow caused this road to become impassable very quickly, so it was important not to remain on-ice too long during these conditions and risk being stranded. An ice road was then plowed out to a general testing area in Allen Bay around 800 metres from shore. Personnel were shuttled to and from the test site by pickup truck.

While equipment preparation was ongoing at the base camp during Days 1 to 4, a series of ice cores were taken at several locations in the planned vicinity of the fracture tests for crystallographic studies. A thermistor string with data logger was installed on Day 4 for Northwest Research Associates and was in place for the duration of the testing program. A wind-resistant shelter was erected for use as an on-ice "cold room" and contained several tables, a bandsaw, microtome for thin section preparation and a universal stage for crystallographic studies. Ice studies were carried out continuously for close to two weeks and are detailed Chang (1994).

All data acquisition equipment was housed in a large trailer equipped with skis for ease of mobility. The D.A. trailer was well-ventilated and kept continuously warm by a 13,000 BTU low-fume kerosene heater. A skidded warm-up shelter was also kerosene-heated and provided a comfortable retreat. Beyond the cold room tent, a wide road was plowed approximately parallel to the shoreline (north-south). Test specimens were prepared on the west side of this road, beginning at the southernmost end. This ensured that the orientation of all specimens was consistent from test to test. After a test, all trailers, heavy equipment and the hydraulic loading system were simply towed north along this road to the next test site.

Specimen Cutting

In Phase 1, specimen preparation was found to be much less difficult and time consuming than previously thought. A Wajax DitchWitch 3210 trenching unit was used based on its ability to cut a wide (4 inch) slot in the ice. An optimum trenching speed of 15 m per hour was realized. A much larger DitchWitch, the R-100, was selected for Phase 2 (see Fig. 8). These units have performed well under similar ice conditions around Arctic exploration structures such as gravel islands and Canmar's SSDC.

To make the cutting procedure as efficient as possible, special ice teeth were installed on the R-100's cutting bar. These teeth were sharp to the touch and became sharper the more they were used, due to the action of naturally occurring silt in the ice sheet. The R-100 exceeded all expectations and achieved a cutting speed of around 90 m per hour through the 180 cm thick ice sheet. Small specimens (0.5 m, 1 m, 3 m and 10 m) were usually prepared in about an hour. Larger 30 m x 30 m specimens were typically 2 hours in the making, while the massive 80 m x 80 m specimen took just under 4 hours to complete. The 15 cm (6 inch) wide slot left by this DitchWitch was large enough to prevent refreezing of the specimen.

Maximum cutting speed was 90 metres per hour.

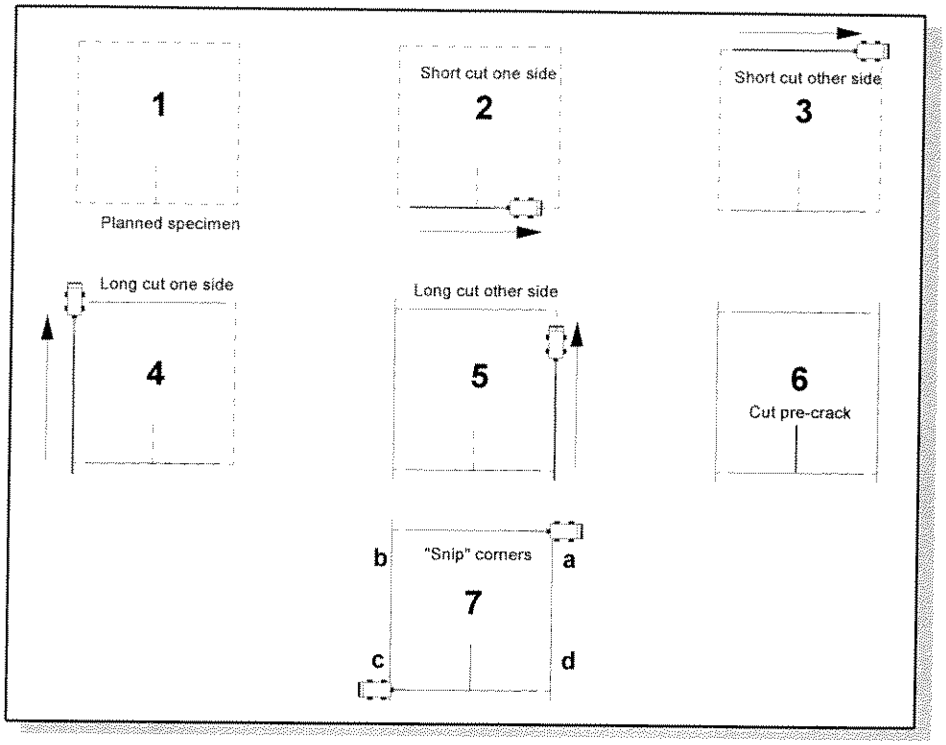
A second, smaller DitchWitch was also required for Phase 2. This machine was provided by the National Research Council Canada and was already in Resolute, as it was used on the 1989 and 1990 Hobson's Choice Ice Island indentation experiments. The unit was fitted with a 2.5 m long chainsaw blade and was used to cut the 0.5 m x 0.5 m specimens and the pre-crack in all specimens (see Fig. 9). This lightweight unit was ideal and cut a straight, vertical slot of width 1.6 cm. Refreezing of this slot was of concern so the slot was manually cleared of slush and occasionally flushed. Since the length of the pre-crack was 0.3 of the plate width, clearing this slot of slush was difficult for the 30 m and 80 m specimens.

A formal cutting procedure was followed for large (3 m and greater) test specimens to avoid placing the wheels of the R100 DitchWitch on the corner of the specimen. This procedure is illustrated in Fig. 10. Two opposite sides of the specimen were "short cut" to within 1.5 m of the corners (Steps 2 & 3), and the other two opposite sides were then "long cut" to a distance of 1.5 m beyond the corners (Steps 4 & 5). Since the specimen was still fixed at the four corners, the NRC DitchWitch was able to easily drive out onto the specimen and cut the pre-crack (Step 6). Once the crack had been properly instrumented, the R100 DitchWitch backed up to the edge of the "long cut" sand snipped the corner by dropping the blade and

Fig. 8
R-100 DitchWitch
used for Phase 2

Fig. 9
Lining up NRC
DitchWitch to cut the
pre-crack

Fig. 10
Specimen cutting procedure



driving forward (Step 7). This was repeated for the other three corners.

Immediately prior to a test, the specimen was rocked manually or with the blade of a loader to ensure it had not refrozen and was completely free. However, it was observed in the first few tests that if the snow cover was not removed along the cutting track, the DitchWitch blade would not cut completely through the ice cover and the specimen would remain attached at the bottom in some places. In all subsequent tests, one tractor blade width of snow was cleared along the centerline of each side of the specimen's surveyed dimensions. The problem was not encountered again.

Crack Scribing

An important parameter in fracture toughness tests is notch acuity, or the degree of sharpness of the introduced crack. In metals, a sharp crack is fatigued into the test specimen. In laboratory fracture tests on ice, a scalpel or similar instrument is used to manually etch or scribe the notch. In Phase 1, a reciprocating saw was developed to scribe a straight, sharp crack at the end of the pre-crack. In retrospect, the device would have been more effective if used manually. This modification was made for Phase 2, along with increasing the blade length to around 2 m. Overall, the device worked very well and was easy to use. Refreezing was prevented by inserting a very thin piece of formica into the scribed crack. As in Phase 1, it was not feasible to directly observe or measure the acuity of the notch.

Test Matrix

Development of the test matrix for Phase 2 was on ongoing process and many test parameters were not finalized until on site conditions could be assessed. A square plate geometry (Fig. 11) was selected for Phase 2 and this did not change during the test program. The square plate tests were specifically designed to investigate the fracture resistance of sea ice over a large size range. Additionally, the square geometry allowed the results of Phase 2 to be compared more easily to fracture scale effect theories proposed by other researchers. Though the scale effect tests were of highest priority, a series of flexural/tensile strength experiments were also necessary to index the *in situ* properties of the ice sheet.

The test matrix for Phase 2 is presented in Table 1. Tests labelled "SQ" were square plates of dimension "a" and pre-crack length "d" (equal to either 0.3a or 0.5a). Flexural index (FL) tests differed in that the specimens were rectangular of width "a" and length "d". These specimens were not pre-cracked and were intended to determine the flexural and tensile strength of the ice sheet, a material property. These specimens proved very difficult to work with, and one actually split before the test even started (FL-1). A different type of index test (TE) was adopted to alleviate the problems with the FL tests. This geometry was identical to the SQ except that a 20 cm diameter hole was drilled at the tip of the pre-crack. The tensile strength of the ice sheet was then back-calculated from the final failure load.

Fig. 11
Square plate test specimen

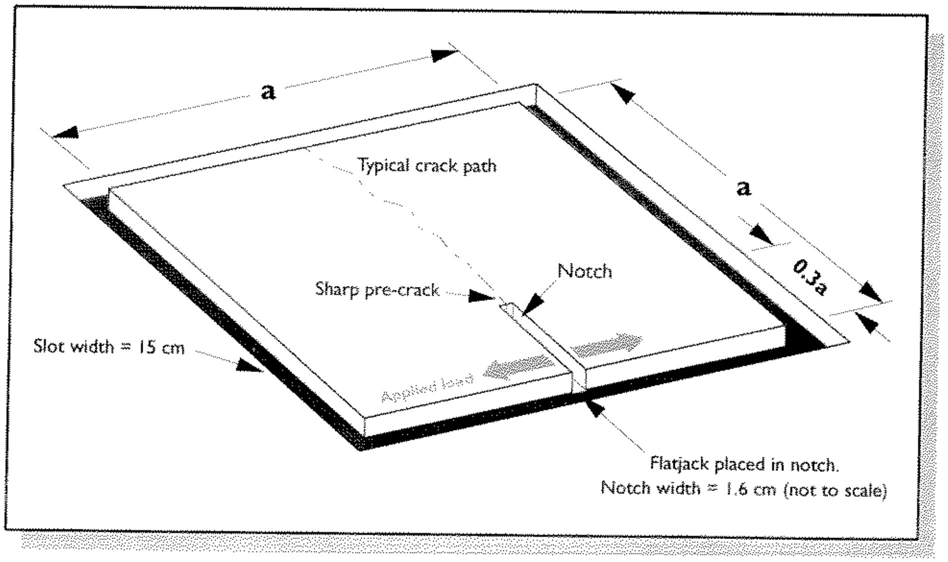


Table 1
Phase 2 Test Matrix

	Test I.D.	Date	Test Mode	# of Loadings	a (m)	d (m)
Square Plates	SQ-1	04-22-93	Nitrogen	1	1	0.3
	SQ-2	04-23	Nitrogen	1	1	0.3
	SQ-3	04-23	Nitrogen	1	10	3
	SQ-4	04-24	Nitrogen	1	10	5
	SQ-5	04-24	Nitrogen	1	30	9
	SQ-6	04-25	Nitrogen	1	30	9
	SQ-7	04-27	Nitrogen	3 cycles	30	9
	SQ-8	04-27	Nitrogen	3 cycles	3	0.9
	SQ-9	04-30	Servo	3	3	0.9
	SQ-10	04-30	Nitrogen	1	0.5	0.15
	SQ-11	05-01	Servo	1	30	0.9
	SQ-12	05-01	Servo	1	0.5	0.15
	SQ-13	05-02	Nitrogen	1	80	24
	SQ-14	05-03	Servo	1	30	9
	SQ-15	05-04	Servo	1	3	0.9
Rectangular Index Tests	FL-1	05-04	Nitrogen	1	0.25	1
	FL-2	05-05	Servo	n/a	1	4
Square Index Tests	TE-1	05-06	Servo	2	3	0.9
	TE-2	05-06	Servo	1	3	0.9

All specimens were loaded by inflating a thin stainless steel bladder, or flatjack, placed in the mouth of the pre-crack. All flatjacks used in Phase 2 were 160 cm long, but the width varied depending on the specimen size. Flatjacks were inflated with either nitrogen gas or hydraulic oil (peanut oil, actually), depending on the loading rate desired. Slow tests were generally performed with the gas system and involved programming a linear ramp to reach a peak pressure in a specific amount of time. In two of these gas tests, the specimen was unloaded by manually shutting off the valve and bleeding off the flatjack, then reloaded by opening the valve again.

A photograph of specimen SQ-1 (1.0 m x 1.0 m) is presented in Fig. 12. Two crack opening displacement gauges (*Kaman®*), housed in watertight acrylic mounts, were fixed across the 30 cm long scribed pre-crack. The specimen was loaded with a flatjack placed between the gauges in the pre-crack (the flatjack was removed before the photograph was taken). The crack path was essentially straight.

