The Story of Offshore Arctic Engineering

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By

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To
My Wife Ginny and my sons,
Greg, Andrew, and Mark
Who lived through this work as my partners
In life

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The author does not pretend that the work and / or projects described in this book were the achievement solely of the author's effort and knowledge. Many people with different knowledge, skill sets, and interests were required to pool their efforts and abilities to sell and then ensure the success of the work. The author feels very privileged to have worked with a large number of wonderful, competent people over the years, many of whom are still friends.

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Chris Masterson (brother), Denis Baudais, Roger Pilkington, Bill Graham, Carolyn Matiisen, Ginny Masterson (my wife)

PREFACE

In the fall of 1971, I just happened to be in the right place at the right time. I had just completed my PhD and was looking for work. I was told to contact Hans Kivisild, an engineer with FENCO, Toronto, who had just been given a contract from an oil company to investigate an engineering issue in the Arctic. This started my career in Arctic engineering, just when the second major exploration phase was beginning in the western Arctic, 123 years after Franklin started the first phase of exploration in the area looking for the Northwest Passage. This recent phase was also filled with individuals who were going "where few had gone before," but unlike the earlier explorers, these recent explorers were accompanied by regulators, scientists and engineers who wanted to ensure that the environment was protected and also to ensure that the operations were carried out in the safest and most cost-efficient manner.

Between about 1970 and 1995, several oil companies and Arctic consulting companies turned Calgary into a world leader in Arctic technology. It was a time that one could have an idea, check it out in small scale, and within one or two years, use it in a full-scale operation. During this 25-year period, industry drilled many wells in the Arctic using the technologies described in this book. In 1995, the oil industry pulled out of the Arctic mainly due to lack of government incentives and poor drilling results, and then in 2016, both the Canadian and United States governments declared a moratorium on Arctic drilling. I retired in 2015, so I was fortunate that my career spanned the period of Beaufort Sea and Arctic Island exploration from start to end. Most of my work involved investigating pioneering ideas, which originated from my many colleagues and me, into the use of ice as a construction material for ice islands and ice platforms for exploratory drilling, and ice roads for moving the heavy equipment required by the oil and mining companies working in the Arctic both on grounded and floating ice. The remainder of my work involved measuring the failure strength of ice to support the operational projects, and for use in ice interaction models to determine loads caused by both sea ice and glacial ice impacting structures.

Most of this work has been written up over the years in many technical papers, which have been published in journals or presented in conferences by my colleagues and me. This book brings together this work into one place and presents it in a form that is of interest to engineers and non-engineers who have a keen interest in the Arctic. I also present anecdotal information of things that happened to me “behind the scenes” that have not been published anywhere else, but which, I feel, were interesting aspects of my career.

This book is composed of the main body, from section 1 to 26 which give the interesting details, technology and results of ice engineering and exploration. However, the reader is directed to sections 27 through 32 for additional information, especially sections 31 (Appendix D, which is a paper given to the Society of Naval Architects and Engineers in 2010 in Calgary which summarizes many of the works in this book and public technical information) and 32 (Appendix E, which is a list of papers authored by this writer alone or together with others that bring all of this information into the public domain). They are crucial reading if one is interested in obtaining the detail behind all of the technical aspects of ice engineering as developed over the past 45 plus years and actually incorporating this technology into practical works.

1. INTRODUCTION – THE GENESIS OF ARCTIC EXPLORATION

Interest in the Arctic Offshore was initially shown by explorers who sought a reliable route from east to west through the ice-covered waters of the region. This was the "Genesis" period of Arctic knowledge for Europeans. However, in the twentieth century mankind's appetite for coal and oil and gas was growing rapidly. This growing demand, coupled with knowledge that the technology required, such as shipping, air transport, heavy mining and drilling equipment had been established, spurred activity. The logging industry in northern Ontario, Quebec and other cold regions of Canada contributed much needed knowledge, especially as regards the transport of heavy loads over floating ice covers.

