SECOND INTERNATIONAL CONFERENCE ON
PORT AND OCEAN ENGINEERING UNDER ARCTIC CONDITIONS
UNIVERSITY OF ICELAND
DEPARTMENT OF ENGINEERING AND SCIENCE

UNDERWATER LABORATORY IN SUB-ARCTIC WATERS

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INTRODUCTION

The Faculty of Engineering at Memorial University of Newfoundland initiated the design of an underwater laboratory in March 1970 and had it installed by September 1971. The idea behind LORA (Low-temperature Ocean Research Activity), as the project was eventually named, was to develop a capability for studying engineering problems in Arctic waters. Although the project had virtually no supporting funds, material support from the local business community together with the enthusiasm of the designers carried the project to completion. The lack of funding naturally imposed restrictions on every stage of the design and also the installation. However, the project demonstrated that a low cost underwater habitat is within the capabilities of any educational institution or indeed any interested group of individuals with some engineering background.

In developing the design criteria it was decided that the habitat should be located in 35 to 40 feet of water and thus be non-saturated, so that people of average diving capability could use it. We hoped to popularize and encourage underwater research because of our belief that to solve problems in the ocean requires that people experience being in it. In this way they are better able to understand the special constraints of this environment. Obviously we had no desire to design a facility that could be used only by professional divers.

The structure had to be simple to construct and easy to install, requiring the minimum of site preparation. These criteria logically lead to our chosing commercially available, off-the-shelf equipment and instrumentation. In addition, the habitat had to be situated close to the University, to reduce travelling time, and on a location with a flat, bed-rock bottom for the anchoring system. Such a site was eventually found 12 miles from the University at St. Phillips, Conception Bay.

The main shell of LORA is made from an old cylindrical fish digestor tank, 8 feet in diameter and 16 feet long with a 5/8 inch wall thickness. This tank was modified to permit installation of two 30 inch diameter acrylic plastic domes, one in the end and another on the topside of the tank when lying horizontally. The end opposite the one with the dome has a flat disk of plastic fitted as a third viewing port. On the bottom side of the shell about midway along its length is a 3 feet diameter entrance hatch. The shell is held horizontally on a rectangular base frame of one foot H-beam, 9 X 16 feet, by three equally spaced hold down frames made of 6 inch U-channel. Four legs, of one foot H-beam and 4 feet long, support the shell and base frame. The total weight of the structure is 11 tons and the estimated cost of the complete structure is $5,000.

The interior of LORA is laid out to provide comfortable quarters for two men. The living area includes sanitation and cooking facilities, food storage area, sink and fresh water supply, communications equipment and berths. The work area, or wet-room, takes up approximately one half of the interior and contains tank storage racks, hookah supply system, suit storage area and the entry hatch. The interior is maintained at 70 - 80°F and 45 - 65 percent, relative humidity, using electric heat. A 2 inch thick foam urethane material coats the hull interior to provide thermal insulation. The ventilation system uses compressed air, with flow rates and patterns adjusted to maintain CO_2 levels within Canadian breathing gas standards.

Power, for light and heat, air, and communications links are provided through a composite umbilical cord which runs some 500 feet from the shore facility. This facility houses the compressor, electrical distribution panels, a data collection and control room, changing facilities, and work and equipment storage areas.

The LORA anchoring system consists of two types of mooring for ease of installation and to ensure resistance to even the severest storm conditions. Dead weight in the form of six concrete blocks was attached to the structure after it had been lowered over the side of a ship and into the water. The habitat floated without these concrete blocks. When LORA had been weighted down to the bottom by the blocks, rock bolts were placed through the footing plates attached to the habitat legs and guy wires, also rocky bolted to the bottom, were attached. These rock bolting techniques provided resistance to horizontal motion and to some extent to vertical movement.

A severe storm struck the area before LORA could be completely anchored thus forcing us to flood the interior to keep the structure on the bottom. It became obvious that we needed additional dead weight. Twelve tons of railway track were added to LORA with completely satisfactory results. This system has withstood many severe storms and a number of impacts with heavy arctic ice.

DIVING UNDER ARCTIC CONDITIONS

To install, maintain and use a facility such as the habitat, extensive diving operations are required. A major concern of the program was to determine exactly what difficulties there are in performing work under arctic conditions. The term "arctic conditions" is used since in the underwater phase, water temperatures (- 2°C) are equivalent to any found in the far north. The dynamic ice field also makes this valid term. To date, many observations have been made concerning divers ability to work in the cold environment, and many problem areas identified. Some of these will be studied in detail in the future.

The use of divers plays a major part in many construction projects, and with increasing development of the north, divers must develop the capability of staying in the water for extended periods. Oil exploration and scientific investigation depend heavily on diver support. The following briefly describes a few areas of concern in cold water diving operations.

