Ice Island Study

Final Report

MMS Project #468

APPENDIX A

Prepared for:

Minerals Management Service
US Department of the Interior

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THE ICE ISLANDS PROJECT (MMS)

31 October 2003

142687

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Table of Contents

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GROUNDED ISLANDS

Sandwell

GEOTECHnical resources ltd. / GOLDER & ASSOCIATES
CLIENT: SOHIO PETROLEUM COMPANY et al
REPORT DATE: SEPTEMBER, 1985

Construction, Testing & Monitoring Spray Ice Island (Main Report) (MARS)

Overview:

The objectives of the project were as follows:

Evaluation of the influence of construction factors (e.g. environmental conditions, pumping equipment and procedures, etc.) on the quality and quantity of spray ice produced.

Evaluation of conventional and novel techniques for drilling and sampling, in situ testing and performance monitoring.

Evaluation of the macro-performance of a full scale spray ice island.

Development of a constitutive model for describing the behaviour of spray ice based on in situ testing together with laboratory testing on both undisturbed and reconstituted samples.

Preparation of a factual report summarizing the data obtained together with preliminary evaluation of construction techniques, sampling, in situ and monitoring techniques and laboratory data.

The island was constructed in a 30 day period in February and March, 1985. The grounded portion of the island had the following dimensions:

Diameter	- 350.0 ft.
Average Freeboard	- 16.5 ft.
Water Depth	- 30.0 ft.

The planned sampling, in situ testing and monitoring installation programs were completed between April 2 and 11, 1985. Monitoring of island performance was continued on a periodic basis until June, 1985. The laboratory program on undisturbed samples was carried out at the same time as the field work while testing on reconstituted samples was carried out in Calgary after the field work was completed.

Construction

The island was designed to resist a global ice load of 137 kips/ft assuming that the below water spray ice had zero cohesion and an effective angle of shearing resistance of 30°. It was assumed that excess porewater pressures would not develop during shear. Based on the calculated design volume and an efficiency of 60%, a large capacity pump (3800 US gpm) and a smaller capacity pump (1000 US gpm) were selected for construction and were housed in skid-mounted containers. Spraying operations and monitoring during construction (i.e. build-up, ice temperature, environmental data) were carried out on a 24 hr/day basis with two personnel on each of two shifts. Thermistors, flatjacks and piezometers were installed during the construction process. Samples were obtained for calorimetry experiments and studies were made of drop size formation.

It was the intent that spraying would produce as uniform a material as possible. The freshly deposited material would be such that 1-2 in. deep footprints would be formed. However, it was found that a wide variety of environmental and operational factors affected both production rates and material type. Wind speed and direction together with air temperature were the significant environmental factors. Spray direction relative to wind direction, vertical angle of spraying and nozzle setting were important operational factors. The large pump performed satisfactorily and with small modifications is suitable for spray ice island construction. The smaller pump was generally ineffective and pumps of this nature (centrifugal) and capacity should not be used for future construction.

During the first two weeks of construction, an average build-up rate of about 1 ft/day was achieved. With increased experience and equipment modifications an average build-up rate of 2 ft/day was achieved in the second half of the construction period. During a 3-day period of relatively warm weather production rates were low. The overall efficiency achieved in construction, defined as (volume of spray ice/volume of water pumped) was about 43%.

A significant feature of the spray ice island was the development of cracks during construction. The majority of the cracks occurred when the base of the island grounded on the seabed. Only two significant cracks remained within the grounded portion of the island following completion of construction; monitoring indicated that these cracks were not active.

The total direct cost of island construction including mobilization/demobilization, equipment development, pump rental, accommodation, etc. was about $560,000 U.S. This represents a unit cost of about $3.50 to $3.80 U.S./yd^3 in place, but does not include the cost of subsequent investigation and monitoring.

Investigation Program

The investigation program involved the following:

- 9 Sampled boreholes - sampled using Shelby tubes, the Delft continuous sampler and a specially designed sampler.
- 14 Cone penetration tests (CPT) using a 3 channel acoustic cone (700 ft of useable record).
- 51 Self-bored pressuremeter (SBP) tests in 3 boreholes.
- 1 In situ falling head permeability test.
- 8 Horizontal flatjack panel installations to determine vertical total stress.
- 6 Vertical flatjack panel installations to determine horizontal total stress and stress-strain behaviour.
- 24 Borehole jack tests in one borehole above water level.
- 4 Slope indicator casings.
- 3 Sondex settlement systems
- 3 Piezometers
- 2 Thermistor strings
- 52 Thermal drill holes to map the underside topography of the island.

The following is a summary of observations related to the useability of the individual investigation and monitoring techniques:

Drilling - Penetration using a 6 in. diameter solid stem auger yielded entirely satisfactory borings. Boreholes remained open above the water level, but freezing occurred at the water line.

Sampling - Shelby tubes were used with mixed success - this approach is suitable for softer layers, but tubes tended to buckle in the harder layers.

- The Delft continuous sampler provided reasonable to good quality samples provided lubrication/pressure equalization fluid between the "sock" and liner was not used.

- A special thick-walled steel sampler, which freezes the bottom of the sample, was developed for this project and provided good quality samples.

- Samples of both above water line and below water line materials were obtained in a relatively undisturbed state.

Sample Transportation

- Local (near site) transportation of both saturated and unsaturated samples was successfully achieved using brine barrels.

- Samples were successfully transported from site to Calgary in refrigerated trucks.

Cone Penetration Testing

- This was a highly successful technique which provides an excellent definition of in situ stratigraphy (i.e. consistency variations). Minor equipment modifications would further enhance future CPT work.

Self Bored Pressuremeter Testing

- After experience was gained in the first borehole, these tests could successfully be carried out.

Flatjack Tests

- Horizontal flatjacks did not work effectively because the pressure associated with the fluid-filled line was greater than the in situ vertical stresses. Vertical flatjack installations were more effective.

Borehole Jack Tests

- These tests were effective in above water materials only; the stroke of the equipment was not adequate for testing the below water line materials, partly due to the enlarged borehole diameter.

Falling Head Permeability Tests

- These tests provided reasonably credible data but boundary conditions are not well defined.

Monitoring Installations

- Slope indicator casings, Sondex settlement casings and piezometers were effective and no major problems were encountered with their operation. Backfilling around instruments installed in boreholes was not effective. Only two of four thermistor strings operated effectively; problems associated with these installations can be readily overcome.

Site Investigation Results

Geometry

- The grounded portion the island was about 330 ft. in diameter. Side slopes to sea ice level varied between 2.5(H):1(V) and 6(H):1(V). Below water slopes are reversed (i.e. sloping under the island) at 5(H):1(V) to 3(H):1(V).

Stratigraphy

- The above water materials consist of relatively uniform size (0.04 in. diameter) white or clear ice granules. Significant layering was observed with layers of ice rich material and layers of essentially granular material. The below water materials were wet. Below water ice granules were typically clear and slightly larger than above water granules. Much of the below water material comprised frequent harder/bonded layers although the intervening material had little or no cohesion.

Density

- The density of above water materials increased from about 35 pcf at surface to 47 pcf at the water line. The density of below water materials was difficult to determine because of pore fluid loss during sampling and a wide range in density (40 - 63 pcf) was obtained.

Salinity

- The salinity of the above water materials ranged between 0 and 1%. The bulk salinity of below water samples was higher (0.5 - 1.5%) because of the presence of saline pore fluid (1.9 to 2.4%).

Frozen Content

- Calorimetry experiments on the below water samples indicated a frozen water content of 70-90% by weight, which is slighty greater than would be expected based on the density of the above water materials.

Cone Penetration Tests

- The measured tip resistance during CPT penetration was highly variable ranging from close to zero over some depth intervals to an average minimum of 215 - 285 psi. Friction ratios were relatively low at about 0.5 - 1%. Excess porewater pressures were not recorded during cone penetration; hydrostatic pressures were measured below the water line. The cone tip resistance provided a good indication of stratigraphy but a poor measure of in situ strength.

Self-Bored Pressuremeter Tests

- These tests yielded consistently high values of modulus and maximum inflation pressure. This was in contrast to the CPT results and reflected the fact that the tested zone in an SBP test incorporated both strong and weak layers. Creep rates observed in SBP tests were proportional to inflation pressure when expressed on a log-log plot.

Permeability

- The falling head permeability test indicated a coefficient of permeability of 3×10^{-4} to 3×10^{-3} ft/sec. These values are typical of a clean sand or sand/gravel material, which is consistent with the grain size of spray ice. However, because of difficulties in defining test boundary conditions, these permeability values are only approximate.

Flatjack Tests

- Interpretation of the vertical flatjack tests indicated high modulus values (average based on 10 tests of 13400 tsf). These high values reflect the fact the stiffness of the harder layers.

Borehole Jack Tests

- These test were carried out in above water materials only and indicated plate pressures typically in the range 26 to 31 tsf. Locally soft zones were observed at some depths.

Instrumentation and Monitoring Results

Temperature

- The above water temperatures varied with air temperature and at depths near surface varied from 28°F to -30°F. Temperatures at sea level were fairly constant at 29°F. The below water spray ice temperature was relatively constant with depth and throughout the monitoring period remained at about 29°F.

Porewater Pressures

- Significant excess porewater pressures were not recorded during the monitoring period.

Lateral Deformations

- Significant lateral movements were not recorded with depth through the island (slope indicator casings) nor on the island surface (direct surveying).

Vertical Settlement

- About 1 ft of settlement of the island surface occurred in a two month period. The settlement rate decreased only slightly with time during this period. The Sondex casings indicated that settlements were concentrated in the vicinity of the water line but these data may be affected by non-uniform freeze-back around the casings.

Crack Monitoring

- Monitoring of the major crack remaining following construction indicated only slight relative movements (less than 1.5 in.) across this feature.

Ablation

- Until late May, when air temperatures rose to above freezing, negligible ablation or ice degeneration was noted. The island remained relatively intact until July.

Constitutive Behaviour of Spray Ice

Triaxial tests were carried out on both undisturbed and reconstituted samples of spray ice. Testing of undisturbed samples was generally carried out under in situ conditions. The testing conditions for reconstituted samples were varied to determine their effect on material behaviour. The results of testing on reconstituted samples provide the basis for a behavioural model for spray ice under both drained and undrained conditions as follows:

Strength

- The ultimate shearing resistance of spray ice is controlled by the effective stresses existing in the sample. Failure conditions are represented by a linear failure envelope in q-p' stress space. The final location on the failure envelope (i.e. the shearing resistance of the material) is controlled by the porewater pressure response during shear which varies depending on factors such as strain rate and length of the consolidation/creep period prior to shear. Temperature conditions also affect strength.

Stress-Strain Behaviour

- Typically for most test conditions, the initial response of spray ice to load application is small strain followed by a reasonably well defined yield. Following yield, the observed stress-strain behaviour was generally either plastic or strain hardening behaviour depending on test conditions. Although the data are scattered because of varying test conditions, it appears that yield occurs within a narrow range of stress ratio.

Time Dependency

- Spray ice is a highly time dependent material as is evidenced by plots of normalized strength and porewater pressure parameters vs strain rate in strain controlled tests, and in the variation in failure envelopes depending on time related test factors. Stress controlled creep tests also exhibit strong time dependency. However, creep rates are low and relatively constant up to yield. At higher stress ratios, creep rates increase with increasing stress ratio.

Compressibility

- Under drained conditions, spray ice is highly compressible, even at low stresses. However, given its high permeability, spray ice consolidates rapidly; most of the observed volume change under load is due to creep.

The stress conditions in the triaxial test control the strength which is measured in relatively competent natural materials (i.e. undisturbed samples). The shear strength of these materials is high and is dependent on initial density. Tests on weak natural materials indicate failure states which lie on the failure envelope observed in laboratory tests on "aged" reconstituted samples.

<u>Conclusions and Recommendations</u>

Construction

- The construction phase of the operation was successful in that useful information related to construction of spray ice islands was obtained and the final island was suitable for investigation and monitoring. Recommendations related to future island construction are provided.

Investigation and Monitoring

- These programs were successfully completed and recommendations related to future work of this nature are provided.

Preliminary Design Recommendations

- Based on the results of this project and previous experience, it is reasonable to expect that spray ice islands could be used for offshore hydrocarbon exploration in the Arctic. Strengths can be developed to sustain design ice loads and deformation can be maintained within acceptable limits. Construction cracks do not present operating difficulties. However, it should be appreciated that only limited understanding of spray ice is available and experience related to the performance of full scale structures is meagre. Therefore, considerable further effort is required to improve the current status of knowledge involving these materials including both the basic physical processes which govern its macroscopic behaviour and the engineering behaviour of the material.

  Notwithstanding the above, the results of this project clearly identify two major areas of concern with respect to island design as follows:

1. Variability of material type and consistency is a major feature. Thus, weak layers, which can be considered to be effectively continuous over the plan area of the island, will control design. The question is - what is the shearing resistance in these materials? Tip resistances measured in cone penetration tests are, in some cases, close to zero; possible reasons for this phenomenon are discussed. It is

concluded that the strength of these apparent weak layers is not zero - strengths can be calculated from the behavioural model developed from laboratory test data with due regard for deformation criteria. The large strengths and stiffness of both below and above water materials indicated in large volume tests (i.e. SBP, flatjack tests) are not appropriate for design.

2. Spray ice is a highly time dependent material. Therefore creep deformation under sustained vertical and lateral loading is a major design consideration. At present, little data are available to permit extrapolation of laboratory or field creep data to higher stress levels and protracted time periods which, for example, would be associated with rig loading.

Sandwell

McCLELLAND-EBA, Inc.
CLIENT: AMOCO PRODUCTION COMPANY, DENVER
REPORT DATE: October, 1985

Design Basis MARS Spray Ice Island

Background

Amoco Production Company plans to construct a spray ice island in Harrison Bay, Alaska, during the 1985-86 winter season. The island will stand in 25 feet of water and will serve as a temporary platform for exploration drilling. Pre-design feasibility studies have shown that with normal weather conditions, a 60 day drilling season will be available after pad construction and drill rig mobilization. Construction of the spray ice island will commence about December 15, 1985 and the island will be ready for occupancy by February 1, 1986. A one-week period will be provided prior to spudding the well for verification testing to ensure compliance with the design.

Multi-year ice features are infrequent or can be avoided at the site, therefore the design ice load has been derived from movement of the first-year ice sheet past the island. Local failure within the spray ice initiates bending and pile-up of the natural sea ice. Once flexural failure is initiated in the ice sheet, the maximum ice load that can be transferred to the spray ice island is that associated with building of rubble at the sea ice/island contact. With provision for a sacrificial fringe on the spray ice island, the maximum global ice forces that can be transmitted to the island will be less than those associated with ice crushing against a fixed, rigid structure.

Engineering data for design of the spray ice island were obtained from a prototype island constructed during the winter of 1985. Properties of the spray ice were determined by sampling and in situ testing. Strength properties were determined from unconfined and confined (triaxial) testing. These data were supplemented by temperature, settlement and lateral displacement monitoring.

Island Geometry

The proposed island has an outer diameter of 944 feet. Included within this dimension is a 400 foot diameter centrally-located drill pad, a 152 foot wide berm and a 125 foot wide ice/island interaction fringe. The berm surrounds 75 percent of the drill pad perimeter. The drill pad will have an end-of-construction elevation of +20 feet and the berm an elevation of +40 feet. The interaction fringe rises from sealevel to a maximum elevation of +5 feet. To account for settlement over the 60 day operation period, the island has been designed with two feet of overbuild on the drill pad and three feet on the berm. A 100 foot diameter helipad and 80 foot wide 1V in 20H access ramp are positioned on the southern perimeter of the drill pad. The island design configuration and construction specifications are provided in Drawing 4242-1, Appendix A.

Island Stability

The island is designed for a horizontal ice load of 100 kips per foot of projected width. This is equivalent to a global ice load of 94,400 kips acting on the structure. The global force is resisted by the strength of the island and the shear resistance that can be developed at or near the island/seabed interface. Drained and undrained sliding resistance has been examined. The critical condition for the island is dependent on the drained (frictional) resistance that can be mobilized in the spray ice near the seabed. A factor of safety of 1.5 against lateral island translation has been obtained for the island weight acting on a horizontal spray ice surface with an angle of internal friction of 30 degrees. Factors of safety greater than 4.0 are calculated under undrained loading conditions on a clay seabed.

Rig Foundation Stability

The spray ice behaves as a visco-elastic material. It deforms under a constant load at a rate that is predictable using creep theory developed for ice and permafrost soil. The amount of creep settlement is dependent on the creep parameters, the magnitude of the applied load, and the duration of load application. For a given set of creep parameters, increases in load magnitude or load duration will result in larger settlements.

The maximum average vertical stress in the drill pad area due to self-weight is about 720 psf. The highest applied rig load, derived from the substructure of the derrick, is 900 psf. Based on numerical modelling, this component is estimated to settle about 2 feet during the proposed 60 day well program. Differential settlements between various components are anticipated to be less than 1 foot. The settlements will develop slowly, allowing time for maintenance if necessary.

A timber rig foundation system that allows circulation of cold ambient air below all heated structures has been developed. This foundation system will distribute the rig loads and eliminate heat transfer to the underlying spray ice.

Construction Várification and Monitoring

A comprehensive verification and monitoring program is recommended during construction of the island and subsequently during drilling operations. The program has two main objectives: to ensure that the island is constructed to meet the conditions and criteria adopted for the design; and to permit safe operation of the island under the imposed environmental conditions.

Construction verification is achieved through observation and control of the island geometry during construction, and quality assurance testing of the

Design Basis MARS Spray Ice Island

spray ice properties. Control of geometry will require precise position surveying prior to and during construction, and subsequent monitoring of as-built island dimensions.

The size and elevation of the island components specified are minimums. Over building is acceptable but under building of either size or elevation will require review of the design analyses.

Operational monitoring should include ice/island interaction observations, lateral deflection measurements, temperature changes and settlements. The performance of heated surface facilities is of particular importance. The program must provide early detection of adverse temperature changes within the spray ice platform that could accelerate creep settlements.

Sandwell

GEOTECHnical resources ltd.
CLIENT: CHEVRON U.S.A. Inc.
REPORT DATE: November, 1988

Design Basis Karluk Prospect King Spray Ice Island

Overview:

DESIGN BASIS OF

CHEVRON KARLUK PROSPECT KING SPRAY ICE ISLAND

GEOTECHnical resources ltd.
CLIENT: CHEVRON U.S.A. Inc.
REPORT DATE: November, 1988

Design Basis Karluk Prospect King Spray Ice Island

Chevron's Karluk grounded spray ice island will be located in Stefansson Sound at the co-ordinates N70° 19.44737', N147° 30.3193', as shown in Figure 2.1.1.

The island is located approximately 20 nautical miles northeast of Deadhorse in twenty four feet of water.

Access to the island, during construction and drilling, will be provided by 13.5 miles of ice road with approximately 8.5 miles of the road floating. The road will be routed to avoid the boulder patch as shown in Figure 2.1.1., and will be staged from the Endicott causeway.

The ice road design requirements are included in Chevron Karluk Ice Island - Construction Methodology, reported by GEOTECH, 1988.

The road routing, thickness specifications for the anticipated loading conditions and markings are specified in Drawing No. 9600-D-002.

A detailed ice physical environment and meteorological report for the Chevron Karluk site was prepared by Vaudrey and Associates and is included in Appendix A.

The report provides historical and statistical data on ice and meteorological conditions necessary for establishing:

- o Mobilization and Demobilization Planning
- o Ice Island Construction Strategy
- o Design Criteria for establishing horizontal design loads for the island.

The Mobilization and Demobilization planning and Ice Island Construction Strategy is discussed extensively in Chevron Karluk Ice Island - Construction Methodology, reported by GEOTECH, 1988.

The design criteria for establishing the horizontal loads for the grounded ice island is presented in Section 3.1.

GEOTECHnical resources ltd.
CLIENT: CHEVRON U.S.A. Inc.
REPORT DATE: November, 1988

Design Basis Karluk Prospect King Spray Ice Island

Harding Lawson Associates prepared a detailed geotechnical report for the Chevron Karluk site location. The report is included in Appendix C. A generalized subsurface profile and geotechnical properties for the site is presented in Figure 2.3.1.

The lateral stability and bearing integrity of the ice island, as controlled by the foundation, is based on the data included in this report and is discussed in Section 3.3.1 and Section 3.3.2 respectively.

The design parameters for the foundation in the finite element modelling of the island (included in Appendix C) is based on the data included in the Harding Lawson report.

Laboratory and field data is available to evaluate the elastic and strength parameters of spray ice above water line.

The elastic and strength parameters established for design is based on data available from the following sources:

- o Panarctic's Buckingham 0-68 Platform, reported by GEOTECH, 1984
- o Panarctic's N. Buckingham L-71 Platform, reported by GEOTECH, 1986
- o Panarctic's N. Cornwall N-49 Platform, reported by GEOTECH, 1986
- o Sohio Test Island, reported by GEOTECH and Golders, 1985.

Sandwell

SANDWELL SWAN WOOSTER INC. / CATCO
CLIENT: CHEVRON U.S.A.
REPORT DATE: September, 1989

Karluk ice Island Project Report

Overview:

In 1988, Chevron U.S.A. as operator with Mobil as a partner decided to drill an offshore well near Prudhoe Bay, Alaska using a grounded ice island as the drilling structure. Ice Construction and Engineering (I.C.E.), a Joint Venture between CATCO, a division of Crowley Maritime, and Sandwell Swan Wooster (SSW) designed and constructed the ice island for Chevron. The construction and monitoring were conducted by I.C.E. under a turnkey, fixed price contract, the first time this type of contractual relationship had been attempted for an ice island project.

The island was located 7 miles ENE of Cape Brower in 21 feet of water. The island was built by spraying sea water using 20 m^3/min. (5000 g.p.m.), 1400 kPa (200 p.s.i.) pressure pumps equipped with nozzles and swivels. An island with a total thickness of 14 m (46 ft.) and a diameter of 270 m (890 ft.) was designed and built. Unfactored, design lateral ice loads of 1370 kN/m (92 k/ft.) were used for the stability analysis. Ice loading was the dominant design force. The ability of the ice island to support the rig and associated supplies and equipment in bearing was also assessed. The design included mechanical systems to protect against thawing of the ice by heat generated by the drilling activity.

Construction of the 20 km. (12.6 mile) ice road began on November 19, 1988. By December 12, the ice thickness was sufficient to mobilize the island construction equipment. Construction of the island began on this date with the required volume of ice in place by January 20, 1989.

Between January 20 and February 2, 1989, the island surface was prepared, the integrity of the island was verified and the instrumentation required for the monitoring program during drilling was installed. Drilling began February 20, 1989 and rig release was April 7, 1989. During construction, ice build up, ice volume constructed, pump moves and position, water volume pumped, ice temperature and ice density were monitored. Daily progress was reported and daily contour maps were plotted to help in planning the next days activity. During drilling, horizontal ice movement, vertical ice settlement, ice temperature under the rig and meteorological conditions were monitored. Most of the data was logged in real time using a custom built data acquisition system.

The project is described in five (5) separate reports. For convenience, these five reports, initially issued to Chevron as individual reports, have been bound into one document for limited distribution to Chevron and the Joint Venture partners.

Sandwell

SANDWELL SWAN WOOSTER INC. / CATCO
CLIENT: CHEVRON U.S.A.
REPORT DATE: September, 1989

Karluk ice Island Project Report

The **QUALITY CONTROL REPORT** describes the quality control procedures in place to ensure that the island would meet the design specifications. The results of the program are also included.

The **VERIFICATION REPORT** describes the measurements taken, once the island was completed, to certify that the island satisfied the design specifications.

The **INSTRUMENTATION REPORT** describes the instrumentation and data acquisition system installed at the end of construction to monitor the engineering performance of the island during drilling.

The **ENGINEERING PERFORMANCE REPORT** describes the performance of the island from construction completion through to rig out.

FLOATING ICE - PANARCTIC

FENCO CONSULTANTS LTD.
CLIENT: PANARCTIC OILS LTD.
REPORT DATE: November 19, 1974

Ice Platform for Offshore Drilling Hecla N-52

INTRODUCTION

During the spring and summer of 1973, Foundation of Canada Engineering Corporation Limited (FENCO) designed an ice platform to be used by Panarctic Oils Ltd. in the Arctic Islands as an offshore drilling base. Prior to the design, a considerable amount of horizontal ice movement data had been collected by Panarctic. The natural ice at the well site, 8 miles offshore in Hecla and Griper Bay, was thickened by flooding and freezing in layers to provide an adequate support for the rig. Flooding began November 28, 1973, and was completed February 3, 1974. The Panarctic Tenn et al CS W Hecla N-52 well was spudded March 5 and the rig released April 15, 1974.

The results collected by us as a result of the monitoring during construction and drilling have been recorded and analysed exhaustively. Creep theory has been developed for the prediction of long-term deflections and stresses and ice buildup rates have been correlated to ambient temperature and wind. The elastic modulus for the ice was obtained for various depths and checked with surface values. Strength was also checked at different depths.

Design of the ice platform was based on the theory for elastic, homogeneous and isotropic plates of uniform section resting on an elastic foundation. Maximum extreme fibre stresses beneath the rig were calculated and were limited to between 25 and 30 psi, providing a safety factor against failure of around 6 in the uncracked state and 3 in the cracked state. The platform section tapered to the natural ice thickness at approximately 225 feet from the moon pool.

FENCO CONSULTANTS LTD.
CLIENT: PANARCTIC OILS LTD.
REPORT DATE: November 19, 1974

Ice Platform for Offshore Drilling Hecla N-52

Long-term deflections of the ice were estimated using a 1/30 reduced elastic modulus as it was desired to avoid flooding of the working area during drilling.

During construction and drilling, ice temperatures, total ice buildup, ice quality and vertical deflection measurements were taken. The results of these measurements and the subsequent analysis are outlined below.

1) <u>Ice Buildup</u>

The natural ice beneath the rig location was thickened to a maximum depth of 17.5 feet by flooding in thin layers with small pumps and allowing the layers to freeze before applying another lift. Between the beginning of December, 1973 and February 3, 1974, a maximum of 135 inches of ice was built up. The average buildup rate was 2.5 inches/day.

Statistical analysis showed a strong correlation between ambient temperature and buildup rates but none between wind velocity and buildup rates. It is felt that the adverse effects of wind on men and equipment offset any advantages gained from increased cooling of the flood water.

2) <u>Vertical Deflection Measurements</u>

Vertical deflections in the rig vicinity were measured frequently during drilling. As well, deflections were measured at fuel storage bladders placed on first-year sea ice at the aircraft turnaround area.

Total deflection next to the rig over a period of 40 days averaged 0.44 feet. Creep theory, developed from the basic creep power law, gave a total predicted deflection of 0.31 feet. However, this same theory showed good correlation with measurements taken at the bladders. Since the rig platform continued to deflect downwards after the start of rig down, it was felt that the ice had still not reached isostatic equilibrium after flooding. The small stresses introduced by the rig were not large enough to overshadow these other effects.