The exploration history of the U.S. offshore oil and natural gas industry began in the Pacific Ocean more than 100 years ago. America's offshore petroleum industry began in the late 19th century in the Pacific Ocean with drilling and production piers at Summerland, California. In 1896, as enterprising businessmen pursued California's prolific Summerland oilfield all the way to the beach, the lure of offshore production enticed Henry L. Williams and his associates to build a pier 300 feet out into the Pacific, and mount a standard cable-tool rig on it. By 1897 this first offshore well was producing oil and 22 companies soon joined in the boom, constructing 14 more piers and over 400 wells within the next five years. The Summerland offshore field produced for 25 years – fuelling the growth of California's economy.

Drilling platforms also appeared on lakes in Ohio and Louisiana. By the 1940s, technology was taking wells far into the Gulf of Mexico, but as recently as 1947 no company had ever risked drilling beyond the sight of land.

The Canadian petroleum industry arose in parallel with that of the United States. Because of Canada's unique geography, geology, resources and patterns of settlement, however, it developed in different ways. The evolution of the petroleum sector has been a key factor in the history of

Canada, and helps illustrate how the country became quite distinct from her neighbour to the south.

Although the conventional oil and gas industry in western Canada is mature, the country's Arctic and offshore petroleum resources are mostly in early stages of exploration and development. Canada became a natural gas-producing giant in the late 1950's and is second, after Russia, in exports; the country also is home to the world's largest natural gas liquids extraction facilities. The industry started constructing its vast pipeline networks in the 1950's, thus beginning to develop domestic and international markets in a big way.

Despite billions of dollars of investment, its bitumen - especially within the Athabasca oil sands - is still only a partially exploited resource. By 2025 this and other unconventional oil resources - the northern and offshore frontiers and heavy crude oil resources in the West - could place Canada in the top ranks among the world's oil producing and exporting nations. In a 2004 reassessment of global resources, the United States' EIA put Canadian oil reserves second; only Saudi Arabia had greater proven reserves. In 2014, the EIA ranked Canada as third in World Oil Reserves at around 175 billion barrels, while Saudi was 2nd with around 268 billion barrels and Venezuela was ranked first with around 297 billion barrels of reserves.

Many stories surrounding the petroleum industry's early development are colourful. The growing oil patch involved rugged adventurers, the occasional fraud, important innovations and, in the end, world-class success. Canadian petroleum production is now a vital part of the national economy and an essential element of world supply. Canada has become an energy giant.

In the early 1970's when interest in the Arctic offshore was developing, engineers had little hard information and virtually no past operational experience from which they could evaluate the probability of success of future operations. Except for a few limited cases, we had no precedents to draw from. For example, we were forced to rely on theory for the bearing capacity and creep deflection of laterally loaded floating ice sheets. As you will see in later chapters, our guesses and assumptions, although somewhat conservative, were mostly correct.

With time, more and more exploration was accomplished, more testing was done and data on ice forces, creep deflection and ship transit and station keeping was accumulated and reported at numerous Arctic conferences in the U.S, Canada and other parts of the world. Compared to Genesis, we now had plenty of good data upon which to base design codes. And government and industry were fully behind this effort.

Panarctic Oils was formed in 1968 as a result of the Canadian government's eagerness to encourage exploration of the Canadian Arctic islands and to assert Canadian sovereignty in the region. That company consolidated the interests of 75 companies and individuals with Arctic Islands land holdings plus the Federal government as the major shareholder. It played an important part in the development of the petroleum industry in Canada.

The company had a long and complicated birth. When the deal was complete in 1968, the Federal government held 45% of the new company's equity. Panarctic marked the Federal government's first direct entry into the oil and gas business, except for a brief period of involvement during World War II. After its formation, the company became the principal oil and gas operator in the Arctic Islands.