The servo-controlled hydraulic system was used to test at loading rates much greater than that of the gas system. Two air-over-oil accumulators provided the high pressures necessary to inject oil very rapidly into the flatjack, thereby achieving the desired loading rate. The output from a crack opening displacement gauge was used as feedback to the servo system, i.e., the desired crack opening rate was compared with the actual rate and the flow of oil adjusted to match the actual rate with the programmed ramp.

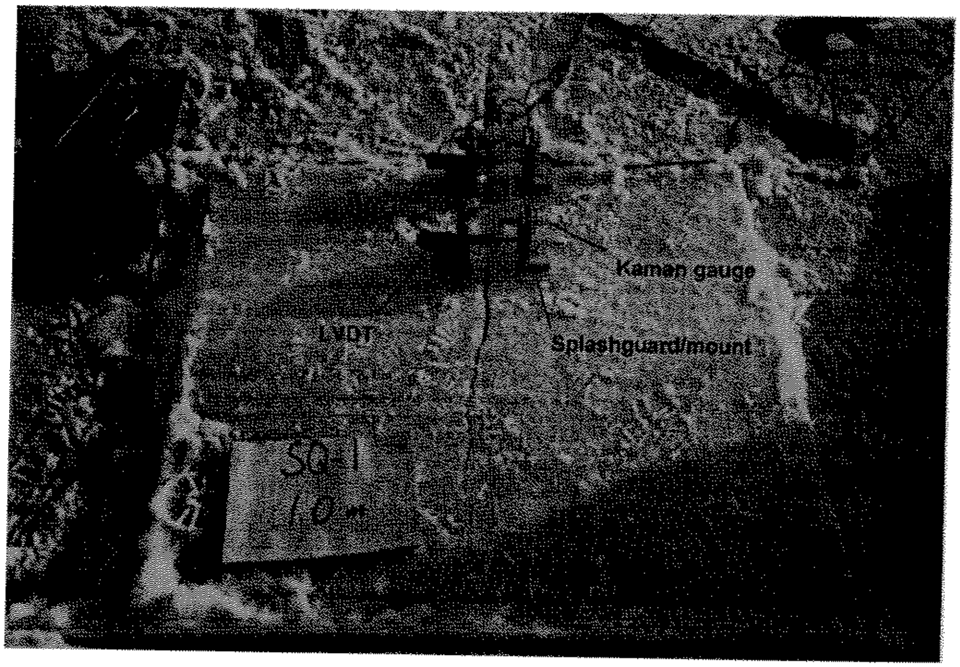


Fig. 12
Test specimen SQ-1
(1.0 m x 1.0 m)
after failure

Preliminary Results

An enormous amount of data was collected during Phase 2. The high sampling rates required to detect crack initiation and crack growth to the end of a test resulted in very large data files. More significantly, full analysis of the data set is a formidable task and requires considerable computing power.

Some example data traces are presented in Fig. 13 through Fig. 16 for fracture test SQ-7 (30 m x 30 m). In this particular test, the specimen was loaded with the nitrogen gas system and three loading cycles on the specimen were applied over a total test time of approximately 10 minutes. The correlation between the data traces for flatjack pressure (Fig. 13) and crack mouth opening displacement (Fig. 14) is especially significant as is proves the test was behaving properly.

The importance of high speed data sampling is reflected in the unloading "loops" visible in the pressure vs. crack tip opening displacement graph (Fig. 15) and the pressure vs. near crack tip opening displacement graph (Fig. 16). These unloading curves are generally only observable under laboratory conditions. Recording this phenomenon under field conditions for very large specimens was a major achievement of Phase 2.

The Phase 2 data set will be fully analyzed by Clarkson University and the results of that analysis used to calibrate the original theoretical splitting model. This is a major effort and work is expected to be completed by mid-1995. The raw data files, compressed to fit on 3.5-inch diskettes, are available for those wishing to perform their own analysis. Details of channel parameters and other important D.A. information necessary for analysis is included in **Appendix F**.

Video Records

A 75 minute VHS video of Phase 2 is included with this report and gives a good overview of the project. Major activities shown in the video are documented in **Appendix E**.

Fig. 13
Pressure vs. time
trace, SQ-7

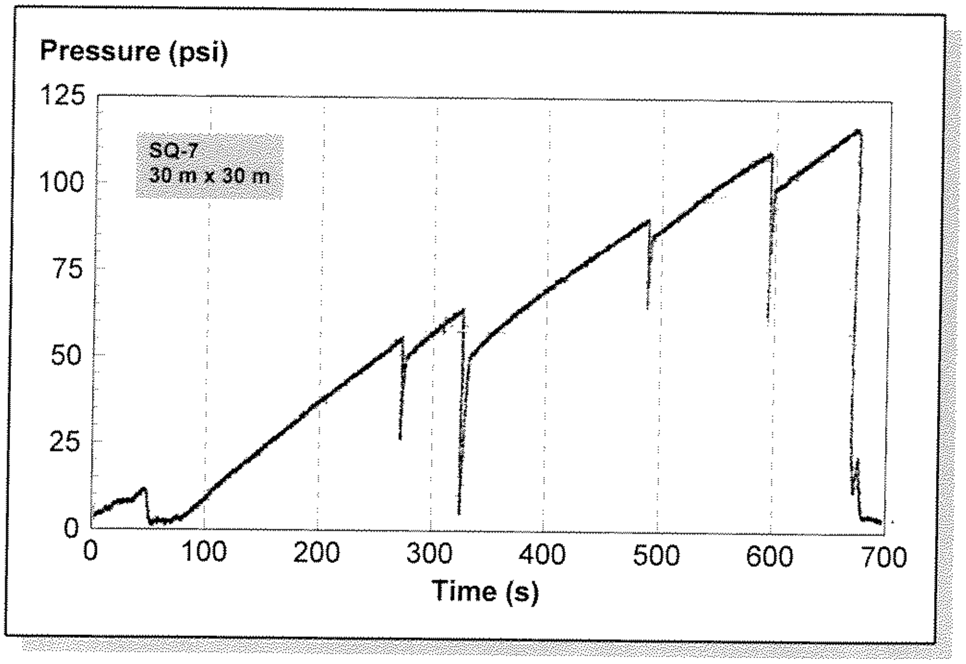


Fig. 14
CMOD vs. time
trace, SQ-7

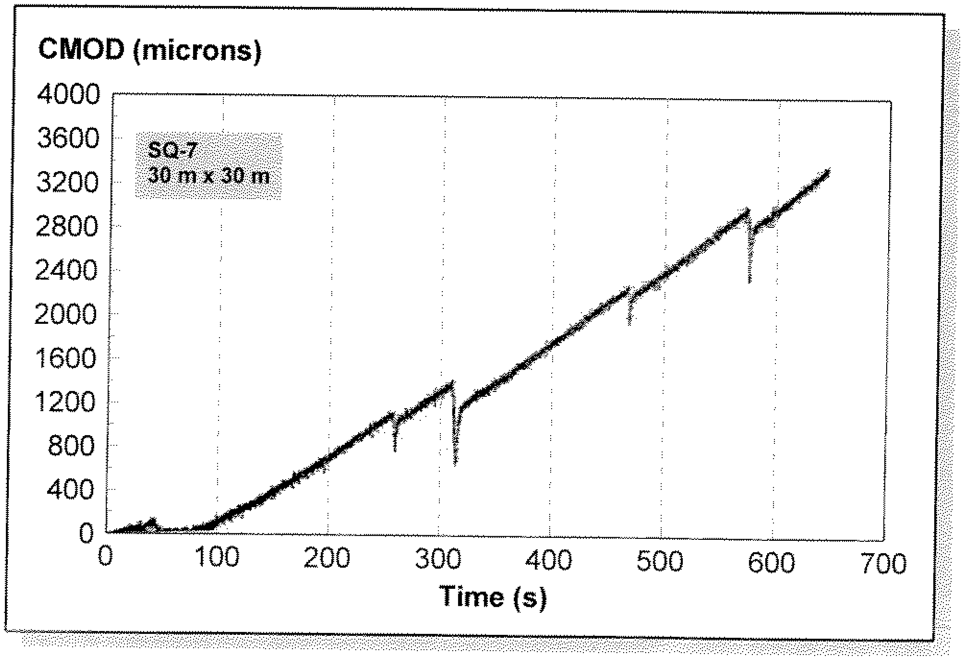


Fig. 15
Pressure vs. NCTOD
trace, SQ-7

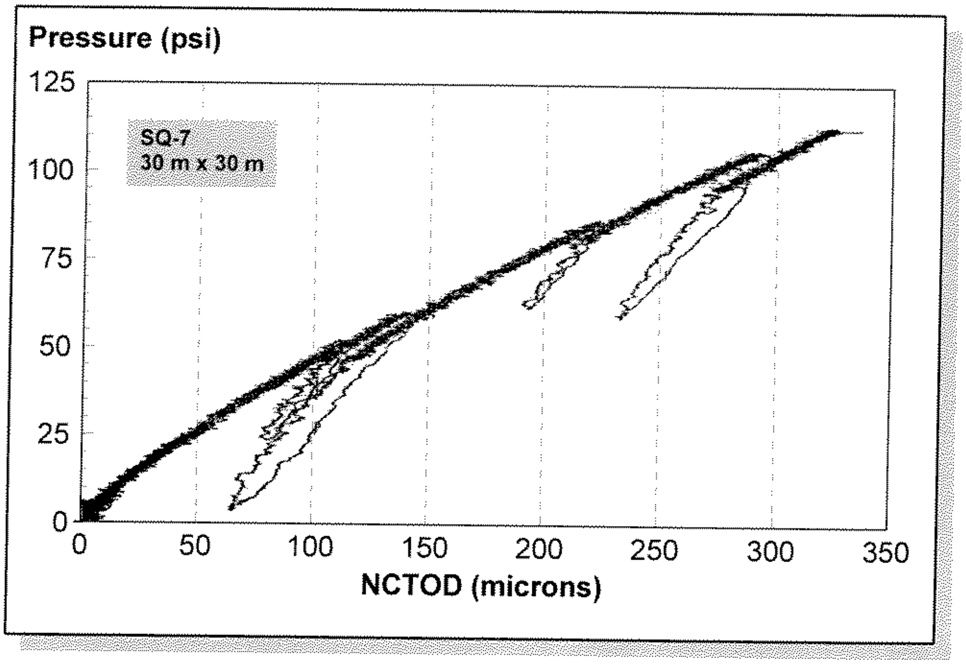
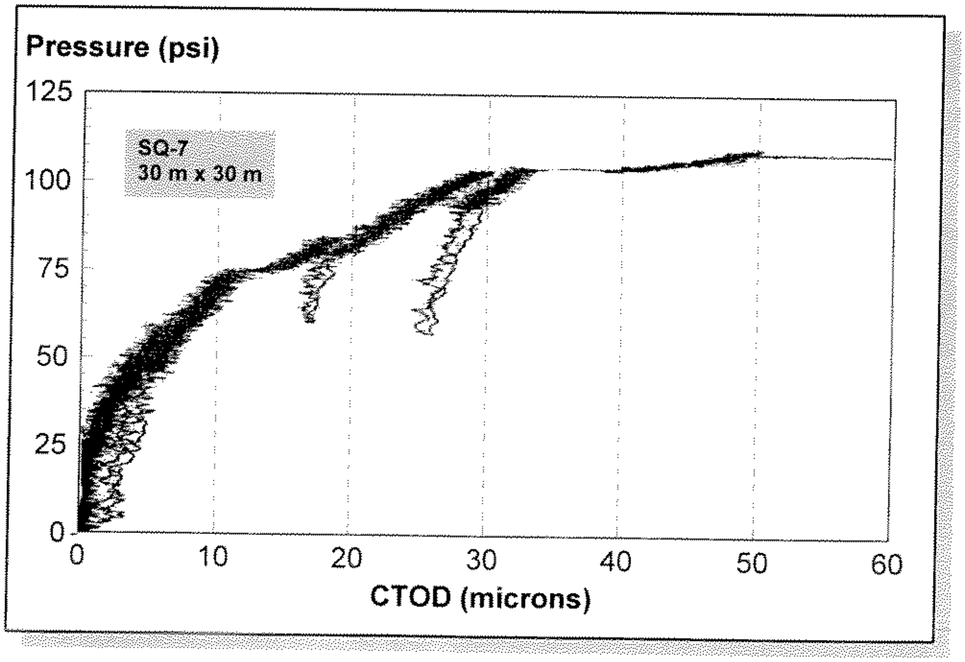


Fig. 16
Pressure vs. CTOD
trace, SQ-7



Approvals & Safety

It was important to have the full co-operation and support of the residents of Resolute and the Government of the Northwest Territories. It would have been unwise to arrive on Day 1 and begin plowing roads and cutting ice without advance notice to the community. Since the experiments required a lot of heavy equipment and personnel on-ice, it was necessary to select a specific test site in conjunction with local residents.

