C-CORE

Statement of Qualifications
Ice Engineering 2007

2007

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1 ICE ENGINEERING

C-CORE provides ice engineering services to manage and mitigate the risk of operations in offshore ice environments. These services for offshore exploration and production structures, seabed installations and pipelines include:

Risk Analysis and Engineering Design

- Probabilistic design loads for iceberg and sea ice environments;
- Risk analysis of iceberg, pressure ridge and stamukha interaction with seabed facilities and pipelines;
- Subsea systems and pipeline protection;
- Ice/soil/pipeline interaction and burial depth analysis;
- Ice impact mechanics and dynamics;
- Finite element and numerical analysis;
- Large-scale impact testing; and
- Centrifuge model testing.

C-CORE and Ian Jordaan & Associates have developed proprietary software for ice engineering design. The application of Iceberg Load Software (ILS) has reduced engineering costs significantly for structure in iceberg regimes. The Sea Ice Load Software for other ice regions is being enhanced and will be available for applications in the near future.

Ice Management

- Ice management logistics for drilling and production operations;
- Integrated management systems and operations for multiple facilities;
- Development of innovative physical management systems and performance analysis;
- Development of innovative detection systems and performance evaluation;
- Development of data fusion systems to improve detection performance;
- Development of a threat analysis decision making system to optimize strategic management;
- Numerical modeling of ice management, risk mitigation, and subsequent influence on design loads; and
- Development of a management simulation software for personnel training.

Ice Environment

- Field measurements (ice thickness, movement, iceberg and ridge survey/profiling, in situ strength testing, temperature profiling) ;
- Iceberg and ice ridge scour characterization
- Ice regime studies;

- Ice occurrence and characterization using remote sensing techniques (e.g. Satellite Radar);
- Insitu field instrumentation to monitor Ice motion and movement; and
- Laboratory testing.
- Centrifuge model testing.

C-CORE has access to specialized ice engineering facilities that include cold rooms and refrigerated centrifuge testing.

C-CORE's integrated services in ice engineering, geotechnical engineering and remote sensing provide our clients with a unique combination of world class expertise.

2 C-CORE'S ICE-ENGINEERING CLIENTS

Aker Kvaerner
Aker International
Arctic Pacific Contractors
BP Amoco
Canada Newfoundland & Labrador Offshore Petroleum Board
Canadian Ice Services
Chevron
Conoco-Phillips
ExxonMobil
Fluor Daniel Canada
Geological Survey of Canada
Government of Newfoundland & Labrador
Husky Energy Limited
IMV Projects Atlantic
Marathon Oil Company
Norsk Hydro
North Atlantic Pipeline Partners
Pan Maritime Energy Services
Petro-Canada
Pipeline Research Council International
Provincial Airlines Limited
Shell Canada
Shell International
Tatham Offshore
Technip Coflexip Stena Offshore Norge AS
Terra Nova Alliance
TRC Environmental Corporation
U.S. Mineral Management Service

3 REPRESENTATIVE PROJECT EXPERIENCE

Risk Analysis and Engineering Design

3.1 Offshore Exploration and Production Structures

Ice Design Loads for Caspian Sea Structures
Development of ice loading algorithms as well as estimation of probabilistic design loads based on an analysis of ice conditions (i.e. occurrence, formation, season length, movement), effect of structural geometry on failure mechanisms and loading scenarios, ice loading event frequency and ice pressures.

Ice Design Loads on Arctic Production Facility, Beaufort Sea
Probabilistic sea ice design loads were estimated for a production facility in the Beaufort Sea based on an assessment of ice conditions (multiyear ice ridges), ice/structure interaction processes and frequency of ice loading events. An analysis of ice pressures was carried out based on a probabilistic averaging process to reconcile uncertainty in large scale measurements based on Molikpaq and Hans Island data.

Ice Design Loads on Drilling/ Production Facility, Barents Sea
Probabilistic sea ice and iceberg design loads were estimated for a facility in the Barents Sea based on an assessment of ice conditions (icebergs, multiyear ice ridges), frequency of ice loading events, ice/structure interaction processes and load mitigation through ice management (change in ice failure mode).

Ice Design Loads on LNG terminal
Probabilistic sea ice loads were estimated for a LNG terminal (specific project details currently confidential). Work included an assessment of ice conditions (level ice and ridges) and movement, frequency of ice loading events, ice/structure interaction processes associated with structural geometry, and design loads.

Arctic Engineering Workshop
Provide an overview of the engineering challenges associated with oil and gas developments in Northern Frontier regions. Workshop addressed key issues associated with the design of both production facility and pipeline infrastructure including: ice conditions and monitoring; classification and design loads; geo-hazards and foundation design; ice scour, subgouge deformation and pipeline design; design criteria and target safety levels.