3) <u>Ice Temperatures</u>

Ice temperatures were monitored continuously during flooding. Because of the salinity of the built-up ice it had been decided to ensure that the built-up ice temperatures never exceeded -5^{o} C so that the brine volume would be kept at an acceptable level. Ambient temperatures during flooding varied between -17^{o}C and -47^{o}C with an average of about -30^{o}C. At the flooding rates experienced, no problem was encountered keeping built-up ice temperatures at or below -10^{o}C.

Temperatures were monitored during drilling beneath the rig, the rig heater, and other buildings and excessive warming of the ice was not a problem. The two 2-inch layers of urethane insulation (k=0.13 Btu-in./hr.ft.^{2}F^o) and the 4-inch thickness of the wooden matting were effective in ensuring that ice temperatures did not exceed -5^o C.

4) Ice Salinity

Ice salinities in the natural ice were low, around 1 ppt, indicating multi-year ice beneath the rig platform. During construction and drilling, average salinities in the built-up ice were 15 ppt with peaks to 30 and 40 ppt. By the end of summer, approximately 4 feet had melted off the top of the platform and the average salinity of the remaining ice was 1 ppt.

5) Ice Strengths

Unconfined compressive strengths of the built-up ice near the surface varied between 600 psi and 1610 psi. Stress rates for these tests were between 600 and 1200 psi/min.

Confined compressive strengths near the surface averaged 2728 psi in the built-up ice.

The elastic modulus of the built-up ice near the surface was 580,000 psi and that of the natural ice averaged at 600,000 psi.

Borehole tests at various depths showed little variation in elastic modulus or strength. At 9.5 feet, the deepest test, a modulus of 450,000 psi was obtained.

6) Snow

Natural snow accumulation was not a problem. Specific gravities of naturally-deposited snow and of snow piled by machines were 0.5.

FENCO CONSULTANTS LTD.
CLIENT: PANARCTIC OILS LTD.
REPORT DATE: July 9, 1975

East Drake I-55 Offshore Drilling Ice Platform

The platform was constructed by successive flooding and freezing of thin layers from electric submersible pumps at fixed locations. The electric pumps were a significant improvement over the gasoline screw-type pumps used previously at Hecla N-52 in terms of reliability, ease of operation and flow rates.

Vertical ice deflections were monitored by the use of optical levels and water level recorders. A deflection of 10 inches over a 50-day period left 18 inches of available freeboard at the conclusion of drilling.

A summary of the important factors in this project is given below.

Ice Buildup

The original natural ice thickness for pads 2 and 4 was 6.1 and 6.7 feet respectively on November 23, 1974. By flooding thin layers of 1 - 2 inches, an average buildup rate of 3.5 inches/day was achieved to give a final centre ice thickness of 16.3 feet for Pad 2 and 16.7 feet for Pad 4. There was no measurable natural growth in the centre pad areas thereafter. It is anticipated that, with improved working methods, a buildup rate of 4 inches/day can be realized for similar environmental conditions. In practice, winds over 10 mph reduce flooding efficiency.

Ice Temperatures

During flooding the temperature gradient of the ice sheet was monitored to prevent overheating. Flooding was resumed once the top foot of ice had reached a temperature of -5°C or lower. Once the platform was constructed, the temperature gradient became approximately linear from an average ambient -30°C at the surface to -1.7°C at the sea water interface. Temperatures remained stable in the ice platform during rig-up and drilling except in the moon-pool cribbing where there was a warming trend. It is recommended that the insulation be placed between the cribbing and ice in future projects.

Vertical Deflections

Measurements of the vertical movement of the ice sheet due to creep were made by optical survey and water level recordings. At the time of rig-up the available freeboard of 28 inches at Pad 2 was in excess of what would be expected from 16-foot thick ice. Therefore the platform behaved as if an effective load of 2,300,000 pounds was placed on it. A deflection of 10 inches in 50 days for this load is consistent in comparison to the deflection of 5 inches at Hecla N-52 where no excess freeboard existed. The long-term deflection of both I-55 and N-52 can be described by using an effective bulk elastic modulus of 30,000 psi in the deflection equations.

FENCO CONSULTANTS LTD.
CLIENT: PANARCTIC OILS LTD.
REPORT DATE: July 9, 1975

East Drake I-55 Offshore Drilling Ice Platform

There was no measurable deflection of Pad 4 during the same period although there was an effective ice load due to excess freeboard. The comparative low stress produced by the distributed ice load resulted in a lower deflection rate.

The experience of N-52 and I-55 indicates that the allowable tensile stress used in the design can be increased to 70 psi and this increased design stress would be consistent with the limitations for long-term deflections. It is estimated that a factor of safety of 4 against failure exists whenever deflections are limited to the available freeboard.

The updated platform design for rigs No. 2 and 4 and the revised monitoring schedule are included as Appendix F and G to this report.

Ice Quality

Throughout the course of flooding and construction, the ice quality was determined from cores and strength tests. The ice cores taken from various locations in the pads showed the ice to be intact through the entire natural and built-up thickness with occasional high salinity pockets throughout the built-up thickness. Borehole tests confirmed that the strength of the built-up and natural ice decreases with depth or temperature but not to the degree that was previously assumed.

The average confined compressive strength of built-up and natural ice was calculated to be 3170 psi and 4210 psi respectively. Flaking tests gave corresponding values of 1205 psi and 570 psi for unconfined compressive strength.

Tides

Tides measurements gave a range of 40 inches vertical movement in the period January 2 to April 22, 1970.

The information gained from I-55 and previously at N-52 indicates that an ice platform is a feasible method for offshore drilling in areas of the high arctic where the horizontal ice movement is limited. The platform construction is essentially limited to the period November to February depending upon the available natural ice thickness in the fall.

FENCO CONSULTANTS LTD.
CLIENT: PANARCTIC OILS LTD.
REPORT DATE: November 23, 1977

Offshore Drilling Ice Platforms for West-Hi Rig #1 at Drake F-76 and Roche Point I-43

The Marc CDC finite element program for short term load analysis and the Effective Modulus Equation for long term analysis were used to analyse stresses and deflections. Data from all previous platforms was extensively studied in order to produce a platform design which would limit deflections to available freeboard and short term maximum stresses to 70 psi.

The design of the two ice platforms is based on an available freeboard of 11% of the overall ice thickness. This particular value of 11% and more was found to be present at the Jackson Bay G16-A ice platform which is in many ways similar to the above two platforms. Additional information regarding the magnitude of the available freeboard can be obtained from Fenco's project report "Offshore Drilling Ice Platforms" submitted to Panarctic in July 1976.

In the additional amendment both platforms have been redesigned as a result of the recent changes in the rig weights and their durations. The locations of the weights remain the same, therefore, it seems reasonable to utilise the previous calculations plus the computer results as a basis for the redesign of the platforms.

The total weight on the Drake F-76 platform has been increased by 55 kips (1.5% of the total weight) resulting only in minor changes in deflections and stresses. The previously determined ice thicknesses remain unchanged. In the case of the Roche Point platform the total weight is reduced by more than 400 kips. This beneficial effect, however, has been taken up by an increase in the duration of some of the dead weights resulting in an increase in the long term deflections. For multi-year ice and the additional weights of tool shack and pipe storage a minimum ice thickness of 22 feet should be used for the Roche Point platform (see page 6 of the amendment).

We trust, for the given weights and their durations the most unfavourable cases have been investigated in both the original design as well as in the amendment.

FENCO CONSULTANTS LTD.
CLIENT: PANARCTIC OILS LTD.
REPORT DATE: November 30, 1977

Drake Point Offshore Pipeline Near Shore Resistance to Ice Scour

Overview:

Fenco Consultants Ltd. were requested by Panarctic Oils Ltd. on October 11, 1977, to review a proposed system for protecting the Drake Point pipeline, to run from the F-76 offshore well to land, from scour by ice in the near shore regions. It had been proposed to pump a cold glycol-water solution through the annulus of a 24 inch pipe encasing the 18 inch conductor and thus to freeze a bulb of soil around the pipe from the 20 metre water depth to shore. The bulb of frozen soil would stiffen the pipe and presumably render it resistant to lateral and vertical ice forces from ice grounding in the shallower water.

Fenco were specifically asked to:

1) Review the effect of frost bulb growth with time.

2) Assess the danger of frost heave and buoyancy.

3) Examine several aspects of the soil capacity and reaction including but not limited to the following:

   a) Evaluation of the capacity of the pipe in conjunction with the frozen soil bulb to withstand normal and vertical forces from ice masses.

   b) Reaction of the unfrozen soil beneath

      i) the pipe and frozen soil bulb and
      ii) the 18" pipe bundle with no frost bulb protection.

   c) A prediction of ice lensing within the soil.

   d) Examination of soil-pipe composite interaction.

   e) Backfill recommendations.

4) Examine methods of monitoring the freezeback and pipeline reaction.

5) Chilling system design.

Fenco, in cooperation with its sister company, Geocon (1975) Ltd., has assessed the effectiveness of the frozen soil system according to the above outline with minor exceptions.

In addition to the above tasks, Geocon was asked to conduct a review of a proposed frost heave test program, to analyse results from a plow model test program and to review frozen soil strength data.

FENCO CONSULTANTS LTD.
CLIENT: PANARCTIC OILS LTD.
REPORT DATE: November 30, 1977

Drake Point Offshore Pipeline Near Shore Resistance to Ice Scour

CONCLUSIONS

Ice Pack of the Area and Scour Possibility

Conclusions

Scour action by ice on the pipeline in the nearshore region is possible. Two basic types of scour action are considered possible.

The first type is by ice with 5 metres or less keel depth and this occurs every year.

The second is by ice 5 metres to about 20 metres keel depth. While scour at these depths is possible, the probability is unknown and is guessed to occur with a frequency of one in ten to one in one hundred years.

Sea Bottom Conditions - Geotechnical

Interpretation of provided data shows the sea bottom to be underlain by a very soft marine clay which is sensitive to disturbance. In the first 1.5 m (5.0 ft.) depth the water content of this clay is greater than the liquid limit and the clay has an undrained shear strength of 1.5 kN/m^2 (30 psf) which will decrease on remoulding. These shear strength values are very low resulting in settlement and sloughing of sea bottom under any construction activity.

Unconfined compression tests on frozen clay samples showed marked increase of the frozen shear strength with decrease of temperature. However, it should be noted that the frozen shear strengths were lower than for clays with fresh pore water. This can be explained by the salinity of the pore water.

Ice Forces and Action

Lateral scour action finds the pipe at its weakest and is the criteria for design of protection systems.

Wind stress in the ice pack is transferred to the buried pipe by thicker ice which is pushed by the pack and then scours the bottom.

Calculations based on limiting wind fetch and ice sheet internal stability showed that maximum concentrated ice forces of 3800 to 30,400 tonnes (8400 to 66,800 kips) are possible.

Maximum possible resistances of the bottom soil to scour are 4 to 10 times less than the corresponding ice forces. The soil cannot prevent scour.

There are limitations on scour depth as determined by the upward push of the soil on the shoreward side of the scouring ice mass. These limiting depths are far below the planned burial depth of the pipe and still allow maximum force application.

Stability against overturning of multi-year floes common to the area does not in general limit scour forces.

Thermal Analysis of Frozen Bulb

Freezeback calculations using one and two-dimension solutions from various sources for various pipe coolant temperatures (-10°C, -20°C, -40°C) show that about one year is required to grow frost bulbs of a diameter 3 to 4 times greater than that of the 24 inch pipe. Since freezing progresses as a root function of time, increasing the bulb beyond this diameter requires years of time.

Thawing of the frozen soil completely takes appreciably more time than freezing because the temperature differentials are lower, with heat transfer being to the soil at -2°C and the water at about -1°C. Years are required to completely thaw a metre or two of the bulb.

However, as pointed out under the geotechnical section, frozen soil strengths are highly temperature dependent and the frozen bulb strength is reduced to low values long before complete melting with subsequent loss of ability to resist ice scour action has occured.

Scour Resistance by the Pipe and Frozen Bulb System

The pipe and soil bulb were analysed as a beam on an elastic, perfectly plastic foundation subjected to small deflections and as a catenary subjected to large deflections. The beam analysis was for a cracked bulb surrounding a flexurally stiff pipe and an uncracked bulb surrounding a pipe with no flexural stiffness. Stiffness properties of the naked pipe and the frozen soil bulb were compared. The following conclusions are drawn.

The pipe and/or soil bulb do not act as a catenary as large deflections are required for this which flexural strain limitations and geometry would not permit.

Comparison of pipe and frozen bulb section properties revealed that for frozen bulb diameters greater than 2.5 to 3.7 metres (8 to 12 feet) it is much stiffer and stronger than the naked pipe. Frozen soil tensile strength values of 138 to 345 kPa (20 to 50 psi) and elastic modulus values of 35 to 138 MPa (5,000 to 20,000 psi) were used in the analysis. Only frozen soil of -10^{o}C or colder was considered to contribute to the frozen bulb section strength.

Deflections of an uncracked soil bulb are much less than those of a cracked bulb and pipe at allowable stresses. Both systems had an elastic, perfectly plastic foundation. An uncracked bulb cracks before deflections large enough to exceed the foundation soil yield strength are reached.

A diagram comparing forces causing maximum allowable pipe and frozen soil beam deflections with maximum expected ice forces was presented. Uncracked, frozen soil bulbs of up to 40 feet in diameter, requiring some 20 years to grow, will not resist expected ice forces. The ice forces exceed the allowable forces by a factor of 10 or more.

Similarly, a flexurally stiff pipe surrounded by a cracked soil bulb will not come close to resisting ice scour forces. Both of the above systems are much stronger than a naked pipe but are not strong enough.

The pipe and frozen bulb system will not resist lateral scour forces from yearly expected ice any better than from the less frequent scouring ice of greater thickness. Little reduction in total ice force can be expected as one approaches nearer to shore and shallower water.

The ability of the frozen soil bulb and pipe system to resist vertical forces from the onshore movement of ice is marginal at best.

Frost Heave and Buoyancy

Estimates of frost heave of the proposed chilled pipelines indicate it to be in the range of 0.1 m (0.3 ft.) to 1.5 m (5.0 ft.) for an estimated 30 year lifespan of the operation. It is felt that the actual total frost heave will be closer to the lower value. Frost heave test results provided by Panarctic support this conclusion.

However, this frost heave may be compensated and even be exceeded by settlement of the frost bulb due to consolidation of the underlying soft clay. This is due to the fact that the freezing will break the hydrostatic condition at the frost front thereby increasing the weight within the frost bulb from submerged to total weight condition.

A review of buoyancy of the flowline during different stages of installation and operation show that a buoyant condition may develop only at one stage. This could occur during the dragging of the pipe along the trench through remoulded clay. If this clay was remoulded sufficiently enough that it acted as a fluid, the pipe would float within this remoulded clay.

Pipe Trench

Analysis of the designed trench geometry with about 1.4 m (4.5 ft.) depth indicates that the trench walls would be stable in subject sea bottom with undisturbed clay. The construction of the trench with the prepared plan will remould the clay under the action of the skids, plow and floating boards resulting in sloughing of the trench walls. It is believed that the trench may fill up to nearly half of its design depth. This conclusion is supported by model test studies carried out by R.J. Brown and Associates.

RECOMMENDATIONS

The following recommendations regarding placing of the pipe and protecting it from scour by ice in the near shore regions are made.

1. Since the pipe and bulb of frozen soil cannot resist expected ice scour forces, the concept of freezing soil around the pipe by circulating a cold fluid should be abandoned.

2. The pipe can be protected from ice scour at 5 metres water depth or less by constructing a berm of frozen material over it in this region using only natural freezing. The berm could consist largely of ice with a granular soil insulating blanket on top. The buoyancy of the ice would ensure that the weak soil beneath were not overloaded with resulting failure or large deflections.

   The berm could be constructed using standard ice platform construction techniques and could be instrumented with banks of thermistors for quality control during flooding and subsequent performance monitoring.

Ice forces would be transferred to the berm and thence to shore by compression or shear action. Freezing to bottom in the first year is not critical and would occur with time, adding to the already considerable strength of the system. The installed thermistors would quite effectively monitor this gradual freezeback.

Some maintenance at the front of the berm may be necessary from year to year but experience with similar structures indicates it should not be expensive. The granular insulating layer on top of the berm and the low average ambient temperatures will obviate the use of artificial freezing.

3. The pipe can be protected from ice scour in deeper water only by burying it to a depth of about 20 metres (Figure 4.5 of report). If this is not practical, then it is best to leave the pipe naked. As stated, the probability of scour in deeper water is not known but is less frequent than in 5 metre water and the chances of survival may be good. At any rate, the frozen soil bulb will not protect it.

4. It is recommended that the possibility of pulling the pipe right behind the plow be reviewed. Our understanding is that the present procedure will consist of first plowing a trench followed by pulling of the pipe through the trench. We believe that it will be difficult to install the pipe at the desired depth and possibly even in the desired pipe alignment because of the in filling of the trench by sloughed material, also the trench walls might not provide sufficient control to keep the pipe aligned within the trench.

Sandwell

FENCO CONSULTANTS LTD.
CLIENT: PANARCTIC OILS LTD.
REPORT DATE: September 4, 1978

Offshore Drilling Ice Platforms Roche Point O-43 and Cape Grassy I-34

Overview:

During the 1977-78 winter season, the drilling of three offshore wells from ice platforms brought the total of wells drilled by this method to ten. This report deals with the Cape Grassy I-34 and Roche Point O-43 ice platforms. Previous offshore wells completed by this method were Hecla N-52, Drake I-55, Hecla P-62, Hecla M-25, Jackson Bay G-16A, Drake P-40, and Hecla C-58.

The fact that Rig #2 has drilled from a first-year ice platform is an important occurrence because the data collected will allow a comparison of first-year ice and multi-year ice platform behaviour. The six previous Rig #2 ice platforms were all multi-year ice platforms. Also the drilling of Roche O-43 with Adeco Rig #4 on a multi-year ice platform will allow a further first-year and multi-year comparison because Adeco Rig #4 drilled Jackson Bay G-16 on a first-year ice platform.

Operation Schedule:

Site	Start Flooding	Complete Flooding	Initial Thickness	Final Thickness	Start of Rig-Up	Spud Date	Release Date
Cape Grassy I-34 (Pad 2)	Dec 2	Jan 27	2.9'	17.0'	Feb 14	Mar 11 Mar 3	Apr 18
Roche Point O-43 (Pad 4)	Nov 10	Dec 28	6.4'	17.6'	Dec 28	Jan 18	Apr 18

FENCO CONSULTANTS LTD.
CLIENT: PANARCTIC OILS LTD.
REPORT DATE: September 29, 1978

Offshore Drilling Ice Platform Drake F-76

Overview:

In the winter season of 1977-78 a sea ice platform was constructed at Drake F-76 to allow West-Hi Rig #1 to drill and complete a production well. In the design of the platform, parameters were used which were taken from the performance of former ice platforms. This report studies the behaviour of the ice platforms of Drake F-76 in terms of measurements obtained during the operation of the Rig #1 and the results are compared with predicted design data.

The total depth of the well was approximately 1128 m (3700 ft) and the maximum total load applied to the ice platform was about 3800 kips. Starting on a 1.03 m (3.4 ft) ice thickness of first-year ice, the ice platform was built up by flooding and freezing the surface to a final average thickness of 7.10 m (23.3 ft) at January 26 1978.

Construction Operation Dates:

Start Flooding:	**Nov. 14, 1977**
Completed Flooding:	**Jan. 26, 1978**
Initial Thickness:	**3.4 ft.**
Final Thickness:	**23.3 ft.**
Start of Rig-Up:	**Feb. 4, 1978**
Spud Date:	**Mar. 2, 1978**
Release Date:	**Apr. 28, 1978**

A first at this site was the collection of high quality strain data at five different levels in the ice platform at one station. This data allowed a strain profile to be calculated and very interesting and important observations were made from the results.

This report presents field data collected, studies platform performance and gives future recommendations.

FENCO CONSULTANTS LTD.
CLIENT: PANARCTIC OILS LTD.
REPORT DATE: August 16, 1979

Offshore Drilling Ice Platforms W. Hecla P-62, NW Hecla M-25, Jackson Bay G-16 & 16A

Overview:

During the winter drilling season of 1973-74 Panarctic Oils Ltd. demonstrated the feasibility of sea ice platforms for arctic offshore drilling when they successfully tested the well at N-52. Another well was drilled at Drake I-55 during 1974-75 and this year three offshore wells brought the total to five.

There were a number of interesting "firsts" to this year's wells which further defined the limitations of ice platforms. For the first time two holes were drilled by Commonwealth Hi Tower Rig No. 2 at P-62 and M-25 during the same winter season. The thinnest pad was 14.7 feet at P-62 and it appears that even thinner ice can be used in future pads.

SITE	START FLOOD	COMPL FLOOD	INITIAL THICKNESS	FINAL THICKNESS	START RIG-UP	RIG RELEASE
G-16	14 NOV 75	7 JAN 76	3.9 ft	18.0 ft	11 JAN 76	27 APR 76
P-62	22 NOV 75	20 DEC 75	6.1 ft	14.7 ft	22 DEC 75	27 FEB 76
M-25	10 JAN 76	12 FEB 76	8.0 ft	16.3 ft	1 MAR 76	17 APR 76

The heavier Adeco Rig No. 4 was initiated at Jackson Bay G16 and remained on the ice for over 100 days. Ice movement necessitated respudding and therefore a thorough study should be made into means of staying over the hole when large ice movements occur.

The purpose of this report is to present and discuss the data gathered, analyze the platform performance and to make recommendations for future improvements.

FENCO CONSULTANTS LTD.
CLIENT: PANARCTIC OILS LTD.
REPORT DATE: September 21, 1979

Study to Improve Method of Construction of Ice Platform for West-Hi Rig No. 1

Overview:

A number of contractors, chemical specialists, equipment manufacturers, etc. were contacted to determine the feasibility of operating the systems which were considered. Where systems were judged to show potential a detailed analysis was completed to determine the structural performance.

In total 7 methods as listed were studied:

(1) Foam cells frozen into the ice platform
(2) Snow pad on partially completed ice platform
(3) Air filled bladders on the bottom of the ice platform
(4) Empty fuel drums frozen into the ice platform
(5) Fans to create high winds over the ice platform
(6) Rotating irrigation system flooding
(7) Reinforcement in tension zone of the ice platform

Upon completion of an individual analysis of each system all the systems were ranked in order of how effectively we felt they would improve the construction of the ice platform. Reduction in time of construction and structural performance were the most important factors considered. Secondary factors in ranking the systems were cost, ease of installation, and possible future improvements. We felt that a system should be given greater merit if there is potential in the method to further reduce time of construction through expanded use.

(1) Foam Cells Frozen Into the Ice Platform: we recommend that this system be considered at present as the most feasible and practical method to improve the construction of the Rig 1 ice platform. A detailed study determined that a rigid pour-in-place urethane foam 1SO-100 Resin 22-1 which is marketed by C.I.L. be considered for ice platform construction. This material is a flammable foam which can be disposed of through burning. The design presented for Hazen F-54 produces a reduction in ice thickness of 1.1 m through use of a 500 tonne buoyancy system which represents 14 days of flooding. The distinct advantage of this system over the fuel bladders would be that they could be installed during the construction period and consequently no time would be lost for installation. Also in the future increased amounts of foam could be employed to further reduce required ice thickness.

(2) Air Filled Bladders on the Bottom of the Ice Platform: we recommend that this system be considered as a feasible method. Calculations show that at Hazen F-54 a reduction in ice thickness of 1.1 m could be achieved through use of a 500 tonne buoyancy system. This represents 14 days of flooding and will significantly add to the time to complete the well to total depth. The only drawback to this system would be that about 4 days would be required to install the equipment after the moonpool is excavated. During this period we anticipate that the rig-up operation shall have to come to a near stop.

(3) Rotating Irrigation System Flooding: we recommend that this system should be considered as a feasible method. Calculations show that a buildup rate of 144 mm/day could be possible with this system under good weather conditions. Experience, however, has shown that this system is prone to breakdown and the actual buildup rates are not much higher than the conventional free flooding methods. It is conceivable that given properly designed and maintained equipment, significantly higher flooding rates could be achieved.

(4) Snow Pad on Partially Completed Ice Platform: we recommend that this system not be considered due to the small amount of time which would be saved (3 to 4 days) on platform construction.

(5) Reinforcing in Tension Zone of the Ice Platform: we recommend that this method not be considered at present until experiments are carried out to determine design parameters. Also at present it appears that a considerable cross-sectional area of steel in the order of .028 m^2 per metre of ice platform would be required. Also this method could only be employed on first-year ice due to the fact that reinforcement must be near the bottom of the platform.

(6) Fans: we recommend that this system not be considered due to the small amount of time (2 to 5 days) which would be saved in construction. The inconvenience and dangers to personnel of such a system also are of concern should the method be employed.

(7) Fuel Drums Frozen Into Ice Platform: we recommend that this method not be considered. The difficulty in transporting and installing such a large number of barrels would be insurmountable.

Sandwell

FENCO CONSULTANTS LTD.
CLIENT: PANARCTIC OILS LTD.
REPORT DATE: October 10, 1979

Offshore Drilling Ice Platform Hazen Strait F-54

Overview:

The drilling Hazen F-54 occurred over the past winter season of 1978-79. The presence of thick multi-year ice through the Hazen area and a concentrated flooding schedule allowed for an early completion of the ice platform. Significant dates of construction and drilling follow:

Start Flooding:	**Nov. 19, 1978**
Complete Flooding:	**Jan. 20, 1979**
Initial Thickness:	**2.09 m**
Final Thickness:	**6.54 m**
Start of Rig-Up:	**Jan. 21, 1979**
Spud Date:	**Feb. 4, 1979**
Release Date:	**May 19, 1979**

CONCLUSIONS AND RECOMMENDATIONS

The Hazen F-54 ice platform was completed at an early date of January 20 through an intense flooding schedule and an early start-up date of November 19.

Studying the loads present showed that the long term load was 1303.6 tonnes. It was decided that the 148.8 tonne casing storage load should be classed as a short term load because this load was never present for longer than about 5 days.

Upon completion of the ice platform borehole jack tests on January 20 showed an average ultimate strength of 11.3 MPa for 39 tests done in built-up ice with an average calculated E_0 value of 359 MPa. Both of these values are lower than the values recorded at Drake F-76 which can be attributed to the heavy flooding schedule at Hazen and the presence of multi-year ice which has served to trap the brine in the built-up ice. Also it was found that as the season progressed the strength parameters increased considerably as drilling proceeded. This indicates that a heavy flooding schedule may cause lower initial strength parameters but this is not of concern because the platform will strengthen as cooling is allowed to occur.

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CLIENT: PANARCTIC OILS LTD.
REPORT DATE: October 10, 1979

Offshore Drilling Ice Platform Hazen Strait F-54

The operation of the tide station showed a total tide range of 100 cm and no problems were experienced with the mechanical operation of the system.

