INSTALLATION OF A CROSS-SHORE CABLE
JOLLIFFE BAY, 1994

by
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INTRODUCTION

The Spinnaker Project was a joint Canadian/US endeavour to install an array of Hydrophones on the bottom of the Arctic Ocean north of Alert and to bring the data back to CFB Alert via fibre-optic cable. There were many unusual and interesting problems to overcome during this project, both in the installation of the array, which was the American responsibility, and in the laying of the 180 km of fibre-optic cable, which was the Canadian responsibility.

One of the problems, which on first sight seems rather minor, is that of protecting the cable as it passes from deep water up onto the shore. Unless it is well protected in the shallows just off-shore, the cable will be destroyed by the heavy pack ice that is pushed into the shallow water and up onto the foreshore. No matter how well a cable is armoured, it cannot withstand the forces involved when the heavy ice freezes itself to the cable and then moves. Moreover, our previous experiences had shown that keeping this cable away from the ice was not at all easy. In past installations we had tried to protect the cable from the ice by burying it several feet deep as it crossed over the danger zone. We had used both high-pressure water-jets and explosives to dig a deep enough trench to hide the cable away from the ice. In all cases (but one) we had failed. The ice bulldozed away the gravel, found the cable and destroyed it. We had been burned too many times to think of this as minor problem. The considered judgment was that unless we could reliably protect the cable as it crossed the shore, there was no point in installing an expensive array and laying 180 km of cable.

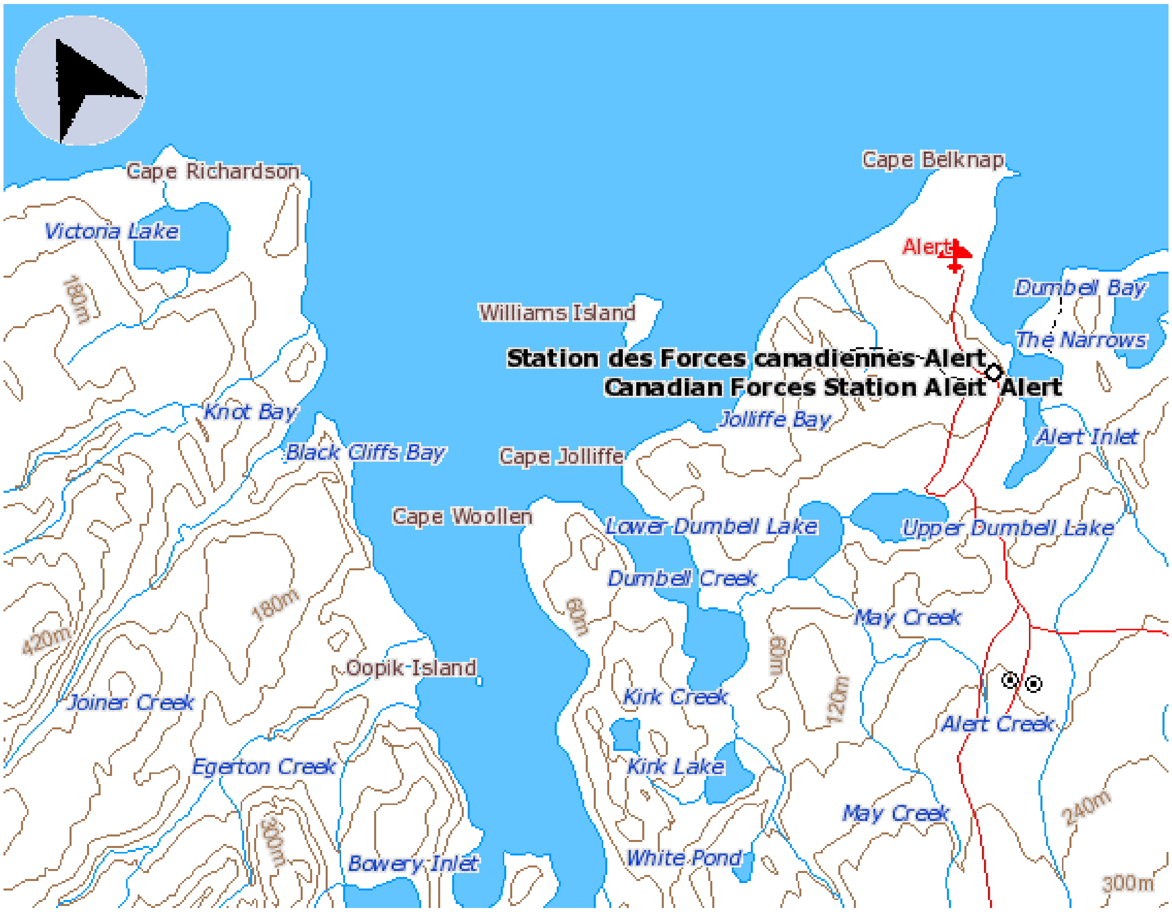
The only way that we had found to protect the cable reliably was to drill a conduit for the cable through the rock of the foreshore. The hole started on the shore well above the reach of the pack ice, and it passed through solid rock under the silt and gravel of the foreshore. The hole then curved upwards until it entered the ocean bottom at a point too deep for it to be disturbed by the heavy keels of the pack ice.