Ice Loads on Offshore Structures, Sakhalin II

Ice design loads assessed for the gravity based concrete structures of PA-B and LUN-A platforms in the Sakhalin II development. Since ice loads were expected to govern the shaft design, C-CORE provided an independent assessment of a study undertaken by the

client's prime consultant. Work included characterization of ice data including conditions and ice loading scenarios and resultant probabilistic design loads.

Ice Design Loads on Deepwater facility for Orphan Basin

Pack ice design loads were estimate for a moored drilling/production facility concept for operations in the Orphan Basin.

Iceberg and Pack Ice Encounter Probabilities

Iceberg and pack ice conditions determined to provide the impact probabilities on proposed installations in the Orphan Basin. These were compared to the encounter probabilities for the Terra Nova/Hibernia region.

Sea Ice Design Loads on Natuashish Wharf

A full probabilistic sea ice design loads were estimated for a new wharf construction in the community of Natuashish in northern Labrador. The work included an assessment of wind and sea ice climatology in characterizing the inputs for the design loads calculation.

Ice Loads on Confederation Bridge

A number of contracts were completed by C-CORE and its Cold Ocean Design Associates (CODA) affiliate relating to sea ice design loads on the 13 km long Confederation Bridge, linking Prince Edward Island to mainland Canada. The work included ice basin experiments in level ice and ice ridges for cylindrical and upward-breaking conical structures. It also included a comprehensive assessment of sea ice conditions, on-ice ridge keel strength measurements and full probabilistic ice load analyses for different bridge pier designs. The work also involved an extensive independent review process.

Iceberg Impact Avoidance in Deepwater

Probability-based risk assessment of iceberg contact conducted for a 50 m wide FPSO in deep water having sidetracking capability. Sidetracking capability was evaluated with buffer zones ranging from 0 m to 300 m incorporated around the facility. Side-tracking performance was quantified by comparing expected iceberg encounter rates to a comparable facility with no sidetracking capability.

Jack-up Operations, Newfoundland Offshore

Seasonal operating windows for Jackup drilling operations offshore Newfoundland for various geographical areas were determined. The study considered in the potential hazards imposed by pack ice and icebergs on the installations. Risk was evaluated based on shutdown, evacuation and disconnection proceedures as well as upstream detection, exclusion zone definition and sea state persistence.

Construction and Maintenance of Ice Islands

Available research, design, construction and maintenance history of ice islands assimilated and current state-of-practice in the industry identified. The study identified potential advances through further research to produce cost efficient design, construction and maintenance of ice islands for use in offshore oil and gas activity. Centrifuge model tests established its use of the operational behaviour of ice islands.

Ice Design Loads, GBS Structure

A number of projects have been completed by C-CORE focused on Iceberg design loads for a number of alternative Gravity Based Structure (GBS) concepts for the Hebron development.

Ice Design Load Software

A probabilistic iceberg design load software was developed to estimate both global and local design loads on concept facilities for Hebron offshore oil & gas project. Factors considered in the model included iceberg shape, size, drift and impact speed, interaction mechanics, ice pressure, the concurrent environmental conditions and the effectiveness of ice management. Concept facilities that can be analyzed include, cylindrical, stepped, and sloped Gravity Based Structured (GBS) as well as FPSO's.

Ice Load Design Basis for Hebron

An ice design basis was developed for the Hebron project. Data necessary for estimating ice design loads were identified, analyzed and documented. Data included, iceberg and pack ice occurrence, drift velocity, iceberg size and shape characterization, as well as expected performance of ice management systems including detection and towing.

Iceberg Design Loads for a Concrete Wellhead Platform

Iceberg design loads associated with specified exceedence probabilities were estimated for two offshore structure concepts at Hebron. C-CORE defined the basis for subsequent ice load calculations for inclusion in design basis document, estimated global iceberg loads on the wellhead at Hebron, determined the overall loads on the structure, as well as the loads on the base and shaft of the structure and considered the effect of iceberg detection and management on the design loads.

White Rose Hearings

Participated in the public hearings for the White Rose Development. C-CORE's participation centered on ice issues.

Bergy Bit Impact Experiment

Glacial ice masses were impacted using the icebreaker CCGS *Terry Fox* in June 2001. Impact forces, pressure distributions and associated contact areas on the ship's hull were measured using three instruments: an internally strain-gauged portion of the hull, a new externally mounted impact panel and a full ship motion measurement device. Other measurements included three dimensional profiles of the target growler/bergy bits (measured using a multi-beam sonar and stereo photography) and temperature profiles. Detailed FE analysis were carried out to assess the resistance of the ships hull to impact loading as well as to assess optimal placement of the strain gauges and calibration of the measurement system. Program was lead by IOT-NRC, in conjunction with C-CORE, R.P. Brown Consultants, Avron Ritch Consulting Ltd, and NRCs Canadian Hydraulic Centre.