The measurement of long term deflection was accomplished through use of a float recorder and a level surveying system. Both methods functioned very well but start-up was about 7 days late in both cases. A total deflection of 440 mm was recorded over the period of drilling. In the future the start-up date of at least one of the systems has to be before the start of rig-up date. Also the level survey shall be tied into the float recorder in the tide shack for a double check on the recorded elevations.

Temperatures recorded under Rig 1 during the drilling period showed a very stable safe temperature range in the ice platform. Circulation of water in the moonpool and the refrigeration system served to keep the moonpool area well frozen.

The strain gauge installation at Hazen was a success and very useful data was collected. The time versus maximum principal strain showed a direct relationship with the deflection versus time plot. This fact is an important consideration in platform design.

A study of long term deflection results showed that the following equation best fits all available Rig 1, Rig 2 and Rig 4 data.

$$W_2 = W_1 \left(\frac{P_2}{P_1}\right)^{1.8} \left(\frac{h_1}{h_2}\right)^{3.0} I_f$$

In order to reduce the amount of time required to construct the ice platform it is recommended that an artificial buoyancy system be used. Neth and Strandberg (1978) presented a number of possible devices which could be employed. The most feasible appears to be urethane foam cells which would provide 500 tonne uplift and reduce the design thickness by 1.1 m. At an average built-up rate of .074 m per day this represents 15 days of flooding.

Sandwell

FENCO CONSULTANTS LTD.
CLIENT: PANARCTIC OILS LTD.
REPORT DATE: October 15, 1979

Offshore Drilling Ice Platform Whitefish H-63

Overview:

The thick multi-year ice present over the past winter season throughout the Whitefish area was of sufficient thickness to support Rig 4 with only limited flooding being required to level the platform area. The operation of Rig 4 at Whitefish H-63 adds an important area of data to ice platform theory. It will be possible to compare the long term deflection of a totally multi-year ice platform with a built-up ice platform. Also the degree to which tapered section affects long term deflection can be estimated.

Construction of the airstrip and lease road and transportation of the rig over the rough ice area presented considerable problems but a start of rig-up date of January 24 was still achieved.

SITE	START FLOODING	PAD 4 PROFILED	INITIAL THICKNESS	FINAL THICKNESS	START OF RIG-UP	SPUD DATE	RELEASE DATE
Whitefish H-63	Dec. 2/78	Dec. 17/78	6.26 m	6.36 m	Jan. 24	Feb. 18	May 21

CONCLUSIONS AND RECOMMENDATIONS

The Whitefish H-63 area was covered with extremely thick multi-year ice in the order of 6 m thickness. For this reason flooding with the submersible pump system was not required and flooding to level the lease was completed with the mobile pump units (Imps).

The January 24, 1979 start date for rig-up reflects the inavailability of Adeco Rig 4 which was drilling on a land location. The ice platform and airstrip were ready for the drilling rig on December 17, 1978, however, the first rig loads were not made available until January 7, 1979.

In previous years, Rig 4 had drilled offshore holes at Jackson Bay G-16A and Roche O-43 with start of rig-up of January 11 and December 28, respectively.

The borehole jack test as completed on December 18 and March 17 showed average ultimate confined borehole strengths of 21.6 MPa and 21.1 MPa, respectively. These values are typical for multi-year ice and indicated that the platform was comprised of sound ice.

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CLIENT: PANARCTIC OILS LTD.
REPORT DATE: October 15, 1979

Offshore Drilling Ice Platform Whitefish H-63

The measurement of temperatures in the moonpool area showed that the ice in this area was maintained well below the freezing point throughout the drilling period.

The start-up of the refrigeration system on February 8 prior to the spud date and circulation of water out of the moonpool ensured that melting did not occur.

A study of long term deflection at Whitefish showed that the long term deflection was higher than expected.

FENCO CONSULTANTS LTD.
CLIENT: PANARCTIC OILS LTD.
REPORT DATE: October 30, 1979

Drake Point Offshore Pipeline Ice Berm for Near Shore Scour Protection

On April 23, 1978 Panarctic Oils Ltd. completed its Drake F-76 gas well off the Sabine Peninsula of Melville Island in the High Arctic. Six days later gas flowed to shore by a marine flowline and a test program was started to evaluate the performance of the well-flowline and a test program was started to evaluate the performance of the well-flowline combination. This was the culmination of a two year engineering and construction program to demonstrate the feasibility of drilling such a well offshore in the Arctic, of completing it with a subsea wellhead and of connecting it to a marine flowline to onshore process facilities. This report is concerned with the design, construction and performance of the near-shore flowline protection system developed by FENCO CONSULTANTS LTD. and R.J. Brown Associates, to resist potential ice scour of the pipeline.

SUMMARY AND CONCLUSIONS

To protect the Panarctic Oils Ltd. Drake Point pipeline from ice scour damage in the near shore regions, a berm of grounded ice was designed and constructed during the winter of 1977/78. The natural ice from shore to the 5 m water depth was thickened by freezing and flooding in thin layers until the ice grounded. A 1 m layer of granular material was placed on top to protect the ice from thermal degradation. The design, construction, instrumentation and performance of this permanent facility are summarized below.

Cold fluid was also pumped through the annulus of a 610 mm pipe surrounding the 457 mm conductor to freeze soil around the pipe in an attempt to stiffen the system. The result of this program are described as well.

Berm Design

Ice and Soil Conditions

The ice in the Drake area is usually a mixture of multi-year and first-year ice, with the multi-year ice usually comprising 5/10 to 9/10 of the cover. Average thicknesses of 2.6 and 3.6 m and maximum thicknesses of 8.5 and 17.4 m were reported from ice thickness surveys.

Wind stress is the main driving force of the ice pack. Sustained wind velocities are often high and fetches large and maximum ice forces are often limited by the thickness, strength and stability of the ice sheet.

The Drake F-76 site is underlain by thick deltaic-marine deposits consisting of a highly plastic silty clay with occasional low to medium plastic clays and silt lenses with traces of sand. The marine clay exists both as unfrozen soil and as permafrost. The unfrozen clay has a high moisture content (approximately 70% near the surface) and as a result is in a semi-fluid state with shear strengths of 1.5 to 4.8 kPa. As a result it is a material incapable of supporting a buried pipeline against lateral or vertical push by scouring ice masses.

Berm Purpose

Scour by ice thickness of 5 m or less is considered to be possible frequently on the basis of data gathered from ice thickness surveys. Thus the ice berm extends from the 5 m water depth to the frozen shore and acts as a bumper, transmitting forces from its front to the frozen shore material. It also acts as a stiff matt and increases the weak soils ability to carry loads, such as the berms granular cover.

Ice Forces, Berm Stresses and Dimensions

The initial forces are those applied to the berm parallel to shore as they cause flexural tension at shore which could result in failure. The design of the as-built berm is summarized thus:

Allowable flexural stress (at shore)	500 kN/cm^2
Allowable shear stress (at shore)	500 kN/cm^2
Long-term ice load parallel to shore	38000 kN
Short-term ice load parallel to shore	136500 kN
Ice thickness at shore	2.13 m
Length of shear failure zone	152 m
Width of berm at seaward edge	150 m
Width of berm at shore	195 m
Factor of safety for shear - long-term	11.1
Factor of safety for shear - short-term	3.1
Factor of safety for flexure - long-term	3.8
Factor of safety for flexure - short-term	1.1

Berm Construction

Construction of the berm began in January, 1978, and ended in April, 1978. Initial ice thickness were about 2 m where the ice was not grounded. Small tracked vehicles with portable pumps were used in the initial stages and later electric submersible pumps were installed seaward of the berm. Fire nozzles were attached and water was shot onto the berm.

Initially, flooding only proceded on the east and west sides of the berm so pipe laying operations would not be interfered with. At no time were the flooding operation or flexural cracks at the edges a threat to the pipe laying operation.

Waste material from the pipe trench and ice blocks were flooded into the berm and reduced considerably the amount of flooding necessary. On April 8, flooding was completed, the berm was grounded and the placing of a 1 m cover of granular material began.

Monitoring of the Berm and Pipeline

Strings of thermistors were installed in the ice and soil of the berm and in the soil around the pipeline so that temperatures could be monitored and performance of the berm and the pipeline soil bulb freezing system monitored. Readings were taken 13 times between May 1, 1978 and March 10, 1979.

A Nikon F2AS camera was mounted on a tower near shore on the pipe centreline and kept a continuous photographic record of ice action and berm performance. The camera was in operation between June 27 and November 11, 1978, taking photos at intervals of 2 to 6 hours.

Performance of Berm

The berm successfully weathered its critical first year in operation. No thermal degradation of the ice in the bulk of the berm occurred and temperatures in the ice remained well below freezing, the active layer being confined to the granular cover. It is interesting to note that 2 m melted off the top of the ice drilling platforms over the wellhead. Deterioration was limited to 10 percent of the surface area. Principal areas where thawing and/or breaking away occurred were in the plow-hole area on the north edge and the north-east and east perimeter. Failure occurred in these areas since proper grounding of the berm could not be acheived. The plow-hole area had to remain open until the pipeline was in place and time did not submit grounding here. Along the perimeter, the natural ice sheet prohibited the edges of the berm from grounding and subsequent melting of the local ice freed these sections.

Drake Point Offshore Pipeline Ice Berm for Near Shore Scour Protection

The photo monitoring of the berm and local ice conditions showed that no large floes came in contact with the berm. The local ice sheet did not completely thaw and open water conditions occurred in the near shore region. A number of small floes drifted harmlessly parallel to the north edge of the berm.

The progressive deterioration of the north edge of the berm was also captured on the photographs. Second year local failures of the berm are expected to be minimal.

Wave erosion of the berm ice at the waterline was also noted. During the winter this largely froze back. This type of erosion may come to equilibrium with restoration of summer eroded material during the winter.

Performance of Pipeline Refrigeration System

The pipeline refrigeration system performed to specification while in operation producing a frost bulb extending approximately 2 m around the pipe. Shut down of the plant on October 3 allowed the frost bulb to warm to a semi-frozen state by March, 1979.

RECOMMENDATION

Based on experience gained and measurements taken during the last year, the following recommendations are made.

Temperature monitoring of the berm and pipeline should continue through a second year. Photographic monitoring should also be continued.

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CLIENT: PANARCTIC OILS LTD.
REPORT DATE: October 30, 1979

Drake Point Offshore Pipeline Ice Berm for Near Shore Scour Protection

The area of the berm comprising the plow-hole should be repaired. This hole could be filled with granular material, especially since the weak soil has been somewhat stabilized by the pipeline refrigeration system and would probably support the material. Any areas where the berm's granular cover has been eroded or scraped away should be repaired as this cover is the key to protecting the berm from thermal erosion. This was emphatically illustrated by the ice drilling platform which lost 2 m of ice off the top over the summer months.

In view of the high cost of running the refrigeration system (approximately $10,000.00/day) and in view of the limited effectiveness of the frozen bulb produced in resisting ice scour, it is recommended that system not be used at all and that scour protection be left to the berm. The refrigeration system could be useful during production of the well to prevent thawing of already frozen soils by warm gas and would be cheaper to operate at that time.

It is recommended that, in the future, where weak soils of considerable depth near shore are encountered, that scour of pipelines should be prevented by burying the pipe deep near shore so it is below the zone of possible scour. Newly developed tunneling and directional drilling methods make this feasible. If extra protection is needed, the feasibility of permanent ice structures anchored to shore has been demonstrated.

Sandwell

FENCO CONSULTANTS LTD.
CLIENT: PANARCTIC OILS LTD.
REPORT DATE: May 9, 1980

Drake Point Offshore Pipeline Ice Berm for Near Shore Scour Protection Monitoring Summer 1979

INTRODUCTION

In April of 1978, a marine flowline was completed which brought gas ashore from Panarctic's Drake F-76 well off the Sabine Peninsula of Melville Island in the High Arctic. (See location plan shown in Figure 1). A grounded ice berm was constructed to protect the flowline to the 5 m water depth contour from potential near shore scouring by ice masses in the area (Reference 1,2).

During the first summer season of operation, a refrigeration system was used to create a bulb of frozen soil around the pipeline to provide added protection from ice scour to a distance of 280 m offshore. Due to the associated high costs, the refrigeration system was not operated after the first season. Since then, the ice berm and the remnants of the frost bulb have been the means of protection for the flowline from ice scouring.

This report contains the results of second-year monitoring of the ice berm and the frost bulb around the pipeline.

SUMMARY

Analyses of the photographs show that deterioration of and loss of material from the berm during the second year in operation was limited to less than 5% of the total area. This loss was confined to the northern perimeter, mainly near the flowline. No significant deterioration occurred along the east and west perimeters. Two large pieces which had broken off the east and north edges the previous year have completely deteriorated. Two large stress cracks in the N.W. and N.E. sections of the berm, observed the previous year, have remained static.

The 1 m insulating gravel cover continues to maintain ice temperatures in the bulk of the berm below freezing. This gravel has eroded where 'spring' runoffs have created rivulets. Some sink holes were also in evidence, especially near the flowline and plowhole.

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REPORT DATE: May 9, 1980

Drake Point Offshore Pipeline Ice Berm for Near Shore Scour Protection Monitoring Summer 1979

Photo monitoring of the berm and offshore vicinity showed more ice cover than last year. No large ice floes came in contact with the berm nor were any large multi-year floes observed to enter the bay during the summer. As in the previous year, undercutting of the berm edge at the water line was in evidence, this undercutting being about 2 m, the same as the previous season. Thus the undercut remained nearly static since the first summer. Material from above this undercut may slough off, allowing more sloughing to take place.

Temperatures taken along the pipeline show that deterioration of the frost bulb around the pipeline continues since operation of the refrigeration system ceased. In general, less that 0.5 m of soil around the pipeline is -4°C or colder.

The thermistor strings through the berm show that it is cooling and the -2°C isotherm, taken as the limit of frozen soil, is descending through the berm and into the soil beneath. At the S.W. thermistor string 4.5 m of freezing occurred between November 10, 1978, and April 29, 1980. Water layers found at the time of installation of the thermistors have now been frozen. The berm is behaving as anticipated and is becoming part of the shoreline.

RECOMMENDATIONS

Based on the observations made and measurements taken at the flowline shore approach during the past year the following recommendations are made:

1. Efforts should be made to patch the major sink holes and to fill in the rivulets formed during runoff. Spare granular material for this purpose is stockpiled in the S.W. corner of the berm.

2. Efforts should be made to divert any major runoff of water from eroding the berm and creating sink holes and rivulets. Remedial work on the granular cover of the berm near original shoreline would probably take care of this.

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REPORT DATE: May 9, 1980

Drake Point Offshore Pipeline Ice Berm for Near Shore Scour Protection Monitoring Summer 1979

3. Little can be done at present to stop undercutting at the north end of the berm near the waterline. This undercut area should be watched carefully and measurements and photographs should be taken during any site visits.

4. Visits to the site should be made two or three times during the summer. Temperature readings on the thermistor strings and photos should be taken during these visits. Good aerial photographs are particularly useful.

5. The Nikon F2AS camera should be installed again this year to monitor any ice impingement on the berm. This unit has been made operable by battery without aid from the thermal generators and the blower has been eliminated. Power requirements are small and installation has been simplified.

6. Near the end of the summer a survey of the berm should be conducted. Linear measurements of the perimeter should be obtained and levels should be taken on the reference pins installed on the berm.

FENCO CONSULTANTS LTD.
CLIENT: PANARCTIC OILS LTD.
REPORT DATE: October 7, 1980

Offshore Drilling Ice Platform Whitefish H-63A

INTRODUCTION

The site for Whitefish H-63A was the same as the previous season's Whitefish H-63 site. Whitefish H-63's relief pad 1 was used as H-63A's main pad 1 and H-63's main pad 4 was used as H-63A's relief pad 4.

The thick multi-year ice in the area was sufficient to support Rig 1 with only minor flooding being required to level the platform.

SITE	START FLOODING	COMPLETE FLOODING	INITIAL THICKNESS	FINAL THICKNESS	START RIG-UP	SPUD DATE	RELEASE DATE
Whitefish H-63A	Oct. 31/79	Nov. 8	6.93 m	7.24 m	Nov. 10	Dec. 3	May 15/80

CONCLUSIONS AND RECOMMENDATIONS

The Rig 1 187 day loading duration at Whitefish H-63A represents the longest rig load duration achieved on an ice platform. The typical load duration for an ice platform deep hole (3000+ m) is in the order of 90 - 100 days but due to the long testing program at Whitefish considerably more time was required. In future cases the only time that 190 day duration load cases should occur would be in extremely thick multi-year ice cases where the ice platform construction period would be in the order of 3 - 4 weeks. In such long duration load cases the predicted deflection would have to be altered slightly to reflect the extra load duration. The difference however, is not considerable.

The Rig 1 loading at Whitefish H-63A was identical to the Hazen F-54 loading with a long term load of 1304 tonne.

The average ultimate borehole compressive strength for the 24 tests done at Whitefish H-63A on Nov. 9, 1979 was 18.12 MPa. This value is slightly lower than the value recorded at Whitefish H-63 (21.6 MPa) under similar ice conditions.

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REPORT DATE: October 7, 1980

Offshore Drilling Ice Platform Whitefish H-63A

The tide recorder at Whitefish H-63A worked very well as it appears very little anchor settlement occurred and the datum was not lost during the tide record. Previous experience, however, has shown the anchor settlement can be quite a problem for offshore tide gauges and for this reason we recommend either using an umbrella or penetration type of anchor. The umbrella anchor basically is an anchor which spreads below the ice surface to present a high surface area to weight ratio while the penetration anchor uses a pounding mechanism to penetrate the anchor into harder bottom mud.

The melting of a 7.0 m x 6.7 m x 7.0 m cavity in the ice platform near the disposal line at Whitefish H-63A was an undesirable occurence. Care should be taken in the future to ensure that the two sections of the 12 m discharge pipe do not separate and leave a 6 m pipe which disposes waste at the ice-water interface as occurred at Whitefish H-63A.

Overall with the exception of the large melted cavity the construction and operation of the ice platform at Whitefish H-63A was uneventful. Although this fact limits the discussion of the platform, it does ensure a safe operation for all the people involved.

FENCO CONSULTANTS LTD.
CLIENT: PANARCTIC OILS LTD.
REPORT DATE: November 11, 1980

Offshore Drilling Ice Platforms Char G-07 and Balaena D-58

Overview:

The construction and performance of the ice platforms at Char G-07 and Balaena D-58 have given further important performance data relevant to the ice platform projects.

The operation of Rig 2 at Balaena D-58, although on a small scale when compared to the other heavier rigs in the Arctic, should not be overlooked. The performance data from this rig on various ice platform thicknesses has allowed us to determine the relationship between ice thickness and long-term deflection. This data has been most important in the design of the ice platforms for the heavier rigs.

The building of the Rig 4 ice platform at Char G-07 introduced a new method of ice platform construction to the Arctic. In order to test the feasibility of decreasing the required ice thickness by increasing the buoyancy of the platform through the use of foam, 271 m^3 of urethane foam was frozen into the neutral axis area of the Char G-07 ice platform.

The 271 m^3 of urethane foam results in a reduction of ice platform weight of 241.2 tonne. Thus the long-term rig load for Rig 4 of 678.6 tonne could be reduced to a resultant long term load of 437.4 tonne for the ice platform design.

This 241.2 tonne long-term load reduction was noted to decrease the required ice platform thickness, based on long-term deflections, by 0.9 m for both the first-year and multi-year ice platforms. At a typical daily buildup rate of 76 mm/day this represents a saving of 12 days. It should be emphasized, however, that this saved time was not a factor in the use of urethane foam at Char G-07. The reasons for its use were to test the theories and construction methods relevant to ice platform design.

Laboratory test on the urethane foam showed an average compressive strength of 110.7 kPa which was above the 100 kPa specified in the design. Also water penetration tests showed an average water absorption of 1.8% for 8 samples removed from the in-place blocks on March 15, 1980. This was well below the 5% assumed in the design.

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REPORT DATE: November 11, 1980

Offshore Drilling Ice Platforms Char G-07 and Balaena D-58

The long-term deflection performance of the Char G-07 platform is the most important performance parameter. At the start of deflection measurements, the average freeboard taken at the 10 design-thickness stations was 13.7%. A solid ice platform has a usual freeboard of 11%. Thus there was 2.7% or .14 m of excess freeboard due to the buoyancy of urethane foam cells. The first .14 m of settlement due to rig load brought the ice platform to the 11% freeboard line which is the level from which we normally measure our deflections. Since a total deflection of 0.390 m was observed from start of rig-up, the settlement below the 11% freeboard level was .25 m. This amount of settlement was exactly as predicted and this fact has added confidence in the methods used to predict the results.

FENCO CONSULTANTS LTD.
CLIENT: PANARCTIC OILS LTD.
REPORT DATE: June 30, 1981

Drake Point Offshore Pipeline Ice Berm for Near Shore Scour Protection Monitoring Summer 1980

INTRODUCTION

In April 1978, a marine flowline was completed which brought gas ashore from Panarctic's Drake F-76 well off the Sabine Peninsula of Melville Island in the High Arctic. (See location plan shown in Figure 1). A grounded ice berm was constructed to protect the flowline to the 5 m water depth contour from potential near shore scouring by ice masses in the area (Reference 1 and 2).

During the first summer season of operation, a refrigeration system was used to create a bulb of frozen soil around the pipeline to provide added protection from ice scour to a distance of 280 m offshore. Due to the associated high costs, the refrigeration system was not operated after the first season. Since October 3, 1978, the ice berm and the remnants of the frost bulb have been the means of protection for the flowline from ice scouring.

This report contains the results of third-year monitoring of the ice berm and the frost bulb around the pipeline.

Sandwell

FENCO CONSULTANTS LTD. CLIENT: PANARCTIC OILS LTD. REPORT DATE: June 30, 1981
Drake Point Offshore Pipeline Ice Berm for Near Shore Scour Protection Monitoring Summer 1980

SUMMARY

Analysis of the aerial and closeup photos show that pieces which broke off in 1979 had completely deteriorated by the end of the 1980 summer season. No large pieces broke away during the 1980 season. Two large stress cracks in the N.W. and N.E. sections of the berm observed for two years, have remained static. Deterioration of the berm edge was constant in all areas and limited to one to two metres. This would be due to wave and tidal action and the resultant undercutting. Undercutting on the north side of the berm was less than in 1979. Deterioration of the berm has slowed since 1978. The rivulet west of the flowline area deepened and was probably the cause for the beach which appeared in that area. Repair work was carried out on the front of the berm which involved filling in the rivulet and sinkholes caused by spring runoffs.

Photo monitoring of the berm and offshore vicinity showed less ice cover than last year with frequent movement of ice floes across the front of the berm. Ice which came in contact with berm was no more than 1 m in thickness. In three years of monitoring this was the first year that the large ice pack further offshore drifted out of the bay.

Temperatures taken along the pipeline show that deterioration of the frost bulb around the pipeline continues at a slow rate since operation of the refrigeration system ceased.

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CLIENT: PANARCTIC OILS LTD.
REPORT DATE: June 30, 1981

Drake Point Offshore Pipeline Ice Berm for Near Shore Scour Protection Monitoring Summer 1980

The thermistor strings through the berm show that it is cooling and -2°C isotherm, taken as the limit of frozen soil, is descending deeper into the soil beneath.

At the S.W. thermistor string 1.5 m of freezing occurred between August 19, 1979 and August 27, 1980.

Settlement of the west side of the berm was approximately 25 cm in the period May 1978 to August 1980. On the east side it is negligible.

The berm continues to behave as anticipated and is becoming part of the shoreline and, thus, its deterioration rate is slowing.

RECOMMENDATIONS

Based on the observations made and measurements taken at the flowline shore approach during the past year, the following recommendations are made:

1. Following last summer's example of remedial work on the berm cover (1980), efforts should be made to patch the major sinkholes and to fill in the rivulets formed during runoff.

2. Efforts should be made to divert any major runoff of water from eroding the berm and creating sinkholes and rivulets. Remedial work on the granular cover of the berm near original shoreline would probably take care of this.

3. Little can be done at present to stop undercutting at the north end of the berm near the waterline. This undercut area should be watched carefully and measurements and photographs should be taken during any site visits.

FENCO CONSULTANTS LTD.
CLIENT: PANARCTIC OILS LTD.
REPORT DATE: June 30, 1981

Drake Point Offshore Pipeline Ice Berm for Near Shore Scour Protection Monitoring Summer 1980

4. Visits to the site should be made two or three times during the summer. Temperature readings on the thermistor strings and photos should be taken during these visits. More attention should be spent on attaining a good set of aerial photographs.

5. The Nikon F2AS camera should be installed again this year to monitor any ice impingement on the berm. This unit has been made operable by battery without aid from the thermal generators and the blower has been eliminated. Power requirements are small and installation has been simplified.

6. Near the end of the summer a survey of the berm should be conducted. Linear measurements of the perimeter should be obtained and levels should be taken on the reference pins installed on the berm.

FENCO CONSULTANTS LTD.
CLIENT: PANARCTIC OILS LTD.
REPORT DATE: October 1, 1981

Offshore Drilling Ice Platform Cisco B-66

Overview:

The Cisco B-66 wellsite was an area of extremely thick hummocked multi-year ice (up to 12 m) with pressure ridge in the region. The presence of the extremely thick and rough multi-year ice enhanced the performance of the platform while at the same time creating unforeseen difficulties in the construction of the platform and especially the airstrip.

The Rig B loading period was approximately 100 days. This is a normal load duration for ice platforms. The loading at Cisco B-66 was 1304 tonnes, similar to two previous Rig B platforms – Hazen F-54 and Whitefish H-63A.

The average confined compressive strength for 13 tests done on January 24, 1981 was 21.7 MPa.

Ice temperatures during the drilling season showed a very safe stable range through the ice platform. Circulation of water in the moonpool served to keep the area frozen. The moonpool refrigeration system using Synflex hose was not as effective as was hoped. A temperature change of only -0.5°C was noted after start-up of the system.

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CLIENT: PANARCTIC OILS LTD.
REPORT DATE: October 5, 1981

Offshore Drilling Ice Platform Skate B-80

Overview:

The relatively thick multi-year ice that was present, coupled with the fact that no pressure ridges were encountered, made for an early start of rig-up date. The significant dates of operation at Skate B-80 are

SITE	START FLOODING	COMPLETE FLOODING	INITIAL THICKNESS	FINAL THICKNESS	START OF RIG-UP	SPUD DATE	RELEASE DATE
Skate B-80	Dec. 1, 1980	Dec. 23, 1980	3.90 m	5.43 m	Dec. 28, 1980	Jan. 20, 1981	Apr. 4 1981

The design criteria which dictate the dimensions of an ice platform are that:

a) long-term settlement be limited to available freeboard;

b) any combination of stresses within the ice platform, due to short-term and long-term loads be limited to 500 kPa.

In order to ensure that the above two conditions are met, the average thickness of the ice platform over the design area must be greater than a stipulated design thickness. Over recent years Panarctic have viewed the design thickness as a minimum ice thickness while requiring, where possible, that the ice platform be built to an optimum thickness which is 10% greater than the design thickness.