In 1976, the federal government transferred its stake to Petro-Canada who later raised its stake to 53%.

Panarctic spent some $900 million on exploration and was the operator for perhaps three fourths of more than 175 wells drilled in the high Arctic. Panarctic began its exploration program with seismic work and then drilling in the Arctic Islands. By 1969 its Drake Point gas discovery was probably Canada's largest gas field. Over the next three years came other large gas fields in the islands. These and later discoveries established reserves of 17.5 trillion cubic feet (500 km^3) of dry, sweet natural gas. The company also discovered oil - on the islands at Bent Horn and Cape Allison, offshore at Cisco and Skate.

Exploration moved offshore when Panarctic began drilling wells from "ice islands" - not really islands, but platforms of thickened ice created in winter by pumping sea water on the polar ice pack. Oil was discovered in 1974 at Bent Horn N-72, the first well drilled on Cameron Island.

2. THE BEGINNING OF MY ADVENTURES INTO ARCTIC R&D

My adventure in the Arctic offshore, and onshore, started in late 1971 when I had just graduated from Queen's University at Kingston, Ontario, Canada. I had finished a Ph.D. on "The punching strength of reinforced concrete flat slabs" in the spring and had stayed around Queen's to write and publish two papers with my supervisor, Dr. Adrian E Long. I had been offered a position at FENCO, Foundation of Canada Engineering Company, by the head of their bridge department but had declined in order to publish the papers. Adrian had obtained funding for this effort and I wanted to take advantage of it. When the papers were finished and published, my wife Ginny (short for Virginia) took a month off in the fall of that year to do a tour of Europe. We carried a book titled "Europe on Five Dollars a Day" and most of the time it worked!

We returned to Kingston in late September of that year and I started searching for employment in Toronto. There was no point in trying Kingston as it was too small and the job situation there was very limited. Ginny had a good position at Kingston General Hospital as head nurse in the dialysis unit but I had to find work. The position in FENCO's bridge department was by now filled and I had to find something else. It was the middle of an economic downturn and gloom was everywhere. There was even an incidence of a person jumping out of an office window to his death. I met rejection after rejection from different engineering firms. Employment agencies were unhelpful and simply toyed with me on the phone. I finally went to see Ron Temple, head of the bridge department at FENCO and he directed me down the hall to Dr. Hans Kivisild who was an expert in river hydraulics and the effects thereof of ice cover and ice jams. He was doing some initial work for Home Oil, Shell Oil, Sun Oil, Imperial Oil and other companies who were evaluating ways of exploring for and transporting to market offshore oil and gas reserves in the Beaufort Sea and in the Queen Elizabeth Islands or Arctic Archipelago. The French oil companies, Aquitaine and Total, were particularly interested in drilling on the west side of the Arctic Archipelago to test the theory that the Prudhoe Bay field geology did extend along this area. It did but the drilling revealed that any petroleum reserves had long since drained away.

The Alaskan Prudhoe Bay Oilfield had been discovered in 1968 and a year later was shown by British Petroleum, who drilled a well 30 miles to the west of the discovery well, to be a 13-billion-barrel reservoir. Geology predicted that this large reservoir could extend eastward into Canada's Beaufort Sea. Prudhoe Bay was a totally land based reserve but the geology indicated that it should or would extend to the offshore and eastward. Thus, major oil and gas companies were interested in how this vast acreage might be economically explored and produced. Hans was in on the ground floor and he offered me a position as an engineer to do required calculations related to ice loads and ice effects on offshore installations, including islands, large structures and pipelines. So I was also being introduced to a new area where I could apply knowledge and experience from my university training and, as it turned out, from my experience gained from being raised on a farm in south western Ontario. The latter experience and knowledge turned out to be as valuable as the former.

