C-CORE'S 30 YEARS OF PAY DIRT

Ryan Phillips and Gerry Piercey

This article introduces the C-CORE based in St. John's, NL. It follows on the introductions of the Institute Nordique du Quebec (June 2020 issue), the Yukon University Research Centre (September 2020 issue), and the Pipeline Integrity Institute in Vancouver (Spring 2021 issue).

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Introduction

When life gives you lemons, make lemonade. When life gives you towering icebergs, fathoms-deep swells and crushing northerly winds, what do you make with that? Well, a lot actually. But it helps to have a world-leading research and development corporation that understands these conditions and how to operate within them.

That was the thinking in the early 1970s when Memorial University President **Mose Morgan** and the first dean of the university's new engineering school, **Angus Bruneau**, conceived of the Centre for Cold Ocean Resource Engineering. It was founded in 1975 to address challenges facing oil and gas development offshore of Newfoundland and Labrador and other ice-prone regions of Canada, a country with the world's longest coastline and largest ocean estate – much of which lies in the Artic and subarctic.

Today, now known simply as C-CORE, this R&D enterprise employs more than 90 scientists, engineers, and other professionals to understand the needs of companies operating in all harsh environments, including terrestrial and space.

With a home on the St. John's campus of Memorial University, and adjacent to the university's Faculty of Engineering and Applied Science, C-CORE provides research-based solutions to manage operational risk, and helps clients improve safety, efficiency, and cost-effectiveness in remote or challenging environments worldwide. Clients are typically global enterprises in the resource development, transportation, and aerospace/defense sectors. Public sector clients also use the services of C-CORE to address security, sustainability and safety issues related to their regulatory and operating needs.

A significant asset in the Canadian innovation ecosystem, C-CORE creates value in the private and public sectors by undertaking applied research and development, generating knowledge, developing technology solutions, and driving innovation.

C-CORE's three closely integrated areas of technical expertise – geotechnical engineering, ice engineering, and remote sensing (both applications and systems development) – work together to address specific challenges posed by clients. With satellite offices in Ottawa and Halifax, C CORE brings scientific rigour and business discipline to real-world problems.

C-CORE is also home to LOOKNorth, a Canadian Centre of Excellence for remote sensing innovation to support remote resource development and operations.

With unparalleled harsh environment expertise acquired over 45 years, C-CORE has focused primarily on the behaviour of sea ice and icebergs, and on developing techniques to mitigate risk to companies operating in this environment. In the mid-1980s, C-CORE evolved to meet the demands of the nascent oil and gas sector in Eastern Canada. As C-CORE matured alongside that industry, it has focussed on a global horizon as it diversified its technical capabilities and market portfolio.

The late **Jack Clark**, a preeminent Canadian geotechnical engineer (and former CGS President), became President of C CORE in 1984. Reflecting Jack's energy and vision, C-CORE developed an entrepreneurial ethic, diversifying its portfolio from oceans to land and space. Nothing better exemplifies this innovative vision than C-CORE's first foray into the world of global aerospace contracts. Jack had learned of a project opportunity with the European Space Agency, not fazed that a proposal deadline was four days away. Of the 50 submissions, C-CORE won, and a Newfoundland and Labrador company was now working in space. Today more than 50% of C-CORE's business is related to the aerospace sector.

Remote Sensing

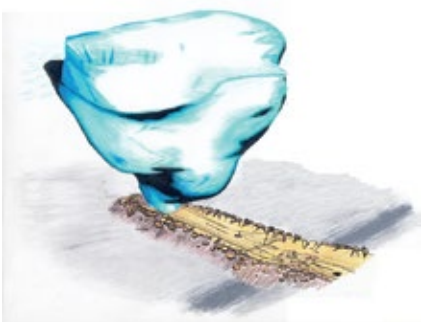
With about 30 remote sensing engineers and scientists – the largest concentration of diverse remote sensing expertise in Canada – C-CORE is committed to advancing the use of space technologies for safe, efficient, environmentally-responsible and sustainable activities on Earth.

Their work uses the breadth of information collected from satellite data to provide environmental information and credible intelligence for companies in the resource development, environment stewardship and defence/security sectors. C-CORE has also investigated and advanced the monitoring capabilities of Earth Observation (EO) and other remote sensing technologies, developing systems such as sea-ice charting and oil slick detection that bring valuable new insights to industries and communities, and helping protect people, infrastructure, and the environment. C-CORE's systems expertise focuses on product and technology development including radar, satellite ground stations and systems testing.

Ice Engineering

C-CORE's ice engineering expertise works to understand the material properties, behavior and prevalence of sea ice and icebergs, and to develop techniques to mitigate risk through protective design and physical management. This ice expertise provides products, services, and tools to support appropriate design for and safe operations in ice-prone environments.