The Skate B-80 wellsite was an area of relatively thick multi-year ice which resulted in an early start of rig-up date of December 28, 1980.

The average confined compressive strength for 10 tests done on January 17, 1981, was 23.6 MPa. This value is slightly higher than the value recorded at Whitefish H-63 (21.6 MPa).

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CLIENT: PANARCTIC OILS LTD.
REPORT DATE: October 5, 1981

Offshore Drilling Ice Platform Skate B-80

Ice temperatures in the platform remained within expected limits throughout the drilling season even without the refrigeration system in operation. However, in an extended drilling season this system would have played an important role in keeping ice temperatures cold.

Tides recorded were of good quality. The new penetration-type anchor has reduced sea bottom settlement. Problems were encountered with the use of this anchor but tide datum was not lost due to the presence of a second anchor system. In future, a two-anchor system is recommended in conjunction with the umbrella-bearing anchor that was used at MacLean I-72.

The measured maximum deflection was 317 mm which left an available freeboard of 350 mm after 90 days of rig loading.

The melting of a 9 m X 9 m X 5.5 m cavity at the rig disposal line was an unfortunate incident. Care should be taken in future to monitor the temperature of fluids being disposed down this line.

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CLIENT: PANARCTIC OILS LTD.
REPORT DATE: October 15, 1981

Offshore Drilling Ice Platform MacLean I-72

INTRODUCTION

The construction and drilling program at MacLean I-72 proved to be a credit to the personnel in all phases of the project. In particular, the construction of the ice platform proceeded at a rate which saw the final flooding date earlier than has occurred before for such a heavy-rig platform.

Start Flooding	Complete Flooding	Initial Thickness (m)	Final Thickness (m)	Start of Rig-Up	Spud Date	Release Date
Nov. 30 1980	Jan. 1 1981	2.79	6.24	Jan. 2 1981	Jan. 27 1981	Apr. 27 1981

Overview:

The construction of the Rig A ice platform at MacLean I-72 proceeded more rapidly than ever before with the final flooding date of January 1, 1981. The relatively high 105 mm/day built-up rate and the use of 553.3 m^3 of urethane foam were the reasons for completing the flooding in such a short period.

Between November 27 to December 1, 1980, Engineered Urethanes Ltd. of Edmonton manufactured 48 urethane foam blocks for use in the ice platform. The use of this foam material reduced the weight of the ice platform by 500 tonnes without reducing its structural stiffness. This in effect allowed this platform to carry an additional rig load of 500 tonnes over the drilling period.

During the construction of the 48 foam blocks 13 foam samples were tested to determine the actual density of the blocks. The results indicated an average density of 37.0 kg/m^3 ; higher than the design density of 26.0 kg/m^3.

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CLIENT: PANARCTIC OILS LTD.
REPORT DATE: October 15, 1981

Offshore Drilling Ice Platform MacLean I-72

A carefully planned flooding schedule at MacLean helped to achieve the high rate of ice buildup. When winds were below 4.9 m/sec. (10 knots), nozzles were frequently used to achieve a high rate of heat transfer. When winds were between 4.9 - 9.8 m/sec. (10 - 20 knots) flooding was carried out in the usual manner. When winds were between 9.8 - 14.7 m/sec. (20 - 30 knots) upwind flooding was used to take the snow out of the air. And finally when winds were greater than 14.7 m/sec. (30 knots) all flooding was stopped.

Temperature monitoring of the ice during flooding, with the use of thermistor banks, showed the highest average ice temperature recorded was -6.6°C. This was well below the maximum allowable high of -5.0°C.

On January 4, 1981, two days after the completion of flooding at MacLean I-72, an average confined borehole ice strength of 13.7 MPa was recorded of built-up ice. This value was higher than the 11.3 MPa strength recorded at Hazen F-54 for tests in built-up ice upon completion of flooding.

On January 1, 1981, the average ice thickness over the design area was measured at 6.24 m and the average freeboard was 0.850 m or 13.6% of the average ice thickness.

Since the ice was sufficiently thick to accommodate all types of aircraft, only levelling of the airstrip was necessary. Because of the limitations of the machinery, however, the construction period was quite long. The 727 jet strip was completed on January 13, 1981.

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CLIENT: PANARCTIC OILS LTD.
REPORT DATE: October 15, 1981

Offshore Drilling Ice Platform MacLean I-72

The use of synflex hose, in the refrigeration system around the outside of the moonpool cribbing, was not successful. It is recommended that copper coils be reconsidered in future refrigeration system. In addition, the Tioga which heats the subsea area should be regulated for heat. The relatively high (-4°C) temperatures which were observed in the platform below the subsea area were warmer than in previous years.

Vertical ice platform deflections were measured daily with an automatic level and a continuous-plot freeboard recorder which gave maximum deflection of 458 mm and 435 mm respectively below the 13.6% freeboard level. The survey deflection of 458 mm was judged as the more accurate and a deflection of 298 mm below the 11% freeboard level was calculated.

This agrees rather well with the predicted long-term deflection of 390 mm below the 11% freeboard level for Rig A on a 6.24 m ice platform.

A study of the strain data from MacLean I-72 and other platform sites revealed that a strict relationship exists between platform strain rate, ice thickness and platform deflection rate.

In an effort to determine the hydrostatic position of the MacLean I-72 ice platform with the 553.3 m^3 of urethane foam, a float recorder was installed on the platform while the rig was removed. Data from this recorder illustrated that after an ice platform supports a rig load for a winter season it becomes severely deformed and does not readily rebound to its preload level.

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GEOTECHnical RESOURCES LTD.
CLIENT: PANARCTIC OILS LTD. ET AL
REPORT DATE: September 1982

Ice Platform Construction Manual Cape Allison C-47, Rig A

Overview:

This internal manual outlines procedures for the construction of the ice platforms at the Cape Allison C-47 location. The well will be drilled to about 2100 metres by Rig A.

King Christian Island will be used as a staging base for the ice camp and equipment. Logistics are outlined in Items 1-17.

The ice platforms should be construction to the following ice thicknesses:

Description	First Year Ice	Multi-Year Ice
Minimum Thickness Rig A	6.2m (20.3 ft)	6.0 m (19.7 ft)
Optimum Thickness Rig A	6.8 m (22.3 ft)	6.6 m (21.6 ft)
Minimum Thickness Rig 4	5.1 m (16.7 ft)	4.9 m (16.1 ft)
Optimum Thickness Rig 4	5.6 m (18.4 ft)	5.4 m (17.7 ft)

Flooding procedures, Main Pad Pump Installation, Relief Pad Pump Installation and Reporting procedures are identified in the manual.

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GEOTECHnical RESOURCES LTD.
CLIENT: PANARCTIC OILS LTD. ET AL
REPORT DATE: September 1982

Ice Platform Construction Manual N. Buckingham B-69, Rig A

Overview:

This internal manual outlines procedures for the construction of the ice platforms at the Buckingham B-69 location. The well will be drilled to about 2500 metres by Rig A.

Graham Island will be used as a staging base for the ice camp and equipment. Logistics are outlined in Items 1-17.

The ice platforms should be construction to the following ice thicknesses:

Description	First Year Ice	Multi-Year Ice
Rig A with foam*	5.6 m (18.4 ft)	5.6 m (18.4 ft)
Minimum Thickness Rig A	6.6 m (21.6 ft)	6.4 m (21.0 ft)
Optimum Thickness Rig A	7.3 m (24.0 ft)	7.1 m (23.3 ft)
Minimum Thickness Rig 4	5.1 m (16.7 ft)	4.9 m (16.1 ft)
Optimum Thickness Rig 4	5.6 m (18.4 ft)	5.4 m (17.7 ft)

***To be used only if original ice thickness is less than 3 m.**

Flooding procedures, Experimental Flooding Procedures, Pump Installation, and Reporting procedures are identified in the manual.

Sandwell

GEOTECHnical RESOURCES LTD.
CLIENT: PANARCTIC OILS LTD. ET AL
REPORT DATE: September 1982

Ice Platform Construction Manual N. Buckingham L-71, Rig A

Overview:

This internal manual outlines procedures for the construction of the ice platforms at the North Buckingham J-71 location. The well will be drilled to about 2800 metres by Rig A.

Graham Island will be used as a staging base for the ice camp and equipment. Logistics are outlined in Items 1-17.

The ice platforms should be construction to the following ice thicknesses:

Free Flooding	First Year Ice	Multi-Year Ice
Minimum Thickness Rigs A & C	6.2 m (20.3 ft)	6.0 m (19.7 ft)
Optimum Thickness Rigs A & C	6.8 m (22.3 ft)	6.6 m (21.6 ft)
High Pressure Spray		
Minimum Thickness Rigs A & C	6.5 m (21.3 ft)	Use free-flooding
Optimum Thickness Rigs A & C	6.9 m (22.6 ft)	Method

Flooding procedures, Main Pad Pump Installation, Relief Pad Pump Installation and Reporting procedures are identified in the manual.

GEOTECHnical RESOURCES LTD.
CLIENT: PANARCTIC OILS LTD. ET AL
REPORT DATE: September 1982

Ice Platform Construction Manual N. E Drake L-06, Rig B

Overview:

This internal manual outlines procedures for the construction of the ice platforms at the N.E. Drake L-06 location. The well will be drilled to about 1300 metres by Rig A.

Drake F-76 will be used as a staging base for the ice camp and equipment. Logistics are outlined in Items 1-17.

The ice platforms should be construction to the following ice thicknesses:

Description	First Year Ice	Multi-Year Ice
Minimum thickness Rig B	6.2 m (20.3 ft)	5.9 m (19.4 ft)
Optimum Thickness Rig B	6.8 m (22.3 ft)	6.5 m (21.3 ft)
Minimum Thickness Rig 4	5.1 m (16.7 ft)	4.9 m (16.1 ft)
Optimum Thickness Rig 4	5.6 m (18.4 ft)	5.4 m (17.7 ft)

Flooding procedures, Main Pad Pump Installation, Relief Pad Pump Installation and Reporting procedures are identified in the manual.

FENCO CONSULTANTS LTD. / LAVALIN
CLIENT: PANARCTIC OILS LTD.
REPORT DATE: September 15, 1982

Offshore Drilling Ice Platform Cisco C-42

Overview:

The initial average rig 4 design ice thickness of 5.69 m required only a minimal amount of flooding. Most of this work was concentrated in the tapered zone of the platform.

A mobile flooding unit and a backhoe were employed to excavate the main and relief platform moonpools. This procedure substantially reduced the number of man-hours that would ordinarily be required to complete the moonpools and released personnel for other duties.

The late rig-up date of February 10 allowed the moderately thick, multi-year ice at the wellsite time to reach a colder, stronger state. On January 29, two weeks after flooding was completed, borehole jack tests were conducted. The ultimate confined compressive strengths averaged 29.4 MPa. These high strength values are indicative of very strong, good quality ice found in multi-year ice floes which are left unoccupied and allowed to cool to a low temperature.

The actual long-term deflection of -228 mm was 26% greater than the predicted deflection from previous load cases. The large difference is due to the close proximity of a first-year lead to the wellsite. The weight of the rig on the edge of the multi-year floe resulted in a higher actual deflection.

The two anchor tidal recording system operated acceptably and continuously throughout the drilling period. The freefall anchor stabilized on the ocean floor on January 16. Thereafter, the two anchor systems displayed identical tidal fluctuations.

Ice platform thermistor readings, throughout the entire drilling period, indicate a very stable, safe ice temperature condition. At the date of rig release ice temperatures averaged -8.1°C at the centre of the platform.

The extension of the vertical section of the rig disposal pipe to 18 m below the ice surface effectively eliminated the previous problem of ice decay. A thermistor bank was installed near the rig disposal line to monitor ice conditions. No evidence of ice decay was found.

Sandwell

FENCO CONSULTANTS LTD.
CLIENT: PANARCTIC OILS LTD.
REPORT DATE: September 16, 1982

Offshore Drilling Ice Platform Cape Mamen F-24

Overview:

The Cape Mamen F-24 well marked the first time that Panarctic Rig C has operated from an offshore ice drilling platform. The design of the Panarctic Rig C platform was identical to the platform for Panarctic Rig A due to duplication of rig weights and layout. Over the design area the required average ice thickness for Rig C is 6.6 m and 6.4 m on a first-year and multi-year ice platform respectively.

The initial profiled average thickness of 4.59 m meant that the Rig C platform could be classed as a multi-year ice platform and a final average thickness of at least 6.4 m would be required. The profiled final average ice thickness over the design area of the Rig C pad at Cape Mamen F-24 was sufficient at 6.60 m.

The November 30, 1981, start of flooding date on the main pad at this site is typical for an ice platform in this area. In previous years the Maclean I-72, Char G-07, and Hazen F-54 had start-of-flooding dates of November 30, November 14 and November 19 respectively.

The total dead weight and variable long-term loads for Rig C while operating from an ice platform are 1000.9 tonnes and 628.8 tonnes for a total 90 day load of 1630 tonnes. This design rig load is for a water depth of 420 m, however, the 363 m water depth at Cape Mamen F-24 caused only a slight reduction in the above load therefore the 1630 tonnes will be used to represent the long-term load.

The construction period in various aspects was affected by the unusually warm weather conditions up to December 15, 1981 (rarely did air temperature fall below -30°C). The average buildup rate of 80 mm/day over the flooding period could have been increased given consistently colder weather.

Temperature monitoring during the drilling period revealed that the ice platform was experiencing unusually warm temperatures and measures were taken to reduce the heat input from the rig. Therefore, we can conclude that the temperature monitoring program served as a useful tool in ensuring that the ice platform was operated in a safe manner.

FENCO CONSULTANTS LTD.
CLIENT: PANARCTIC OILS LTD.
REPORT DATE: September 16, 1982

Offshore Drilling Ice Platform Cape Mamen F-24

Strain monitoring in the ice platform around the perimeter of the moonpool proved to be of limited success. Due to warm ice temperatures below the subsea shop, the gauges in this area were not properly anchored and strain results are therefore not valid. Strain rosettes 9 m from the moonpool and in the area of the pipe rack and mud tanks, however, were functional and accurate data was collected at these locations.

A maximum long-term deflection of .447 m was measured at Y1 by level survey at Cape Mamen F-24. This value is 10% lower than the value of .500 m predicted by the use of the ice thickness, long-term load versus long-term deflection equation.

FENCO CONSULTANTS LTD. / LAVALIN
CLIENT: PANARCTIC OILS LTD.
REPORT DATE: September 16, 1982

Offshore Drilling Ice Platform Sculpin K-08

Overview:

The Sculpin K-08 well was the second offshore well drilled with Rig A; the first was completed over the 1980-81 winter season at the MacLean I-72 site.

Sculpin K-08 was the thickest multi-year ice platform encountered to date for an offshore well. The platform construction period was essentially an extensive ripping and grading operation with minimal flooding required for levelling purposes.

START FLOODING	COMPLETE FLOODING	INITIAL THICKNESS	FINAL THICKNESS	START OF RIG-UP	SPUD DATE	RELEASE DATE
Dec. 3 1981	Jan. 2 1982	10.10 m	10.35 m	Jan. 3 1982	Jan. 27 1982	May 3 1982

Introduction:

The extremely thick ice encountered at Sculpin K-08 enhanced the performance of the platform. The final average thickness within the design area was 47% greater than the optimum requirement of 7.1 m on multi-year ice. While the deflection power relationship does not accurately predict the actual deflection at Sculpin K-08, the available freeboard recorded at the time of maximum deflection was 1.003 m indicating a very safe platform.

Borehole jack tests at Sculpin K-08 yielded excellent ice strength results. The average confined compressive strength for 41 tests on April 7, 1982 was 25.7 MPa and the average value of the elastic modulus was 2908 MPa.

The average ice temperatures recorded through the main platform remained well below the accepted safe value of -5°C. On April 26, 1982 an average temperature of -7.5°C was recorded on thermistor bank ACG which is indicative of the platform as a whole (directly under the rig). Ice temperatures close to the moonpool were somewhat higher averaging approximately -2°C. This was due in part to the inoperative condition of the moonpool refrigeration system as well as to the fact the ice in this vicinity is in close proximity to the seawater. An underwater T.V. inspection showed no deterioration of the ice around and below the bottom of the moonpool crib.

The construction period was essentially a ripping operation by D3 and D4 dozers with minimal flooding required for levelling. Ice which was ripped from the high areas of the platform was placed in 0.3 - 0.5 thick lifts over the low areas. This method which accelerates the freezing process, allowed for longer individual floods and effectively shortened the flooding program.

The problem of continual power outages with the simultaneous running of two or more of the four electric submersible pumps significantly increased the total flooding time, however, there was no delay in the start of rigup. This problem nevertheless should be rectified for future platform construction where substantial delays could occur in a long flooding program. The use of a backhoe at Sculpin to excavate for the moonpool crib was a tremendous improvement over the previous method of using chainsaws and manual labour. Whereas in the past this operation took up to five days to complete, it was done at Sculpin in one day. A backhoe should be standard equipment for future platform construction particularly on thick multiyear ice.

The excavation for the moonpool crib should be limited to a depth of no more than 5 m in thick multi-year ice. This would reduce the possibility of water seeping into the excavation which usually occurs at a depth below 5 m.

The practice of building the crib inside the moonpool excavation should be adopted whenever possible since it eliminates the possibility of damaging the crib while also guaranteeing a square and level structure.

The tide data recorded at Sculpin K-08 was of excellent quality. The use of the umbrella type anchor appears to have solved the problem of anchor settlement and erroneous tide data associated with other type anchors in previous years.

There were no spills reported within the fuel storage area but the advantages of the Level Area Bladder Farm were still evident. A grader was used regularly to keep the area clear of snow thus increasing the validity of the daily inspection. The problem of the fuel containers being spaced too close together was remedied quickly without incident but care should be taken in the future to space the containers a minimum of 6 m apart.

FENCO CONSULTANTS LTD. / LAVALIN
CLIENT: PANARCTIC OILS LTD.
REPORT DATE: September 17, 1982

Offshore Drilling Ice Platform Whitefish A-26

Overview:

The main platform was located on thick, multi-year ice. Flooding commenced on November 24 and was completed on December 19 for a final average ice thickness of 7.07 m and an average buildup of 0.46 m, representing an average daily buildup of 18 mm per day.

Flooding of the airstrip began on November 16, 1981 and was completed to 1830 m on December 30, 1981. Twenty-six borehole jack tests were completed on December 16, 1981, for an average ultimate confined compressive ice strength of 13.9 MPa.

Borehole jack tests were completed on December 19, 1981, the day of the final flood on the main pad. Thirty tests were completed at three different sites for an average confined compressive strength of 26.2 MPa. This value is slightly higher than the previous results found at Cisco B-66 and Whitefish H-63A and indicated the very high strength qualities of the multi-year ice at Whitefish A-26.

SITE	START FLOODING	COMPLETE FLOODING	INITIAL THICKNESS	FINAL THICKNESS	START OF RIG-UP	SPUD DATE	RELEASE DATE
White-fish A-26	Nov. 24 1981	Dec. 19 1981	6.61 m	7.07 m	Dec. 25 1981	Jan. 15 1982	Apr. 30 1982

The predicted 90 day long-term deflection, based on the 1340 metric tonne design load, was 0.365 m while the actual maximum level survey deflection was 0.326 m. The difference between the predicted and actual deflection was 10.7%. This result provides further confidence in the use of the equation for predicted long-term deflections.

The two anchor tide recording system operated effectively throughout the entire construction and drilling programs. The highest tide was recorded on March 9, 1982 (1609 mm) and the lowest tide was recorded on December 13, 1981 (449 mm) for a total range of 1160 mm.

FENCO CONSULTANTS LTD. / LAVALIN
CLIENT: PANARCTIC OILS LTD.
REPORT DATE: September 17, 1982

Offshore Drilling Ice Platform Whitefish A-26

Ice platform thermistor measurements of the Whitefish A-26 main platform indicate very stable safe ice temperatures during the entire drilling program. Thermistor beads near the bottom of the ice platform at the end of the drilling program reached a temperature of -1.5°C. With the operation of the lower refrigeration coils, ice temperatures would have remained at a colder state.

The installation into the ice of a double length of vertical disposal pipe and the careful monitoring of rig discharge temperatures resulted in a minimal amount of ice erosion at the rig disposal line.

Throughout the field operating season, FENCO on-site personnel monitored the level area fuel storage system daily. No major spills occurred at Whitefish A-26. The ease with which the undyked bladder farm system was monitored and cleared of snow indicates the effectiveness of this design.

FENCO CONSULTANTS LTD.
CLIENT: PANARCTIC OILS LTD.
REPORT DATE: October 19, 1983

Offshore Drilling Ice Platform Cisco K-58

Overview:

This report covers the construction and performance of the offshore ice platform Cisco K-58.

The operation of Panarctic Rig B at Cisco K-58 marked the sixth time this rig has operated from an offshore platform. Close monitoring of the ice quality relative to temperatures and strength at Cisco K-58 proved to be quite useful as a zone of low strength ice below the generator area of the rig required attention in order to ensure that a problem did not develop.

The October 24 commencement of flooding operations at Cisco K-58 marked the earliest start to date for an offshore ice platform. The presence of thick multi-year ice contributed to a relatively short construction period lasting approximately 3-1/2 weeks. Flooding for the airstrip was carried out in an area of first-year ice. No difficulties were encountered in this phase of the operation.

START FLOODING	COMPLETE FLOODING	INITIAL THICKNESS	FINAL THICKNESS	START OF RIG-UP	SPUD DATE	RELEASE DATE
Oct. 24 1982	Nov. 18 1982	4.98 m	6.64 m	Nov. 20 1982	Dec. 6 1982	Mar. 28 1983

After flooding was complete, borehole jack testing on November 18 and 20 revealed an average built-up ice confined compressive strength of 10.8 MPa for seven tests. In the multi-year ice near the moonpool an average confined compressive strength of 23.6 MPa for 21 tests was noted. However, at Station GC an average confined compressive strength of 9.8 MPa for six tests was recorded in the multi-year ice. The low ice strengths at Station GC illustrated the fact that this area was a zone of low relief where water must have ponded before freeze-up. Snow cover after the start of freeze-up evidently kept this area of water-saturated ice from freezing properly and subsequent flooding over the area ensured the existence of warm ice temperatures.

FENCO CONSULTANTS LTD.
CLIENT: PANARCTIC OILS LTD.
REPORT DATE: October 19, 1983

Offshore Drilling Ice Platform Cisco K-58

A detailed study of platform ice strengths at the end of the winter season was carried out to determine the extent of the ice erosion under the rig matting. In total, 199 individual borehole tests were completed over the platform rig area for an average strength of 14.7 MPa for all tests. Again the average borehole strength at Station GC of 10.8 MPa proved to be the zone of lowest strength on the pad area. During this testing process distinction between multi-year and built-up ice was not made. Visual records of the top surface of the ice platform showed that a considerable amount of heat from the rig complex was migrating down into the ice surface and it was concluded that two layers of purlboard should be placed under the rig matting for future ice platforms.

Also presented within this report is a study on the relationship between lab tested ice unconfined compressive strength and field tested borehole compressive strengths. Briefly, it was found that for the granular built-up ice, the ratio of confined to unconfined strength was 2.9 which compared well to the expected value of 3.0. However, for the natural columnar grained ice the ratio of confined to unconfined strength was not as expected due to the fact that the borehole testing and uniaxial testing were done in perpendicular ice crystal direction.

In summary, the construction and monitoring of the ice platform at Cisco K-58 has given important new experience to the people involved with the ice platform programs. The early start of rig-up on November 20, 1982, and the slightly low ice strengths have illustrated the extent to which ice platforms can be used over a winter season.

FENCO CONSULTANTS LTD.
CLIENT: PANARCTIC OILS LTD.
REPORT DATE: February 3, 1984 (Final)

Offshore Ice Platform Grenadier A-26

Overview:

The Grenadier A-26 platform was of special interest since this was the first time Panarctic Rig C had operated from first-year ice conditions. The initial and final ice thicknesses were 1.3 m and 6.87 m on November 14, 1982, and January 13, 1983, respectively. The overall average buildup rate was calculated at 87.5 mm/day giving consideration for a shift in the pad axis after the start of flooding.

The Hercules airstrip was flooded from November 10, 1982, to January 5, 1983. On December 11, 1982, a lead opened up through the strip requiring the strip to be extended. This in turn lengthened the flooding period. The ice quality proved to be excellent, as the borehole jack tests conducted on January 1, 1983, showed an average ultimate borehole compressive strength of 16.7 MPa, 39% above the minimum allowable airstrip strength of 12.0 MPa.

The ice quality on the main platform was quite good. The four holes tested in January, after completion of flooding, showed an

average ultimate borehole compressive strength of 14.0 MPa for 35 individual tests. A similar series of tests later in the season, during April, showed that the average strength had increased to 19.5 MPa.

Ice temperatures at Grenadier remained low and steady throughout the drilling period. The moonpool cooling system of 50 mm diameter steel pipe joined by synflex hose proved successful in operation. Also, at the insulated rig disposal line, there was virtually no rise in temperature or ice decay.

The strain gauge program generated accurate strain results from one rosette. The data from this rosette showed a virtual zero magnitude strain in approximately the radial direction from the moonpool and a 1000 microstrain maximum in the tangential direction.

FENCO CONSULTANTS LTD.
CLIENT: PANARCTIC OILS LTD.
REPORT DATE: February 3, 1984 (Final)

Offshore Ice Platform Grenadier A-26

At this site an innovative attempt was made to measure the stresses generated within the upper compression zone of the ice platform through use of MEDOF brand stress panels placed 6 m from the moonpool. The development of equipment and theories relative to this type of stress field measurement, was judged to be of importance since, in order to achieve a better Arctic engineering design basis, more understanding should be gained on the ice material which dominates the environment. The measured radial stress was low at no more than 100 kPa. It appeared that the presence of the moonpool and warm rig area allowed rapid stress relaxation in this direction. The tangential stress values were broken into two categories - those which occurred before spud date and after spud date. The 180 kPa measured tangential stress before spud date was judged to be accurate. The 750 kPa value recorded after spud date was judged to be a local stress generated around the panel due to a mismatch of panel and ice elastic modulus. The 180 kPa value was well within the 500 kPa limit for platform design limitations. For future ice platform work panels of effective modulus 1270 MPa were recommended.

The platform deflection was recorded at .502 m which is 9% lower than the predicted value of .550 m.

The bladder farm monitoring program allowed for the early detection of a bladder leak and a successful cleanup. On February 14, 1983, the raised snow pad underneath the bladders made a small leak visible. The loader removed the contaminated snow to where it was melted and the fuel burned off.

tti GEOTECHnical resources ltd.
CLIENT: PANARCTIC OILS LTD.
REPORT DATE: June 13, 1984

Panarctic Proposal for 1984-85 Ice Platforms

Discussion document – A study of new methods to accelerate freezing of sea water in nozzle sprays.

This report summarizes the results of a field assessment of the factors which influence the freezing dynamics of a sea water spray.