Figure 1 N Polar Region

Figure 2 Western Arctic Islands & Alaska

We did our first testing at Yellowknife in the early spring of 1972 and soon moved on to Tuktoyaktuk (or Tuk) where we were mobilized via helicopter to a test site approximately 50 miles offshore. We were ferried to the test site by a Sigorsky S-68 helicopter each day and ferried back at night. One afternoon a white-out occurred and the pilot informed us we would be staying on the ice with the helicopter for the night. It was -40 C that night and the inside of the helicopter iced from breath moisture and became much like an icebox. It was warmer outside. Fortunately, Sun Oil had a small, heated building at the site to house recording instruments, so we could take turns going in there and get some hot soup or tea. We had a Herman Nelson oil fired heater but that was reserved to warm the helicopter engine whenever the weather cleared enough to let us leave. Fortunately, the weather cleared the next morning and we were able to leave. We did have drums of jet fuel aboard and the pilot warned us not to smoke while we were sitting in the back of the helicopter during flight, or any other time! Now HSE procedures would not even allow us to fly in any aircraft carrying drums of fuel. We all got back to Tuk that day and had a nice warm supper in camp.

At the time there was only one phone in Tuk and calls to the south had to be booked. The following era of oil exploration in the Beaufort would change all of that. Old timers told me the same about Prudhoe Bay in the early days. There was one phone and one had to line up to make a call south. We made jokes about being in the ice testing lab at “Old Tuk U”.

3. THE TESTING

We were conducting compressive strength tests in pits dug in the ice using chain saws. These tests were regarded as equivalent to cylinder tests conducted in the laboratory. In fact, such tests were common in the fields of soil and rock mechanics so we had good precedent to go by. We were also conducting ice strength profiles through the ice using a Menard pressure meter, a hydraulic device which fitted down a 70-mm hole. By pumping hydraulic fluid into the flexible cylinder it expanded against the hole and gave a pressure-deformation curve. The problem with the device was that it was intended to test a much weaker material than ice and, in our attempts to fail the ice, we blew up the apparatus. High pressures in soil were low pressures in ice. Another set of tests were beam tests to attempt to get tensile/flexural strength. The first tests were tests on cantilever beams cut from the ice sheet. Three sides were cut free from the ice and the fourth was left attached. The problem with this test was, ice being a brittle material, the beam would break itself at the attached end before any load was applied. Later we tried "encastre" (a word used by Dr Kivisild) beams where both ends were attached to the parent ice sheet. These tests were much more reliable but also much harder to interpret. The pit tests for compressive strength were definitely the easiest, most reliable and readily interpreted and yielded a lot of data on basic ice strength. My role in the tests was to assist with their execution and then to work with Hans Kivisild to interpret the results and to report them to the client. I do remember that Gary Rose came back with the results of an early set of tests recorded in a field book that had been dropped in a barrel of diesel fuel. I had to hold my nose while extracting the numbers from the book.

But the results were all useable and revealed small scale ice strengths much in excess of those derived from lab tests and commonly thought to apply to naturally occurring ice. These principles would be carried through to much larger scale tests and more sophisticated recording techniques in the future. At the time we were manually recording pressure and deformation readings from analogue dial gauges. And when our fingers got too cold we often missed a point of recording.

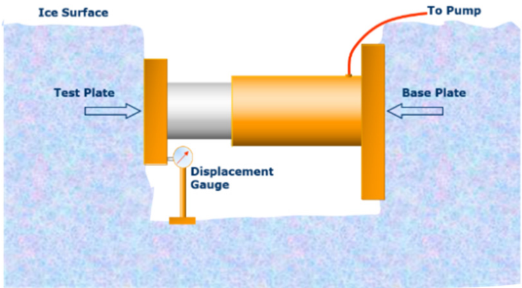

Figure 3 Pit Test

We drilled holes through the ice by hand or with a standard powered soil's auger. We cut pits and beams with chain saws which froze solid from the cold air and water combination. Whenever we could, we avoided cutting through the ice as this meant seawater was brought up by the saw chain and working was miserable to impossible. Chain saws have drags behind the cutting teeth to remove wood cuttings. We found that for cutting ice it was necessary to file these drags off as the saw then cut much faster and more easily through the ice. Needless to say, the chain saws had a short life. We tried Pioneer and Homelite saws and then changed to Stihl saws. The Stihl were better but still had a short life. We would put the saws on the exhaust stack of the Herman Nelson heater to thaw them out or at least "unfreeze" them.