For example, C-CORE's accurate characterization of ice regimes in frontier regions supports vessel and infrastructure design and limits operational risk. The ice environment is analyzed based on imagery from satellite and aircraft-borne sensors, along with onsite measurement and field observations, that detail iceberg location, size, shape, and areal density, as well as sea ice concentration, type and floe size. In areas where infrastructure such as pipelines and subsea wellheads are being considered, C-CORE also uses its geotechnical expertise in interpretation of seabed data to determine potential for, frequency of and depth of ice-keel scour.



Sketch of Iceberg Bertha gouging seabed off Labrador in 1990. Domed Bertha as shown is approximately 1.2 million tons in 110 m water depth. All photos courtesy of C-CORE

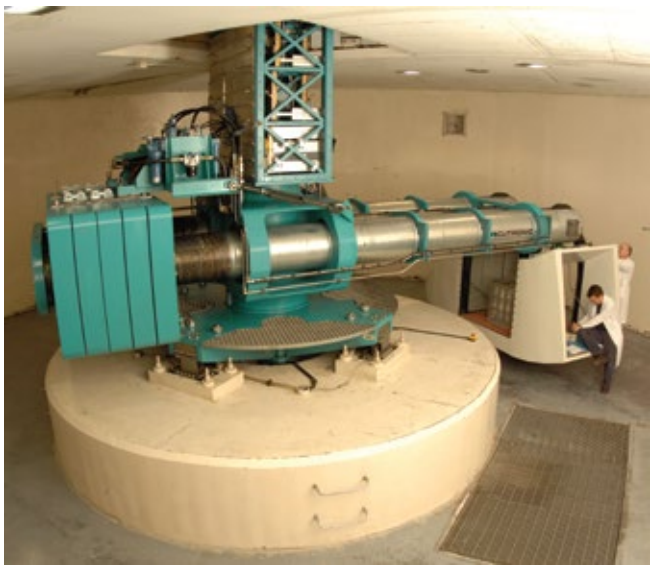
Geotechnical Engineering

Jack Clark started C-CORE's geotechnical engineering activity around 1990 to complement its seabed geophysics work, providing research-based advice and innovative design solutions for the geotechnical aspects of infrastructure projects subject to unusual conditions, both onshore and offshore. C-CORE's geotechnical expertise, founded in physical and numerical modelling, includes ice-seabed interaction, pipeline soil interaction and offshore foundation design using reduced scale physical modelling primarily in their geotechnical centrifuge facility.

The C-CORE geotechnical centrifuge arrived in spring of 1993 along with the new centrifuge director, **Ryan Phillips** from Cambridge University. **Gerry Piercey**, from Memorial University, joined C-CORE in 1998 and became the centrifuge manager. Ryan and Gerry are now C-CORE's principal consultant for geotechnics (only partly filling the shoes vacated by Jack Clark) and experimental systems team lead, respectively.

C-CORE now has unique capability for modelling physical phenomena using full, medium and laboratory scale tests. To support conceptualization and design of innovative facilities for operations in ice-prone regions, C-CORE has developed specialized tools to test and model ice interaction with infrastructure and the seabed, including models for estimating optimal pipeline burial depth. Developing advanced numerical models for, say, ice interaction on surface and subsea facilities is a key strength.

Centrifuge modelling uses scale models subjected to increased gravity to simulate full-scale geotechnical phenomena, enabling reliable and cost-effective investigation of the response of equipment and facilities to real-world conditions.



C-CORE's 5.5 m radius centrifuge in Dr. Jack Clark Geotechnical Engineering Building

"Business end" of C-CORE's centrifuge

C-CORE's geotechnical facility is equipped with soils and model preparation laboratories, as well as a 5.5-metre-radius, 200G payload-capacity geotechnical centrifuge with a fully computerized control system to activate and control tests in flight. It is one of the largest in the world and the only one in North America designed to model cold region conditions. Together, these give C-CORE researchers the ability to closely replicate real-world conditions, including extreme cold, soils comparable to site conditions and multi-directional stresses and strains, like those caused by wave action or earthquakes, for example.

C-CORE has turned its expertise from challenges, such as pipeline ice risk assessment and mitigation, to solving the challenges of northern pipelines and physical modelling of steel catenary risers (SCRs).