The spring field trip of 1994 was devoted to the drilling of this hole and the stringing of the cable through it. This is the story of that project.

LOCATION

In 1993, several candidate sites were examined. The near-shore bathymetry was measured to ensure that it was deep enough for the cable where it entered the ocean and that there was a channel deep enough for the cable-laying AUV to get out into deep water. Also, rock cores were taken at each site to ensure that the rock formation was hard enough (‘competent’ was the geologist’s term) to support the drilling of a curved hole.

After all the evidence was examined, Jolliffe Bay, which was about 5 km north-west of Alert, was chosen as the most promising site. In the map below, note the diamond that indicates CFS Alert. Jolliffe Bay is to the east of Alert and to the south of Williams Island. The cable crossed the shoreline at the slight promontory east of the Bay.



The major requirement was to have a steel-cased hole connecting the shore to the ocean in the vicinity of CFS Alert, NWT, and inside this pipe there was to be a fibre-optic cable linking the ocean bottom with the shore. The hole's entrance on the shore was to be sufficiently removed from the ocean that it would not be endangered by pushed-up ice. The exit point in the water was to be deep enough that the possibility of ice scouring was negligible. A fifty-metre depth was the aim.

WHAT WAS ACHIEVED

After all the problems had been solved and all the compromises had been made, a cased hole complete with fibre-optic cable was in place. The entrance hole on shore was 14 m above sea level, well away from pushed-up ice, and the underwater exit point was in 36-m deep water. This depth is somewhat short of 50 m but is still deeper than that of any measured ice ridge. The steel encased hole is threaded by a doubly-armoured fibre-optic cable which is terminated with a junction box at the wet end. The junction box was lowered to the bottom to await recovery next year. Its position, relative to the Jolliffe

Bench Mark, is 275.8 m at 340° 29', using as bearing reference the cairn on William Island at 359° 46' 44". The dry end of this cross-shore cable will be spliced to another cable that runs to Alert.

COMPANIES PARTICIPATING

Foundex Ltd. Prime Drilling contractor
Computalog Ltd. In charge of directional drilling and down-hole surveying. (Subcontracted by Foundex.)
HBT AGRA Ltd. Geophysical engineering expertise. Contracted by DREP to act as advisor before and during the drilling.

THE DRILL PATH

The drill path consisted of three major sections. The first, as shown in Figure 1, was the passage through the overburden down into the solid bedrock below. Overburden, which is gravel or shattered rock, or both, is often porous, especially when the entrained water is not frozen. This can make drilling difficult because the cutting fluid (or 'mud') may drain into the surrounding rock instead of returning to the surface around the drill pipe. Then, instead of coming to the surface, the cuttings may pack around the turning drill rod and jam it. The first part of the drilling, then, was to install a conduit for the returning drill mud and cuttings. A large hole was drilled through the overburden and into the bedrock. A pipe (or casing) was fed down this hole and sealed into the bedrock. The remainder of the drilling was done through this (large) casing with a smaller drill rod.