One lesson we quickly learned was if you were drilling holes in fresh water and there was an unfrozen layer of water near the surface, then this water would run into the hole and freeze instantly, resulting in a stuck auger which, without the aid of a steam hose, was impossible to retrieve. Similarly this happened in low salinity sea ice and in one instance we had to get a D4 Cat to yank the auger out of the ice. A stuck auger could take hours to retrieve. Eventually we used cheap grain auger as flights and, if the auger became stuck, it stayed stuck.

4. THE ICE ROAD AT JAMES BAY

During the summer of 1972, a barge load of heavy construction equipment under tow to the James Bay hydroelectric project became grounded on a shoal at the mouth of the Fort George River, only a few miles from its intended destination. The towing contractor, Federal Commerce and Navigation Limited (FedNav), contracted FENCO to study the removal of the equipment by an ice road to shore. The total length of the road was approximately 1 mile and the ice was floating over this distance. We designed the road, which was 30 m in width and 1.9 m thick, and it was built by Sainte-Marie construction in late December 1972 and early January 1973. Small gasoline auger pumps were used to pump water onto the surface of the ice, so it could freeze in layers about 25 mm thick (1 inch).

Gary Rose was the field engineer and signed off on the road before it was used to transport the equipment. I was sent north with him to support the drilling and testing of the ice. Later FedNav would question the need for my presence at site and any billing related thereof. I did the calculations for required ice thickness and optimum road width before going north to the site. At site, Gary and I drilled holes and took cores to check ice thickness and ice quality. This was the site where we learned about the problems with surface water running down hole and freezing our auger. We did not have cheap, disposable auger flights at the time and thus had to retrieve the frozen-in auger using chain saws and lots of picking with bars. There was no steam hose. Sainte-Marie Construction had begun construction before our design was completed since they had built several floating ice roads across rivers in northern Quebec and Ontario. They were most cooperative and were good to work with. I learned a lot about ice construction techniques from them since they were very open with their knowledge and information.

This project was very political in that the purchaser of the equipment, a Quebec contractor, offered salvage value for the equipment at the barge. FedNav and Lloyd’s of London did not look favourably on this offer and undertook to deliver it to the contractor at their construction site for the stipulated selling price. One side was trying to show that it was damaged and only of salvage value and the other side was saying that it was delivered intact and new condition. Using the ice road enabled the shipper to deliver the equipment intact at the original sale price. Thus, there was a lot of pressure to show that the ice road could perform, which it ultimately did. Gary was “under the microscope” when it was time to sign off on the road. I went for a walk on the road every time there were doubts and differing opinions and always felt good about the road. We monitored the deflections and any cracks most carefully, especially in the tidal crack zones near shore. In the meantime, St Marie Construction was using some of the lighter equipment, such as a grader and Cat, from the barge. When it came time to transfer the heavy ore crusher, we had built up our confidence and that of FedNav and Lloyd’s. The ore crusher came off without incident and the concept was proved and accepted. Later we did publish a paper on this project which appeared in the Canadian Geotechnical Journal in 1975. This project would lead to many others, including floating ice platforms for offshore drilling in the Arctic Islands for Panarctic Oils Ltd. and to offshore ice roads on the North Slope of Alaska.