Research Licence

An information meeting to discuss the plans for Phase 2 was held in mid-February, 1993 at the Renewal Resource Office, Resolute with representatives of the local Hunters and Trappers Association and the Renewal Resource Officer . The meeting was arranged by Jessco Operations, logistics coordinator for Phase 2 and a licensed outfitter for the Northwest Territories. The research plan presented met with approval.

An invitation to view the tests and to meet with the key researchers during Phase 2 was extended. A second information meeting was held with Fisheries and Oceans Canada, which also approved the research plan. Several seal denning areas were identified, however, and Phase 2 operations kept well clear of these areas.

A scientific research licence for Phase 2 was secured from the Science Institute of the Northwest Territories (SINT) based on their detailed review of the test plan and community meetings. This licence, reproduced in **Appendix D**, was posted at the test site for the duration of the project.

Environmental

Special care was taken to minimize environmental hazards during the experiments, e.g., peanut oil was used in the hydraulic loading system. The test site was also regularly visited by representatives of Fisheries and Oceans Canada and Environment Canada throughout the three-week testing period. No operational or environmental concerns were identified by these groups.

As an interesting aside, the DitchWitch trenching machine hooked a small codfish and threw it, somewhat mangled, at the feet of a very surprised Fisheries and Oceans officer. The fish was taken away for examination, as it was rare to see the species in the area at that time of the year.

Safety

Personnel safety and protection of the environment were uppermost concerns in Phase 2. The project team was highly experienced in Arctic work and a series of operating procedures were set out on site. Though isolated, Resolute has a Nursing Station and airlift for serious injuries is readily available. Additionally, one of the project team was a fully trained paramedic and an extensive first-aid kit was kept in the heated warm-up shelter. The data acquisition trailer and warm-up shelter were well-ventilated and heated with new 13,000 BTU "Kerosun Omni 85" low emission kerosene heaters.

The most obviously hazardous piece of equipment was the R-100 DitchWitch, but it didn't take long to realize that it was wise to give the machine a wide berth! Spectators were kept well back of both the R-100 and NRC DitchWitch, and the units were only driven by experienced operators. Other heavy equipment such as snowplows and loaders were only brought out to site when required. Once a test was completed, work areas were roped off and marked for identification. Generators, tools and other loose articles were stored away at the end of the work day.

Unfortunately, an incident did occur on Day 18 of the program. One of the operators of the hydraulic loading system was struck on the arm by an extension pipe that connected the accumulator bank to the flatjack. The worker was stabilized and rushed to the Resolute Nursing Station and treated for what turned out to be only a bad bruise. A small modification to the loading system ensured that the incident could not be repeated. No other incidents occurred.

Loading Systems

Two loading systems were designed and built by Sandwell for Phase 1. For the faster tests (typically unstable fracture) with displacement feedback control, a servo-control system was designed. For tests of longer duration and those needing less control, a nitrogen regulated system was employed. These systems were again used for Phase 2 with some minor modifications.

Servo-Controlled System

Closed loop or feedback control is a method by which system output is fed back for comparison with the input to minimize the difference between the input command and output response. Closed loop control offers the advantages of increased linearity and high performance. Since the command signal typically takes the form of a time varying voltage, the ability to automate or test using complex signal profiles is inherent to the system. The system must be carefully designed to avoid instability, however.

The servo-controlled loading system is illustrated in Fig. 17. An air-over-oil accumulator was used to provide power to the servo-valve and was pressurized using a high pressure air compressor. Oil was then pumped into the other side of the accumulator. Oil chosen for the tests was a biodegradable vegetable based oil, so if a spill had occurred (which it did not), there would be minimal environmental impact. Filters capable of filtering to 3 microns absolute were used to ensure that dirt fragments did not interfere with the operation of the servo-valve.

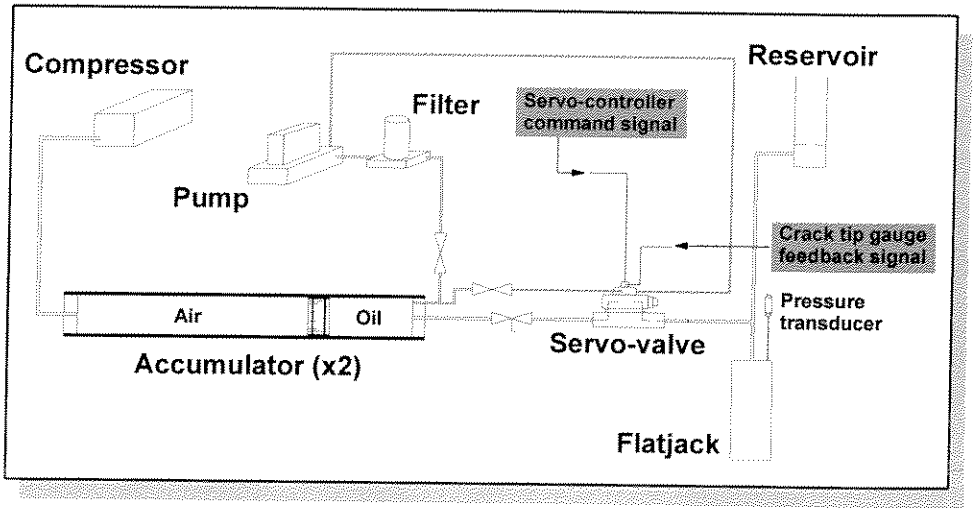


Fig. 17
Servo-controlled
loading system

A Moog Model DO79B-211 servo-valve was employed, capable of flows up to 900 litres per minute at pressures up to 35 MPa. This valve was provided free of charge to the project by Memorial University of Newfoundland.

Another difficulty to be overcome was start-up transients in the servo-system. Although it is a closed-loop system, until the servo-valve is open and oil is flowing, the feedback loop is broken. This was overcome by manually setting the error signal to the servo-controller such that the valve was just closed, and then providing a small DC offset to just barely open the valve. Once oil was flowing, the command ramp signal was applied.

The stability of the feedback signal was crucial in terms of control. The system cannot distinguish between a real change in (crack) displacement and an electronic/mechanical drift in the displacement sensor. This mechanical stability is emphasized by noting that crack propagation can occur at displacements of about 2 mm to 5 mm. Warm temperatures (above freezing) in the field made mechanical stability difficult to achieve and drift made the technique marginal. A distinct advantage of closed-loop control was the ability to reduce the applied load to zero at crack initiation. This type of feedback had not previously been used in either field or laboratory ice fracture experiments.

The servo-valve employed was capable of flows and pressures higher than the test requirements and modifications were necessary. A technique of flow-splitting was used to lower the pressure at the flatjack. To function properly, a drop of 7 MPa across the valve was needed. Pilot valve requirements dictated that oil be supplied to the servo-system at a pressure of 15 MPa.

At the outlet of the Moog valve, an orifice plate was mounted in the oil line which caused a drop in pressure and restricted the oil flow. Pressure supplied to the flatjack was at a maximum of around 1.4 MPa and flow rate was kept to an allowable range. The line then split into two, one line going to the flatjack and the second to a storage tank. The line to storage was sized to give the appropriate back-pressure at the flatjack.

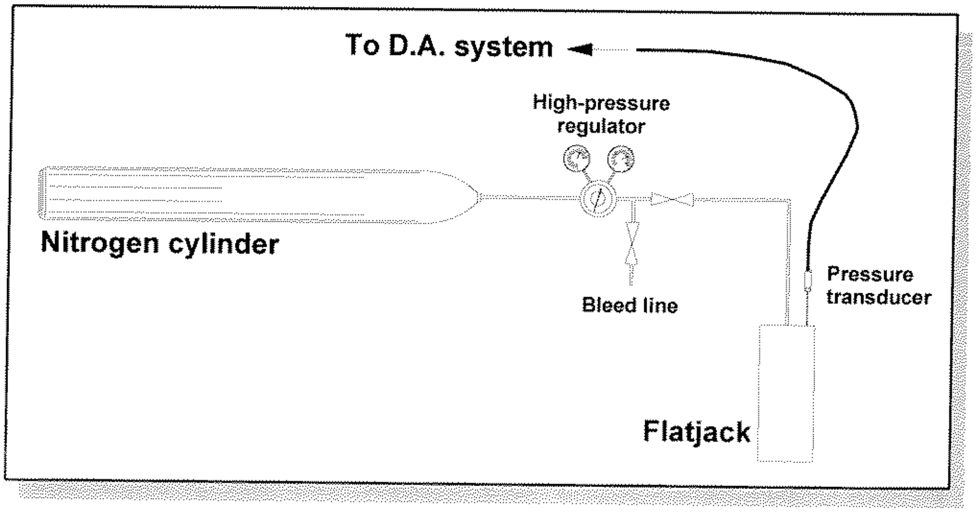
Many factors had to be considered to achieve proper displacement rates including the required pressure drop through the valve, orifice size, specified rate of flow into the flatjack, pressure required to propagate the cracks, flatjack size resistance down the return hose, and total oil flow. The crack tip opening signal ultimately controlled the opening and closing of the servo-valve which, in turn, controlled the crack opening.

Nitrogen Regulated System

This system was not servo-controlled and was therefore much simpler in design and operation. A high pressure nitrogen cylinder was connected to a high pressure, high flow regulator through a long, small-bore tube to the flatjack. When test speed, flatjack size and approximate maximum pressure were known, pressure through the regulator was set and the feed tube bore and length were determined. The system is illustrated schematically in Fig. 18.

Test speed and loading rate could be varied by changing the initial pressure, tube length and tube diameter. Once the crack was initiated in the ice specimen, there was no further control on the rate of load application and crack opening displacement. This arrangement provided for a linear load ramp relatively independent of beam displacement. Tests indicated that the pressure rise in the flatjack was linear to about 1% - 2% up to half of the final (supply) pressure.

Fig. 18
Nitrogen-regulated loading system



Data Acquisition

As in Phase 1, the design of a data acquisition system for the experiments was based on the need for high speed sampling and post-time plotting. Additional requirements for Phase 2 were the recording of tests of very long duration, real-time plotting and high reliability (due to the cost of the experiments). Once again, a digital system was used, plus a backup.

Apparatus

Main components of the digital data acquisition system included:

1) *Tangent*® 486DX, 33 MHz tower computer with *CTX*® 15-inch SVGA monitor, *ATI Ultra Pro*® SVGA graphics adapter, 32 MB of RAM, 520 MB hard drive, 3.5-inch high density disk drive, 5.25-inch high density disk drive, an *Iomega Insider*® tape backup drive. *Windows 3.1*, *MS-DOS 5.0* and *CP Backup*® were also included.

2) A *Sheldon Instruments SI-100*® Data Acquisition and Control System allowed data to be collected at 25 kHz per channel, with data streaming directly to the hard drive of the Tangent computer via *Hypersignal*® software. Test duration was limited only by the space on the hard drive, which could be hours depending on the sample rate.

   The SI-100 was connected to the computer by an RS-422 data line and an RS-232 control line. The SI-100 could handle up to eight channels, was equipped with automatic filtering, AC or DC coupling, gains from ± 0.8 to ± 100 and up to 12 bits resolution per word.

3) The Tangent computer was equipped with a *Digital Signal Processing*® board, based on *AT&T's 50 MFlops WEDSP32C*® processor. This board received data from the SI-100 via the RS-422 line. A software program called *Hypersignal*® was used to store the data to the hard drive. This program separate channels automatically, and allowed the data to be viewed in both the time and frequency domains. The data could be stored as ASCII on request.

4) *Gateway 2000*® model 486/33C computer with SVGA 15-inch monitor, 16MB of RAM, a 210 MB hard drive, two floppy disk drives and a 250 MB *Colorado*® tape drive was used both as a backup computer for reliability and for some real time viewing of the data.

5) A *Keithley DAS-40®* card was used with the Gateway 2000 computer. The DAS-40 is a high-speed 12-bit, A/D and D/A data acquisition board and accepts inputs from -10V to +10V, and as many as eight channels. The program *Viewdac 2.0®* was used on the Gateway. Capabilities of the software include comprehensive data acquisition, control analysis, graphics and applications development functions. Data was acquired, converted to engineering units and stored on the hard drive at a slow, yet effective, rate of 30 samples per second for each channel. Data was simultaneously output to the screen on five strip charts, providing real-time viewing of the data and immediate information on how the specimen was behaving during the course of the loading. In the event that the specimen was reacting differently than expected, steps could be taken to ensure the success of the test.

6) 386 SX notebook computer with 387 math co-processor was used for real-time viewing of the tests. The computer had a grey scale VGA LCD monitor, 8 MB of RAM, an 83 MB hard drive, a 3.5-inch high density disk drive, serial port for a trackball and one parallel port.