ACCESS PROBLEMS

The dynamic nature of the ice found in Newfoundland, and the speed with which conditions change, make diving in and around ice extremely dangerous. Diving procedures must be adapted to meet the particular circumstances encountered. For example access from shore is limited since the slush density is such that the diver loses mobility to the point where it becomes dangerous. Heavy slush retards small craft movement and can completely stop it. Loosely packed ice pans present no major access problems, as boats and divers can route through natural openings. The danger arises in the ever present, and highly likely possibility that wind shifts will pack the flows together entrapping the diver. A tightly packed field will support divers and equipment but it is extremely difficult to keep a hole open once one has been made. Heavy arctic ice and growlers pose a serious threat to boats and the habitat itself. To the divers, the most serious threat is breaking ice or instability which could cause the mass to roll over on them.

Figure 1.
ICE DIVING

Diving through ice in the high arctic may prove less hazardous, since the ice is in very large sheets and is often shore fast. In this case transport to the dive site by vehicle is possible, and once an opening is made there is little danger of it closing in.

THERMAL PROTECTION

The most obvious difficulty in operating in cold water is keeping the diver warm enough to perform useful work. A variety of protective suits are available, each of which has specific application. For shallow water work (0-150 feet) variable and constant volume dry suits, used with scuba or light surface supplied gear, are ideal. These provide the diver with a high degree of mobility and good thermal protection. In our operation, dry suits, combined with adequate work-rest cycles enable divers to spend over five hours out of ten in water at $-2^{\circ}C$. It should be noted that for many construction-salvage operations, conventional heavy gear is widely used, and for deep, mixed-gas work, supplemental heat sources are required.

AIR LINE FREEZING

In water below $1^{\circ}C$, demand regulators are prone to "freeze-up" in which ice formation hinders proper mechanical function and may cut off the divers air supply. This is a very critical situation, especially if the dive involves decompression or under-ice activity. All regulators are subject to this problem unless modified. Double hose units are less likely to freeze, but they do so on occasion. A new model incorporates "anti freeze" protection which appears to be effective. It is extremely important that compressed air for breathing use in cold water be free of all moisture content. This entails addition of extra drying processes to most compressors.

Our experience has been that large diameter air lines in excess of 100 feet in length will accumulate sufficient moisture to cause the line to become completely blocked by ice. This occurred frequently in our 1.5 inch diameter supply line feeding air to the habitat. The same freezing problems occurred while using compressed air tools (drills etc.). The length of line is the major cause for concern since we find that lines 100 feet or less in length pose no icing problem. Most of our work was done using 500 feet of hose, and this caused major difficulties. When considering operations in arctic waters, steps must be taken to use the minimum amount of hose and to dry the air before it enters the line.

Figure 2.
DRILLING UNDERWATER

ICE OBSERVATIONS

The following comments are based on subjective observations made while diving under and around ice in the habitat area. Future detailed study in one or two areas is planned for the future.

Ice conditions vary yearly, with the last season being exceptionally severe. Long range forecasts indicate equivalent or heavier conditions for the next few years. The seasonal ice cycle is fairly regular.

From early to mid December, water temperatures fall steadily until they reach -2^{o}C. The temperature remains sub-zero until spring. The first signs of ice are the freezing of the river fed harbour area, and the appearance of a thin "oily" layer of slush in the cove. Sustained on-shore winds compress this layer horizontally and it becomes visible as a grey slush lining the shore. By early February the slush layer will extend 200 to 300 feet from shore and be 2 to 3 feet thick at the shore. The near shore slush has a very grainy texture, with solid ice particles suspended in it. This gradually changes as one proceeds from shore, with the outer portion of the layer giving the water a glassy appearance. The layer is dense enough to retard boat traffic and damp wave action, reducing wind chop to rolling swells. The density and expanse of the layer increases until, by mid February, it begins to consolidate and large pans form. The ice will extend one to three miles from shore and vary in thickness up to eight inches. By the end of February, the slush layer is no longer observed and evidence of local rafting is noticed.

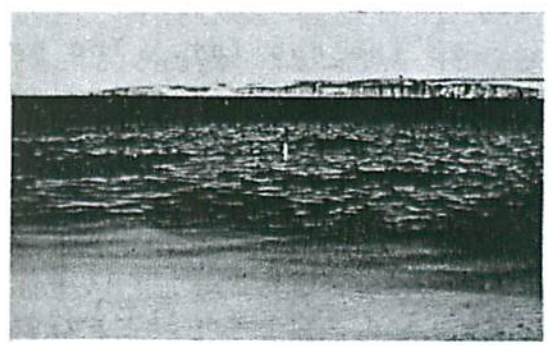

Figure 3
SLUSH LAYER

From March to May heavy arctic ice enters the bay and cove area. Large masses of ice, called growlers in Newfoundland, are seen among flat ice pans. The growlers and pans vary in size up to 200 feet in diameter, and some of the growlers run aground in over 60 ft. of water.