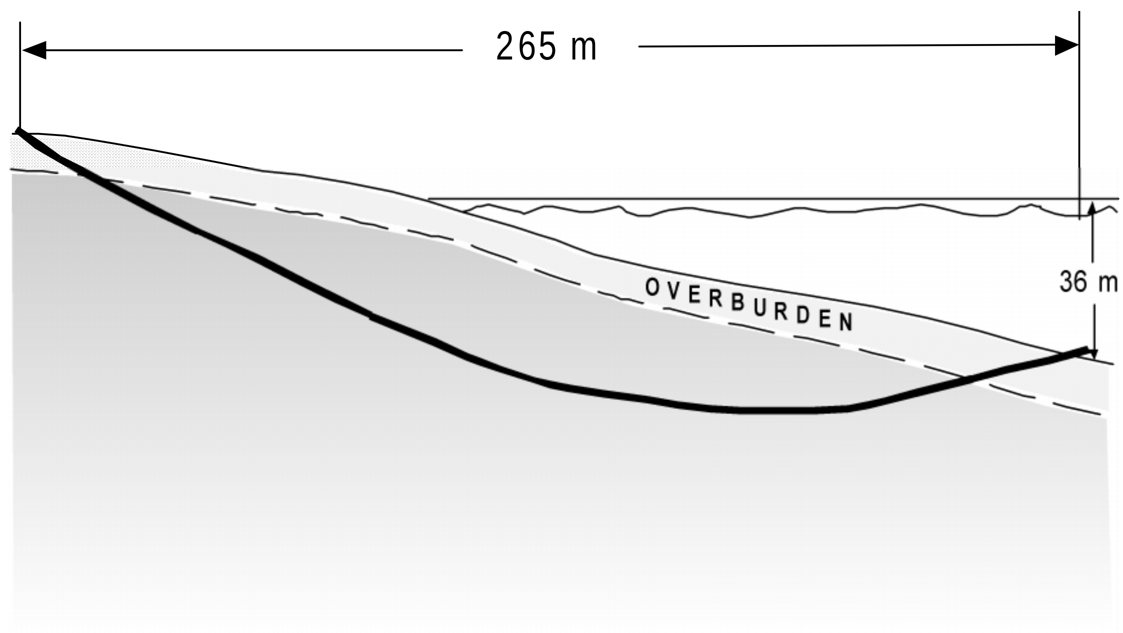


Figure 1: Profile of the drill path from the shore (on the left) to the sea bottom (on the right).

The second section of the drill path went through the bedrock. Here there was little concern that the drill mud would be lost unless a bad fault was encountered. It was in bedrock that the direction of the hole could be controlled. A problem that arose in this project was that the rock was harder than expected, and the drilling was very slow. Moreover, the high ram forces associated with the difficult drilling resulted in repeated equipment failures.

The third section of the drill path was that of the passage back up through the overburden and into the ocean. During the planning period this was considered to be the most dangerous part of the project because loose rocks in the overburden might fall into the cavity behind the bit, preventing the drill from being withdrawn. It was the drillers' hope that they could pass quickly through this section without ever having to withdraw the drill rod.

DRILLING TECHNIQUES

Two drilling techniques were used. In one, the bit was turned by the drill pipe, which was rotated by the drill rig at the surface. This was the technique used in passing through the overburden, both going down and coming up. It does not require a great deal of mud - just enough to clear the cuttings from the bit.

In the other technique, the drill pipe did not supply the drilling rotation. Instead, a Directional Drilling Assembly[1] was attached to the bitter end of the drill pipe. This Assembly, which was about 20 ft long, contained the bit and a motor to spin it. The motor, known as a mud motor, was powered by the flow of mud through a helical passageway. The mud was pumped down the drill pipe from the surface, through the mud motor and thence to the surface through the annulus between the pipe and the bedrock. Since a lot of special mud was used in powering the down-hole motor, it was important that it be returned to the drillers and not be lost into the overburden. Hence the care in casing the surface overburden. At the surface, the rock cuttings were centrifuged out of the mud, and the mud was reused.

The end of the Assembly that contains the bit is bent at the end to enable the drilling of a curved hole. This section is known as the ‘bent sub’. From on-top the drillers could control the orientation of the bent sub so that they could drill upwards or downwards or in any other direction. When they wanted to drill in a straight line they rotated the whole drill stem slowly while continuing to drill with the mud motor. On some Assemblies the bend at the end can be adjusted. On other models the angle is pre-set. On the adjustable assemblies used on this project, the angles ranged from 0.5^o to 1.5^o. The curvature of the hole produced by the Assemblies was measured in the number of degrees of curvature per 100 ft (30 m). They could easily curve the hole more than 10^o per 100 ft; however, for the safety of the equipment the crew liked to limit the curvature to 7^o per 100 ft. The rock formation, itself, has a number of factors that can either increase or decrease the rate of

[1] For an overview of directional drilling, see Scientific American, May, 1994.

bending. Consequently, a given angle on the bent sub does not always produce the same curvature in the hole.