7) A *Keithley/Metrabyte DAS-20®* high performance A/D card was used with the notebook computer. This card allowed a maximum of 100 kHz A/D, 16 single-ended or 8 differential input channels and two 200 kHz analog output channels. Four SSH-4 simultaneous sample and hold cards, each capable of data acquisition over four channels were also used. Viewdac 2.0 software was used with this computer.

8) 1400 Series 1000 VA *Uninterruptable Power Supply®* (UPS) for power conditioning. This was a vital element, as power to the data acquisition system was supplied by gas-powered portable generators.

9) *Hewlett Packard 8116A-001®* function generator. This was used to provide a ramp of varying durations and peak voltages to trigger the control/feedback circuit used for certain experiments.

For each test, measurements of Crack Mouth Opening Displacement (CMOD), Crack Opening Displacement (COD), Near Crack Tip Opening Displacement (NCTOD) and Crack Tip Opening Displacement (CTOD) were recorded. For small (< 1.0 m) tests, the NCTOD gauge was not used. At each sensor location, a *Kaman®* non-conducting displacement gauge was mounted in parallel with a *Sensotec®* LVDT. The Kaman gauges were able to record small crack openings and advancement. The LVDT's provided data after large displacements (crack growth) occurred. This combination provided detailed information on the crack profile throughout the test.

D.A. Procedures

With three computers, a function generator and external data acquisition system running simultaneously, an organized routine was necessary to ensure data was acquired to specifications. The Tangent computer was used to acquire data at high speed; no real-time analysis was possible. Again, the Hypersignal software was used for data acquisition and had to be set up for each test, i.e., sample rate, test duration and file name. The Sheldon also had to be initialized with the number of channels, gains, offsets and filtering for each channel. This data was uploaded before each test. Each of the sequences was saved along with the data acquired during the test.

During data acquisition, Hypersignal stored the output of all eight data channels in one file. Following a test, acquisition was stopped and the data divided into separate files, one for each channel (the amount of time required for this procedure depended on the amount of data acquired). Finally, for detailed data analysis, DADisp software was used. This was useful as it accepted the file format generated by Hypersignal without further conversion and had a wide variety of analysis options.

The Gateway computer was used primarily as a backup, but was sometimes used to view the data in real time. In fact, the Gateway was often used to both accept data and allow simultaneously viewing. Data acquisition was controlled on the Gateway system with the software package Viewdac. Data was acquired and stored on the hard drive at the slow, but effective, rate of 30 samples per second. At the same time, data was output to the screen on five strip charts. This was very convenient; data could be viewed in simple terms as it was being acquired and then analyzed in more detail with a very good post-time viewing program (DADisp).

The notebook computer was used only for real-time viewing of data. Viewdac was also used on this computer, and the main display window consisted of an eight-channel digital readout (scanned once every second) along with scrolling strip charts for every channel. While an experiment was in progress, continual updates for the strain gauges were given via two-way radio from the data acquisition trailer to the test observers on the ice.

Once the test was completed, data from the hard drive of the Tangent computer was backed up on tape using CPBackup software. Two separate tapes were made to ensure that the data was completely backed up and preserved. The Sheldon SI-100 test sequence was also saved to tape, as well as the daily log showing all test parameters. The daily test record, data channel designations and general notes are included as **Appendix F**.

Conclusions

The primary goal of Phase 2 was the collection of full-scale data on the fracture behaviour of full-thickness sea ice. This goal was successfully met. The information was necessary for future calibration of a theoretical model of floe splitting developed for use in probabilistic design ice load models.

Overall, the equipment and procedures used in Phase 2 performed well. The experience gained by the project team during Phase 1 was very valuable. On of the major highlights was ability of the R-100 DitchWitch trenching machine to cut 180 cm thick ice at a rate of 90 m per hour. This was unexpected and resulted in more tests over the three-week period than originally planned.

A very significant milestone in Phase 2 was the successful testing of a 80 m x 80 m specimen in 180 cm thick sea ice. To our knowledge, this represents the largest fracture test ever performed in any material. Additionally, as the smallest specimen in Phase 2 was 0.5 m x 0.5 m, the scale ratio achieved was 1:160, almost twice that of Phase 1. Another important feature of Phase 2 was the ability to record the unloading curve for full-scale specimens at the instant of crack propagation. This has previously only been possible under laboratory conditions.

The volume of data acquired during Phase 2 is immense, owing to the high data sampling rates used to effectively monitor crack initiation and propagation. Detailed analysis of the data set is underway at Clarkson University and is estimated to be completed by mid-1995.

Acknowledgements

The efforts of many individuals contributed greatly to Phase 2. John Dempsey and Bob Adamson (Clarkson University) acted as scientific and technical advisors for the experiments and were instrumental in the success of the project. While at Clarkson University, Sam DeFranco (Amoco Production Research) was also greatly involved in the planning of Phase 2. Thanks also to Denis Blanchet (Amoco Production Research) and Anton Prodanovic (Mobil R&D Corporation) for their continued interest and support of this research.

Design and construction of loading systems, control systems, heavy equipment operation and numerous other vital activities were capably performed by Sandwell, Inc. Special thanks to Bill Graham, Dan Masterson, John Robertson and Paul Spencer and support staff for another successful project.

Field logistics, accommodations and heavy equipment operations were the responsibility of Jessco Operations, Inc. Once again, great thanks to Richard Day, Frank Jensen and Pete Jess for their excellent work under often difficult conditions.

Detailed ice characterization was carried out by Ying Chang (Clarkson University) and Michelle Johnson (Ocean Engineering Research Centre, Memorial University of Newfoundland). Special thanks are extended to the Polar Continental Shelf Project in Resolute and the National Research Council Canada for their valuable assistance and support of the project. Thanks also to the staff of the Narwhal Hotel, Resolute for an enjoyable stay.

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Appendix A
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Appendix B
Limit Fracture Concepts

Large-scale ice fracture, or splitting, has been observed to occur over half of the time in full-scale ice-structure interactions (Blanchet et al, 1989). 50% of all instrumented multi-year ice floes in the 1980, 1981 and 1983 Hans Island experiments split globally, while both multiyear floes instrumented during two pack ice stress measurement programs also split (Croasdale et al, 1987; Comfort & Ritch, 1990). SLAR and STAR imagery of the arctic offshore indicates that fractures may propagate for tens of kilometres through a variety of ice features (Churcher et al, 1987).

Ice failure mode analyses for such structures as the SSDC/MAT, Molikpaq and CIDS indicate that cracking, bending, buckling and ridge building occur more than 90% of the time for ice thicknesses up to 4 m. These observations suggest that the maximum global ice load on an arctic structure or vessel may be limited by large-scale fracture, i.e., floe splitting may result in a physical limitation of the total force transferred from ice to structure.

Three primary load-limiting scenarios have been identified to date - limit momentum, limit stress and limit force - and are well documented in the literature. It was proposed by Blanchet (1990) that global splitting be recognized as a primary load limiting scenario and introduced into probabilistic ice load models. Implementation of an appropriate fracture theory could then lead to significant reductions in probabilistic ice loads.

The fracture process represents both a local and a global phenomenon. A crack is formed locally, but it is the propagation or extension of that crack that may result in a global floe failure. The impact zone during an interaction with a thick floe includes a local zone of fractured, damaged and crushed ice (**Fig. A-1**).

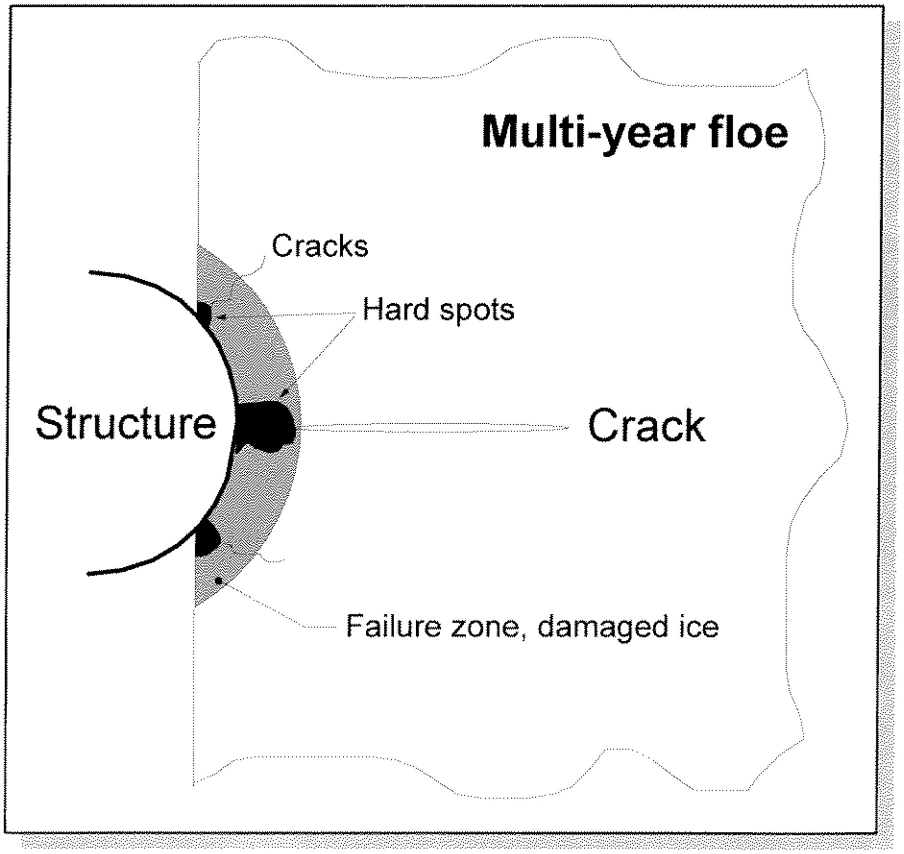
A finite element analysis by Bhat (1988) on an uncracked ice floe suggests that the normal stress along the center line of the floe varies from compression (at a distance of up to 0.15 times the floe diameter) to tension beyond that distance. The high compressive stresses result in a damaged and crushed zone, while high tensile stresses may cause a macrocrack if the tensile fracture stress is attained. Microcracks initiated in the damaged zone may also become unstable and propagate as a macrocrack. In either case, the maximum load experienced by the structure will occur prior to the formation of the critical, load limiting macrocrack.

Linear elastic fracture mechanics (LEFM) and finite element analyses (FEM) are useful modelling techniques for floe splitting. As demonstrated by Bhat (1988) and Bhat et al (1989), LEFM is applicable only when a microcrack is present in the floe, the fracture processes brittle, and all energy dissipation goes towards forming and propagating the macrocrack. In the presence of a crushed and damaged interface, however, it is unclear why one particular microcrack would become unstable and propagate.

The key issue is how large-scale fracture (under the effects of crushing) influences the maximum global ice load experienced by an arctic offshore structure. Quantification of the parameters relevant to this problem is the goal of this jointly-funded research project.

Fig. B-1

Ice fracture processes (after Bhat, 1988)



Appendix C
Daily Log Summary

April 17, 1993

- Arrival of equipment and personnel.

April 18, 1993

- Arrival of equipment and personnel.

April 19, 1993 Clear and sunny, winds light, -20 C

- Preparations for D.A. trailer in lodge garage.
- Assembly and preparations of accumulator skid and NRC DitchWitch.
- Road cleared from beach to site using Polar Shelf's CAT loader. Transition zone of rafted ice required work to get past; a particularly deep section was plowed in with snow and gravel and a wooden bridge placed over the tidal hinge.
- Large DitchWitch brought out on the ice in the afternoon and a series of test slots cut. Machine works very well, advancing around 1.0 m per minute in 180 cm thick ice! This rate can probably be exceeded with practice.
- Some cores taken around the site using Clarkson University's 8" corer.
- Ice characterization tent erected during the evening.

April 20, 1993 Clear and sunny, winds light, -20 C

- D.A. trailer towed to site in the morning. Ice characterization equipment packed up and trucked to site, set up in ice characterization tent. Warm-up shelter brought on-site.
- Work continued readying accumulator skid and NRC DitchWitch (both brought to beach by late morning).
- Thermistor string and data logger for Northwest Research Associates installed in mid-afternoon.

April 21, 1993 Clear and sunny, winds light with gusts, -21 C

- D.A. system preparations (some minor problems with Sheldon unit and UPS).
- Shelter constructed for accumulator skid.
- Road clearing on-site.
- Accumulator skid and NRC DitchWitch brought to site.
- Calibration test on a single slot cut in the ice readied and completed by evening. Servo-control system not responding properly.

- Square "core" (approximately 45 cm x 45 cm x 180 cm) cut from the ice sheet with NRC DitchWitch. This core will be used for extensive ice characterization.

April 22, 1993 — Clear and sunny, winds light, -20 C

- Continuing work on servo-control system.
- Set up test SQ-1 (1.0 m x 1.0 m), completed at 5:40 p.m.
- Serious problems with videocamera (new one being shipped in).