The ice field is highly influenced by wind changes, and moves in and out very quickly and frequently. By the end of May the ice field is substantially reduced in size, with only occasional, isolated pieces appearing in the bay. These tend to be quite large and present a significant threat to the habitat. From early April until July, large icebergs enter different parts of Conception Bay, but none have passed within five miles of the habitat. The large bergs are no danger since they ground in much deeper water than that in the habitat area.

Figure 4.
EXTENSIVE LOCAL ICE COVER

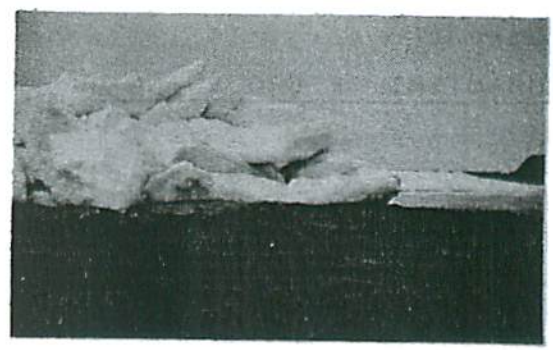

Figure 5
GROWLER

GENERAL DESCRIPTION OF GROWLER ICE

Growler ice was responsible for severe bottom scouring and damage to the habitat structure. The composition of a growler can best be described as being a mass of rafted ice. This mass consists of a "main" plane, composed of a single or composite pan, in a near horizontal position, at water level, with smaller pieces of ice heaped at assorted angles above and below. The surface mass appears rather loosely packed with voids and snow filled spaces between the hunks. The sub-surface mass is composed of similar pieces, with the major difference being that the total mass is much greater than the surface counterpart. The average thickness of the pieces in both masses is of the same order as that of the sheet making up the main plane. Also the ice pieces in the underwater mass are held by a "mortar" of slush ice and/or hardened ice in areas where above water there would be spaces. The hardness of the icy mortar varied with the time of year, but on many occasions, both hard and soft areas were common on the same growler. There was no apparent pattern to the variation.

The underwater profile of the ice is quite irregular with tunnels, indentations and sharp protrusions. Late in the season, the local features became well rounded but the overall shapes remained typical.

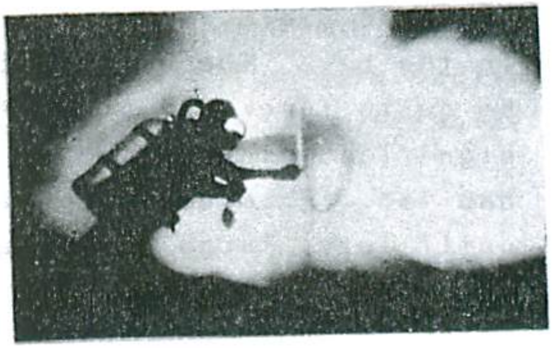

Figure 6.
UNDERWATER FEATURE OF A GROWLER

MECHANISMS OF GROUNDING

A series of divers and daily surface observation provided a record of how the ice grounded, its action while aground, and in depths from 20 to 60 feet and ranged up to 150 feet in diameter.

Isolated growlers, entering the cove, normally were affected by wind and current and contacted ledges and outcrops around the perimeter rather than grounding in the middle of the cove. These pieces proceeded in deep water until their leading edges contacted a ledge. Wind and wave action held them in a state of dynamic contact with the rock. The horizontal component of the roughly orbital motion appeared the largest and the result was a regular, audible impact. The impact, which was over a small area due to surface irregularities, resulted in the rock face being shattered, scraped clean of encrustations and marine life, and left with a rather polished appearance.

Figure 7.
ICE ROCK INTERFACE

No appreciable wear was apparent on the ice, although small bits of stone and seaweed were imbedded in it. The observation periods were relatively short, and measurements will be required to determine ice erosion.

Grounding on the sloping bottom in the centre of the cove occurred when the growlers moved in surrounded by pack ice. The ice progresses inshore until the deepest protrusion makes contact with the bottom. A subsequent lifting, forward motion and settling process caused by wave and tidal action, results in the ice moving ahead in a step progression. As the ice settles in the wave trough or with falling tide, it also twists and tilts due to subsurface irregularities and forces exerted by the pack This combination of motions results in the bottom being pitted, boulders being uprooted and overturned, and all marine life and encrustation being removed. The area affected by an individual piece varies in diameter up to 80 feet.

In sandy areas, gouging and pitting was observed. The pits were 6 to 10 inches deep and 3 to 5 feet in diameter and were apparently caused by sharp protrusions settling into the bottom. Nowhere in the area was there evidence of a continuous gouge or track being caused by a steady progression of a single piece of ice. The size of the ice, surface condition, and the tidal influence would prevent this occurrence.