The spraying of sea water is a common method employed in cold regions such as the Canadian Arctic to construct ice structures which are a necessary part of an offshore oil and gas drilling system. The structures are used to support the drilling equipment and in some instances to prevent disruption of the drilling equipment by mobile sea ice.

Included is a brief summary of the Buckingham B-69 ice platform construction and performance. High pressure pumps were used at this site to enhance freezing. This was accomplished by providing a higher pressure at the nozzle, resulting in smaller water drops travelling a greater distance with resultant beneficial heat loss to the atmosphere (ref.1). A full account will be given in the project report to Panarctic.

Laboratory tests were carried out in Calgary and analysis was conducted in Salt Lake City and in Calgary. The objective was to identify methods that could be applied in the field to accelerate the rate of ice production from a sea water spray. The tests compliment and allow even further optimization of the techniques tried during the B-69 platform construction.

The various elements which comprised these studies included a laboratory evaluation of water soluble chemical agents having the ability to significantly alter the freezing mechanism of sea water. Laboratory results, suggested that the injection of certain chemicals would accelerate the rate at which droplets freeze by virtue of improved heat exchange with the air. The freezing point of a salt solution is depressed relative to deionized water owing to the effect of the dissolved salts. It was hypothesized that use of an effective ice nucleation agent might overcome the freezing point depression effect of dissolved salts in sea water resulting in a solution with a high freezing point relative to the untreated water.

A field evaluation of spray nozzle parameters, chemical injection and compressed air injection on the freezing rate of a sea water spray was carried out at the PANARCTIC OILS LTD., Buckingham ice platform, located at 77 08' 02.8" N latitude, 91 25' 29.2" W longitude, from April 18, 1984 to April 26, 1984. This effort demonstrated the efficacy of chemical injection on accelerating freezing rates of a sea water spray. Typical spray procedures for the spraying of sea water were developed. The new procedures include the use of mobile spraying skids and improved nozzles. Preliminary air injection studies indicated the need for modified equipment. Droplet breakup by air injection will require the use of air dryers to eliminate freezing problems at the air injector ports.

The field experiments were conducted at a time when the ambient air temperature was relatively warm. The rather significant effects of chemical treatment of sea water at these temperatures is extremely encouraging. Field procedures for treatment of sea water with chemicals are straight forward and can be implemented without serious difficulties.

Sandwell

FMS ENGINEERS / LAVALIN
CLIENT: PANARCTIC OILS LTD.
REPORT DATE: September, 1984 (Final)

Offshore Drilling Ice Platform Cisco M-22

Overview:

The Cisco M-22 well was the third offshore well drilled with Rig C. The previous two wells were Cape Mamen F-24 and Grenadier A-26. The wellsite for the main pad was located in relatively thick multi-year ice. This provided for a comparatively short construction period of approximately 5-1/2 weeks.

Construction/Drilling Schedule:

Start Flooding:	**Nov. 27, 1983**
Complete Flooding:	**Jan. 03, 1984**
Initial Thickness:	**5.47 m**
Final Thickness:	**7.02 m**
Start of Rig-up:	**Jan. 04, 1984**
Spud Date:	**Jan. 22, 1984**
Release Date:	**Apr. 12, 1984**

This report presents field data collected, studies platform performance and gives recommendations.

Sandwell

FENCO CONSULTANTS LTD. / LAVALIN
CLIENT: PANARCTIC OILS LTD.
REPORT DATE: SEPTEMBER, 1984

Offshore Drilling Ice Platform Skate C-59

Overview:

The Skate C-59 well is the seventh offshore well drilled with Rig B. The presence of thick multi-year ice allowed for a relaxed construction program of low priority. The initial thickness exceeded the 6.3 m minimum design thickness by 0.25 m. Thus, the aims of the construction program were merely to thicken the thin areas and level the pad.

SITE	START FLOODING	COMPLETE FLOODING	INITIAL THICKNESS	FINAL THICKNESS	START OF RIG-UP	SPUD DATE	RELEASE DATE
Skate C-59	Dec.5	Dec.22	6.55 m	7.32 m	Dec.30	Jan.15	Apr.12

<u>Platform Design</u>

The design criteria are:

1. That stresses from the total of short and long-term loads be limited to 500 kPa.

2. That long-term deflections be limited to the available freeboard.

<u>Platform Loading</u>

The 90 day long-term load was 1340 tonnes, consisting of 928 tonnes dead weight and 412 tonnes variable load. Short-term dynamic loads, if applied simultaneously, would total 487 tonnes. The maximum possible total load is 1827 tonnes.

CONCLUSIONS AND RECOMMENDATIONS

The 920 loader flooded the main pad with one half the effectiveness of the conventional pump system, and at the cost of more man-hours.

The strengths and temperatures of the main ice platform were excellent because of the thick multi-year ice conditions, the double layer of purlboard insulation and an effective moonpool cooling system.

The quality of the airstrip ice was excellent.

The diesel fuel spill of December 14, 1983, indicates that extra care must be taken to ensure that all valves are completely closed.

GEOTECHnical resources ltd.
CLIENT: PANARCTIC OILS LTD.
REPORT DATE: November 20, 1984

Offshore Drilling Ice Platform Buckingham O-68

1.0 **INTRODUCTION**

1.1 MAIN PROJECT EVENTS

GEOTECH was retained to design, construct and monitor the ice platform constructed to support Panarctic's Rig A during the 1983/84 drilling program in the high Arctic. The construction, data acquisition and platform performance evaluation for this program forms the basis for this report.

The dates of the main events for the construction program are presented in Table 1.1.1 while Table 1.1.2 features the highlights of the drilling phase of the operation.

TABLE 1.1.1 HIGHLIGHTS - CONSTRUCTION PHASE

	Flooding Started	Flooding Completed	Initial Thickness mm	Final Thickness mm	Build up Rate mm/day
PAD A	**Dec 4/83**	**Jan 29/84**	**980**	**6900**	**104**
PAD 4	**Dec 8/83**	**Feb 15/84**	**1030**	**5460**	**85**
Otter Strip	Nov 25/83	Nov 26/83	900 to 1350	–	–
Herc Strip	Dec 1/83	Dec 26/84	1000	1530	21

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REPORT DATE: November 20, 1984

Offshore Drilling Ice Platform Buckingham O-68

TABLE 1.1.2 HIGHLIGHTS - DRILLING PHASE

	Start Rig-up	Rig up Completed	Spud	Rig Release
0-68	Jan 30/84	Feb 16/84	Feb 17/84	May 4/84

The Otter strip was operational on November 26, 1983

The Herc strip was approved for Hercules landings December 26, 1983 and was approved for Boeing 727's on January 13, 1984.

1.2 SITE LOCATION

Panarctic et al Buckingham 0-68, site of Rig A 1983/84 drilling operations, was located offshore Buckingham Island which lies to the South West of Graham Island (refer to Figure 1.2.1). The site coordinates are 77° 08' 00.190" north latitude and 91° 23' 55.263" west longitude. Appendix A includes a detailed site plan, showing location of the main and relief platforms, rig and construction camps, along with the Herc strip.

GEOTECH personnel arrived on site November 27, 1984 where they remained until May 13, 1984.

tti GEOTECHnical resources ltd.
CLIENT: PANARCTIC OILS LTD.
REPORT DATE: December 28, 1984

Creep and Relaxation Behaviour of Ice Platforms

Overview:

A study to optimize platform thickness. Based on review of historical platform performance, existing design thickness specifications for Panarctic's conventionally flooded ice platforms are conservative. Platform thickness, loading, ninety-day deflection and initial freeboard is presented for various platforms used in support of Panarctic's drilling operations from 1979 to 1983. The ratio of ninety-day deflection to initial freeboard is plotted against the ratio of platform thickness provided to the existing minimum required thickness. The data was subjected to a regression analysis.

Based on existing minimum thickness requirements and a review of this data, it indicated that the available freeboard at the end of drilling operations, for all these platforms, was in excess of 40% of the initial freeboard. Coupled with the fact that all platforms were in primary creep, this showed that existing design thickness specifications would be improved.

The statistical evidence supports a case for the reduction of ice thickness below minimum requirements presently used. However the extrapolation of the regression curve below $h/h_{min} < 1$ would have no basis in present design.

In order to establish and quantify the deflection and stress behaviour of conventionally flooded ice platforms, in the range $h/h_{min} < 1$, on an engineered basis, required finding a suitable viscoelastic platform model. The model had to be of sufficient complexity to describe the actual behaviour of ice plat forms while not depending on sophisticated and costly computer techniques for their solution.

A viscoelastic floating beam model, which with appropriate modifications, was found to be representative of the long and short term behaviour of ice platforms. The model had the added advantage of being suitable for programming on a desktop calculator.

This report describes the theoretical development of this model as applied to floating ice beams. The modifications and a development of a design procedure for ice platforms, based on the floating beam model, is also described. The design procedure is then applied to the optimum thickness design of Panarctic's Platforms A, B and C.

Recommendations, based on this design, for future platform thickness specifications are also presented for conventionally flooded platforms.

Sandwell

GEOTECHnical resources ltd.
CLIENT: PANARCTIC OILS LTD.
REPORT DATE: December, 1985

Thermal Analysis Sprayed Ice Platform

Overview:

During drilling of the Cape Allison C-47 well the rig derrick was found to be out of plumb and had to be relevelled several times. After rig out, a depression of the ice surface under the rig matts was noticed. This area was carefully surveyed and contours plotted.

The total ice lateral deflection between the moonpool and mud tanks was 90% of the available freeboard. This was the point of largest deflection and was unacceptably high. It was determined that considerable heat had been supplied to this area of the ice platform by rig matt washing and heater ducts.

The problem experienced can largely be avoided by implementing operating procedures outlined in the report. As well, GEOTECH will carry out extra monitoring during drilling of both temperatures and local deflections.

The principal solution recommended by GEOTECH to deal with the local deflection problem consists of identifying the concentrated heat sources, then making simple modifications to these heat sources and to rig operations to minimize the heat transfer from the rig floor to the ice pad. Specifically this would be the following:

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REPORT DATE: December, 1985

Thermal Analysis Sprayed Ice Platform

1) Insulation of the end of the duct from no. 1 Tioga heater as well as insulating the sub structure beam area.
2) Modify the baffles of the end of no. 1 Tioga heater duct such that hot air is not blown directly onto the rig floor.
3) Raise the flexible heat duct and provide an insulated pad at the end of this duct such that air is not blown directly onto the rig floor.
4) Minimize washing of the rig matts. Any water used to clean matts should be collected using portable pumps - which is a normal procedure on most rigs. It is vital to minimize the amount of water on the rig matts since much of this eventually reaches the ice surface.
5) Pump excess water out of the spaces between the rig matts. Water should not be allowed to stay on the rig floor or between the matts. This can be accomplished using an air powered pump.
6) Eliminate, or minimize at least, leaks in steam and water lines.
7) Keep external steam lines off the surface of the ice to minimize any heat transfer to the ice platform.
8) Minimize subsea hydraulic fluid spillage.

During the drilling of the well GEOTECH proposes to carry out certain procedures as well.

GEOTECHnical resources ltd.
CLIENT: PANARCTIC OILS LTD.
REPORT DATE: December, 1985

Thermal Analysis Sprayed Ice Platform

a) GEOTECH has installed extra thermistors in the ice and will be monitoring these thermistors on a daily basis so that if a problem such as last year is detected, a warning can be given and remedial measures can be implemented.

b) GEOTECH will perform a survey of the sub structure beams and other major load components inside the rig buildings. This level survey will be tied in to the main ice platform survey. Thus local deflections will be monitored with the temperature measurements. They will aid in the identification of any problems occuring locally beneath the rig.

c) GEOTECH will inform the Panarctic foremen of the local deflection progress so that remedial measures can be taken, if required. This information will be reported in a daily report to Panarctic in Calgary.

GEOTECHnical resources ltd.
CLIENT: PANARCTIC OILS LTD.
REPORT DATE: December 17, 1985

Global and Local Deflections Cape Allison C-47

Overview:

Concerns regarding the deflection, thermal behaviour and strength of the ice in the Cape Allison C-47 platform are addressed herein. Ice platform A at Cape Allison C-47 was built up using spray ice techniques. High pressure 50 hp pumps were used to build 6 metres of ice on top of an initial first year ice layer 1 metre thick.

During the drilling of the well at Cape Allison last year excessive tilt of the rig derrick was experienced with the result that levelling had to be carried out during drilling. It nearly became necessary to jack the whole sub-structure of the rig in order to restore the derrick to a plumb condition. In addition, after the rig was removed and the mats taken up, there was a deep depression in the ice beneath the mats. These problems have been analyzed in considerable depth during the summer and fall and conclusions drawn along with recommendations for future operations.

Vertical global deflection of the ice platform was measured in the traditional way and total deflection during the drilling of the well was found to be acceptable. The curve of deflection vs time is presented in Figure 1. The final deflection at Station K-1 left adequate freeboard for the rig. The total global deflection was 584mm whereas the initial available freeboard was 910mm. The behaviour globally of this platform was similar to the flooded ice platform at East Drake and to other flooded ice platforms.

GEOTECHnical resources ltd.
CLIENT: PANARCTIC OILS LTD.
REPORT DATE: December 17, 1985

Global and Local Deflections Cape Allison C-47

During the drilling of the well at Allison it was found that the derrick was out of plumb and that corrections had to be made to compensate for this. At the end of drilling when the mats were removed a deep depression in the ice was observed underneath the mats. This depression was surveyed in detail by GEOTECH and the results are shown in Figure 2. The depresssion was largest between the substructure of the rig and the mud tanks, and was about 300mm where the two heaviest loads are. The depression was visible to the eye and the surface of the ice platform was visibly contoured.

The global deflection of 584mm plus the local deflection resulted in a total deflection of 826mm. This is abnormal and is generally not observed on ice platforms of any type whether they are sprayed or flooded. With 826mm of deflection there was only 10% of the original freeboard remaining. The ice platform was very close to a situation where water could well up on the top surface of the ice.

In addition to the problem of losing freeboard it is possible that the ice was in some stage of failure. In structures where such large local deformations occur one is justified in suspecting that a punching failure is developing.

PROCEDURES TO CORRECT THE PROBLEM

The principal solution recommended by GEOTECH to deal with the local deflection problem consists of identifying the concentrated heat sources. Then make simple modifications to these heat sources and to rig operations to minimize the heat transfer from the rig floor to the ice pad. Specifically this would be the following:

GEOTECHnical resources ltd.
CLIENT: PANARCTIC OILS LTD.
REPORT DATE: December 17, 1985

Global and Local Deflections Cape Allison C-47

1) Insulation of the end of the duct from no. 1 Tioga heater as well as insulating the sub structure beam end area.
2) Modify the baffles of the end of no. 1 Tioga heater duct such that hot air is not blown directly onto the rig floor.
3) Raise the flexible heat duct and provide an insulated pad at the end of this duct such that air is not blown directly onto the rig floor.
4) Minimize washing of the rig mats. Any water used to clean mats should be collected using portable pumps - which is a normal procedure on most rigs. It is vital to minimize the amount of water on the rig mats since much of this eventually reaches the ice surface.
5) Pump excess water out of the spaces between the rig mats. Water should not be allowed to stay on the rig floor or between the mats. This can be accomplished using an air powered pump.
6) Eliminate, or minimize at least, leaks in steam and water lines.
7) Keep external steam lines off the surface of the ice to minimize any heat transfer to the ice platform.
8) Minimize subsea hydraulic fluid spillage.

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GEOTECHnical resources ltd.
CLIENT: PANARCTIC OILS LTD.
REPORT DATE: March 1986

Offshore Drilling Ice Platform Project Report Cape Allison C-47

Overview:

Table of Contents:-

HIGHLIGHTS - CONSTRUCTION PHASE

Events Location	Flooding Started	Flooding Completed	Initial Thickness (mm)	Final Thickness (mm)	Build Up Rate (mm/day)
Pad A	Dec 03/84	Jan 16/85	844	6973	136.3
Pad 4	Dec 11/84	Jan 31/85	854	5130	82.2
Otter Strip	Nov 25/84	Nov 25/84	Leveled		
Herc Strip	Dec 03/84	Dec 20/84	1346	1786	24.4

HIGHLIGHTS - DRILLING PHASE

Start Rig-Up	Rig-Up Completed	Spud	Rig Release
Jan 18	Jan 30	Jan 31	May 08

The Otter Strip was operational on November 25, 1984. The Herc Strip was approved for Hercules landing December 22, 1984 and was approved for Boeing 737's on January 3, 1985.

Sprayed ice at Cape Allison C-47 had accumulated at a rate of 136 mm/day, an improvement of 11.5% over the 122 mm/day rate achieved at the Buckingham 0-68 site during the spray flooding portion of the construction.

The build-up rate improvement is attributable to the superior mechanical performance of the swivel and improved spray flooding techniques. The effectiveness of AFA-6 was not conclusive and it is suggested that it be used in higher concentrations on future platforms.

The main ice platform thickness was 6973 mm which lies within the minimum to maximum range of 6400 mm to 7100 mm respectively. The ratio of ninety day deflection to the initial available freeboard was 55%, essentially the same as Buckingham 0-68 at 56%. The ratio of the initial freeboard to the final platform thickness was 13.1% whereas Buckingham 0-68 was 14.0%. This indicates the accumulated ice was slightly less porous at Cape Allison. The density of the sprayed ice retrieved from cores is 882 Kg/m^3 which is essentially the same as the 890 Kg/m^3 typical of freeflooded ice.

The ice quality tests performed by the borehole jack indicate a mean confined compressive strength of 9.07 MPa, more than adequate for the loads incurred.

The ease of acquiring data generated by the field measurements would be made less arduous a task and facilitate the data reduction procedure in the office if a computerized data acquisition system were implemented at the ice platform construction site.

The continuation of a field and laboratory monitoring/testing program is necessary. The results of such testing will aid in the evaluation and improvement of spray flooding techniques, additives and platform design.

GEOTECHnical RESOURCES LTD.
CLIENT: PANARCTIC OILS LTD.
REPORT DATE: April 1986

N. Buckingham L-71 Offshore Drilling Ice Platform

SITE LOCATION

N. Buckingham L-71, site of Rig C 1985/86 drilling operations, was located at coordinates 77°, 10', 41.669" N and 91°, 29', 27.650" W, approximately 5 km west of Buckingham Island. It is approximately 5 km northwest of the previous Buckingham 0-68 offshore well.

HIGHLIGHTS - CONSTRUCTION PHASE

Location	Flooding Started	Flooding Completed	Initial Thickness	Final Thickness	Build Up Rate
Pad C	Dec 2/85	Jan 16/86	2846	6362	76.4
Pad A (relief)	Dec 7/85	Feb 5/86	2663	6612	64.7
OTTER STRIP	Nov 26/85	Dec 3/85	multi-year	multi-year	N/A
HERC STRIP	Nov 26/85	Dec 24/85	multi-year	>1.68 m	N/A

HIGHLIGHTS - DRILLING PHASE

Start Rig Up	Spud Date	Rig Release
Jan 17/86	Jan 28/86	April 5/86

The Otter Strip was operational on December 3, 1985. The Herc Strip was approved for Hercules and Boeing 737 aircraft on December 28, 1985 and January 3, 1986 respectively.

RECOMMENDATIONS

A review of the data and information contained within this report, has lead to the following recommendations:

1) Relocation of the ice platform should be considered if the designated position places the moonpool in a low area of the platform.

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GEOTECHnical RESOURCES LTD.
CLIENT: PANARCTIC OILS LTD.
REPORT DATE: April 1986

N. Buckingham L-71 Offshore Drilling Ice Platform

2) The wind and temperature regime of a site should be considered as part of the decision to use either the spraying or flooding method for ice platform construction. The final decision should also be delayed until a complete profile of the platform thickness has been completed. This will ensure that the average platform thickness is either above or below the threshold thickness determined for this decision.

3) Steaming and washing of rig structures and matts should be minimized. Water produced from such activities should be immediately pumped away.

4) All rig disposal lines should be installed in such a manner so as to avoid the erosion that occurred at the corelab disposal line this season.

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GEOTECHnical resources ltd.
CLIENT: PANARCTIC OILS LTD.
REPORT DATE: April, 1986

W. Cornwall N-49 Offshore Drilling Ice Platform

Overview:

Table of Contents:

Location	Flooding Started	Flooding Completed	Initial Thickness (mm)	Final Thickness (mm)	Build up Rate (mm/day)
Pad A	Dec 6/85	Jan 25/86	894	7090	121.5
Pad C	Dec 9/85	Mar 4/86	859	6451	65.0
OTTER STRIP	N/A	N/A	890	890	N/A
HERC STRIP	Dec 1/85	Dec 23/85	890	1800	39.6

TABLE 1.1.2
HIGHLIGHTS - DRILLING PHASE

Start Rig Up	Spud Date	Rig Release
Jan 27/86	Feb 12/86	April 4/86

The Otter Strip was immediately operational. The Herc Strip was approved for Hercules on December 28, 1985 and Boeing 737 aircraft on January 3, 1986.

West Cornwall N-49, site of Rig A 1985/86 drilling operations, was located at coordinates 77°, 28', 53.020" N and 97°, 17', 32.296" W, approximately 25 km west of Cornwall Island (see Figure 1.2.1).

RECOMMENDATIONS AND CONCLUSIONS

A review of the material and data contained within this report has led to the following recommendations and conclusions:

1) Berming methods and flood timing can be modified to reduce the time required to complete the final stages of the construction program.

2) Spraying efficiency is not significantly affected by ambient conditions, although the actual build up is affected by temperature and windspeed.

3) Active management of build up material on the platform by utilizing a vehicle dedicated to platform construction will improve build ups.

4) AFA-6 at a concentration of 40 mg/L is beneficial in promoting the freezing of sprayed material. It is recommended for use during warm periods (> -30°C) since excess snow is produced at temperatures below this level. If snow is produced it can be spread over the platform using the means discussed in item 3 above and saturated with water to provide a dense ice.

5) The AFA-6 injection system using a methanol mixture worked well and is recommended for future platforms.

6) Calorimetry testing should be performed on future platforms, using the touchdown pattern method discussed in this report. This will allow further evaluation of the effectiveness of spraying methods and additives, and provide a means for validating the assumptions used to analyze the West Cornwall calorimetry data.

7) The global deflection performance of the West Cornwall platform was well within design limits.

8) Local deflection has been identified as a problem. The following recommendations should alleviate this problem:

a) production of high quality (density) ice in the moonpool area.
b) Good thermal management of rig operations i.e. minimal steaming, removal of waste water, reduction of heat input to the rig floor.
c) Construction of a pre-grade of the platform surface prior to rig up, in order to counteract the local deflection.
d) The platform surface should definitly be surveyed and graded if required prior to rig up.
e) Investigate the possibility of improving derrick levelling methods to adjust for local deflection.

9) Flatjacks cannot be used as pressure panels given the present methods of monitoring flatjack response. A data acquisition system would be required to provide sufficient sampling frequency and accuracy to record the small pressure changes.

However, further analysis of the available data and the development of a model may allow the flatjacks to be used as an in situ creep sensor.

10) Platform surface erosion and deflection can be reduced by limiting steaming activity in the rig, removing waste water from between the matts, immediate repair of steam, water and oil leaks, and eliminating or reducing any other potential heat sources to the ice surface.

11) Thermistor installation and locations should be reviewed. Possibilities include the use of more horizontal banks and fewer vertical banks, improved protection for thermistors installed during construction, and installation during construction to allow proper freezeback.

12) Salinity and density profiling and testing should be continued, as this provides an excellent monitor of ice quality during and after construction.

13) Ice coring and visual logging should also be continued for the reasons given in 12.

14) The compressive strengths determined by the borehole jack for sprayed ice are more than adequate for the loads applied to the platform.

15) Elastic moduli of sprayed ice should not be taken as absolute values but rather as index values, due to the nature of sprayed ice.

16) Flatjacks provide an in situ monitor of ice strengths and elastic moduli (as index values) beneath the rig. Flatjacks should be used in the future for this purpose.

17) The compression/ablation monitoring strips have provided valuable data in regards to the behaviour of the top 1.0 metres of ice. Unfortunately, this is a one time only measurement device. The use of instruments used to monitor soil compression may be suitable for providing a continuous measurement of the platform behaviour throughout the platform profile.

18) Sprayed ice is seen to be of lower quality than flooded ice, but sprayed ice quality is still more than sufficient to meet design and performance criteria.

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GEOTECHnical resources ltd.
CLIENT: PANARCTIC OILS LTD.
REPORT DATE: May 1986

Analysis and Design of Floating Spray Ice Platforms

Overview:

Platform A at Cape Allison C-47 was constructed using spray ice techniques. High pressure 37.3 kW (50 hp) pumps were used to build 6 metres of spray ice on top of an initial first year ice layer 1 metre thick.

Vertical global deflection of the ice platform was measured in the traditional way during the drilling of the well and was found to be acceptable. The global deflection measured at station K-1 was 526 mm whereas the initial available freeboard was 953 mm. The global behaviour of this platform was generally similar to the flooded ice platform at East Drake and to other flooded ice platforms.

However, during the drilling of the well at Cape Allison excessive tilt of the rig derrick was experienced with the result that levelling had to be carried out during drilling. It nearly became necessary to jack the whole substructure of the rig in order to restore the derrick to a plumb condition. After the rig was removed and the matts taken up, a deep local depression in the ice beneath the matts was observed. The depression was greatest, about 280 mm, between the substructure of the rig and the mud tanks.

The global deflection of 526 mm at station K1 plus the local deflection of about 280 mm (between the lowest point and station K1) resulted in a total deflection of 806 mm. This is abnormal and is generally not observed on ice platforms. With 806 mm of deflection, only 15% of the original freeboard remained.

To investigate the cause of this local deflection a thermal analysis was commissioned (GEOTECH, 1985). It was determined that considerable heat had been supplied to this area by rig matt washing, heater ducts and other sources. The analysis concluded that the problem of local deflection can largely be avoided by implementing operating procedures to reduce heat transfer from the rig to the ice platform. Specific recommendations were presented in the thermal analysis report (GEOTECH, 1985).

RECOMMENDATIONS

SPRAY ICE PLATFORM THICKNESS

Given the present level of development of the limit states design of spray ice platforms, no change in the design thickness of 6.8 m can be justified at this time. Further work on a comprehensive deflection model will lead to a rational basis for optimizing the thickness of spray ice platforms. The following section highlights the areas of refinement needed in the overall limit states design method for spray ice platforms, and particularly the aspects related to deflection behaviour.

FURTHER DEVELOPMENT OF LIMIT STATES DESIGN FOR FLOATING SPRAY ICE PLATFORMS

1) The data base on physical and mechanical properties of spray ice must be expanded. This will improve the confidence in design values of material resistances and parameters (S, σ_i, E) necessary for design optimization. Also, using these data the material resistance factor ($\emptyset$) must be refined according to the limit states design guidelines (see Section 5.2.3).

2) Materials testing must also continue on spray ice to improve our understanding and data base on the time-dependent properties of spray ice. Creep coefficients under shear and normal stresses must be determined along with their sensitivity to stress level and temperature.