April 23, 1993 — Overcast, winds moderate, -18 C

- Preparing to repeat test SQ-1.
- Test SQ-2 (1.0 m x 1.0 m) completed at 1:20 p.m.
- Slot refreezing doesn't appear to be a problem.
- Test SQ-3 (10 m x 10 m) readied, completed at 6:15 p.m. Essentially straight crack propagation.
- Channel switching problem with Sheldon D.A. system identified.

April 24, 1993 — Clear and sunny, winds strong, -20 C

- Preparing test SQ-4 (10 m x 10 m).
- A second D.A. system is being set up to record test data simultaneously, thus preventing data loss experienced due to the channel switching problem. The two separate D.A. systems are the Sheldon/Tangent computer combination and the Keithley/Gateway computer combination.
- SQ-4 is identical to SQ-3 except the initial crack length is 5 m instead of 3 m.
- SQ-4 not exactly square, more like 11 m x 10 m.
- Test completed at 11:30 a.m.
- Preparing test SQ-5 (30 m x 30 m).
- The large DitchWitch appears to be cutting at around 1.0 m per minute, e.g., 90 m cutting length was completed in 100 minutes, including time spent lining up, etc.
- SQ-5 tested at 5:15 p.m. and lasted around 30 minutes. It appears that a significant bending moment was present across the pre-crack due to the unequal snow depths on each side.
- Dimensions of SQ-6 (30 m x 30 m) laid out.

April 25, 1993 — Sunny breaks, winds light, -19 C

- CAT loader would not start (broken starter motor; replacement ordered).
- Test SQ-6 (30 m x 30 m) prepared and completed at 4:30 p.m.
- Failure pressure for SQ-6 was considerably higher than predicted. Two possible reasons for this: (1) slush in slots partially frozen around the sides, or (2) weight of snow cover as per test SQ-5.

April 26, 1993 Clear and sunny, winds light, -20 C

- Hydraulic fluid leak on large DitchWitch. Unit brought back to lodge for service and did not return until mid-afternoon.
- Too late to attempt a test today. Dimensions for SQ-7 (30 m x 30 m) laid out.

April 27, 1993 Clear and sunny, cloudy p.m., winds light, -18 C

- Specimen SQ-7 prepared and tested. Snow removed in a 60 cm wide swath along the expected crack path to see if the snow cover is affecting the crack failure pressure and/or altering the propagation direction.
- Test SQ-8 (3 m x 3 m) prepared and testing in the evening.

April 28, 1993 Snow, high winds (40 knots)

- No testing.

April 29, 1993 Snow, high winds (40 knots)

- No testing.

April 30, 1993 Clear and sunny, winds light, -15 C

- Roads cleared by 10:00 a.m.
- Test SQ-9 (3 m x 3 m) prepared and tested mid-afternoon. First servo-control test of Phase 2.
- Test SQ-10 (0.5 m x 0.5 m) prepared and tested at 9:00 p.m.

May 1, 1993 Clear and sunny, winds moderate, -17 C

- Fuel injection problem with large DitchWitch, fixed by noon.
- Test SQ-11 (30 m x 30 m) completed at 4:30 p.m. Very successful.
- Test SQ-12 (0.5 m x 0.5 m) completed at 9:00 p.m.
- Partially laid out dimensions of SQ-13 (80 m x 80 m).

May 2, 1993 Partly cloudy, winds moderate, -20 C

- SQ-13 (80 m x 80 m) prepared and tested at 3:00 p.m. Again, a successful test.

May 3, 1993 Sunny, winds light, -16 C

- Test SQ-14 (30 m x 30 m) prepared and tested at 8:45 p.m.

- NRC DitchWitch chain bent (replaced).
- Block of ice 1 m x 1 m x 1.8 m cut out and retrieved for IMD small scale beam fracture tests.

May 4, 1993 Overcast, winds light, -25 C

- Test SQ-15 (3 m x 3 m) completed at 11:50 a.m.
- During cleanup after SQ-15, Sandwell crew member struck on the arm by an extension pipe connecting the accumulator skid to the flatjack. The worker was taken to the Resolute Nursing Station and treated for bruising.
- Test FL-1 (0.25 m x 1.0 m), a flexural index strength test, completed in the evening. Rectangular specimen proved difficult to load.

May 5, 1993 Light snow, winds moderate, -12 C

- Test FL-2 (1 m x 4 m) prepared for testing, but the specimen broke during pre-loading. Decided to use square specimens again for flexural strength indexing.
- Weather becoming worse, visibility very poor. Testing stopped for the day by late afternoon.

May 6, 1993 Partly cloudy, winds light, -18 C

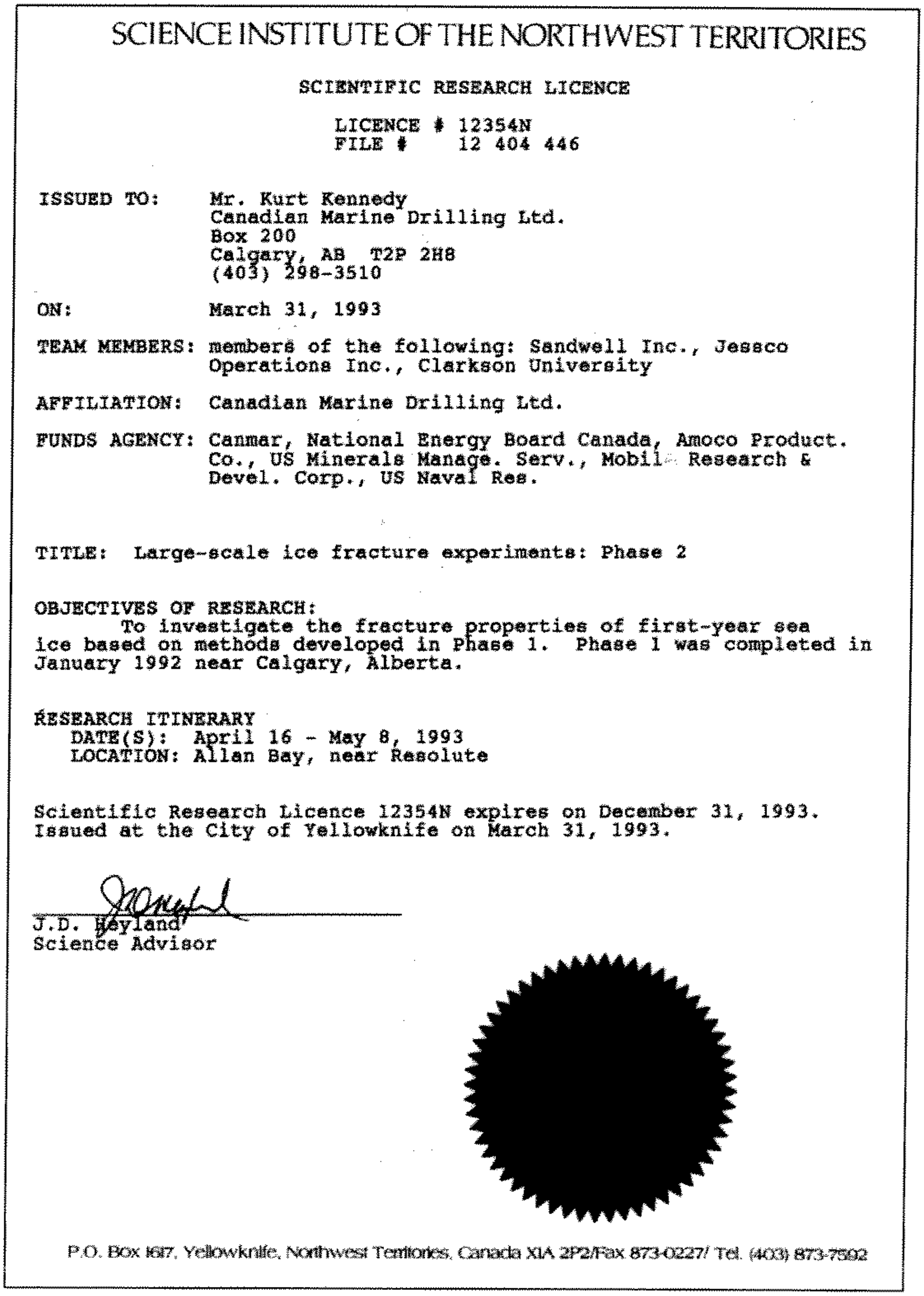
- Large DitchWitch has cracked rim; cannot be used any more.
- Test TE-1 (3 m x 3 m with 20 cm borehole) prepared with NRC DitchWitch (a long process) and tested at 4:40 p.m.
- Test TE-2 (3 m x 3 m with 20 cm borehole) prepared with NRC DitchWitch tested at 10:15 p.m.

May 7, 1993 Overcast, winds light, -20 C

- Demobilization.

Appendix D

Phase 2 Research Licence



SCIENCE INSTITUTE OF THE NORTHWEST TERRITORIES

SCIENTIFIC RESEARCH LICENCE

LICENCE # 12354N
FILE # 12 404 446

ISSUED TO: Mr. Kurt Kennedy
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ON: March 31, 1993

TEAM MEMBERS: members of the following: Sandwell Inc., Jessco Operations Inc., Clarkson University

AFFILIATION: Canadian Marine Drilling Ltd.

FUNDS AGENCY: Canmar, National Energy Board Canada, Amoco Product. Co., US Minerals Manage. Serv., Mobil Research & Devel. Corp., US Naval Res.

TITLE: Large-scale ice fracture experiments: Phase 2

OBJECTIVES OF RESEARCH:
To investigate the fracture properties of first-year sea ice based on methods developed in Phase 1. Phase 1 was completed in January 1992 near Calgary, Alberta.

RESEARCH ITINERARY
DATE(S): April 16 - May 8, 1993
LOCATION: Allan Bay, near Resolute

Scientific Research Licence 12354N expires on December 31, 1993.
Issued at the City of Yellowknife on March 31, 1993.

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Appendix E
Videotape Description

Tape Count	Date	Activities
0	April 30	General view of site showing equipment location
80	"	Large DitchWitch cutting specimen slot
350	"	Data acquisition trailer interior and description
450	"	Cutting specimen SQ-9 (3 m x 3 m)
575	"	NRC DitchWitch cutting pre-crack
1080	"	Snipping beam corners with large DitchWitch
1230	"	Sharpening pre-crack with special scribing saw
1270	"	Keeping pre-crack clear of slush and preventing refreezing by insertion of formica strips
1340	"	Servo-control loading system
1370	"	Gauge mounting and other specimen preparation
1440	"	Installing hydrophones for acoustic monitoring
1450	"	Test readied and completed
1570	May 1	Preparations for test SQ-11 (30 m x 30 m)
1600	"	Large DitchWitch cutting specimen SQ-11
1645	"	Gauge mounting and test completed
1755	"	Post-test analysis of crack path
1800	"	General preparations for test SQ-12 (0.5 m x 0.5 m)
1938	"	Specimen SQ-12 failure
1990	May 2	Preparations for test SQ-13 (80 m x 80 m)
2035	"	Example of corner snipping by large DitchWitch
2080	"	Cutting pre-crack with NRC DitchWitch
2120	"	Final preparations for test SQ-13
2160	"	Specimen SQ-13 failure, ballooned flatjacks

Tape Count	Date	Activities
2210	May 3	Cutting out 1 m x 1 m ice block for IMD
2300	"	Preparations for test SQ-14 (30 m x 30 m)
2340	"	Full procedure shown for gauge mounting on specimens
2380	"	Rocking specimen for ensure it is free-floating
2430	"	Test SQ-14 begins and visible crack opens at 2460
2520	May 4	Complete video of drive from lodge to Allen Bay test site
2840	"	NRC DitchWitch cutting pre-crack for SQ-15 (3 m x 3 m)
2880	"	Large DItchWitch snipping corners, specimen floats free
2915		Crack scribing of specimen SQ-15
2940	"	Final preparations and gauge mounting
2970	"	Specimen SQ-15 failure
3000	May 5	Preparations for flexural index test FL-2
3015	May 6	Tension test TE-1
3100	"	Final preparations for TE-1, failure at 3145
3155	"	Preparations for TE-2, failure at 3170
3180	"	End of tape

Appendix F

Data Acquisition Log

April 21, 1993

15:30 Up until today, we have been setting up equipment for the experiments. Today is the first full day we have spent on site, getting the data acquisition trailer ready. At this point, we have tested the ramp generator, one Kaman gauge and one LVDT. Everything is functional. One problem encountered so far is that gains in the Sheldon DA System vary randomly between negative and positive values. To help alleviate this problem, the sequence and parameters will be uploaded to the Sheldon from the computer before EACH test, hopefully just moments before.

The real time viewing system on Viewdac works fine. Tonight, the gains will be set correctly back at the lodge, so that the graphs read in actual values. The maximum test length with the function generator is 450 seconds, using a triangular wave at 1 MHz, with a 90 per cent duty cycle (bipolar wave).