Figure 8.
SAND PIT

By using highly mobile divers and proper diving procedures, it should be possible to obtain direct mechanical measurement of such things as impact force, ice wear over time, and a number of other parameters of interest. Observations have been made of the break up of growlers, and past experience indicates that we must be able to predict such break up to ensure the safety of the divers and boat operators. Signs of impending break up have been noticed and it is hoped that these will provide a reliable warning system.

ICE DAMAGE TO HABITAT

During the period of heavy ice, the habitat received direct hits by growler ice. The resulting structural damage was insignificant, a fact directly attributed to the presence of a guy wire system which served to deflect the ice and lessen the force of contact made.

The habitat has six, one inch cables (6 X 19 IWRC galvinized) running from the four corners and two midpoints of the superstructure to rock bolts (1 inch X 30 inch M.S.)placed in the bottom in appropriate positions. These tensioned guy wires were originally intended to provide vertical stability and reserve hold down capability, and thus were not designed specifically to act as ice protection.

From March to April, extremely heavy ice cover existed and ice was observed resting on top of and beside the habitat.. This was directly evidenced by a significant change in the height of the ice showing above water at low tide. The complete cover prevented diver access, but dives made immediately after it moved out revealed considerable scraping on the side and front of the hull, destruction of a welded steel mounting bracket, and the parting of a one-quarter inch stainless steel subsurface buoy line. Of particular interest was the effect of the ice on the guy wire system.

Two rock bolts were bent, causing the attached cables to lose tension, and ice contact on the two cables which terminated in buried boulders (as opposed to bedrock on four) had pulled these boulders free of the bottom and dragged them close to the habitat, effectively making the cables useless. Both boulders were over four feet in diameter and between 75 and 80 percent buried.

At this point in time it was suspected that the cables had been, and were, deflecting ice away from the main body of the structure. This view was supported by the fact that the only evidence of direct contact was found on the side where the cables had been left slack. A subsequent, and fortunate, set of circumstances provided direct observations on the ice-cable interaction.

In mid May an isolated growler, some 150 feet in diameter and 30 feet deep, was observed approaching the habitat.

Diving and photography commenced immediately and the ice was observed as it contacted the cables and subsequently moved inshore. The leading edge of the ice contacted the inshore, forward guy wire and remained in contact. The ice motion caused the rock bolt to flex and relax, introducing some spring in the cable. The ice, under continuous wind stress,pivoted around the point of contact and was left orientated along the side of the habitat completely covered and surrounded on one side and one end. The ice rode slowly up and down on the two cables. At this time, the ice was also contacting the bottom at several points directly under its mass. A gradual wind shift moved the ice inshore and the structure was no longer in danger.

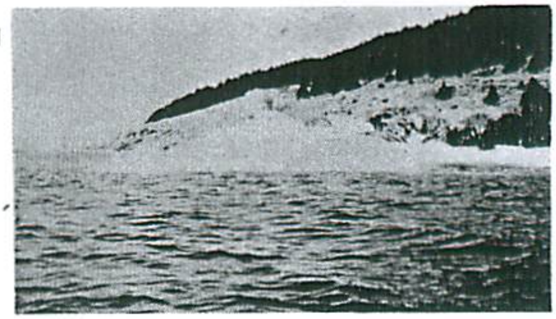

Figure 9.
GROWLER

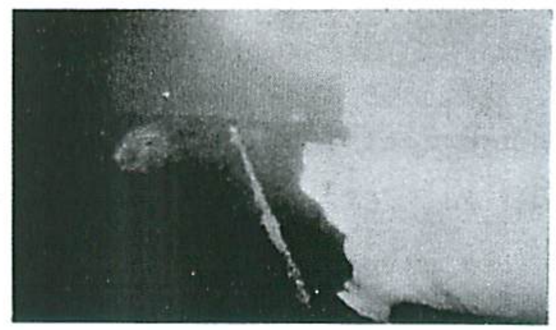

Figure 10.
GROWLER ON HABITAT

Based on the entire season's survey, and the specific incident described above, the following observations are significant:

> There was no failure of the hardware involved.
> None of the rock bolts were pulled free of the rock into which they were placed.
> There was no geological failure associated with the cables terminated in bedrock.
> Underwater observation showed that the cables formed a spring system which caused the ice to deflect from the structure.

These observations provide strong evidence that shallow, subsea structures can be protected from heavy inshore ice, by the use of a properly designed and installed guy wire system. There are a number of constraints, some being: depth, bottom type, type and size of structure, and above all, size of ice involved. The effectiveness of any exposed mechanical system in deflecting large icebergs is doubtful, but where intermediate and small ice masses are