3) The formulation of a rational, constitutive model for spray ice behaviour and overall ice platform behaviour is needed. This is especially true for flexural stress and deflection (local and long-term). Some advances in this area have been made recently through ongoing, in-house work. The yieldline method of analysis for a three dimensional, hinged plate model is summarized in Appendix C. Ultimately a finite element or finite difference program based on such a model may be the most effective tool for design optimization.

4) In light of the sensitivity of spray ice behaviour to variations in its density and porosity, construction methods and control must be assessed and refined to keep the variability of spray ice within quantifiable bounds. Ice quality criteria (density, porosity, temperature) should also be assessed and adjusted if necessary.

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SANDWELL INC.
CLIENT: PANARCTIC OILS LTD.
REPORT DATE: November 29, 1994

Drake F-76 Abandonment Floating Ice Platform Design

Overview:

To support the equipment spread provided by Panarctic, an ice thickness of 2.7 m was required to ensure that initial elastic stresses did not exceed the allowable and that creep deflections remained less than the initially available freeboard. Data from past Panarctic ice platforms was also used and also from thinner platforms used in Northern Alberta.

A schedule for construction of the platform was presented as well as a program for monitoring quality and progress during construction and performance during the abandonment operation

FLOATING ICE - OTHER

Sandwell

FENCO CONSULTANTS LTD.
CLIENT: SUN OIL COMPANY LIMITED
REPORT DATE: May 16, 1975

Ice Platform Construction Resolute Bay NWT November – December 1974

Overview:

The test program called for ice platforms to be built by freezing thin layers of ice about 100' offshore in the bay area at Resolute. Four of the platforms were 400 ft. by 300 ft. and required 40 inches of ice buildup. The remaining platform was 400 ft. square with 15 inches of built-up ice. Before work teams arrived, a few days were spent surveying the pads and arranging equipment. The drawing in Appendix I shows the dimensions of the pad and the location of depth stakes, thermistor banks and pump holes.

A number of Flygt pumps of 500 gpm capacity were available with lengths of 4 inch ID hose. However, only two pumps were used at a time. Enough hose was attached to the pumps to reach the whole flood area from four holes spaced out over the pads. Power plants and shelters were placed around the flooding area to provide power and light.

Stakes with tape measures were placed in the pads to measure built-up ice thickness. About twenty stakes were placed on each pad at places where depth measure would be important.

Three thermistor probes were prepared and placed on the pads. Each probe had thermistors spaced out from below the natural ice to the top of the built-up ice.

When further personnel arrived, flooding was begun and was continued mostly on a twenty-four hour basis until the required ice had been made. Different methods of flooding were used with varying degrees of success. However, periods of warm weather during flooding made progress slow.

Besides reading thermistors and thicknesses regularly during flooding, FENCO personnel took cores for salinity, density and visual inspection and performed strength tests in the ice. Also, weather information was gathered for comparison with growth rates. Data obtained is included in various forms in the appendices.

Introduction:

Ice Buildup

An average buildup rate of 1.4 inches per day was achieved for this project. The pumps performed satisfactorily when they were kept submerged. Metal fittings tended to freeze up and it was necessary to bring the hoses into a heated shelter when they were not in use. Warm temperatures and the logistics of flooding a large area were the main factors contributing to the late completion date. Our experience is that an average of 3 inches per day buildup is possible at temperatures below -30°F. Near the end of the flooding program, the centre pad thicknesses were at or above the required thickness whereas localized areas, particularly around the sides, required some 10 inches of buildup.

On the 3rd of November 1974 the natural ice thickness was approximately 20 inches with the variance increasing from pad X to D. The mean thickness achieved on December 6, 1974 is as follows:

Pad A: 60 inches
Pad B: 61 inches
Pad C: 60 inches
Pad D: 63 inches
Pad X: 34 inches

It is anticipated that there was little or no natural ice growth underneath the flooded areas during the period of Nov. 3 to Nov. 30/74. A natural ice growth of 10 inches per month is predicted for December and January.

An attempt was made to correlate the buildup rates to a theoretical development. During the initial floods, warm temperatures and the insulating effect of snow prevented any freezing of the underlying layer. In the latter stages of the flooding program when the temperatures were conducive to freezing, the pad centres were complete. The total buildup rates were low although there was considerable growth around the extremities. It is our experience that winds beyond 10 mph have a mitigating effect such as blowing snow. In any one day, the buildup varied between stake locations. Therefore the lack of correlation is understandable because controlled experiment results from a construction engineering project of this magnitude are difficult to obtain.

Ice Temperatures

During the course of flooding, the temperature near the surface was kept below -10°C to prevent excessive heating. The temperature graphs show the gradient stabilizing to a linear gradient from an average ambient air temperature at the surface to a -1.7°C at the ice-water interface. Nevertheless, the top foot will be sensitive to ambient air temperature fluctuations.

Ice Salinity

The salinity measurements of the built-up ice gave an average of 20°/oo and were highly variable, from a low of 10°/oo to 33°/oo. The average salinity of the built-up sea ice near the surface is approximately 23°/oo. We would expect this salinity to be equal to that of pump water samples (27°/oo) but apparently the high salinity brine is lost during the course of taking a core. Significant brine drainage did not occur during flooding.

Ice Density

The computer average density of sea ice was 0.92 gm/cm^3 with a standard deviation of 0.054.

Ice Strength

Values for confined and unconfined compressive strengths were obtained by circular and triangular plate tests respectively. The results give a confined compressive strength of 2,047 psi for natural ice and 1,911 psi for built-up ice. Unconfined strengths are 724 psi for natural and 927 psi for built-up ice.

In addition, values for the modulus of elasticity were computed to give 2.1×10^5 psi and 1.35×10^5 psi for natural and built-up ice respectively.

FENCO CONSULTANTS LTD.
CLIENT: SOHIO PETROLEUM COMPANY/ BP-ALASKA PRODUCTION DIV.
REPORT DATE: July 12, 1979

Reindeer Island Floating Ice Road Preliminary Report Vol. 1

A 14-mile ice road was constructed at Prudhoe Bay for Sohio-BP Alaska Product Division of Sohio Petroleum Company.

A 7-mile section of the ice road floating on sea water connected the shore and Reindeer Island over a water depth of as much as 30 feet. Two miles offshore, a branch road led to an artificial gravel island. This island was constructed through the use of the ice road to haul gravel. Within a 3-week period, 105,000 cyd of gravel was hauled over the road using 75-ton heavy gravel trucks. This meant trucks passed any given point on the ice road at the rate of one every 3 minutes.

The main construction of the ice road itself was accomplished within 4 weeks. Ice was built up from 2 feet natural ice thickness to 6 feet artificial ice thickness over a width of 100 feet with an additional 50-foot taper width to natural thickness.

During and after construction of the road, a wide range of ice testing and quality control was performed, several methods of flooding were investigated. Studies and analyses were made on flooding methods, pump types and economical aspects.

Based on experience gained from previous FENCO projects and the above project, various road tests were performed, essentially resulting in more frequent and rapid travel over the floating ice road than has been considered possible.

Two drilling rigs were moved over the road with weights up to 350 tons during transport. One rig was set up on Reindeer Island and the other rig on the artificial gravel island. No accidents or failures on the floating ice road have occurred. The ice road was maintained in good condition so that the rigs received continuous truck service during the entire drilling period.

FENCO CONSULTANTS LTD., represented by Dan Masterson and Raimund Haspel, was responsible for the design and road performance. Laying out the ice road, monitoring and consulting during its construction was given by Lewellen Arctic Research and FENCO CONSULTANTS. After the completion, Clyde Bastian and Raimund Haspel, both from FENCO CONSULTANTS LTD., took turns being on site continuously for road inspection, ice quality control, supervision of maintenance work and general consulting in road use.

Data of construction, road testing and of some costs were collected and evaluated in the FENCO office in Calgary, Alberta. This report represents the first preliminary investigation of all operations and observations on the Reindeer Island Ice Road.

FENCO CONSULTANTS LTD.
CLIENT: SOHIO PETROLEUM COMPANY/BP-ALASKA PRODUCTION DIV.
REPORT DATE: September, 1979

Reindeer Island Floating Ice Road Vol. 3 Field Data Summary

Overview:

Completed report contains all raw information from the field.

1. **Ice Thicknesses from Stakes**
2. **Ice Thicknesses from Profiles**
3. **Ice Thicknesses from Borehole Jack Tests**
4. **Borehole Jack Tests**
5. **Prudhoe Bay Weather Data**
6. **Reindeer Island Weather Data**
7. **Ice Temperatures**
8. **Tides**

FENCO CONSULTANTS LTD.
CLIENT: GULF CANADA RESOURCES INC.
REPORT DATE: 1981

Pack Ice/ Rubble Field Interaction Study – Issungnak 1980

Overview:

This report describes the results of a program to study the interaction between moving pack ice and ice rubble, which had surrounded Issungnak Island during the winter 1979-80. Issungnak Island is an artifical gravel island built to serve as a drilling pad for hydro-carbons in the Beaufort Sea north of Pullen Island in the Mackenzie Delta.

Esso and Gulf conducted this study program in co-operation with ice specialists from government and the consulting sector. Among these was FENCO CONSULTANTS, which was in charge of some of the field observations, ice testing, conducting various types of photography and writing this report.

The report discusses environmental conditions and how the rubble around Issungnak had formed. Furthermore the field study program is explained together with the applied techniques and the results from these. A model of an ice sheet failure in flexure was developed and the safety of Issungnak Island investigated.

Introduction:

Some principal results of the Issungnak Study Program are as follows:

1. General

Issungnak Island was sufficiently stable to withstand all effects of ice impact during the winter 1979-80.

2. Shape

Around the circular island formed an elliptically shaped ice rubble field with its major axis 1500 m long in NW direction and its 800 m minor axis. The island itself was located off centre of the ellipse to the SE.

3. Rubble Field

The ice rubble showed in its profiles, ridge heights up to 11 m and keel depths greater than 19 m. The texture of the ice rubble was 26% consolidated ice, 12% voids, 34% hard ice blocks and 28% slush or soft ice. The latter two changed during the winter to 13% and 48%, respectively. Large areas of the rubble were found grounded up to 300 m away from the island.

An analysis of ice rubble block sizes revealed average dimensions of 0.46 x 1.0 x 1.5 m.

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FENCO CONSULTANTS LTD.
CLIENT: GULF CANADA RESOURCES INC.
REPORT DATE: 1981

Pack Ice/ Rubble Field Interaction Study – Issungnak 1980

4. Photography

Various types of photography were used to study the ice rubble: Time-lapse, hand-held and aerial photography and movie. Time-lapse and aerial photographs showed no long term ice movements during the winter months. Hand-held photos indicate a great variety of observed ice features. A movie showing ridge building in ride-up and ride-downs of an ice sheet documents well ice rubble formation of the early winter season.

5. Ice Strength Tests

Confined compression tests with a FENCO borehole jack showed 15.3 MPa in average and a modulus of elasticity of about 770 MPa.

6. Failure Model Analysis

For a flexural failure mechanism, which was widely observed in the rubble field, a model was derived to calculate ice forces and ice pressure. As an example, for a 30 cm thick ice sheet riding up a 60° rubble slope, a force of 60 kN per metre width of ice was found. The corresponding ice pressure was figured as 200 kPa. An energy of 54 kJ would break the ice into blocks similar in size to those found in the rubble. These calculated results were considered not critical to island stability, except for severe ice push on top of the island.

Sandwell

FENCO CONSULTANTS LTD.
CLIENT: SOHIO CONSTRUCTION COMPANY
REPORT DATE: October 13, 1981

Offshore – Ice Road System Sag Delta and Challenge Island

Overview:

During the winter season 1980-81 a network of ice roads was built in two separate areas of the Beaufort Sea near Prudhoe Bay, Alaska. This Report describes and documents the construction and gives recommendations for future construction.

In the Sag Delta region an 8.5 mile grounded ice road was constructed from the East Dock in Prudhoe Bay along the coast line to a point west of Howe Island. In addition, two floating offshore spurs each approximately 1.5 miles in length, were built to gravel drill pads identified as Sag 7 and Sag 8. A grounded spur about 200 yards in length was connected to Sag 5 on the southerly most Niakuk Island.

In the area of the Maguire Island chain a floating ice road 3.5 miles in length was built from Challenge Island to Point Gordon on the mainland. An airplane landing strip, 2,000 ft. long on floating ice, was placed near the southwest end of Challenge Island.

The construction was extended in spring 1981 by a layout of ice roads for gravel haul eastwards to Alaska Island, and from there to Point Hopson.

The total length of ice road construction was 7 miles of floating road, and 9 miles of grounded ice road not including the gravel haul roads, which were about 15 miles in total over floating, partly grounded ice and tundra.

The ice road network was owned by Sohio Alaska Petroleum Company and built by Sohio Construction Company as General Contractor. Subcontractor was Northwestern Construction Company Inc. FENCO CONSULTANTS LTD was retained by Sohio for design and monitoring the ice road construction and writing this Report.

The Sag Delta and Challenge Island ice road network was considered as a successful transportation system for rig haul and service. The construction was well within time schedule and budget limits. The ice roads proved to be a competitive and economic solution for arctic offshore winter operations at the North Slope of Alaska.

Sandwell

FENCO CONSULTANTS LTD.
CLIENT: SOHIO CONSTRUCTION COMPANY
REPORT DATE: November-December, 1981

Sag Delta Ice Road System Nov/Dec 1981

Overview:

Various pictures showing Dale Payne pump tests (August-September, 1981) and the Sag Delta Ice Road System. (No narrative)

Sandwell

FENCO CONSULTANTS LTD. CLIENT: SOHIO CONSTRUCTION COMPANY REPORT DATE: November-December, 1981
Sag Delta Ice Road System Nov/Dec 1981


Sandwell

FENCO CONSULTANTS LTD. CLIENT: SOHIO CONSTRUCTION COMPANY REPORT DATE: November-December, 1981
Sag Delta Ice Road System Nov/Dec 1981

FENCO CONSULTANTS LTD.
CLIENT: SOHIO CONSTRUCTION COMPANY
REPORT DATE: November-December, 1981

Sag Delta Ice Road System Nov/Dec 1981

Sandwell

FENCO CONSULTANTS LTD.
CLIENT: TRI OCEAN ENGINEERING
REPORT DATE: December 31, 1981

Rea Point Dock Design Criteria (Draft)

Overview:

Expected ice forces on the dock have been tabulated and a preliminary dynamic analysis of a free standing sheet pile cell conducted to examine the possibility of using time average rather than peak ice crushing forces.

Ice pile-ups, downdrag and uplift loads and direction of loading as well as forces driving the ice sheet are discussed. The maximum wave height, although not discussed in the draft, has been checked. Since the shoal area is deeper than originally thought the maximum wave height should probably be increased to 3.8 or 4 m form the 3.2 originally presented in the Feasibility and Budget Cost Estimate report.

Sandwell

FENCO CONSULTANTS LTD.
CLIENT: SOHIO CONSTRUCTION COMPANY
REPORT DATE: July 16, 1982

Sag Delta Offshore Ice Road System

Overview:

This report is an account of construction procedures, techniques and observations of the Sag Delta Ice Road Construction during November and December of 1981, east of Prudhoe Bay, Alaska. The construction involved two 1.5 mile floating ice road sections offshore of the Sag Delta and an 8.5 mile access shore road over mostly grounded ice. The floating offshore sections were built in about 5 weeks time using flooding and freezing techniques to build up 3 ft. of ice on top of 2 ft. of natural ice. The total thickness was designed to carry rig haul and service vehicles to artificial gravel islands, Endeavor and Resolution Island, called briefly Sag 7 and 8.

New flooding equipment and strict project control assisted in improving typical buildup rates and maintaining an adequate level of ice quality run though a slightly warmer winter season was experienced than in years before. The shore road was cleared wide enough to serve required traffic needs with typical snow removal equipment in only a few days.

In addition to the roads, a snow and ice ramp was built to Sag 8 and rig storage areas were established.

The Sag Delta ice road construction was critically reviewed with suggestions for improvements for future ice roads. Ice related data were evaluated and documented in tables and figures. Work specifications were briefly reviewed to facilitate future planning of similar ice road structures.

In general, it was found the 1981 construction of the Sag Delta Ice Road System was a success and an improvement in most aspects. It compared to previous ice road constructions, in 1981 there were higher buildup rates, a shorter road construction and a more economical use of man-power and equipment.

FENCO CONSULTANTS LTD./ LAVALIN
CLIENT: SHELL OIL COMPANY, ALASKA OPERATIONS
REPORT DATE: September 8, 1982

Seal Island Floating Ice Road Report on Construction and Monitoring

The report contains an analysis and summary of data and sketches taken by FENCO field personnel from December 1981 to April 1982.

The construction consisted of about 10 miles of ice road of which 3.5 miles were floating offshore of the Barrier Islands at the North Slope of Alaska. The ice road was built to serve as access for a gravel haul to an offshore location designated for construction of a gravel island. Ultimately, the island is scheduled to support offshore drilling operations for hydrocarbons by Shell Oil Company.

The ice road construction started in December 1981. Flooding and freezing techniques were used to thicken the floating ice road sections from about 3.5 ft. up to a 9 ft. target thickness. The width of the road was staked out as 150 ft. whereas the flooding width reached more or less 350 ft. After construction, the road was kept free of snow for traffic for the rest of the winter.

The average daily ice buildup due to surface flooding as measured with buildup stakes was 1.10 in./day. The average daily natural ice growth measured 0.3 in./day over the construction period. Two contractors supplied flooding equipment both using rolligon vehicles carrying, or having mounted, 14 in. to 18 in. diameter ice drill and water pump systems. The system with encased pumps was by far superior to the unencased pumps because it experienced only minor break-downs and offered a 5000 GPM output without any water loss caused by draining back into the ocean.

The ice quality was tested through measurements of ice strength, salinity and temperatures. The quality was sufficient for the purpose of the road but could have been even better if the weather temperatures had been more consistently cold as was observed in previous years.

During the road use, static and dynamic load tests were carried out with typical loads such as belly dump and B70 gravel trucks. Less than 1 in. deflection was measured and the dynamic amplification of this did not exceed a multiple of 1.5. This is in accordance with previous experience on similar ice roads.

A documentation of all data is included in this report accompanied with sketches and drawings. Photographs were added to illustrate construction events, equipment and situations. A chronological list of field notes made by FENCO personnel also represents a part of this report. The Appendix contains tables and lists which were produced with the help of a computer program.

Sandwell

FENCO CONSULTANTS LTD.
CLIENT: SHELL OIL COMPANY, ALASKA OPERATIONS
REPORT DATE: December 1981 to April 1982

Seal Island Ice Road and Gravel Island Construction Dec 1981 – Apr 1982

Overview:

This report contains various photographs of Seal Island's Ice Road and Gravel Island.

CATCO Rolligon R85 Flooding Unit

Sandwell

FENCO CONSULTANTS LTD.
CLIENT: SHELL OIL COMPANY, ALASKA OPERATIONS
REPORT DATE: December 1981 to April 1982

Seal Island Ice Road and Gravel Island Construction Dec 1981 – Apr 1982

GSL Pump Hole Drain Water

Section of Flooded Ice Road

Sandwell

FENCO CONSULTANTS LTD.
CLIENT: SHELL OIL COMPANY, ALASKA OPERATIONS
REPORT DATE: December 1981 to April 1982

Seal Island Ice Road and Gravel Island Construction Dec 1981 – Apr 1982

Fenco Road Survey

Ice Profiling with electric drill

Sandwell

FENCO CONSULTANTS LTD.
CLIENT: SHELL OIL COMPANY, ALASKA OPERATIONS
REPORT DATE: December 1981 to April 1982

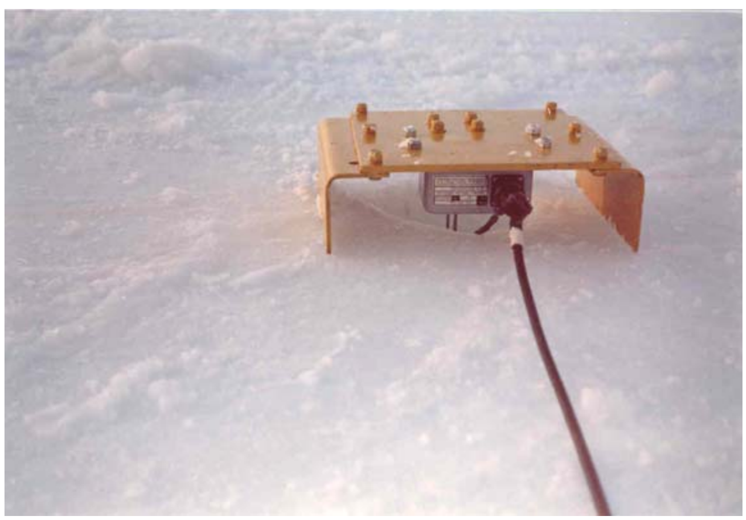
Seal Island Ice Road and Gravel Island Construction Dec 1981 – Apr 1982

Deflection measurements with level and rod

Sandwell

FENCO CONSULTANTS LTD. CLIENT: SHELL OIL COMPANY, ALASKA OPERATIONS REPORT DATE: December 1981 to April 1982
Seal Island Ice Road and Gravel Island Construction Dec 1981 – Apr 1982

Ice coring and sampling for salinity measurements



Dynamic deflection gauge installed over an ice hole

Sandwell

FENCO CONSULTANTS LTD. CLIENT: SHELL OIL COMPANY, ALASKA OPERATIONS REPORT DATE: December 1981 to April 1982
Seal Island Ice Road and Gravel Island Construction Dec 1981 – Apr 1982

Edge of flooded ice and designated island location

Widening of the ice hole with a Ditchwitch cutting machine (equipped for buoyancy tanks in case of break-in)

Sandwell

FENCO CONSULTANTS LTD.
CLIENT: SHELL OIL COMPANY, ALASKA OPERATIONS
REPORT DATE: December 1981 to April 1982

Seal Island Ice Road and Gravel Island Construction Dec 1981 – Apr 1982

Gravel is pushed into ice hole using dozers

Backhoes catch cut ice blocks out of the water

Sandwell

FENCO CONSULTANTS LTD.
CLIENT: SHELL OIL COMPANY, ALASKA OPERATIONS
REPORT DATE: December 1981 to April 1982

Seal Island Ice Road and Gravel Island Construction Dec 1981 – Apr 1982

Ice blocks loaded on end dump trucks

After surfacing of the gravel, trucks drive onto the new island to unload

Sandwell

FENCO CONSULTANTS LTD.
CLIENT: SHELL OIL COMPANY, ALASKA OPERATIONS
REPORT DATE: December 1981 to April 1982

Seal Island Ice Road and Gravel Island Construction Dec 1981 – Apr 1982

Typical Euclid B70 Gravel Truck

Typical Belly Dump Gravel Truck

Sandwell

FENCO CONSULTANTS LTD.
CLIENT: SHELL OIL COMPANY, ALASKA OPERATIONS
REPORT DATE: December 1981 to April 1982

Seal Island Ice Road and Gravel Island Construction Dec 1981 – Apr 1982

Road Maintenance (grader followed by a snow blower)

Gravel Pit for Seal Island Construction

Sandwell

FENCO CONSULTANTS LTD. CLIENT: SHELL OIL COMPANY, ALASKA OPERATIONS REPORT DATE: December 1981 to April 1982
Seal Island Ice Road and Gravel Island Construction Dec 1981 – Apr 1982

Loading Gravel Trucks at Pit Site

FENCO CONSULTANTS LTD.
CLIENT: SOHIO CONSTRUCTION COMPANY
REPORT DATE: June 22, 1983

Thetis Island Ice Road Volume 2 Construction and Monitoring Report

During the winter season 1982-83 an ice road was built in Harrison Bay of the Beaufort Sea west of Prudhoe Bay, Alaska. This report documents and describes the construction and use of the ice road and gives recommendations for future ice road projects. A previous report of December 10, 1983, covers design and construction specifications for the road.

The Thetis Island ice road was 8.1 miles long offshore of which almost 3 miles was grounded. The road ran between a point onshore southeast of Oliktok Point to the southwestern tip of Thetis Island. At this location a grounded ice pad was constructed to store the bulk material from the gravel haul.

Construction began on January 10 and was completed on February 20. The gravel haul took place between February 23 and April 14, 1983, with 1.25 million cubic yards of material hauled.

The ice road project was a success with a serviceable transportation route available throughout and beyond the gravel haul period.

RECOMMENDATIONS

In the following discussion several recommendations are made to improve ice road construction and use.

The unfortunate 2 to 3 week period of warm temperatures in early February caused serious concerns of completing the ice road on time. The amount of gravel required to be hauled by the critical completion date of April 15, made the ice road construction completion date also a very specific and crucial point in the construction schedule. It is recommended that the acquiring of permits, issuing of contract awards and scheduling of construction, wherever humanly possible, be done sufficiently ahead of time in order to allow an early start of construction. This will assure a weather safety factor in the schedule. This warm period of weather has occurred on the North Slope in late December to early February over the last five or so years.

Thetis Island Ice Road, because of the pressure ridging and environmental concerns, required considerable time to reconoitor for location, investigate for ice thicknesses, check water depths, and select proper curve alignments. The ice engineer had an appreciable input into this phase of the work. It would save time and expense if the ice engineer would arrive early on the site by at least one week. Some realignment of the road was necessary at the southeast tip of Thetis Island based on the engineers decision to select the best location to cross the pressure ridge. If the engineer had been on site before layout of the initial centreline, realignment of 2 miles of the ice road would have been avoided.

It is felt that road alignment was probably more precise than necessary. Location of design width stakes, curves and centreline alignment can be laid out with less accuracy. In some cases this can be accomplished by pacing off or aligning by eye thus reducing the time and man-hours required for layout. An initial alignment by instrument is required for long roads.

Densely packed snow drifts encountered during early construction were difficult to break up and properly saturate with sea water. It has been customary when starting an ice road to drag down drifts and moderate snow cover and to flood this snow into the first stages of the ice road. This saves both time and the significant cost of snow removal equipment. It provides for a large buildup during the first floodings. It also eliminates drifting and ice load caused by the displaced snow being spread along the sides of the road.

In view of the difficulties encountered with the dense hard packed drifts at Thetis Island this past year it is recommended that if similar snow conditions on future work exist, complete snow removal to a safe distance from the design width be ordered prior to flooding.

The bridging designed to cross the pressure ridge worked well to provide a high speed access over the ridge and similar techniques and equipment are recommended for use in future years. Procedures to level the pressure ridge using graders and 'yoyoing' with a drag proved very effective without requiring much time or expensive equipment. Wide flooding of a ridge or tidal crack crossing is also recommended in light of the rerouting which was required. This year the initial temporary rig mat crossing, while functional, was rough. It required slow vehicle speeds and attracted snow drifts due to a high profile. The steel plate crossing proved excellent. The steel plates were easy to place, required minimum maintenance, and slowed the traffic much less than the rig mats. In addition, the low profile of the sheets caused minimal drifting problems.