5. FROZEN ISLANDS AND BEAUFORT SEA EXPLORATION IN CANADA

The very cold temperatures and long winters of the Arctic regions led to thoughts by Dr Kivisild and those working with him that islands could serve very well as cheap support structures for exploratory drilling support and possibly for production support in the Beaufort Sea and even in the Arctic Islands. The water depths of the Beaufort shelf are relatively shallow and would allow grounding with reasonable amounts of construction effort and material quantities. In the early to mid-1970's Imperial Oil, Sun Oil and the French oil companies were exploring or considering exploring for reserves in the shallow water (3 to 10m) depths of the Beaufort. Gravel was being hauled from YaYa lake on Richards Island in the Mackenzie Delta. This was a long haul to the offshore sites and the gravel source was limited in quantity. There had to be an easier and cheaper way to construct these islands.

The thinking was that the core of the island could be built of ice, a material produced by freezing the sea water at the site and grounding it. Ice alone would be problematic beyond the winter season since warm ambient temperatures would cause the core of the island to melt and wave action would quickly erode the perimeter. A solution was to construct the core out of ice and then to use gravel or dredged material to form the outer perimeter. Of course, the perimeter would require slope protection or it also would be quickly transported away by wave action. In addition, the ice core would have to have surface protection from solar radiation. This concept was investigated by FENCO for the French oil companies and, while theoretically possible, was found to be of little or no cost advantage over the hauled gravel or dredged material. A large expense associated with earth islands was the slope protection. However, the engineering performed on ice core islands did introduce us to a host of issues and force us to think through the problems, to understand the physics and to understand how possible solutions could work. This led to an understanding of thermal processes, refrigeration techniques (and costs, which were substantial) and of course coastal engineering and erosion. In the end the concept was not followed.

An interesting anecdote comes to mind. At the beginning Hans Kivisild called me into his office and, with a sheet of paper filled with equations and writing all over it including in the margins, explained his thinking and wanted me to continue the effort and to put it into a more organized form. I had great difficulty even understanding the thinking and his dealing with the differential buoyancy issues related to ice and soil as this structure was being built on the floating ice cover and gradually sunk to bottom. Dismayed at my difficulty grasping the concept, I took the sheet of calculations down to Gary Rose's office and asked for his help. He took a look at the sheet, crumpled it up and threw it in the waste basket, saying: "That will all change by tomorrow anyway"! We did retrieve the paper from the waste basket and I did perform a set of calculations, requiring many sheets of paper. I do wish I had kept that sheet for posterity. In retrospect, this "out of the box" thinking was our bread and butter and was not so much out of line with the thinking of others trying to devise methods of supporting exploration and production in these remote and difficult areas.

The history of Beaufort Sea operations is well documented, and I will not repeat it here. Islands were built by hauling gravel and then by dredging sand from the seabed after sub cutting the surficial soft sediments. Slope protection was provided until it was realized that exploratory islands did not require it since they were seasonal or were two season, and were large enough in plan to accommodate some erosion. Deeper water required the use of submerged berms with concrete or steel structures sitting on them to penetrate the waterline. Even deeper water required the use of floating structures and drill ships. Using drill ships in the ice infested waters of the Beaufort Sea was tricky and definitely a challenge. Nevertheless, Dome Petroleum and its subsidiary, Canadian Marine Drilling (CANMAR) and then Gulf Canada through its subsidiary BeauDrill did manage to drill several wells using floating, moored ships and other structures such as the Kulluk. These efforts were not cheap and the Petroleum Incentive Program instigated by the Canadian Federal Government made the effort possible.

It is incumbent on me to mention that on the Alaskan side offshore exploration was also proceeding in shallow water. There is no large river equivalent to the Mackenzie River there and thus much less sedimentation. The rivers come down from the Brooks Mountain range, flow seasonally at high discharge and deposit gravel near shore. This gravel is frozen but of good quality, and when mined provides a gravel with low fines content, which is good for island building. In addition, the offshore seabed is relatively competent and generally provides a good base for structures.

Shell, British Petroleum and Exxon were pursuing this means of exploration and gravel was used for production islands such as Endicott and Northstar by BP.