All connections are generally BNC, with adaptors to a two-wire system used for strain gauges. The LVDT's have been wired in permanently to channels 6 and 7, the ramp is being fed into channel 1, whether it comes from viewdac or the ramp generator. All wiring in the trailer will stay "as is" during moves, with either people in here holding equipment secure, or bungy straps to hold books, computers etc. in place. In any event, it is a nice, self-contained unit, well heated and comfortable for two people and possibly a third.

The eight channels will be set up as follows for the first experiment (basically a dry run):

Channel 0	Pressure transducer (load)
Channel 1	Ramp signal
Channel 2	CMOD (crack mouth opening displacement) gauge (*Kaman®*)
Channel 3	COD (crack opening displacement) gauge (*Kaman*)
Channel 4	NCTOD (near crack tip opening displacement) gauge (*Kaman*)
Channel 5	CTOD (crack tip opening displacement) gauge (*Kaman*)
Channel 6	CMOD LVDT gauge
Channel 7	COD LVDT gauge

The actual Kaman gauges used will vary from test to test, so the gains will vary. I'll have a chart for tomorrow detailing the gains used for each Kaman gauge, the LVDT's, and the pressure transducer.

16:50 The first test of the day (and Phase 2) is going to be run after supper. It can best be described as a dry Griffith's crack, a 2 m slot which is not cut all the way through the ice.

Four channels to be used; test will be run at 5000 Hz for 10 seconds. The channels are:

Channel 0	Pressure, 5000 psi transducer, 5V, gain of 10, 100 psi/V
Channel 1	Ramp, 0 to 1 volt, 2 seconds to peak
Channel 2	2310-.25s Kaman gauge, 250 um/V, 1V, gain of 10, 25 um/V
Channel 3	2310-.25s Kaman gauge, 250 um/V, 1V, gain of 10, 25 um/V

Since everything should be in metric, a multiplying factor will have to be incorporated into the pressure: 1 psi = 6.894 kPa, or 1 MPa = 145 psi.

18:25 The test will begin soon. The Sheldon sequence is stored in the file S0421a.ini, and the data will be stored in the file d0421a**.tim, with the ** corresponding to the channel number stored in the file. All files will be stored on tape #1. The gains are not set on the DAS-20 system for now; they will be set correctly tomorrow (both in software and hardware).

20:20 The first test has been completed, but the servo system is not working correctly yet. The data was stored as outlined above.

20:45 Two more tests were run with the same Griffith's crack, and the same gauges (with the same settings). The data was stored in files d0421b**.tim and d0421c**.tim. The servo system is still not responding as hoped. All data is backed up on tape #1.

April 22, 1993

09:30 P. Spencer thinks he has found the problem with the servo system. At this point, we're not sure which tests are on tap for today. The chart showing the gains of the gauges is as follows:

Kaman Gauges

KD2310-.25s (4), each 250 um/V, all gauges have 0-1 V range
KD2300-1s (1), 1000 um/V, all gauges will have a gain of 10
KD2300-2s (1), 2500 um/V
KD2310-1u (1), 1000 um/V
KD2310-3u (1), 3000 um/V
KD2310-6u (1), 6000 um/V

LVDT's

#1036 (CMOD) 2V, 1.25 cm displacement, > 6250 um/V
#1040 (COD) .5V, 1.25 cm displacement, > 25 mm/V

13:15 We have returned from lunch. We are likely to run some gas tests today, on a 1m x 1m plate. The servo system still isn't working, but it is getting closer.

15:10 The first test of the day will be on a 1m x 1m plate. The test will be run for 30 minutes

(1800 seconds) at a sample rate of 250 Hz. The Sheldon initialization file is s0422a.ini, and the data will be saved in d0422a**.tim. The channels are set up as follows:

TEST SQ-1: 1.0 m x 1.0 m

Channel 0	500 psi transducer, 5V, gain of 2, 50 psi/V
Channel 1	empty
Channel 2	2300-2s Kaman gauge (CMOD), gain of 10, 250 um/V
Channel 3	2300-1s Kaman gauge (COD), gain of 10, 100 um/V
Channel 4	2310-.25s Kaman gauge (CTOD), gain of 10, 25 um/V
Channel 5	empty
Channel 6	LVDT 1036, (CMOD), gain of 5, 1250 um/V
Channel 7	LVDT 1040, (COD), gain of 20, 1250 um/V

The pressure transducer is Psi-Tronics, model psi-5000, 500 psi, serial # C4200. The calibration data is as follows:

PSIG	INCR (V)	DECR (V)	BFSL (V)	LIN (% FS)	HIST (% FS)
0	0.082	0.082	0.088	-0.115	-0.004
100	1.09	1.09	1.087	0.051	0.003
200	2.09	2.091	2.087	0.078	0.004
300	3.089	3.09	3.086	0.059	0.02
400	4.086	4.086	4.085	0.021	0
500	5.08	5.08	5.085	-0.094	

TEMP (F)	0 PSIG	500 PSIG
0	0.07	5.043
78	0.082	5.08
130	0.088	5.094

18:00 The test, SQ-1, ran from 5:30 until 6:00, with the fracture occurring at approx. 5:40 PM. Channel 3 was empty by the time the test was run, because only two Kaman gauges fit on the test sample. The test was a success. The data was backed up on tape #1 and tape #3, with the pressure backed up in a separate group, because of file unknown problems.

April 23, 1993

09:00 The files from yesterday are now completely backed up. The UPS was tested, on both the 1800 W and 5000 W generators. With the 1800 W generator, and all equipment except the scope plugged into it, the UPS was not able to charge, beeping continuously. When it was plugged into the 5000 W generator, it seemed to work better, holding its charge. To run ALL equipment off it though (gauges, etc.), would be impossible.

11:00 A second test, SQ-2, will be run this morning. This time the sample, a 0.9 m x 0.9 m was cut with the large DitchWitch. SQ-1 was cut completely with the small DitchWitch. This should allow the beam to float more freely. The sample rate will again be 250 Hz, and the test will run for 30 minutes (1800 seconds).

11:10 A quick test was run on hypersignal to see if a test can be aborted half way through, and it can! The program asks if the user wants to save the data already acquired (which we would), and stops there. This means we can set up tests to run for a very long time, and abort them when the useful data has been gathered (i.e.,. up until fracture). The gauges for test SQ-2 are as follows:

TEST SQ-2: 1.0 m x 1.0 m

Channel 0	pressure, 500 psi transducer, gain of 2, 50 psi/V
Channel 1	empty
Channel 2	2310-.25s Kaman (CMOD), gain of 10, 25 um/V
Channel 3	2310-.25s Kaman (CTOD), gain of 10, 25 um/V
Channel 4	empty
Channel 5	empty
Channel 6	LVDT (CMOD), gain of 5, 1250 um/V
Channel 7	empty

13:30 The test ran and was successful. It started at approx. 1:10 PM and was aborted after 10 minutes of data was gathered. The fracture occurred after approx. 9 1/2 minutes. The data was stored in file d0423a**.tim, and backed up on tapes #1 and #3. One change to be made in the future is to give the Kaman gauges a gain of only 5, rather than 10, because it suits the Sheldon D.A. system better.

16:15 The DA trailer has been moved to a new location, next to the next sample, a 10 m x 10 m plate. More details later.

17:30 The 10m x 10m plate is nearly ready and will be called SQ-3. It was cut with the large DitchWitch. The slot will be 3 m long. The sample rate is 250 Hz, as before, and the test duration is expected to be approx. 10 minutes, so data is being taken for 30 minutes. The Sheldon initialization file, s0423b.ini, is about to be set-up.

It may be worth mentioning here that to convert the ASCII values that are gathered by hypersignal into voltages, they must be divided by 2 to the power of 15 (32768), and then multiplied by the gain, as shown in the Sheldon initialization file or in this log. These voltages can be converted to units (either psi or um) by using the multiplying factor given in this log. To convert psi to Kpa, use the conversion given at 4:50 on 04-21, in this log. The channels were set as follows:

TEST SQ-3: 10 m x 10 m

Channel 0	Pressure, 500 psi, gain of 1, 100 psi/V
Channel 1	empty
Channel 2	Kaman, KD2300-2s (CMOD), gain of 5, 500 um/V
Channel 3	Kaman, KD2300-1s (COD), gain of 5, 200 um/V
Channel 4	Kaman, KD2310-.5s (NCTOD), gain of 5, 50 um/V
Channel 5	Kaman, KD2310-.5s (CTOD), gain of 5, 50 um/V
Channel 6	LVDT #1036 (CMOD), gain of 2, 3125 um/V
Channel 7	LVDT #1040 (COD), gain of 10, 2500 um/V

18:20 The test ran successfully, but the Sheldon did not. It shifted channels, putting the data for channel 1 in channel 0, channel 2 in channel 1, etc. This means that the data in channel 0, pressure, was lost. The test ran for 10 minutes, and the fracture occurred at approx. 110 psi.

From now on, channel 0 will be used for an LVDT, in case the problem happens again. As well, the Gateway will be brought out, so a back-up D.A. system can be incorporated. The data was stored in d0423b**.tim, and the Sheldon file in s0423b.ini. It was backed up to tapes #1 and #3.

April 24, 1993

10:50 It has been a strange morning. We now have a third computer (it is a *Gateway* brand) in the trailer, and it will be running Viewdac as a backup. The Tangent computer is still running with the Sheldon, and the laptop is the monitoring computer. The tape drive is malfunctioning at the moment, but it will soon be working (for some reason, the addressing is messed up). The "transportability of files between computers" problem has been solved with a bit of testing.

The next test, SQ-4, is a 10 m x 10 m plate, with a 5 m slot. It will run for 30 minutes, at a sample rate of 250 Hz. The channels are set up as follows (NOTE the major differences from previous tests):

TEST SQ-4: 10 m x 10 m

Channel 0	LVDT #1036 (CMOD), gain of 2, 3125 um/V
Channel 1	LVDT #1040 (COD), gain of 10, 2500 um/V
Channel 2	Pressure, 500 psi transducer, 100 psi/V
Channel 3	empty
Channel 4	Kaman KD2300-2s (CMOD), gain of 5, 500 um/V

Channel 5	Kaman KD2300-1s (COD), gain of 5, 200 um/V
Channel 6	Kaman KD2310-.25s (NCTOD), gain of 5, 50 um/V
Channel 7	Kaman KD2310-.25s (CTOD), gain of 5, 50 um/V

13:40 The test SQ-4 ran this morning before lunch. Channels 0 and 1 were not hooked up today, so there was just five channels of data. The test was successful, with data saved on both computers. The fracture load was approx. 90 psi. The data from the Sheldon was saved in files d0424a**.tim, the data from viewdac was stored in d0424a., and the Sheldon initialization file is s0424a.ini. At this point, it hasn't been stored on tape.

14:05 The plan for the afternoon is to fracture SQ-5, a 30m x 30m plate. The sample is being cut with the big DitchWitch. The slot length will be 9m.

16:20 DaDiSP data analysis software seems to work well. It read in hypersignal binary files, at plotted CMOD vs. pressure graphs easily.

The next test is almost set up. As mentioned earlier, it will be a 30m x 30m plate, the largest surface area (and volume) of ice ever fractured. Very impressive!! As for all earlier tests, the sample rate is 250 Hz and the duration of stored data is 30 minutes. The channels are the same as before, namely:

TEST SQ-5: 30 m x 30 m

Channel 0	LVDT #1036 (CMOD), gain of 2, 3125 um/V
Channel 1	LVDT #1040 (COD), gain of 10, 2500 um/V
Channel 2	Pressure, 500 psi transducer, 100 psi/V
Channel 3	empty
Channel 4	Kaman KD2300-2s (CMOD), gain of 5, 500 um/V
Channel 5	Kaman KD2300-1s (COD), gain of 5, 200 um/V
Channel 6	Kaman KD2310-.25s (NCTOD), gain of 5, 50 um/V
Channel 7	Kaman KD2310-.25s (CTOD), gain of 5, 50 um/V

Since the trailer is closer to the sample, the two LVDT's are probably going to be used.

19:00 The test SQ-5 ran for 30 minutes, and was successful. Final fracture occurred at 27 minutes. By this time, all Kaman gauges had gone off scale. The data is stored in d0424b**.tim, and the Sheldon initialization file in s0424b.ini. The data will be backed up on tapes #16 and #17, as will all data from the experiments so far.

20:30 The tape drive is working again! It was reconfigured, with address 370H, DMA Channel 1 and IRQ Line 5. It works well on medium speed. Now all data will be backed up again, on tapes #16 and #17.