This brings up the question of how the angle with the horizontal is measured. First of all, this measurement was not made continuously, although on some of the new equipment this is possible. Rather, the drillers did a survey every hundred feet or so. Their technique was to stop the drilling and then pump a rod containing the measuring equipment down the drill pipe. When this equipment reached the Directional Drilling Assembly the measurement rod latched into a carefully machined cradle so that it lined up exactly with the Assembly. A plumb-bob ball (in a fluid) and a magnetic compass (useful in the south but not at Alert) indicated the dip and the bearing of the sub at that location. After a pre-set length of time a photograph of the plumb bob and the compass was taken (automatically) in order to record the data. The measuring rod was removed by wire-line, and the photograph was developed and read. The path of the drill between pairs of readings is assumed to be the arc of a circle. (An arc-length and the two angles at the end-points is sufficient to define a circle uniquely.) In this way the shape of the curved hole was monitored. Judging by the precision with which the drillers predicted the exit point, the equipment was remarkably accurate.

DRILLING NARRATIVE

A fairly flat and level location was chosen for the drill rig. It was at a height of 14 m above sea level and about 100 m from the sea. It was 337 m from our desired exit point (horizontal range) and 265 m from the actual exit point.

On 11 April the initial contingent from Foundex started putting up the large tent that was to shelter the drill rig and the drillers. It was completed on 14 April. Also on the 14th the drill rig arrived at Alert and equipment began to move to Jolliffe. By 21 April the rig was in place and anchored, and all the associated engines, motors and pumps were ready to go. From 22 to 25 April the surface casings were installed. A 7 11/16" casing was drilled to a depth of 26.5 ft, and inside this a 5.5" casing was drilled down to 67.5 ft. The bedrock started at 58.5 ft. Two breakages in the drill train (in the Kelley sub) occurred during the first few feet of drilling. These were welded.

On 26 April the drillers started the hole proper with a 4.5" tricone bit. Troubles came thick and fast. The rock was too hard to be drilled by the tricone. They shifted to the directional mud motor with a PDC bit. It, too, was slow. The hydraulic oil was overheating. Everyone was upset about the unexpected hardness of the rock.

From the 27th to the 29 various bits were tried without much success. The survey device was tried and found wanting; it needed to be overhauled. Finally, on the 29th it was decided that key people would go back to Vancouver for a meeting with all concerned in order to work out a realistic approach for the completion of the job. New bits were to be designed and built to handle the hard rock; mud pumps were to be repaired, and hydraulic cooling systems were to be installed.

Little happened until 11 May when new equipment arrived. For the following few days good progress was made, but on 15 May the down-hole mud motor failed. An oil seal had blown, and the unprotected bearings had been rapidly ruined. This was followed by a further stand-down while the crew waited for new mud motors and more diamond bits.

On 19 May the new mud motors (some high speed and some medium speed) arrived. Also, the newly designed diamond matrix bits arrived. On the 20th drilling went well until the new mud motor, which had operated only 13 hours, failed. It was replaced with a new one. At that point the principals began discussing the possibility of a shorter hole and a shallower depth.

On the 21st the second new mud motor failed - bearings again. Only a lower speed motor was available, and it was pressed into service. However, it gave poor drilling production, and the diamond bit was polished and almost useless after a few hours of cutting.

On the 22nd a new diamond bit was sent down the hole. The survey operation was still having trouble with the latching; they took two hours to do a survey. By this time the length of the hole was only 382 ft, and the rate of advance did not look good.