The problems encountered with brine pockets are difficult to avoid as they are essentially the result of flooding operations during abnormally warm weather. As the construction schedule is usually rigid and tight, suspension of flooding activities during periods of warm weather is difficult to justify. Large brine pockets are a sign of too much or too fast flooding during a time of warm temperature and changes in the flooding schedule must be immediately put into effect. Large brine pockets should not be allowed to form but should they occur, the general condition of the road can be determined through a closely spaced profile. It would, however, not be possible to locate all the brine pockets that might exist. Given time and a lowering of temperatures, the brine will drain through the ice and/or freeze.

The reflection of the stake reflectors on the profile stakes obscured viewing of the station numbers by their brilliance. It is recommended that reflectors be separated from the station marker sign by 18 in. A reflector on each side of the profile stake is also recommended.

Snow removal activity on the part of the gravel haul contractor was frequently less than desirable especially in the creation and neglect of berms along the road edge. This was contrasted at other times with a considerable effort at snow removal especially following storms. It is recommended that the contractor responsible for snow removal be impressed, prior to the start of the work, with the required fulfillment of the snow removal specification.

Some problems were encountered in communicating to the haul contractor the importance of proper vehicle use on the road and the safety of the ice for equipment operations. Occasionally, considerable pressure was required on the part of Sohio Construction Company to ensure that unsafe conditions did not occur with respect to the contractor's use of the ice road and surroundings. It is recommended that the required compliance with certain limitations in loading, use of proper vehicle configurations and other regulations dealing with the structural safety of the ice road be included in the haul contractor's contract.

It is recommended, for the protection of Sohio's interests, that a provision be made in any contracts drawn with respect to use of an ice road that the contractor be held responsible if any deemed unsafe activity with reference to the ice occur during a project and that Sohio have ultimate authority in determining the proper solution to this unsafe condition. Such a provision would clear up potential disputes at the contract stage and help prevent unsafe activity with regard to the ice.

Engineering monitoring of any ice road during a major gravel haul is recommended. At Thetis Island, in many cases, this monitoring of the ice road by the ice engineer prevented increased damage to the road, this through recommendations for repairing cracks, changing traffic patterns, evaluating vehicle loading and vehicle configurations and other quality control and road maintenance procedures.

tti GEOTECHnical resources ltd.
CLIENT: SOHIO PETROLEUM COMPANY, DALLAS, TX
REPORT DATE: AUGUST, 1984

SSDC Bow Rubble Generator Ice Island Construction

Overview:

The traditional method of construction of work pads has been by the use of flooding periodically in layers of up to 50mm and allowing these to freeze. While this method works well when thicknesses in the order of 5m are required, greater thicknesses require an excessive amount of time. To obtain accelerated growth of ice the spraying concept was developed. To compare both methods consider a 5cm layer of water on the ice surface contains the equivalent of 1.5 million 4mm drops/m^2 of surface area. This yields a drop surface to water surface area ratio of 75 to 1. As heat transfer is in direct proportion to surface area this represents a very significant increase in freezing rates.

Ice rubble is generated when thin moving ice is obstructed. Laboratory experiments have shown that with the proper mechanism this rubble can be grounded in 30' of water. While neither of these systems is considered satisfactory alone, a combination of both could be developed for the construction of ice islands. To demonstrate the feasibility of the system Sohio decided to build an ice island using this technique.

To produce the rubble a number of "rubble generators" were considered. Based on availability, scheduling and location the bow of the S.S.D.C. was chosen. The bow was modified to generate rubble and also to accommodate a generator building, moonpool and instrumentation building. The bow also provided for a platform from which to spray the rubble. Two fire monitors powered by two 100 h.p. pumps were mounted on the bow. Fig. 2.1.2 shows the finished structure.

Site Location

The bow was towed from McKinley Bay to a point 13km north of Atkinson Point and sunk in 13m of water. Fig. 1.2.1. This site was selected as it had the correct depth of water for the bow to act as a rubble generator. The ice traps are 12.7m from the sea-bed. This location was also in a zone of anticipated first-year ice movement.

Design Philosophy

The initial consideration is the size of the island to be constructed. Using the 100 h.p. pumps with fire nozzles attached spray could be sent over a distance of 60m. Since spraying will be done from a central location the shape of the island will be circular in plan. A pad of diameter 120 m is also the minimum required for actual drilling. If this island were to be utilized to accommodate a drilling rig then prevention of lateral movement would be of prime importance. Therefore the island must have sufficient mass to resist sliding. The force to be resisted is calculated by assuming an ice sheet 2 m thick by 140 m wide exerting a pressume of 1 MPa (typical ice island design) against the island.

tti GEOTECHnical resources ltd.
CLIENT: SOHIO PETROLEUM COMPANY, DALLAS, TX
REPORT DATE: AUGUST, 1984

SSDC Bow Rubble Generator Ice Island Construction

Schedule of Events

October 16, 1983	S.S.D.C. Bow towed to site and sunk in 13 m of water
December 03, 1983	Spraying from structure commenced
January 77, 1983	Spraying from structure discontinued
January 19, 1983	Spraying from Kigoriak initiated
January 24, 1983	Construction terminated

Recommendations:

The largest horsepower pumps commensurate with available power should be used. The exit velocities from the 100 h.p. pumps and the 1600 h.p. were both in the region of 50 m/s. However the water from the larger pump reached a greater elevation. This is due to the larger volume of water pumped and also the shape of the jet which in turn is a function of the nozzle design. Any monitor designs should incorporate turning vanes and swirl damping devices with the overall objective of any monitor/nozzle design being maximum casting distance with minimum break up of the jet until it reaches the apex of its trajectory.

If spraying is to be done from a central location as was done from the rubble generator a number of improvements could be made. The main monitor caused quite a lot of ice build up on the structure especially when spraying across wind. A solution to this problem would be to place four monitors on the structure, one at each corner below the top deck. These would all be interconnected thus giving more flexibility to the system. A typical layout is shown in Fig. 6.1.1. Experience has shown that when the wind is predominately from one quadrant it is difficult to get any ice build up in that quadrant. One method of overcoming this problem would be to have a 50 h.p. "mobile" submersible pump. Three well locations with 60m of aluminum pipe would be sufficient for this pump to spray in any location desired. A second method is to have aluminum pipe from the main piping network to monitors located at the extremes of the build up area.

All swivels on the monitors should be automatic, controlled by limit switches and protected from the elements. Limit switch settings, pump starting switches and valving would all be controlled from an observation deck above the four main monitors.

If a central structure was not to be used then a system similar to that aboard the Kiroriak should be utilized again using the most powerful pumps possible. Without the obstruction of a central structure the efficiency of this system would increase.

Sandwell

tti GEOTECHnical resources ltd. / Golder & Associates
CLIENT: SOHIO PETROLEUM COMPANY, Dallas, TX
REPORT DATE: April, 1985

Spray Ice Island Preliminary Data Package

Overview:

The object of the project was to obtain more information regarding techniques of spraying using high pressure pumps and also to provide data and analysis required by industry for the design and construction of working grounded spray ice structures.

The 350 foot island was constructed between February 18, 1985 and March 18th, 1985. The location of the island as shown in Figure 1 was selected as it had the desired water depth and was also accessible by an existing ice road. On completion this island had an average thickness of 46' (Figure 3). To facilitate testing part of the island was levelled as shown in Borehole location sketch. Data collected includes weather, ice build up, volume of water pumped and densities of 16 cores. Samples of spray patterns are also included. The temperature profiles during construction are not available at this time.

Preliminary uninterpreted data obtained during the post construction field program between April 02, 1985 and April 11, 1985 is also presented. These data include the deep sampled borehole records, most of the CPT data and a selection of the pressuremeter test data. Flatjack, borehole jack and laboratory test data are also summarized.

tti GEOTECHnical resources ltd. / Golder & Associates
CLIENT: SOHIO PETROLEUM COMPANY, Dallas, TX
REPORT DATE: April, 1985

Spray Ice Island Preliminary Data Package

The purpose of this data package is to provide the initial raw data to the study partners for their own evaluation. To date detailed interpretation and checking/correlating of the data has not been carried out, but is currently taking place. A further purpose is to provide sufficient background for planning of the additional laboratory testing to be carried out to complete the program.

Sandwell

GEOTECHnical resources ltd. / GOLDER & ASSOCIATES **CLIENT: SOHIO PETROLEUM COMPANY et al.** **REPORT DATE: September, 1985**
Construction, Testing & Monitoring Spray Ice Island (Appendices)
Overview: **Report includes raw data on Ice Build-Up Data, Weather Data, Spray Patterns, Details of Field Equipment, Diary of Field Program, Laboratory Test Results (Natural Samples), Cone Penetration Tests, Pressuremeter Tests, Flatjack and Borehole Jack Tests, Tabulated Slope Indicator, Sondex and Thermistor Data.**

INTRODUCTION

The design of an ice platform or ice road is based on two criteria. These are:

1. limiting flexural stress in the ice to a safe level
2. limiting long term deflection to less than available freeboard.

Many platforms and roads have been designed based on these criteria and they have all been safe and useful structures.

DEFINITION OF TERMS AND SYMBOLS

σ	stress (kPa)
σ_{max}	maximum stress (kPa)
ν	Poisson's ratio (0.3) assumed
b	loading radius (m)
k	unit weight of water (1000 kg/m^3)
ℓ	stiffness length (m)
h	ice thickness (m)
p	applied load (kN)
E	Elastic modulus (5.52 GPa) assumed
x	distance from x_o to point of interest (m)
x_o	relative position of the applied load P_o (m)
δ	deflection of the ice sheet (m)
δ_{30}	30 day (long term) deflection (m)
P_1, P_2, P_3	applied loads (kN)
x_1, x_2, x_3	distances from point of interest of P_1, P_2, P_3 (m)
E*	long term elastic modulus (MPa)
ℓ*	long term stiffness length (m)
F	freeboard (m)

STRESS ANALYSIS

Stress levels in the ice platform are calculated from the equations for maximum extreme fiber stress of a beam or an elastic foundation. Maximum stress under an applied load, P_1 is given by equation (1).

$$\sigma_{max}=0.275(1+\nu)\frac{P}{h^2}\log\left[\frac{Eh^3}{kb^4}\right] \qquad (1)$$

The effect of multiple loads is taken into account by using the principle of superposition and noting that the effect of a load applied a distance x from the point of interest is given by equation (2).

$$\sigma_x=\sigma_{max} \quad \exp\left[\frac{-x}{0.691\ell}\right] \qquad (2)$$

The stiffness length, l, of an ice sheet is given by equation (3)

$$\ell = \sqrt[4]{\frac{Eh^3}{12(1-\nu^2)k}} \qquad (3)$$

The total stress at a point A due to loads P_o, P_1, P_2, P_3 ... at distances x_o, x_1, x_2, x_3 ... is evaluated from superposition by equation (4)

$$\sigma_{total} = \sigma_o + \sum_{n=1}^{i} \sigma_n \exp\left(\frac{-x_n}{0.691\ell}\right) \qquad (4)$$

where σ_o, σ_1, σ_2, are evaluated from equation (1).

The ice thickness of the platform is calculated based on limiting total stress, σ_{total}, to 520 kPa which is a proven safe value. The value of ice thickness, h, is adjusted until the combined effect of the applied loads is less than 520 kPa as calculated from equations (1), (2), (3) and (4).

DEFLECTION ANALYSIS

The instantaneous deflection of a beam on an elastic foundation under an applied load, P_1 is given by equation (5).

$$\delta = \frac{P}{8k\ell^2} \qquad (5)$$

To calculate the long term (> 30 day) deflection of the platform, a time-reduced elastic modulus, E^*, is used given by equation (6).

$$E^* = 0.1E \qquad (6)$$

This value for E^* is used in equation (3) and equation (5) to calculate the long term deflection, δ_{30}, from equation (7) and (8).

$$\ell^* = \sqrt[4]{\frac{E^*h^3}{12(1-\nu^2)k}} \qquad (7)$$

and

$$\delta_{30} = \frac{P}{8k\ell^2} \qquad (8)$$

The deflection of the ice platform, σ_{30}, is limited to the available freeboard, F, which is measured or calculated from equation (9).

$$F = 0.1h \tag{9}$$

Thus the limiting condition for the ice platform deflection is given by equation (10)

$$\delta_{30} \leq F \tag{10}$$

The long term deflection of the ice platform can also be evaluated by equation (11) which is derived empirically from previous ice platform case histories.

$$\delta_{30} = 0.605F \tag{11}$$

A SAFE DESIGN

A safe design is calculated based on

$$\sigma_{total} \leq 520 \text{ kPa}$$

and

$$\delta_{30} \leq F \quad m$$

The extent of the design area required is predicated on the area of loading from applied loads on the ice platform and the distance from the rig that the ice stresses reduce to a minimal (<10% σ_{max}) level.

GEOTECHnical resources ltd.
CLIENT: BP CANADA INC.
REPORT DATE: February 4, 1986

Marguerite Lake Ice Platforms Detailed Design Report

MARGUERITE LAKE PLATFORM DESIGN

The design of the Marguerite Lake ice platforms was done based on the rig layout and the anticipated loads for Westburne #37 Rig. This rig has been retained to drill these wells. Based on this information, the calculated ice thickness for the platforms is 1.53 m with a radial extent of between 25 and 35 m. Drawings of the ice platform layout and profile are included here. A taper zone of ice thickness decreasing from the design thickness to the natural ice thickness surrounds the design area, an additional 8 m across. A drawing of the layout for Westburne #37 is also included.

Stresses in the ice caused by rig loads are all less than 520 kPa throughout the design area based on the analysis. Available freeboard at design thickness is calculated to be 0.15 m. Long term deflection based on the analysis is between 0.09 and 0.12 m which is safely less than the available freeboard.

GEOTECHnical resources ltd.
CLIENT: B.P. CANADA INC.
REPORT DATE: April, 1986

Marguerite Lake Ice Platforms Final Report

Overview:

ORIGINAL DESIGN

The design of an ice platform is based on two criteria. These are:

1) Limiting flexural stress in the ice to a safe level of 520 kPa.
2) Limiting long term deflection to less than the available freeboard.

A report entitled "Marguerite Lake Ice Platforms Detailed Design Report" was prepared and issued to B.P. Canada on February 4, 1986. This report details the design procedure and equations used in calculation of the ice platform design for the wells at Marguerite Lake.

On January 20, Westburne Drilling was contacted by GEOTECH to obtain rig and component loads for Rig #37 which was to be used for this project. The loads and distribution are shown in Figure 1. Based on this information and the design procedures mentioned, an ice platform 1.53 m in thickness was calculated. The platform was to be egg shaped with a radial extent of between 25 and 35 m. A taper zone of ice thickness decreasing from design thickness to the natural ice thickness surrounded the design area, an additional 8 m across. Drawings of the ice platform layout and profile are shown in Figure 2 and 3. Identical platforms were to be used for each well location and these were identified Pad 12-17, Pad 13-8 and Pad 13-7 following the well designations.

REVISED DESIGN

Difficulties were encountered during the drilling of Well 12-17 (see Section 3) using Westburne Rig #37. These problems were associated with having loads larger than those designed for on the ice pad. It was decided by B.P. and GEOTECH that another rig and a different loading pattern was required for Wells 13-8 and 13-7. A lighter rig, Westburne #40, was selected and loads were determined for it.

At this time, the construction of both Pads 13-8 and 13-7 was complete. Warm weather and operational considerations indicated that further ice build up was not practical. Hence, the rig selection and layout was fitted to the pads already built.

The loads and distribution for Westburne Rig #40 are shown in Figure 4. These loads were independently verified as far as possible to ensure accuracy. These loads and configuration could safely be supported by 1.42 m of ice which was slightly less than the 1.44 to 1.48 m found on each of Pads 13-8 and 13-7. The radial extent of the pads as built was 45 m which was more than required.

The wells at 13-8 and 13-7 were both completed using Westburne Rig #40 and the revised design.

CONCLUSIONS

Construction

Weather conditions prevalent throughout construction were unseasonal, with exceptionally mild temperatures. This adversely affected the build up rates that were achieved. The construction technique used involved dyking the flood perimeter and applying deep (75-100 mm) floods. Warm ($0^{o}C$) ice temperatures were recorded through the ice mass all through construction. This fact and the low (<10%) freeboard values found at the end of construction indicated a non frozen (water) content in the built up ice. A week of cooling after construction was required to freeze the ice mass and achieve the desired freeboard.

Platform Performance

The performance of Pad 12-17 with Rig #37 indicated that accurate, confirmed loads are required from all contractors when operations on the ice are undertaken. A contractor's own estimates are not necessarily reliable.

It is noteworthy that ice platform performance is stable and predictable providing that strict control of load on the ice is ensured.

Special care is necessary in regard to placement and use of support vehicles for rig operations. It is necessary to direct and control these vehicles at all times.

Ice Quality and Testing

Ice temperature, strength and load-deflection behaviour were measured for the ice platforms. This information was essential to the successful completion of the project.

Ice temperatures were important during construction as they indicated the reason for low freeboard values found. The warm temperatures indicated that the ice during construction was of marginal quality. This was tolerated to enable adequate ice to be built in time under the adverse weather conditions. Ice temperatures during drilling were important information to monitor any melting of the pads.

Ice strength information from the borehole jack was important to asses the strength and quality of the pads as built with reference to the design.

Load-deflection information from the load test was very valuable. This data enabled a test trial of platform behaviour to be undertaken before the design loads were placed. This test confirmed the design assumptions and enabled a calibrated prediction of behaviour under the rig loads.

RECOMMENDATIONS

Construction

It is recommended that a change be made in construction procedure especially if adverse (warm) weather conditions prevail during construction. The use of thin (25-50 mm max) flood thickness is desirable without containment dykes as these floods are easier to freeze completely, requiring less time than deep (100 mm) floods. The dykes contain the floodwater and tend to produce deeper floods without careful control of pumping times. Complete freezing of the floodwater is desirable as it would prevent the low freeboard condition found at construction's end and avoid delays required to freeze the built up ice before use.

The equipment used for flooding, small gas powered impeller pumps can be improved upon. The use of larger auger driven pumps is recommended. These pump units can be gas powered or vehicle mounted and run from hydraulic power. This units are currently available in Alberta. These auger pumps will decrease flood time substantially, which promotes built up.

GEOTECH has spray flooding technology and equipment which has proved very successful in the Arctic. The advantage of spray flooding is that substantial improvements in built up rates (50%-100% increase) can be achieved.

A recommended option for well pad construction is the use of spray flooding technology. A large mass of ice can be built in a relatively short period of time.

Build-up of an ice pad can be achieved to a level where the entire structure is grounded (bottom founded). This is a substantial advantage over floating structures as vertical deflections are no longer critical to the design.

With this procedure, it would be possible to build a grounded structure within the construction period.

Platform Performance

In regard to ice loads, it is recommended that a meeting should be held between all contractors, the well operator and any consultants with regard to the scope and details of the project. At this time a rapport can be established and each party can be properly informed regarding to their participation and the completeness of any information that may be required. In terms specifically relating to ice safety, an independent confirmation of all loads to be placed on the ice should be required prior to commitment to the project. It would also be helpful if this meeting also detailed the chain of command and the responsibilities of each party with regard to each facet of the project. This would be particularly helpful if changes in scope of work are required in the field.

It is further recommended that the ice engineer on site have adequate authority to control and direct the loads on the ice. This is particularly important in reference to support vehicles used in well operations.

Ice Quality and Testing

It is recommended that ice quality be tested and monitored during construction and drilling. This is necessary so that design assumptions can be verified and behaviour can be predicted during drilling.

Sandwell

Sandwell Inc.
CLIENT: ARCO Alaska Inc.
REPORT DATE: March 7, 1996

Warthog Ice Structure – Final Design Report

Overview:

This report details the design of a grounded ice island for exploration drilling at ARCO Alaska, Inc.'s Warthog site located in the shallow water of Camden Bay, approximately 100 km east of Prudhoe Bay, Alaska. It will be constructed using ice spraying techniques during the December / January time frame. ARCO Alaska, Inc. contracted Sandwell to design an island which will be capable of resisting the horizontal ice loads from ice sheet movements and be capable of supporting the required vertical rig loads.

A number of design geometries were investigated and a circular plan geometry was chosen as being the most efficient when ice forces, required ice volumes and vertical build-ups were considered.

The general approach for the design was to select the horizontal dimensions of the structure to satisfy the undrained silt shear requirements. Once the overall horizontal dimensions of the structure were selected, the freeboard was then chosen to satisfy the sand friction criteria. A factor of safety of 1.5 has been incorporated in the design. The final geometry was then used to calculate the volumes of spray ice required and the build up times.

The overall advantage of a segmented design, which includes a moat, is that during the construction of the berm in the second stage, spraying can be done down-wind away from the rig from within the moat. For a design not incorporating a moat, spraying would always be performed from the outside perimeter towards the centre, thereby possibly resulting in a larger amount of overspray onto the rig.

The critical design aspects are seabed contact area (dictated by the undrained shear strength of the silt), maximum ice interaction width (determining lateral ice forces), and surcharge weight or volume (determining the sand resistance). The distribution of the surcharge weight among the various parts of the structure can be selected based upon their constructability. This also provides flexibility in the construction process since the total weight of ice is the important factor rather than its precise placement. Thus, the overall structure design is an idealized geometry and considerable deviations are possible while maintaining overall stability. During construction, the final detailed shape will not likely match the design geometry.

Basic Design Parameters

Mean Water depth	12 (ft)
Water density	64 (lb/cu ft)
Spray ice specific gravity	0.62
Spray ice density	38.7 (lb/cu ft)
Design, global ice thickness	6.5 (ft)
Design ice pressure	200 (psi)
Initial ice thickness	2.0 (ft)
Factored, undrained silt shear strength	200 (lb/sq ft)
Sand friction angle	30 (deg)
Factor of safety	1.5
Minimum drill pad radius	300 (ft)
Underwater berm slope	4:1
Above water berm slope	2:1

Sandwell

Sandwell Engineering Inc.
CLIENT: Phillips Alaska Inc.
REPORT DATE: September 29, 2000

McCovey Ice Island – Island Design Report

Overview:

Phillips Alaska, Inc. and its partners intend to construct a grounded sprayed ice island at the McCovey prospect in 36 ft of water approximately 4.5 miles northeast of Reindeer Island and to drill an exploratory well from that island during the winter of 2000/2001. Reindeer Island is approximately 7.5 statute miles northeast of West Dock at Prudhoe Bay Alaska.

Sandwell Engineering Inc. had been retained to design the island and to provide site engineering, quality control during construction and monitoring during drilling. This document addresses the design and principal construction methodology of the island as well as the quality control and monitoring procedure.

The island must be capable of resisting the lateral ice forces and which can be constructed early enough in the winter to allow the rig to be mobilized on-site and safely drill the well and be de-mobilized by early May 2001. The design:

- assesses the risks to the island and the ice supply road from ice movement,
- derives the shear resistance of the island and the lateral ice loads,
- describes in detail the dimensions and material composition of a spray ice island capable of resisting the lateral ice forces and of supporting the drilling rig,
- assesses the pumping equipment required to construct the island using past island experience and a computer model,
- outlines a general construction and spraying procedure and assesses the feasibility of establishing and maintaining an ice access/supply road, and
- outlines the plans for QC during construction and monitoring during drilling, activities key to ensuring the safety of the wells and the operation.

Sandwell Engineering Inc.
CLIENT: Phillips Alaska Inc.
REPORT DATE: September 29, 2000

McCovey Ice Island – Island Design Report

Project Time Line and Effects of Ice Movement

Date	Ph	Major Tasks	Effect of Ice Movement less than 20’	Effect of Ice Movement 20’ to 200’	Effect of Ice Movement greater than 200’
11/24 to 12/1	Pre Grounding	Ice Road to Reindeer Isl.	Minor repairs to road or re-routing of road.	Repairs to or re-routing of road.	May have to re-establish road once ice re-forms.
12/1 to 12/20	Pre Grounding	Ice Road Reindeer to McCovey & site preparation	Repairs to or re-routing of road. No effect on island.	Repairs to or re-routing of road.	Loss of ice road & island site for offshore movement >2000’ Or, formation of extensive ice rubble at or near island site to our advantage.
12/20 to 01/15	Pre Grounding	Spraying prior to grounding	Repairs to or re-routing of road. If leads occur at island pump moves delayed.	Repairs to or re-routing of road If lead occurs at island pump moves delayed or access denied. Possibility of damage to island or island being displaced from original location.	Loss of ice cover & road for movement >2000’ Island may be displaced too far and lost. Extensive rubble may form at or near site to advantage with extreme movement.
01/15 to 02/01	Post Grounding	Spraying post grounding	Repairs to or re-routing of road. If lead occurs at island pump moved delayed.	Repairs to or re-routing of road. If lead occurs at island pump moves delayed. Ice rubbling at island perimeter	Ice rubbling at island perimeter. Loss of ice cover & road for movement > 2000’
02/01 to 02/07	Post Grounding	Island Verification Transport of rig to island.	Possible delay in rig move. Minor ice rubbling at island	Repairs to or re-routing of road. Likely delay in rig move. Ice rubbling at island perimeter.	Movements unlikely
02/07 to 05/01	Drilling	Drilling and testing	Repairs to road. Minor ice rubbling at island	Repairs to or re-routing of road. Ice rubbling at island perimeter.	Movements unlikely

05/01 to 05/15		Transport of rig etc. to shore. Site decommission-ing	Possible delay in rig move. Minor ice rubbling at island.	Repairs to or re-routing of road. Likely delay in rig move. Ice rubbling at island perimeter.	Movements unlikely.

SPRAY ICE RESEARCH

FENCO CONSULTANTS LTD.
CLIENT: APOA (Elf Oil Exploration and Production Canada Ltd.)
REPORT DATE: November 27, 1973

Beaufort Sea Summer Ice Testing Project

Overview:

During the early summer of 1973, Foundation of Canada Engineering Corporation Limited (FENCO) was retained by the Arctic Petroleum Operators Association (APOA) to conduct a survey and strength tests, under the direction of Gulf Oil of Canada, on ice found in the Beaufort Sea within approximately 50 miles of shore. The east-west boundaries were to be approximately Herschel Island on the west and Kugmallit Bay on the east.

Two expeditions, one after breakup and one in mid or late summer were to be conducted. The parameters to be determined were:

- Floe positions
- Floe sizes
- Floe thicknesses
- Ice strengths (insitu)
- Ice temperatures, density and salinity

PHASE I

From July 15 to July 22 a helicopter was used to fly daily, using Swimming Point as a base, to the ice which was about 20 miles offshore in a NNW direction from the camp. The approximate extent of the ice field encountered is shown in Figure 1 (as can be seen from the map in Figure 1 the ice field was extensive). Many of the individual floes landed upon were quite large, greater than 1/4 mile in diameter, and some were of indefinite extent.

Average floe thicknesses were estimated at 20 to 25 feet from observations on the freeboard and bore holes and electronic profiling indicated thicknesses in excess of 10 to 12 feet. The electronic profiling also indicated layers of melted or nearly melted ice within the mass.