As well, DADiSP works well, and is now plotting data like John wants. It can read Hypersignal binary files, as well as viewdac files. It should be a good addition to the D.A. System. Also , the servo system is working. We are not going to use it right away (we will finish the plate program using gas), but it will be used extensively in the near future. Incidentally, it was decided that the idea of coming out to site every night to analyze data was not workable. Therefore, after tomorrow, the Gateway will be brought back to the lodge, and there will be no backup. We are confident in the Sheldon. The procedure to be followed before each test is to calibrate the gauges using the DAS-20, and also make sure the Sheldon is responding for EACH channel. Then, just before the test will start, the Sheldon will be reset. This should ensure that all channels are reading what we are expecting (with no shifting). As well, an LVDT is on channel 0, so it is not vital data.

April 25, 1993

09:00 This morning, all files will be backed up on tapes #16 and #17. All previous entries in this log about back-ups on tapes #1 and #3 can be disregarded. Using medium speed on CPBackup, all files for a particular test can be stored together. Each group of files (for a particular test) will contain the data files dddmml**.tim, the file dddmml.adc, which is an ascii file showing the acquisition configuration in hypersignal, and the file sddmml.ini, which is the Sheldon initialization file. The group of files will be given a label with the date of the test, which test it is for the day (a,b,etc.), the type of sample, and the test label (SQ-1, etc.). This standard will ensure easy restoration of all data.

10:20 All data has been backed up to tape #16, and all back-ups were successful. Next, we will do the same backups to tape #17.

15:00 All backups are done up to this point. The only test of the day being run is SQ-6, another 30m x 30m block with a 9m slot. As usual, the sampling is at 250 Hz, for 30 minutes. The channels are as for the last test, as follows:

TEST SQ-6: 30 m x 30 m

Channel 0	LVDT #1036 (CMOD), gain of 2, 3125 um/V
Channel 1	LVDT #1040 (COD), gain of 10, 2500 um/V
Channel 2	Pressure, 500 psi transducer, 100 psi/V
Channel 3	empty
Channel 4	Kaman KD2300-2s (CMOD), gain of 5, 500 um/V
Channel 5	Kaman KD2300-1s (COD), gain of 5, 200 um/V
Channel 6	Kaman KD2310-.25s (NCTOD), gain of 5, 50 um/V
Channel 7	Kaman KD2310-.25s (CTOD), gain of 5, 50 um/V

The plate is being set-up right now, and the test should begin within the hour.

18:00 The test was completed before supper, and it was a success. Once again, the pressure at fracture was higher than anticipated, and fracture took approx. 20 minutes. As well, just like for SQ-5, all gauges were maxed out before fracture actually occurred. The data was stored in d0425a**.tim, and the Sheldon file in s0425a.ini.

April 26, 1993

14:00 The DitchWitch broke down this morning. Since it will take the whole day to fix it, there will be no tests today. This has given us a good chance to catch up on data analysis, and given everybody a well deserved break.

April 27, 1993

10:00 Back to work! The next test, SQ-7, will be run this morning. It will be a 30m x 30m beam, with the same sampling rate (250 Hz) and the same test duration (30 minutes) as always. The gauges being used have changed somewhat:

TEST SQ-7: 30 m x 30 m

Channel 0	LVDT #1036 (CMOD), gain of 2, 3125 um/V
Channel 1	LVDT #1040 (COD), gain of 10, 2500 um/V
Channel 2	Pressure, 500 psi transducer, gain of 1, 100 psi/V
Channel 3	empty
Channel 4	KD2310-6u Kaman, gain of 5 (CMOD), 1200 um/V
Channel 5	KD2310-2s Kaman, gain of 5 (COD), 500 um/V
Channel 6	KD2310-1s Kaman, gain of 5 (NCTOD), 200 um/V
Channel 7	KD2310-.25s Kaman, gain of 5 (CTOD), 50 um/V

11:55 We have not yet started SQ-7. The problem appears to be that the plate has started to freeze in. I will advise when the test is over.

12:10 The problem is that one of the cuts was not completely through the ice. It has to be recut, and then the slot has to be recut, and then the gauges re-mounted and re-calibrated...the test probably won't begin for quite a while.

The loading plan has changed slightly this time. After about 6 minutes, and 9 minutes, the pressure on the flatjack will be released (unloaded), for one or two seconds, and then reapplied (at about the same pressure it was at before the unloading stage). Because of this, to be safe, the test will be run for 60 minutes, and aborted when it is done.

13:50 The test was successful. It ran for approx. 10 minutes. The data is stored on tape as d0727a**.tim (note the error with the 7 instead of the 4, due to data entry error). On the hard drive, it has been saved as d0427a**.tim. It is saved on tapes #16 and #17.

16:45 The next test, SQ-8 will be performed later today (soon). It will be a 3m x 3m plate, loaded with the gas system. Load-unload stages will again be used, because of their success on test SQ-7. They create interesting 'pressure vs. COD' plots. This test will again be at 250 Hz, for 30 minutes. The channels are as follows:

TEST SQ-8: 3 m x 3 m

Channel 0	empty
Channel 1	empty
Channel 2	pressure, 500 psi transducer, gain of 1, 100 psi/V
Channel 3	empty
Channel 4	Kaman KD2300-2s (CMOD), gain of 5, 500 um/V
Channel 5	Kaman KD2300-1s (COD), gain of 5, 200 um/V
Channel 6	Kaman KD2310-.25s (NCTOD), gain of 5, 50 um/V
Channel 7	Kaman KD2310-.25s (CTOD), gain of 5, 50 um/V

18:15 Again, the test was a success. The data is stored in files d0417b**.tim, and since the same initialization file was used as last time (and will be used until further notice), no new file was made. The data will be backed up on tape #16 and #17, along with the initialization file s0427a.ini.

April 30, 1993

10:30 The last two days were snowed out. The winds were very high, and the roads were snowed in, so we could not get out on site. Even if we could have got out here, the winds were too strong to operate while here. Therefore, we spent two days waiting at the lodge. Hopefully, today we can get two tests done today, one this afternoon and one this evening. We may be working into the evening a few times, which after the last two days would be welcome.

13:35 We are back from lunch. We are planning on testing a 3m x 3m plate today, and would like to use servo-control for this sample. Details will be provided later. A new LVDT will be used for this experiment, because the LVDT #1040 was damaged slightly when the ice heaved on fracture and it was bent. The LVDT #1019 will be used to replace it. This LVDT has 12.5 mm displacement for every volt, and a 2 volt operating range. With a gain of 2, it will be 6250 um/V.

14:40 The test will begin soon. As mentioned earlier, it will be a 3m x 3m plate, and servo-control, and will be labelled SQ-9. The sample rate has changed, to 15,000 Hz (15 kHz), and the test duration is approx. 2 minutes (120 seconds). A ramp is being used to control the pressure, and the CMOD gauge is being used for feedback. The ramp is anticipated to be for 100 seconds, which is why data is being taken for up to 120 seconds. The channels are similar to the last experiment, with the exception being the ramp signal in channel 3 and the different LVDT:

TEST SQ-9: 3 m x 3 m

Channel 0	LVDT #1036 (CMOD), gain of 2, 3125 um/V
Channel 1	LVDT #1019 (COD), gain of 2, 6250 um/V\
Channel 2	pressure, 500 psi transducer, gain of 1, 100 psi/V
Channel 3	ramp signal, 100 seconds duration
Channel 4	Kaman KD2300-2s (CMOD), gain of 5, 500 um/V
Channel 5	Kaman KD2300-1s (COD), gain of 5, 200 um/V
Channel 6	Kaman KD2310-.25s (NCTOD), gain of 5, 50 um/V
Channel 7	Kaman KD2310-.25s (CTOD), gain of 5, 50 um/V

15:50 All gauges are calibrated, and the servo-system is tested and almost ready.

16:40 The test was a success. We were able to control the crack, using the CMOD Kaman gauge as the feedback gauge. This gauge was ramped upward at a rate of 25 um/sec. We didn't have LVDT's for this test. The data (large files) was stored in d0430a**.tim, with the initialization file stored in s0430a.ini.

17:00 It has been decided that we were going to continue to fracture the same block, calling this test SQ-9-2. This time, the sampling rate was dropped to 250 Hz, and the test is to run for 450 seconds. The LVDT at the crack mouth (#1036) is to be used as the feedback gauge. Again, the rate of opening of the LVDT is to be 25 um/sec, up to 12500 um.

It has been determined that the calibration for the LVDT #1036 has been wrong all along. It actually is 5V = .5". In other words, 1V is 2500 um. **For all earlier tests, this adjustment must be made if LVDT data is to be used!** The arrangement of the channels for this test has differed slightly from earlier:

Channel 0	LVDT #1036 (CMOD/Control), gain of 1, 2500 um/V
Channel 1	empty
Channel 2	pressure, 5V, 500 psi, gain of 1, 100 psi/V
Channel 3	ramp, 0-10 volts, gain of 1
Channel 4	Kaman KD2300-2s (NCTOD), gain of 5, 500 um/V
Channel 5	Kaman KD2300-1s (CTOD), gain of 5, 200 um/V
Channel 6	empty
Channel 7	empty

17:40 The test was again a success, although it was stopped after approx. 7 minutes because there was no more movement in any gauges. The data was saved in file d0430b**.tim, and the initialization file in s0430b.ini.

18:15 It has now been decided that a third test on the same sample will be performed, SQ-9-3. The same LVDT gauge will be used for control, but the ramp will be at 250 um/sec. The test will run for approx. 2 minutes at 250 Hz.

The channels are the same as the previous test, except that LVDT #1019 will be in channel 1. A calibration was done on this LVDT, and it too has had the wrong calibration factor. It should be 5V=1", or 1V = 5000 um. In summary, the channels are as follows:

Channel 0	LVDT #1036 (CMOD/Control), gain of 1, 2500 um/V
Channel 1	LVDT #1019 (COD), gain of 1, 5000 um/V
Channel 2	pressure, 5V, 500 psi, gain of 1, 100 psi/V
Channel 3	ramp, 0-10 volts, gain of 1
Channel 4	Kaman KD2300-2s (NCTOD), gain of 5, 500 um/V
Channel 5	Kaman KD2300-1s (CTOD), gain of 5, 200 um/V
Channel 6	empty
Channel 7	empty

18:40 This third test was performed, and it was a success. There will be no more tests done on this sample. The data for this third test, SQ-9-3, is stored in d0430c**.tim. There is no new initialization file.

20:00 All data for SQ-9 has been stored on tape. On tape #16, SQ-9-1 and 2 are in one grouping, and SQ-9-3 is in another. On tape #17, they are all in the same grouping.

We are planning to do another test tonight, a .5m x .5m plate, called SQ-10. This will be like SQ-1 through SQ-8 in that it will be done with gas. The sample rate will be 250 Hz, and the test duration set for 30 minutes. In this case, only three channels are active:

TEST SQ-10: 0.5 m x 0.5 m

Channel 2	Pressure, 5V, 500 psi, gain of 1, 100 psi/V
Channel 4	KD2300-1s (CMOD), gain of 5, 200 um/V
Channel 5	KD2300-.25s (CTOD), gain of 5, 50 um/V

21:20 The test was another success, with fracture at approx. 45 psi, occurring just after the 9 minute mark (of which only 8 minutes had gas pressure applied). The data was stored in d0430d**.tim, and the initialization file was s0430b.ini, the same as earlier. This data was stored on both tapes #16 and #17. We are done for the night.

May 1, 1993

8:45 A new day, a new month. This morning, we will be doing a 30m x 30m plate, SQ-11. Details will follow later. Also this morning, we will try to analyze the data from yesterday, to see how well the servo-controlled test worked.

15:30 After almost a full day of analyzing data, we are soon to do our first test of the day. The data for the first of the three tests with the 3m x 3m plate, SQ-9-1, took a long time to analyze because of the large size of the data files, and problems with the parallel port (and the software key) for DADiSP.

The first test today, SQ-11, will be a 30m x 30m plate, servo controlled. The test isn't likely to last more than 5 seconds (due to limits with the servo system), but data is being taken for 30 seconds, at a rate of 15 kHz. The LVDT set as the NCTOD is the #1036 and it is being used as the feedback gauge. The channels are as follows:

TEST SQ-11: 30 m x 30 m

Channel 0	LVDT #1019 (CMOD), gain of 1, 5000 um/V
Channel 1	LVDT #1036 (NCTOD), gain of 1, 2500 um/V
Channel 2	pressure, 500 psi, gain of 1, 100 psi/V
Channel 3	ramp, gain of .25, 5 V ramp, 1.25 V/V
Channel 4	KD2300-2s Kaman (CMOD), gain of 5, 500 um/V
Channel 5	KD2310-1u Kaman (COD), gain of 5, 200 um/V
Channel 6	KD2300-1s Kaman (NCTOD), gain of 5, 200 um/V
Channel 7	KD2310-.25s Kaman (CTOD), gain of 5, 50 um/V

The test will begin soon. The reason for the gain in the ramp is that Paul often needs a 10V ramp, but the Sheldon can only handle +/- 5V. A summing box (divide by 4) is being used for the gain, thus the gain of 1/4. NOTE (written at 19:30): in this case, only a 5V ramp was necessary, so we really didn't need the summing box. Next time we'll get it right.