On 23 May the rock type changed. The new rock was lighter in colour, softer, and much easier to drill. The hole advanced 79 ft that day, a very encouraging distance. On the 24th the third mud motor failed. It was replaced by another medium speed motor. Apparently, a high speed motor was available, but the bent sub had a pre-set angle of 1^{o}, and the drillers thought that this was dangerously high. They wanted a 0.5^{o} angle. After two days of fairly poor production, they pulled out the medium speed motor and put down the high speed motor that had the 1^{o} bend. Performance picked up, and on the 27th the drillers advanced 107 ft. By this time the hole was angling upwards. A new problem was now worrying the drillers; the mud pump, which had done yeoman service, was starting to leak badly, and they were worried that it might not last the course.

On the 28th, the drill was hitting the occasional short section of fractured rock, which indicated that the overburden was getting near.

On the 29th, the drillers lost circulation at 827 ft (252 m). In other words, the mud no longer returned to the drill head, and this indicated that they were in the overburden. At first they suspected that they had exited into the ocean since the mud dropped away so fast, but this turned out not to be the case. For the passage through the overburden the mud motor was pulled ('tripped') out and was replaced by a casing advancer and a tricone-centre. The casing advancer was a diamond studded annular bit, which was to be left on the casing once it had pushed though into the ocean. The tricone-bit centre, which was there to drill out the centre of the rock core, plugged the pipe and had to be removed before the curved hole was useful to DREP. This centre bit was especially constructed to be removable with a wire-line from the surface.

Once the drillers lost circulation, the small ROV, Seamor, was sent down to look for any evidence of a break-through. NRAD's Seamor, which had a very light-sensitive camera was used, and it found a plume of silt coming from a fairly large area off to the left (as seen by the drillers) of the anticipated track. Shortly after this the NRAD Seamor sprung a small leak, and DREP's Seamor was brought into service. Its camera was not so sensitive, and all subsequent underwater work was hampered by the poorer picture quality.

In the early hours of 30 May, the drill exited into the ocean at a drill length of 922 ft (281 m) and a water depth of 35.8 m. The drillers did not realize this at the time since the drill had been pushing through very soft bottom sediment, and they continued to push rod until 963 ft (285 m) was in place. Seamor then started looking for the pushed-out pipe. For a long time Seamor looked off to the left of the intended track because of the evidence of the earlier silt plumes. During this period more casing was pushed out in order to make sure that the ocean was, in fact, reached. By the time Seamor found the pipe (well off to the right of the intended track) a total of 983 ft (300 m) of casing had been pushed down the hole, about 60 ft (18 m) too much.

Although there was great jubilation on finding the pipe, the problems were not over. What was not known at the time was that the casing advancer and the tricone centre had broken off as the drill had passed through the last hard rock. Also, the 60 ft of pipe that had been cantilevered up from the bottom of the ocean had broken off a little below the surface. Consequently, when the overshot recovery tool that was to capture the tricone centre was sent down, it caught at the break and could not be removed. For a long and very grim time it looked as if the casing would remain permanently plugged. Finally, by dint of a great effort by the drilling crew, they got the recovery tool back.

By this time it was strongly suspected that the pipe was broken, but the location was in doubt. Luckily, the break was just below the ocean bottom, and it was easy to push out a few more feet of pipe. The pipe was flushed out, and a light tag line was pumped down the pipe. Seamor grabbed the float at the end of the line and pulled it up to its ice hole.

The tag line was used to pull the fiber-optic cable back up the casing to the shore. First, the tag line was transferred under the ice to a nearby ice hole which was at the required location for the junction box, the box that would contain the cable spices. The reel of fibre-optic cable was stationed on the ice beside the hole, and the cable was attached to the tag line.

The fibre-optic cable was now pulled down the ice hole, into the steel casing on the ocean bottom and up through the fore-shore onto the land. While three or four people walked the cable up onto the shore, Seamor watched the cable as it entered the casing. It was desirable that the cable enter the centre of the pipe and keep away from the (possibly) rough edge of the steel casing. This was effected by maintaining the correct tension on the fiber-optic cable as it went down the ice hole and into the casing. The cable-reel operator, who was maintaining tension by riding a brake, was guided by the Seamor operator who was watching the cable enter the pipe.

When 50 m of cable was left on the drum the cable-pulling was stopped. This extra slack was left as a possible aid to the next year's operations. The cable end was sealed into the junction box which was then lowered to the bottom together with the remaining cable. The position of the exit hole and of the junction box were surveyed.

On shore, the fiber-optic cable was coiled up and protected, and the open end of the casing pipe was sealed.