Iceberg Impact Experiment

Field tests were carried out to measure impact loading icebergs interacting with a structure. A large-scale field program was carried out at Grappling Island, Labrador where over 30 icebergs were towed into an instrument panel mounted on a vertical rock face. Iceberg size (and mass), Impact velocity, impact forces, pressure distributions and associated contact areas were measured. The analyses from these experiments have contributed to the engineering design of offshore structures in ice environments.

3.2 Seabed Installations and Pipelines

Ice Load Design - Subsea

A number of projects have been completed by C-CORE focused on risk of Ice keel contact with subsea wellhead systems proposed for Grand Banks developments and resultant impact loads. Recommendations on alternative protection systems were also proposed.

Risk Analysis of Subsea facility at Hebron

Analysis of risk of iceberg contact with a pre-drill template at Hebron. Estimated risk was compared with allowable target safety levels specified in the Canadian Standards Code (CSA S471-03) based consequence of failure.

Iceberg Scour, Labrador

Makkovik Bank iceberg scour survey data were processed and interpreted to develop a database of iceberg scour geometric parameters (length, width, depth). New scours and scour rates were identified, including a map to illustrate the overall distribution of scour rates for the Makkovik Bank. A framework for assessing iceberg scour risk to subsea facilities on the Makkovik Bank was established.

Iceberg Grounding, Labrador

A model to simulate iceberg drift and grounding was developed. The simulations were calibrated using the data obtained from repetitive mapping surveys and iceberg scour rates for the Makkovik Bank, Labrador and surrounding region defined. Iceberg scour risk to pipelines and subsea facilities were assessed for a variety of structure sizes/locations and routes.

Iceberg Risk and Pipeline Routing, Labrador Shelf

Pipeline routing options, iceberg scour risk and burial depths assessed to meet specified risk levels for a pipeline linking natural gas reserves on the Makkovik Bank to a landfall on the Labrador coast.

Iceberg Scouring, Grand Banks

Probabilistic analyses of iceberg scour for five Northeast Grand bank transects undertaken. Changes or additions to the existing ice scour population and seafloor sediments were identified. C-CORE developed methodologies to determine the return interval for seafloor iceberg scours based on repetitively mapped sidescan transects.

Iceberg Scour, Terra Nova

Scour formation rate at Terra Nova (offshore Newfoundland) determined using the best available data and methods. C-CORE also determined probability distributions of scour dimensions for Terra Nova, and performed a comparison with distributions obtained from other regions of the Grand Banks.

Pipeline Routing for Natural Gas Development, Grand Banks

Iceberg scour risk evaluated for a direct pipeline route running from the Jeanne d'Arc Basin to the Avalon Peninsula, Newfoundland. It considered variations on the route that minimized distance, iceberg scour risk and challenging bedrock conditions.

Lake Erie Transmission Project

Burial depths for a high-voltage DC cable connection across Lake Erie provided to achieve target safety levels. This burial depth resulted from a risk analysis of ice formations scouring the lakebed, dragged anchors, trawl doors and dropped objects impacting the proposed cable.

Iceberg Risk to Pipelines, White Rose

Design scour depths and pipeline burial depths and pipeline burial depths along various pipeline routes proposed for the White Rose field. C-CORE proposed routing that would potentially mitigate the iceberg scour risk.

Risk of Iceberg Contact in Glory Holes

The risk of an iceberg keel contacting subsea well head systems was assess considering both free floating and scouring icebergs at the White Rose site. The required depth of Glory Holes was specified based on target reliability levels as specified in the CSA code for protection of subsea equipment from iceberg keel contact.

Iceberg Risk to Flowlines, Terra Nova

Probability of iceberg keel impact on flowlines was determined for the Terra Nova field development as well as a proposed Terra Nova field extension (several years later). A risk-based approach was used to determine the frequency at which trenched and untrenched flowlines may be impacted by floating, scouring and pitting icebergs.

Iceberg Grounding Events

Scour records from nine icebergs grounded on the Northeast Grand Banks during 2000 assessed for scour dimensions, iceberg driving forces and soil characteristics and were determined to gain additional insights into the scouring process and to develop case studies of the drift and environmental forces for the nine icebergs. The data was used to direct the 2001 field program.

Iceberg and Geotechnical Data Requirements, Hebron

Ice and geotechnical engineering services provided to the Hebron Asset Team. This included reviewing geotechnical data, and knowledge regarding the sea ice and iceberg environment at Hebron.

Geotechnical Conditions, White Rose

Geotechnical and geological conditions assessed at White Rose based on data and inferences from experiences at other fields on the Grand Banks.