16:25 Due to unfortunate damage to the KD2310-1u Kaman gauge (thanks to the left foot, or maybe right foot, of a visitor) it will not be used. Instead, the Kaman gauge that was supposed to be at the NCTOD will be moved to the COD spot. Thus channel 5 now has what channel 6 was supposed to have, and channel 6 is empty. The test will begin very soon.

19:30 The test SQ-11, run before dinner, was a success. We had good control (or so it seemed). It was intended that the ramp was to climb 312 um every second. The data was saved for approx. 18 seconds, and saved in d0501a**.tim, with the Sheldon initialization file in s0501a.ini. All data was backed up on tapes #16 and #17.

We are going to run one test tonight, SQ-12, on a 0.5m x 0.5m plate. We will use servo-control, running at 15 kHz for 30 seconds. The channels are as follows:

TEST SQ-12: 0.5 m x 0.5 m

Channel 0	empty

Channel 1	LVDT #1036 (CMOD,control), gain of 1, 2500 um/V
Channel 2	Pressure, 500 psi, 5 V, gain of 1, 100 psi/V
Channel 3	ramp, 0-5 V, gain of 1
Channel 4	empty
Channel 5	empty
Channel 6	KD2300-1s (CMOD), gain of 5, 200 um/V
Channel 7	KD2310-.25s (CTOD), gain of 5, 50 um/V

The LVDT in channel 1 will be used for control, which means fracture should occur very quickly. The test will be in approx. 1 hour.

21:30 This test was done with very fast loading, just like the 30m x 30m plate (SQ-11). It was a success, with the fracture pressure being less than for the gas test of the same sized plate. The data is stored in d0501b**.tim, and is backed up on tapes #16 and #17.

May 2, 1993

8:35 Today is the day...we are soon (but not really, too soon) to cut an 80m x 80m plate, far and away the biggest in history, beating our old record by nearly nine times. Since it takes a while to lay out and cut a plate of ice this size, it will probably be the only test done today.

13:40 After a morning of analysis and cutting the sample (and countless measurements to see if the plate is the right size), we are getting ready to begin testing (within 3 hours). The test will be called SQ-13, and as mentioned earlier it will be on a 80m x 80m plate. The loading will be supplied by the gas system. The sample rate will be 2500 Hz. Fracture is expected to happen at the 10 minute mark, so data is being taken for 30 minutes. This means there will approx. 9MB of data for each channel. The channels are being set up as follows:

TEST SQ-13: 80 m x 80 m

Channel 0	LVDT #1019 (CMOD), gain of 1, 5000 um/V
Channel 1	LVDT #1036 (COD), gain of 1, 2500 um/V
Channel 2	Pressure, 500 psi, 5 V, gain of 1, 100 psi/V
Channel 3	empty
Channel 4	Kaman KD2310-6u (CMOD), gain of 5, 1200 um/V
Channel 5	Kaman KD2310-3u (COD), gain of 5, 600 um/V
Channel 6	Kaman KD2300-2s (NCTOD), gain of 5, 500 um/V
Channel 7	Kaman KD2310-.25s (CTOD), gain of 5, 50 um/V

14:40 The test will begin soon...very soon. We are about to calibrate gauges, a procedure we do before every test.

19:35 The test started at about 3:15 PM, and it took 27 minutes to fracture the sample. It was a successful test. The data is stored in (large) files d0502a**.tim, and the Sheldon initialization file is in s0502a.ini. The data is backed up on tapes #18 and #20. The back-ups took an hour for each tape. For the rest of the evening, data analysis will be done.

May 3, 1993

17:00 So far, this day has consisted mostly of problems. We had some problems with the DitchWitch, but they are rectified. A 30m x 30m plate has been cut out, and it will be tested tonight. There will be more details after supper. A lot of data analysis has also been done today, so from that standpoint, the day has been a success.

19:10 The test tonight will be SQ-14, a 30m x 30m plate which will be controlled with the servo-system. This will be done to try to repeat the results of SQ-11, except that this time the ramp will be a 20 second ramp. The control gauge will be an LVDT at the NCTOD, and the ramp will be 62 um/sec. The sample rate will be 15 kHz, and the data will be taken for up to 120 seconds. The channels are set up as follows:

TEST SQ-14: 30 m x 30 m

Channel 0	LVDT #1019 (CMOD), gain of 1, 5000 um/V
Channel 1	LVDT #1036 (NCTOD, control), gain of 1, 2500 um/V
Channel 2	Pressure, 500 psi, 5V, gain of 1, 100 psi/V
Channel 3	ramp, 0-5V, 20 seconds, 1 V/V
Channel 4	KD2300-2s Kaman (CMOD), gain of 5, 500 um/V
Channel 5	KD2310-6u Kaman (COD), gain of 5, 1200 um/V
Channel 6	KD2300-1s Kaman (NCTOD), gain of 5, 200 um/V
Channel 7	KD2310-.25s Kaman (CTOD), gain of 5, 50 um/V

21:00 The test started at 8:45 PM, and lasted for approx. 30 seconds. The data is stored in d0503a**.tim, and the Sheldon initialization file is in s0503a.ini. The data is backed-up on tapes # 6 and #7 (note the logical ordering of numbering tapes for backups).

May 4, 1993

10:55 The next test will be a 3m x 3m sample, called SQ-15. It will be servo-controlled, with a 20 second ramp. The control gauge will be an LVDT at the CMOD, opening up 20000 um. The data will be taken for up to 60 seconds. The channels are as follows:

TEST SQ-15: 3 m x 3 m

Channel 0	LVDT #1036 (NCTOD), gain of 1, 2500 um/V
Channel 1	LVDT #1019 (CMOD, control), gain of 1, 5000 um/V
Channel 2	Pressure, 500 psi, 5V, gain of 1, 100 psi/V

Channel 3	ramp 0-3.94V ramp, gain of 1, 5000 um/V
Channel 4	LVDT #1020 (COD), gain of 1, 5000 um/V
Channel 5	KD 2300-2s Kaman (CMOD), gain of 5, 500 um/V
Channel 6	KD 2300-1s Kaman (NCTOD), gain of 5, 200 um/V
Channel 7	KD 2310-.25s Kaman (CTOD), gain of 5, 50 um/V

12:00 The test was successful, finishing at 11:50 AM. The data is stored in d0504a**.tim, and the Sheldon initialization file is in s0504a.ini. The data is backed up on tapes #6 and #7.

19:30 In the end, a test was run today (which was somewhat of a surprise). The test was a 1.5m x .25m beam, and a flexural test was done, called FL-1. The span was 1m between supports G1 and G2. The sample rate was 250 Hz, and it ran for approx. 30 minutes. The channels were as follows:

TEST FL-1: 0.25 m x 1.0 m

Channel 0	LVDT #1036 (center of beam), gain of 1, 2500 um/V
Channel 1	LVDT #1019 (support G1), gain of 1, 5000 um/V
Channel 2	Pressure, 5V, 500 psi, gain of 1, 100 psi/V
Channel 3	empty
Channel 4	LVDT #1020 (support G2), gain of 1, 5000 um/V
Channel 5	empty
Channel 6	empty
Channel 7	empty

The test was successful, but the data was not captured by the Sheldon, because the coupling of the channels was set to AC rather than DC. The data was captured by Viewdac, on the Gateway, at a sampling rate of 20 Hz. The data was backed up on tapes #6 and #7.

May 5, 1993

13:30 This morning, the hard drives on the two computers were compacted and de-fragmented, enabling better hard drive access, both for storing data and for retrieving it. This took most of the morning. Meanwhile, the next flexural beam test sample, FL-2, is being cut out. Details on what each channel will hold will come later.

14:50 The next test will be FL-2. It is a 1m x 6m beam, and a flexural test will be done on it, with servo-control. The span is 4m between supports G1 and G2. The sample rate will be 500 Hz, and the test duration will be approx. 170 seconds. Therefore data will be taken for up to 240 seconds. The pressure will be the feedback gauge, with a ramp of 1 psi/sec. The channels are as follows:

TEST FL-2: 1 m x 4 m

Channel 0	LVDT #1036 (center), gain of 1, 2500 um/V
Channel 1	LVDT #1019 (support G1), gain of 1, 5000 um/V
Channel 2	Pressure, 5V, 500 psi (feedback), 100 psi/V
Channel 3	0-5 V ramp, 300 seconds
Channel 4	LVDT #1020 (support G2), gain of 1, 5000 um/V
Channel 5	KD 2310-.25s Kaman (support G1), gain of 5, 50 um/V
Channel 6	KD 2310-.25s Kaman, (support G2), gain of 5, 50 um/V
Channel 7	empty

17:20 The test was taking a long time to set up, longer than what is comfortable. Finally, at 17:10, it was almost ready to go. We were loading up the flatjack to a very low pressure to calibrate the system and purge any air out of flatjack and the hoses. Inexplicably, the sample broke. No data was being recorded, so nothing was taken. The weather is becoming increasingly bad, so it looks like the day is over.

May 6, 1993

11:05 The big DitchWitch broke down (possibly for the last time) with a broken rim. It is unlikely to be functional for the next two days. The plan for today is to do tension tests on a size range of plates, .5m x .5m, 3m x 3m, and 30m x 30m. Without the big DitchWitch, we on't be able to do the 30m x 30m plate. Right now, the 3m x 3m plate is being cut. Also being done this morning is testing of the servo-system. We are comfortable with the fact that it works again. Whether or not we are going to use it today is a question mark.

15:20 The next test will be called TE-1, a tension test on a 3m x 3m plate. It will be servo-controlled, with a pressure ramp of 1 psi/sec. The sample rate has been set at 3 kHz, and although the test should be over within 5 minutes, data will be taken for up to 30 minutes. The channels are as follows:

TEST TE-1: 3 m x 3 m

Channel 0	LVDT #1036 (CTOD), gain of 1, 2500 um/V
Channel 1	LVDT #1019 (CMOD), gain of 1, 5000 um/V
Channel 2	Pressure, 5V, 500 psi, (control), gain of 1, 100 psi/V
Channel 3	0-3.5 V ramp
Channel 4	KD2310-3u Kaman (CMOD), gain of 5, 600 um/V
Channel 5	KD2300-2s Kaman (COD), gain of 5, 500 um/V
Channel 6	KD2300-1s Kaman (NCTOD), gain of 5, 200 um/V
Channel 7	KD2300-.25s Kaman (CTOD), gain of 5, 50 um/V

18:45 Two tests were done before supper. In the first, the ramp was set at the wrong speed, so instead of getting a 300 second ramp, we got a 0.3 second ramp, followed by a 3 second ramp. This cracked the block. Some data was captured, and was saved in d0506a**.tim, with the Sheldon initialization file in s0506a.ini. The data was backed up on tapes #6 and #7.

It was then decided to re-zero the gauges, and load up the same sample, calling this test TE-1-b. The same channels were used as above, except that the control channel was now the LVDT at the CTOD, channel 0. This was supposed to be a 60 second ramp (from 0 to 5.88 V), with a slope of 208 um/sec. Unfortunately, the gain was set incorrectly on the servo-system, and the LVDT only opened up to approx. 5000 um, not 12500 um as expected. Nevertheless, some more data was obtained, and stored in d0506b**.tim. This was also backed up on tapes #6 and #7.

21:30 The last test (!!) of phase 2 is being performed tonight, under the starry (well, the sun is a star) sky. Spirits are high, as test TE-2 is soon to be carried out (soon being sometime within the next two hours). This will be a tensile strength test on another 3m x 3m plate, using the servo-system. Again, the idea is to have a 300 second ramp, controlling pressure at 1 psi/sec. The sampling rate will be 3000 Hz, and the data will be taken for up to 15 minutes. The channels are the same as for the test this afternoon, namely:

TEST TE-2: 3 m x 3 m

Channel 0	LVDT #1036 (CTOD), gain of 1, 2500 um/V
Channel 1	LVDT #1019 (CMOD), gain of 1, 5000 um/V
Channel 2	Pressure, 5V, 500 psi, (control), gain of 1, 100 psi/V
Channel 3	0-3.5 V ramp
Channel 4	KD2310-3u Kaman (CMOD), gain of 5, 600 um/V
Channel 5	KD2300-2s Kaman (COD), gain of 5, 500 um/V
Channel 6	KD2300-1s Kaman (NCTOD), gain of 5, 200 um/V
Channel 7	KD2300-.25s Kaman (CTOD), gain of 5, 50 um/V

22:15 The test is complete, and it was a success (finally!). The data is in d0506c**.ini, and the data is backed up on tapes #6 and #7.