Surface and in depth strength tests indicated the following average values:

Unconfined compression	307 psi
Maximum contact pressure	887 psi
Elastic modulus	51,000 psi

Borehole tests indicated that these properties were fairly uniform throughout the depth of the floes.

FENCO CONSULTANTS LTD.
CLIENT: APOA (Elf Oil Exploration and Production Canada Ltd.)
REPORT DATE: November 27, 1973

Beaufort Sea Summer Ice Testing Project

The ice can be described as being quite different in its mechanical behaviour from winter ice. The temperature was at or very near the melting point and the electronic profiling system indicated that much of the latent heat had been lost in some places. It was not brittle as is observed in winter but was very ductile with a well defined yield point. The elastic modulus was about 1/20 of that of winter ice. Large deformations were noted in the strength tests and failure was not sudden but was indicated by the reaching of a plateau.

The ice was porous and blue in color until drained of the brine inside at which point the samples were colorless.

PHASE II

From September 18 to September 21 a small tugboat was chartered and seven floes were boarded and tested during a four day period.

The same types of measurements were taken as for the July tests. The approximate extent of the ice as determined from a reconnaissance flight in a small aircraft and from the boat is shown on the map in Figure 31. The floes were in general smaller than the ones seen in July, averaging about 500 feet in diameter. Larger floes were found to be conglomerates of smaller pieces.

The surface of most floes was smoother than in July and average floe thicknesses were 15 to 20 feet.

The results of the strength tests can be summarized with the following average values:

Unconfined compression	580 psi
Maximum contact pressure	1,110 psi
Elastic modulus	54,000 psi

Again no great variation in mechanical properties with depth was noted. The ice temperature was at or near the melting point and the ice was very ductile in its behaviour. Except for one floe, the elastic moduli were low and no sudden failure was noted in the strength tests.

The ice was very porous and drained easily of the trapped brine.

Sandwell

FENCO CONSULTANTS LTD.
CLIENT: TOTAL EASTCAN EXPLORATION LTD.
(Operator for Labrador Group)
REPORT DATE: August 30, 1977

1977 Winter Field Ice Survey Offshore Labrador

Overview:

This report contains results of the Ice Survey conducted offshore Labrador in February, March , April and May, 1977. What follows are tests and observations:

1. Ice thickness obtained from drilling holes and results of aerial photography.
2. In situ ice strength tests to determine unconfined and confined compressive strengths and the elastic modulus.
3. Ice salinity profiles.
4. Ice temperature profiles.
5. Surface topography measurements by means of aerial photographs.
6. Aerial observations of ice conditions, both visually and by means of photography.

The first-year ice thicknesses ranged from 0.60 m to 5.80 m. The monthly mean thicknesses were 1.00 m for February, 1.77 m for March, 2.08 m for April and 4.62 m for May. First-year ice floe surface areas measured ranged between 145 m^2 and 46,000 m^2

with a mean of 1028 m^2 for February, 754 m^2 for March, 360 m^2 for April and 14504 m^2 for May. The calculated first-year ice floe mass ranged from 300 tonnes to 146,300 tonnes. The monthly mean masses were 3920 tonnes for February, 2158 tonnes for March, 826 tonnes for April and 54,962 tonnes for May.

The mean unconfined compressive strengths of first-year ice were 62.7 Kg/cm^2 for February and 40.0 Kg/cm^2 for May. The mean confined compressive strengths of first-year ice were, 88.8 Kg/cm^2 for February, 102.3 Kg/cm^2 for March, 125.4 Kg/cm^2 for April, and 78.4 Kg/cm^2 for May.

The mean elastic modulus values for first-year ice were, 1521 Kg/cm^2 for February and 2220 Kg/cm^2 for May.

From the salinity profiles the mean salinities for first-year ice were 6.9 o/oo for February, 4.7 o/oo for April and 3.9 o/oo for May.

The mean first-year ice floe temperatures were -5.8^{o}C for February, -1.0^{o}C for April and -0.1^{o}C for May.

The multi-year ice floe thicknesses ranged from 3.0 m to 30.0 m. The monthly mean thicknesses were 6.94 m for March, and 10.18 m for April.

The multi-year ice floe surface areas, from aerial photos, ranged from 100 m^2 to 10,000 m^2. The mean surface areas were 758 m^2 for March and 1345 m^2 for April. The calculated multi-year ice floe mass ranged from 583 tonnes to 174,000 tonnes with a mean of 7,058 tonnes for March and 17,983 tonnes for April.

The mean unconfined compressive strengths of multi-year ice were 62.1 Kg/cm^2 for March, 48.9 Kg/cm^2 for April and 40.7 Kg/cm^2 for May. The mean confined compressive strengths for multi-year ice were 211.0 Kg/cm^2 for March, 198.5 Kg/cm^2 for April and 202.3 Kg/cm^2 for May.

The mean elastic modulus values for multi-year ice were 17,460 Kg/cm^2 for March, 11,680 Kg/cm^2 for April and 17,192 Kg/cm^2 for May.

The mean salinities of multi-year ice were 0.8 o/oo for March, 1.5 o/oo for April and 1.5 o/oo for May.

The mean multi-year floe temperatures were -6.9^{o}C for March, -3.6^{o}C for April and -1.2^{o}C for May.

FENCO CONSULTANTS LTD.
CLIENT: TOTAL EASTCAN EXPLORATION LTD.
(Operator for Labrador Group)
REPORT DATE: August 30, 1977

1977 Winter Field Ice Survey Offshore Labrador

Regression analyses were done on data collected this year as well as that from the two previous surveys. These show a definite relationship between ice strength, ice temperature and ice brine volume.

Through the use of aerial photography, floe size, thickness, surface area and mass were calculated. This is a very quick and efficient way to study the physical properties of ice floes.

Through the use of our new equipment, ice cores greater in length than any previously taken were obtained and auger holes of depths greater than 15 m were made.

The measurements taken this year contribute to the understanding of the composition and characteristics, both physical and mechanical, of the Labrador ice pack. Due to time and operating limitations, sampling was sporadic and limited in quantity.

FENCO CONSULTANTS LTD.
CLIENT: TOTAL EASTCAN EXPLORATION LTD.
(Operator for Labrador Group)
REPORT DATE: June 8, 1978

1978 Winter Field Ice Survey Offshore Labrador

Overview:

This report contains results of the Ice Survey conducted offshore Labrador in January and February, 1978. Flight lines were flow perpendicular to the coastline at the following outboard headings:

107° magnetic from Nain
076° magnetic from Hopedale and
084° magnetic from Cartwright.

The distances measured offshore were in nautical miles from the point of departure, i.e. Nain, Hopedale or Cartwright.

Along these flight lines the following tests and observations were conducted:

1. Ice type and coverage obtained from results of aerial photography

2. First-year ice thickness obtained from drilling holes

3. First-year ice floe surface area and geometry from results of aerial photography

4. Visual observations of ice conditions.

In addition to the above, when flights were made offshore Hopedale, the following tests were performed:

1) In situ ice strength tests to determine confined and unconfined compressive strengths and the elastic modulus of first-year ice

2) First-year ice temperature profiles

3) First-year ice salinity profiles.

In each of the aerial photographs an ice floe, which was representative of all the ice floes contained in the photograph was selected and analyzed. This representative ice floe was labelled average size floe. In addition to the average size floe, the largest size floe contained in each photograph was selected and analyzed this was labelled largest size floe.

From the analysis of the aerial photographs the sea surface was covered by approximately 50% grey ice, 5% brash, 34% first-year ice and 11% open water during the January portion of the survey. During the February portion of the survey the sea surface was covered by approximately 31% grey ice, 13% brash, 50% first-year ice and 6% open water.

The thickness of the first-year ice was quite variable. During the January portion of the survey the first-year ice thickness measured:

FENCO CONSULTANTS LTD.
CLIENT: TOTAL EASTCAN EXPLORATION LTD.
(Operator for Labrador Group)
REPORT DATE: June 8, 1978

1978 Winter Field Ice Survey Offshore Labrador

- from 0.13 m to 2.87 m with an average thickness of 1.09 m and a standard deviation of 0.84 m offshore Nain;
- from 0.21 m to 1.73 m+, with an average thickness of 0.76 m+ and a standard deviation of 0.52 m+ offshore Hopedale;
- from 0.51 m to 1.37 m, with an average thickness of 0.92 m and a standard deviation of 0.25 m offshore Cartwright.

During the February portion of the survey the first-year ice thickness measured:

- from 0.94 m to 4.48 m+ with an average thickness of 1.95 m+ and a standard deviation of 0.92 m+ offshore Nain;
- from 0.79 m to 4.63 m+ with an average thickness of 2.71 m+ and a standard deviation of 1.19 m+ offshore Hopedale;
- from 0.70 m to 4.57 m+ with an average thickness of 1.76 m+ with a standard deviation of 1.10 m+ offshore Cartwright.

The geometry of the observed first-year ice floes varied widely. From the analyses of the aerial photographs the surface areas of the average size first-year ice floes:

- ranged from 10 m^2 to 2590 m^2 with an average surface area of 280 m^2, for the January portion of the survey;
- ranged from 10 m^2 to 13070 m^2 with an average surface area of 320 m^2, for the February portion of the survey.

From the analyses of the aerial photographs the surface areas of the largest size first-year ice floes:

- ranged from 20 m^2 to 28490 m^2+ with an average surface area of 1510 m^2, for the January portion of the survey;
- ranged from 10 m^2 to 28490 m^2+ with an average surface area of 3690 m^2+, for the February portion of the survey.

Approximately 60% of all the observed first-year ice floes were polygonal in shape, and 25% were classified as being rectangular in shape. The remainder of the first-year ice floes were either triangular, circular or elliptical in shape.

From the temperature profiles the average temperature of the first-year ice was -6.9°C during the January portion of the survey and -3.6°C during the February portion of the survey.

FENCO CONSULTANTS LTD.
CLIENT: TOTAL EASTCAN EXPLORATION LTD.
(Operator for Labrador Group)
REPORT DATE: June 8, 1978

1978 Winter Field Ice Survey Offshore Labrador

From the salinity profiles the average salinity of the first-year ice was 7.7 o/oo during the January portion of the survey and 6.8 o/oo during the February portion of the survey.

The first-year ice confined compressive strengths ranged from 59.6 kg/cm^2 to 208.5 kg/cm^2 with a mean confined compressive strength of 143.2 kg/cm^2 during the January portion of the survey and, ranged from 34.7 kg/cm^2 to 178.7 kg/cm^2 with a mean confined compressive strength of 95.3 kg/cm^2 during the February portion of the survey.

Tests for unconfined compressive strength in first-year ice were limited in number, however, during the February portion of the survey unconfined compressive strengths ranged from 62.1 kg/cm^2 to 85.8 kg/cm^2 with a mean value of 70.8 kg/cm^2.

The first-year ice elastic modulus values ranged from 350 kg/cm^2 to 10550 kg/cm^2 with a mean value of 4497 kg/cm^2 during the January portion of the survey, and ranged from 350 kg/cm^2 to 14060 kg/cm^2 with a mean value of 4913 kg/cm^2 during the February portion of the survey.

Regression analyses were done on data collected this year. These show a definite relationship between ice strength, ice temperature and ice brine volume.

Aerial photography was a quick and efficient means of gathering data on ice type, spatial coverage, surface topography , size and shape of floes in the ice pack.

Although a portion of the freeze-up data was missed, due to the lateness of the first offshore flight, the measurements taken this year contribute to the understanding of the composition and characteristics, both physical and mechanical, of the Labrador ice pack. Due to time and operating limitations, sampling was sporadic and limited in quantity.

FENCO CONSULTANTS LTD.
CLIENT: TOTAL EASTCAN EXPLORATION LTD.
(OPERATOR FOR THE LABRADOR GROUP)
REPORT DATE: September 29, 1978

Multi-Year Ice Floe Population Offshore Labrador 1978

Overview:

The purpose of this survey was to study and gather information on the population of multi-year ice floes found offshore Labrador during the season of ice cover in this area. This study was undertaken by means of airborne stereophotography. The operation was staged from Goose Bay, Labrador and primary offshore flights were made from three locations; Fish Cove Point, Cape Kiglapait and Saglek. Personnel flew offshore these locations on an outbound heading perpendicular to the coastline passing over existing well sites, and aerial photographs of the pack ice were taken.

From the analysis of the airborne stereophotographs the population of the multi-year ice floes was studied as well as ice types and spatial distribution of the ice pack as a whole. This airborne stereophotography worked extremely well and will be of considerable use in future ice surveys.

Introduction:

From the analysis of 2900 nautical miles, or 9200 aerial photographs, the population of multi-year ice floes found in the pack ice offshore Labrador vary considerably.

The results indicate that the amount and size of the multi-year ice vary with respect to time and location. Normally the average number of multi-year ice floes observed per flight was larger in the northern portions of the study area. It was also seen that the average number of multi-year ice floes observed per flight was larger in the latter portions of the study. In confirmation of previous observations the multi-year ice floes are generally found in fields of multi-year ice.

The average surface areas of the multi-year ice floe population were generally larger in the northern portion of the study area and were larger in the latter portions of the survey.

The total area of the ice pack photographed during the survey on the three main flight lines, Fish Cove Point, Cape Kiglapait and Saglek, was 4453 km^2. In this area 1277 multi-year ice floes were observed. The combined surface area of these floes was 5.5 km^2 or 0.12% of the total area photographed. As mentioned above, the multi-year floes are normally found in fields of multi-year ice and the coverage of multi-year ice can be somewhat higher than this figure. The distribution of surface areas of the observed multi-year ice floes were generally log normal.

FENCO CONSULTANTS LTD.
CLIENT: TOTAL EASTCAN EXPLORATION LTD.
(OPERATOR FOR THE LABRADOR GROUP)
REPORT DATE: September 29, 1978

Multi-Year Ice Floe Population Offshore Labrador 1978

The number of multi-year ice floes seen from a strip of photography, 10 nautical miles long and .75 nautical miles wide, centered over the existing wellsites, varied from 0 to 15 with a mean of 6 on any given flight at each of the locations.

The number of multi-year ice floes in the area of existing wellsites can vary even more as strong onshore or offshore winds can compact or broaden the width of the ice pack thereby shifting the locations of the floes either towards onshore or towards offshore with respect to the wellsite location. Chances of collision between multi-year floes and structures may be higher than indicated by the aforementioned figures.

The composition of the ice pack is continuously changing with time and with distance offshore. Normally the sea surface in the area of the existing wellsites was ice covered, however, on some occasions the sea surface at these locations was ice free.

Throughout the survey the location and numbers of icebergs was observed. The overall average ratio of multi-year ice floes to icebergs, taken from aerial photographs, was 51:1. These ratios ranged from 12:1 to 209:1. The total amount of icebergs observed visually for the duration of the study was 2214. This is not to be confused with the number of icebergs contained in the aerial photographs. The number of visually observed icebergs per nautical mile of flight ranged from 0.12 in March to 0.55 in June.

Although pack ice is much thinner than multi-year ice, there is extreme danger regarding collisions with structures where pack ice pushes on a multi-year floe which in turn collides with a structure. The pack has ample strength to push these multi-year floes and create high forces.

It is concluded that the forces acting on the pack exceed the actual strength of the pack and a violent process takes place which results in considerable deformations of the pack. Evidence of this was seen in the form of large chunks of ice piled on multi-year ice floes where the multi-year floe's freeboard was 2 or 3 metres.

While the data on the multi-year ice population obtained this year gave an initial data base it is still insufficient to allow for accurate predictions. Data must be obtained for several more years before an understanding of the multi-year ice floe population can be reached.

Sandwell

FENCO CONSULTANTS LTD.
CLIENT: WORLD OCEAN SYSTEM
REPORT DATE: June 16, 1980

Basic Study of Offshore Structures in Ice Affected Waters

Overview:

This study outlines in general terms the present state-of-the-art of offshore structures in ice-affected waters. "General" because environmental information which represents a paramount prerequisite for the design of offshore structures is still scarce for most ice covered waters. This applies in particular to ice, its distribution with time and its mechanical and structural properties. Some of the conceptual designs represented in this report are based on assumed environmental data and hence they should be treated as such.

It would be beyond the scope of this report to deal in detail with the design of each possible structure or even with one particular structure. Instead, a broad spectrum of offshore structures has been presented - supported by some sketches - along with typical ice conditions in which they (the structures) could most likely withstand the expected ice forces.

A novel analytical model was developed representing the sequencial breakdown of an ice edge in a crushing mode. This model can be applied to determine static and dynamic forces on slender structures as well as wide rigid structures by employing probability methods.

The two main objectives of this study are:

(a) A general review of offshore structures applicable for drilling and/or production purposes in ice-affected waters. Advantages and disadvantages have been listed for each structure depending on the severety of the ice conditions, water depth and other parameters.

(b) An evaluation of ice forces in general terms as well as for several offshore structures. The inter-relation between the magnitude of ice forces and the size and the shape of the structures has been demonstrated.

FENCO CONSULTANTS LTD.
CLIENT: INTERNAL USE ONLY
REPORT DATE: October 1980

Monitoring On Ice Platform Construction Manual

Overview:

A manual giving important information concerning travelling, preparing the ice pad for flooding, installation of the Moonpool, Flooding, Thermistor Banks, Borehole Jack Tests, Flaking Tests, Strain Gauges, Installation of tide recorder, Installation of Float recorder, Measurements of Deflection and Floating Ice sheets.

FENCO CONSULTANTS LTD.
CLIENT: DOME PETROLEUM LTD.
REPORT DATE: January 5, 1982

Ice Data Beaufort Sea, August and October 1981

Overview:

This report covers ice data collected from the Beaufort Sea during sea ice trials in August and October, 1981. The study included temperature and salinity profiles, borehole jack confined compressive tests, uniaxial compressive tests, and crystallographic analysis. The uniaxial compression tests and crystallographic analysis were performed in the FENCO Calgary Ice Lab on ice cores brought back from the field.

All of the ice floes tested were multi-year ice with warm temperatures. In the case of the August tests, the second-year ice exhibited extensive ridging.

This report includes a description of the test procedures as well as a presentation and discussion of the results. Ice strengths are described in terms of temperature, grain structure (size, shape and orientation) salinity, and stress rates; a standard format used for similar studies of this type.

Introduction:

The multi-year ice, during both the August and October tests, had very little saline content. The floes tested during the August trials were very ridged, while those tested in October had a lower relief but were more rafted. The grain structure was generally granular snow ice with some horizontally columnar sections. Ice temperatures ranged between 0 to -1°C during the August trials and -1 to -3°C during the October trials.

Borehole jack ultimate compressive strengths, which averaged 7.4 MPa, and elastic modulus values averaging 385 MPa from the August trials, were lower than the borehole jack ultimate compressive strengths (averaging 18.2 MPa) and elastic modulus values (averaging 2183 MPa) found during the October trials. These differences are a result of colder ice temperatures and older ice during the October trials. Ice strengths and elastic modulus values increase as ice temperatures drop.

FENCO CONSULTANTS LTD.
CLIENT: DOME PETROLEUM LTD.
REPORT DATE: January 5, 1982

Ice Data Beaufort Sea, August and October 1981

Uniaxial compressive strengths averaged 2.9 MPa for the August samples and 4.3 MPa for the October cores. The results again indicate the weakness of the test samples due to the warm testing temperatures in the field which were duplicated in the laboratory tests.

Elastic modulus values, calculated from the stress-strain curves of the uniaxial tests, for the two trial periods, averaged 4300 MPa indicating the brittleness of the ice due to its' low salinity content and age.

No definite relationships between ice strengths and crystallographic orientation were reached due to the small number of samples tested.

Uniaxial compressive strength studies of Arctic ice should be tested in the field, especially if they are to be compared to in situ compressive strengths. An alternative to the uniaxial tests is the flaking pit test, which is considerably easier to perform in the field.

Sandwell

FENCO CONSULTANTS LTD.
CLIENT: Department of Supply and Services
REPORT DATE: August 30, 1984

Evaluation of Medof Ice Load Sensor in the Arctic Environment

Overview:

During the winter season of 1983/84, FMS Engineers were contracted by the Department of Public Works, Government of Canada to install, monitor and analyze data from the performance of two MEDOF brand ice load panels. The MEDOF brand name ice stress panel is a hydraulic load versus fluid output device developed in partnership by Dr. M. Metge, Fenco Consultants Ltd. and Dome Petroleum Ltd. This panel has been used extensively by firms operating in Arctic offshore locations, as to date, over 200 of these typical 1 m x 2 m panels have been sold for offshore use.

The MEDOF panel installation at the Nanasivik DPW, Baffin Island, N.W.T. wharf was a remote location and as such a complete -50°C rated data logging system was setup to record the data. Located immediately adjacent to the MEDOF panel installation were similar systems of ice stress panels of three other firms. This entire project was carried out to study the performance of these four different ice stress sensors, relative to each other and also to investigate the ice stress regime around the DPW Nanasivik dock.

MEDOF SENSOR THEORY AND OPERATION

In recent years, offshore development in the Beaufort Sea and other offshore ice infested areas has resulted in the need for a sensing device for ice load measurement in the order of the structural component size of the involved structure. For this purpose, the MEDOF sensor typically of 1.0 m x 2.0 m size was developed.

The basic concept of the MEDOF sensor can be stated as follows: two large (usually 1 m x 2 m x 3.1 mm) steel plates are separated by a porous rubber material (2.5 mm thick) (Figure 2.1). The edges of the steel plates are welded together to form a large contained structure which through a vacuuming process is filled with a non-freezing fluid. This panel structure, when subjected to a load, expels the contained fluid proportional to the total load on the panel. This performance property is due to the fact that the inner rubber material exhibits linear elastic performance up to 20 MPa. Therefore, although the ice pressure over the panel will be non-uniform, the panel integrates the load response over the whole panel area with a resulting proportional total load versus expelled fluid relationship.

The MEDOF sensor has a linear calibration curve up to approximately 10 MPa since the effective inner rubber material area is approximately 50% of the panel area. The effect of temperature is small, less than 7 kPa/°C. The effect of creep in the buttons cannot be neglected, but it is relatively small: 10% in 24 hours at 1 MPa and a further 5% if a load is sustained over a 1 to 2 month period.

To measure ice forces, the MEDOF panel is either inserted in a slot in the ice and frozen in place or bolted or welded to the walls of the structure being monitored. As ice forces are exerted on the panel, fluid is expelled into a standpipe at atmospheric pressure. The amount of fluid or therefore the corresponding load is measured through the use of a 0 to 35 kPa pressure transducer located at the bottom of the standpipe. It is also typical that on a daily basis, a visual reading is taken on the fluid level in the standpipe as a check of the accuracy of the pressure transducer. However, at Nanasivik, this was not done since the site was remote and in the interest of a durable design, a steel standpipe was used instead of the usual plexiglass standpipe required for visual readings.

MEDOF panels constructed to date have varied considerably in size and weight to fit the requirements of various projects. For manual installation, where the use of equipment is restricted, a 100 kg, 1 m x 2 m panel has typically been employed (Figure 2.1). Where MEDOF panels have been welded to structures which are to be used in the Beaufort Sea, panels of up to 650 kg and 1.2 m x 2.8 m have been constructed.

CONCLUSIONS AND RECOMMENDATIONS

The MEDOF panel is not overly sensitive to temperature change where stress levels are in the order of 500-1000 kPa. However, for the Nanasivik project where the maximum stress levels were in the order of 80 kPa maximum, the thermal correction factors became quite significant. Since panels P18 and P10 had thermal correction factors of 7.3 and 4.0 kPa/°C for the 10°C ice temperature change present at the dock site, which represented 73 and 40 kPa. Two thermistors we installed in the ice profile; however, for accurate ice temperature data about 5 beads through the ice profile would have been desirable.

The above fact was noted to have caused a 0 pressure baseline drift in the panel data. In order to compensate for thermal drift a baseline was drawn through the lower peak values of the pressure data. Therefore it was assumed that on a regular daily basis the pressure on the MEDOF panel would drop to near 0 level. With this method the highest stress level observed was 80 kPa by panel P10 on March 22, 1984. The panel P10 pressure data was concluded overall to be quite accurate while the data of panel P18 was concluded to be useful for only qualitative analysis.

FENCO CONSULTANTS LTD./LAVALIN **CLIENT: TRANSPORT CANADA , TRANSPORT DEVELOPMENT CENTRE** **REPORT DATE: September, 1984**
Arctic Marine Design and Construction Handbook – Volumes I and II

Overview:

This handbook presents in two volumes a compendium of information and current practice in the design and construction of marine structures in the Canadian Arctic. The term "Arctic Marine Structures" is defined for the purpose of this handbook, as marine civil structures essential for secure berthing of vessels and transfer of cargo between vessels and a terminal.

The objectives of this handbook are:

1. To consolidate in one document existing knowledge related to the design and construction of Arctic marine structures.

2. To provide a useful reference document for planners, engineers and contractors.

3. To provide a basis for establishing design standards, guidelines and regulations for Canadian Arctic marine construction.

4. To identify gaps in current knowledge of ice engineering and/or Arctic marine design and construction practice.

5. To establish priorities for future research and development in the field of Arctic marine structures.

Volume 1 provides an overview of current Arctic technology as it applies to Arctic marine structures. Chapter contents are summarized as follows:

Chapter 1 presents background information on the Canadian Arctic as related to economic resources and environmental conditions. Basic functional requirements and types of port related civil engineering structures for the Arctic are identified.

Chapter 2 describes the Canadian Arctic marine environment and presents information on wind, waves, currents, snow, and other climatic and oceanographic phenomena.

Chapter 3 presents major aspects of ice technology and provides technical information upon which ice design criteria in the Canadian Arctic are based.

Chapter 4 defines Arctic geotechnical conditions and presents information on permafrost. The geotechnical design aspects of structures in permafrost are discussed. Information on instrumentation and monitoring of structures affected by geotechnical considerations are presented.

FENCO CONSULTANTS LTD./LAVALIN
CLIENT: TRANSPORT CANADA , TRANSPORT DEVELOPMENT CENTRE
REPORT DATE: September, 1984

Arctic Marine Design and Construction Handbook – Volumes I and II

Chapter 5 discusses responses to the Arctic ice environment. Ice control techniques are identified and various options for ice resistant structures are presented.

Chapter 6 presents existing regulations and standards for Arctic marine structures.

Chapter 7 presents design guidelines for Arctic marine structures based upon existing state of the art design practice.

Chapter 8 presents an outline of construction procedures and techniques currently utilized in the Arctic.

Chapter 9 presents an inventory of existing Arctic marine facilities.

Chapter 10 identifies information deficiencies and indicates those areas where research and development are required to upgrade existing knowledge in the design and construction of Arctic marine facilities.

Volume 2 provides a selected inventory of technical data which is most likely to be of value to engineers and contractors working on Arctic marine projects. The volume contains lists of technical publications, according to subject, followed by the abstracts of the listed publications. The appendix portion, in four parts, provides sources of information on the Arctic, as follows:

- List of regulatory agencies and organization, with latest addresses
- List of additional useful references
- List of technical conferences, of interest to the Arctic engineering
- List of Companies providing sealift transportation in the Canadian Arctic