Pipeline Routing Considerations, Grand Banks

Various pipelines route options considered for a pipeline originating in the Jean d 'Arc Basin and making landfall at various locations in Newfoundland. These routes assessed for iceberg risk to establish and an optimum route.

Arctic Offshore Pipeline Risk Assessment

Extensive, non-biased engineering and environmental assessment made of single versus double walled designs for offshore pipelines in an arctic environment. The study reviewed the feasibility of double wall pipe for arctic conditions and assessed advantages and disadvantages, the risks and challenges, and the resources required to meet those challenges. The study also appraised the economics and the potential risks associated with the alternatives.

Pipeline Burial Requirements, Sakhalin II

Engineering analysis undertaken to determine the required depth of burial of offshore pipelines for the Sakhalin II oil and gas project. Work performed included a comprehensive probabilistic risk assessment with a focus on seabed gouging by ice ridge keels. The analysis considered the ice environment, the ice gouge process, soil conditions, sub-gouge deformations, and pipeline response.

Pipeline Burial in Ice Scoured Environments

Engineering Service Capability developed to design pipelines and other seabed installations in regions scoured by ice, taking into account the soil deformations and stress changes which may be caused during a scour event. The PRISE model for ice scour/soil/pipe interaction-engineering was developed. This model was verified and calibrated through finite element analyses and physical model tests.

3.3 Ice Management

Integrated Ice Management

Multi year program focusing on iceberg detection and physical management was undertaken. A number of systems for detecting icebergs were tested and analyzed for performance. Methods of combining detection data from multiple sources to enhance detection performance were developed. The physical management program focused on effectiveness of towing techniques and developing new towing techniques. A system to assess and prioritize iceberg threat based on detection, forecasting, facility operations, towing resources availability is being developed as well as a system for simulation ice management operations for training.

Iceberg Detection, Barents Sea

Detection capabilities of SAR based satellites assessed for detection for icebergs in the Barents Sea. Of particular interest was the proximity of iceberg targets to the Shtokman gas-condensate field.

Jack-up Operations, Newfoundland Offshore

Operating windows for Jackup drilling operations offshore Newfoundland for various geographical areas were determined. The study considered in the potential hazards imposed by pack ice and icebergs on the installation.

Development of Ice Management Plan, Newfoundland Offshore

Development of an ice management plan for drilling and production activities at the Terra Nova development on the Grand Banks. Items addressed inlcuded detection systems, towing resources, threat assessement, order of responsibility and chain of activities assosiated with execution of an ice management plan to mitigate risk based on level to threat to facilty.

Emergency Disconnection Due to Iceberg Encroachment

Influence of emergency disconnect time on potential iceberg impacts with the White Rose FPSO determined and the consequent changes estimated to design ice loads for the FPSO. C-CORE also considered potential changes in iceberg downtime for the structures due to emergency disconnect time.

Microwave Ice Mitigation

Mechanical de-icing system developed inflatable radome, an ice load sensor, and an air supply and control system were designed and fabricated. C-CORE installed these components at a site in coastal Labrador.

Iceberg & Vessel Detection

System developed to detect and automatically classify icebergs and vessels using RADARSAT Synthetic Aperture Radar (SAR). The software algorithm processed images and signals from RADARSAT SAR and discriminated between icebergs and vessels in near real time.

Iceberg Draft Reduction

Field experiments conducted to assess the effectiveness of iceberg mass reduction strategies, and existing sonar technologies for iceberg profiling and draft measurement under operational conditions. These were investigated as practical iceberg management tools for the protection of Grand Banks pipelines.

Aquaculture Design in Ice Environments

Feasibility of installing ice booms around the entrance to Bays to prevent ice from entering and destroying aquaculture facilities. C-CORE assessed the design of ice booms for individual sites to prevent impact from ice and fast ice.

3.4 Ice Environment

Ice Floes, Northumberland Strait

Frequency of floe interactions and influx of new ice from the Gulf of St. Lawrence with instrumented bridge piers investigated. C-CORE carried out the work as part of a long term ice monitoring program.

In Situ Ridge Experiments

Characterization of ice rubble in first year ridges and rubble fields, Sakhalin Island and Northumberland Strait.

Ice Measurements, Labrador Sea

Survey of pack ice conditions, pack ice drift and iceberg size distribution of Nain, Labrador. The work was carried out as part of the study for the transhipment of ore from Voisey's Bay.

Iceberg Conditions, Labrador

Monitoring of icing on transmission lines, onshore Labrador.

Ice Rubble - Structure Interaction

Investigated the capability of modeling the interaction of ice rubble and structures in the centrifuge as a cost efficient alternative to large scale testing.

For more information, please contact:

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