In one project using the geotechnical centrifuge, C-CORE successfully tested the equivalent of a long-submerged SCR over a soft clay seabed. The test was part of a larger research program led by BP America to investigate the fatigue stresses associated with extreme storms and vessel movements on SCRs in the touchdown zone C-CORE's research involved a series of physical centrifuge tests, followed by numerical finite element analyses, drawing heavily on the geotechnical, structural, mechanical and hydrodynamics principles. Riser testing like this in a geotechnical centrifuge is unprecedented, and the results have provided invaluable insight into the riser-soil interaction mechanism.

For more than 20 years, C-CORE has supported numerous graduate engineering students in executing centrifuge testing programs with financial support from NSERC and, recently, industry. Researchers from across Canada – including university partners at Carleton, Dalhousie, McGill, Queens, Alberta, British Columbia, Calgary, and Laval – and internationally have used the facility. These student studies have ranged from effect of climate change on slope stability, frost heave pipe interaction, gassy submarine slope stability, rock fill crushability, structural evolution of bedrock fold-thrust structures, and glide block pipeline impact.

While these studies advanced the understanding of geotechnical principles, they also advanced technology and physical modelling while helping train the next generation of geotechnical engineers across Canada. These developments also assisted C-CORE by providing state-of-the-art test technology necessary to advance C-CORE industry test programs.

Currently, C-CORE is working with energy companies, active on the Grand Banks, to consider the consequence of drifting iceberg contact with surface-laid flowlines. These studies include the interesting technical challenge of the undrained response of very dense surficial sand to flowline penetration.

C-CORE has a strong repeat client base: One Canadian energy company has retained C-CORE repeatedly over the past three decades to address pipeline soil interaction issues including pipeline crossings of slowly moving slopes, cyclic thermal expansion of hot bitumen pipelines, backfill trench effects, and heavy surface loading.

C-CORE has also been involved in many joint industry programs involving large-scale testing of buried pipe systems, multi-disciplinary aspects of long-term pipeline behaviour and offshore pipeline trenching. These studies have led to improvements in pipe-soil design guidelines like those published by the Pipeline Research Council International, who have also retained C-CORE to advance mitigative measures against pipeline frost heave and differential landslide ground movement, among others.

C-CORE is working on the application of a new field test it developed to directly assess pipeline backfill resistance around a Canadian gas transmission pipeline under final stress design. A better understanding of these conditions will allow optimizing burial depths and wall thicknesses, resulting in safer and more economical designs.

One of C-CORE's main geotechnical activities is in improving offshore foundation design by developing understanding of the seabed response, leading to new and improved design methods. These projects, primarily in partnership with offshore energy companies, have studied suction caissons, piles, plate load anchors, mudmats conductors, flowlines and risers in locations worldwide including Australia, West Africa and the Gulf of Mexico.

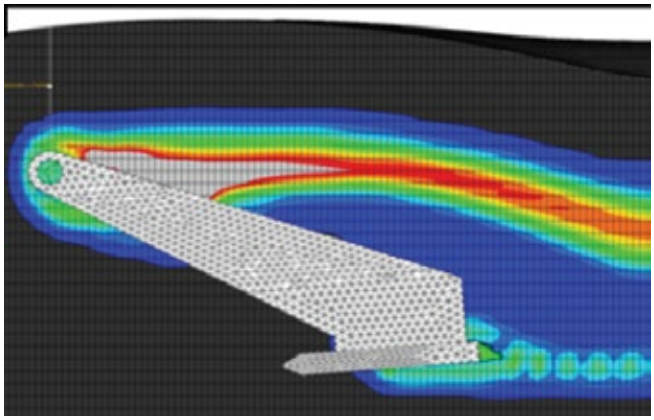
Suction caissons became a viable alternative foundation as the offshore industry extended into deeper water, requiring different styles of floating platforms. C-CORE suction caisson testing is a typical example of how a doctoral student project grew into multiple industry projects and spun off into similar projects: These tests formed the groundwork for measuring the capacity and performance of suction embedded plate anchors in the centrifuge. Centrifuge model testing has played a significant part in addressing many of these issues, developing robust approaches which are now used in design codes such as American Petroleum Institute's RP 2SK and ISO 19901-4.

Recent centrifuge tests have been examining the influence of trench formation around the mooring line on a suction caisson's capacity. Techniques developed in caisson testing programs were extended to drag embedded anchor tests and conductor fatigue tests. These various test programs have spanned 20 years of centrifuge programs, with the complication level of the tests and knowledge gained growing with each program.

Closure

C-CORE looks forward to continuing to provide safe and cost-effective solutions for the development of Canadian resources in harsh environments. For more information about C-CORE, check out https://www.c-core.ca/.

Actual drag embedment anchor, approximately 3 m from top to bottom; Right: scaled drag embedment anchor with "Loonie" for scale



Numerical model of drag embedment anchor dragging

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Gerry Piercey