ICETECH 2014 – ABSTRACTS

I. PLENARY SESSIONS

101-RF	***Kolskaya and Kulluk. A Disaster and a Near Disaster*** Ove Tobias Gudmestad Day 2, Room A, 930-1000 In this paper we will review the loss of the *Kolskaya* jack-up platform and 53 crew members in the Sea of Okhotsk during New Year 2011-2012 and point to causes of the loss. Thereafter we will review the near disaster when the *Kulluk* rig was being towed from Alaska to the US in January 2013. Although both towing incidents could have led to disasters, the operator, Shell, was capable of rescuing all personnel and getting *Kulluk* off its grounding and back to a safe haven. The *Kolskaya* incident did, however, have a sad and tragic outcome. Both incidents happened during towing in harsh weather and we will in particular discuss the characteristics of the rigs and the concerns regarding safe towing. These include: ▪ An evaluation of the rigs' motion characteristics in large waves (*Kulluk* has particularly difficult motion characteristics in waves); ▪ Safe tow using at least two tugs to ensure redundancy during the tow; ▪ The need to move non-essential personnel off a rig during the tow; ▪ Management awareness of harsh Arctic conditions. The outcome of the incidents will thereafter be discussed with an emphasis on the ability to save a rig of the *Kulluk* type and the loss of confidence in Russian project management in the case of *Kolskaya*. We will also discuss how confidence in Arctic activities could be restored. Based on the analysis, we will prepare recommendations for thorough risk analysis, in particular prior to critical tow operations. We will also highlight the responsibility of the marine staff involved in such operations and the need to strengthen their role. Of importance is the need to educate all those involved about the conditions of the physical environment. The companies' safety programs must be updated in the case of Arctic operations with an emphasis on the need for patience and an awareness of the costs for Waiting on Weather. **KEY WORDS:** *Kolskaya*, *Kulluk*, Arctic, tow operations, risk analysis.
109-RF	***Planning for the Unexpected in Arctic Offshore*** Arno Keinonen and Evan Martin *(Presenter)* Day 3, Room A, 900-930 A number of arctic and subarctic offshore oil and gas operations have been conducted over the past nearly 40 years, both by avoiding ice and by operating in it. This paper highlights the common industry practices that have emerged and their associated challenges. The challenge that is expected to pose the biggest risk to future operations is then explored: namely unexpected events. A sample of events is provided and methods available to manage these events are provided. **KEY WORDS:** ice offshore operations; station keeping in ice; ice management; safety in ice.
122-RP	***Arctic EER State of Art*** Frank Bercha Day 1, Room A, 1320-1350 *Abstract not available.*
142-RF	***The Design and Operational Implications of the IMO Polar Code*** Andrew Kendrick Day 3, Room A, 930-1000 It is expected that the new mandatory Polar Code will be finalized in 2014, and come into effect in 2016. Ships covered by the Code will be required to have a Polar Ship Certificate, and a new set of on-board documentation. The Code will also address the crewing requirements for polar ships. The new Code is broad in scope, covering design, equipment and operational issues. This paper outlines the areas which it covers, the obligations that the Code will impose on a range of stakeholders and some of the main challenges that they are likely to face. **KEY WORDS:** IMO; Polar Code; regulations; design; operations.

148-RF	***Literature Survey of Station Keeping and Ice Management***
	Ivana Kubat *(Presenter)* and Mohamed Sayed Day 2, Room A, 900-930 Stationkeeping of drillships in ice has emerged as a key enabling factor for offshore developments in intermediate and deep Arctic waters. A drillship would have to keep position within strict offset limits for safe operations. This requires reliable information concerning levels of ice management, estimates of ice forces, performance of mooring and Dynamic Positioning systems, and the corresponding responses of the vessels. In spite of the importance of these issues, several technical aspects remain poorly understood. This has prompted substantial recent research efforts. The objective of the present review is to provide the reader with efficient and thorough up-to-date information on available literature which deals with the various aspects of stationkeeping in ice. The review includes compilation of the literature and analysis that categorizes the investigations according to their objectives, approaches, scopes and outputs. **KEY WORDS:** Stationkeeping in ice, ice management, literature review, ice forces.
165-RF	***A Short History on Ice Expeditions in the Russian Federation***
	Göran Wilkman Day 2, Room A, 1350-1420 In the field of ice expeditions, we have three main branches of activity where people go to test, observe, measure and map the ice conditions or performance of certain ship. The practices for conducting such exercise are different depending on the country and region. To organize an expedition or ship testing trip in the Russian Federation and former Soviet Union has always been a challenge. Preparations and planning needs to be started well in advance for getting the permits, and even then when you have all the paperwork done you cannot be sure that the expedition will come true. You need to cross the border to Russia and it may happen that you and the customs officer do not come along in a perfect way. This paper will tell the story of how things should or should not be arranged in the changing legislative atmosphere of Russian Federation. Russian Federation is here only as one example as similar practices can be found also elsewhere on this globe.
176-RP	***Introductory Plenary from SNAME President***
	Peter Noble Day 1, Room A, 920-950 *Abstract not available.*

II. TECHNICAL SESSIONS

1. Ships in Ice

1(a) General

Day 1, Room A, 1020-1100

168-RF ***Model Tests of the New Canadian Polar Icebreaker (John G Diefenbaker)***

Jungyong Wang, James Millan, and Dan McGreer

This paper provides an overview of a model test program to evaluate performance of the new Canadian Polar icebreaker, *John G. Diefenbaker* design. The National Research Council Canada (NRC), the Canadian Coast Guard, STX Canada Marine (STXM) and Aker Arctic Technology (AARC) worked closely together to develop a test program, to carry out tests and to discuss test results as well as improvements. The model test program included resistance, propulsion and maneuvering (turning circle) tests both in ice and open water; ice ridge penetration tests; the wake survey, seakeeping and stationkeeping tests in open water. The model tests were carried out at the three model basins (ice tank, open water tow tank and ocean engineering basin) at the NRC's facilities in St. John's, NL. The test results were well utilized in the vessel's design development as well as providing performance evaluation tools at the conceptual design stage. Some of the test results are presented here.

KEY WORDS: Polar Icebreaker, John G. Diefenbaker, model testing, ice tank, offshore engineering basin, towing tank.

160-RF ***Conversions of Icebreakers to Meet New Environmental Standards in Emissions***

Jukka Salminen, Kari Patrakka, and Tero Vauraste

In September 2011 Arctia Offshore Ltd. was awarded a contract with major oil company to assist their project in the Alaskan waters with our multipurpose icebreakers MSV Fennica and MSV Nordica (Figure 1). Customer campaign is carried out in environmental sensitive area and rules in Chukchi Sea and Beaufort Sea are much higher than MARPOL rules. US EPA (Environmental Protection Agency) is monitoring customers air permit and NOx & SOx limits. In order to meet tight limits we found that selective catalytic reduction (SCR) and using Ultra Low Shulphur Diesel (ULSDO) is the best option. This paper will describe the design, installation and user experience of SCR system onboard multipurpose icebreakers Fennica and Nordica.

KEY WORDS: Icebreaker, emissions, arctic

1(b) Design and Tests

Day 3, Room B, 1000-1040

110-RF ***A Risk-Based Evaluation Ice-Strengthened Hull Structures***

Pentti Kujala and Sören Ehlers

Current ice class rules may design a structure that can undergo some plastic deformations during their design life. The amount of allowable plastic deformations is however not clearly defined in these ice class rules so as the critical deformation limit that requires repair. It is possible to increase the scantlings until no plastic deformations occur during the ship's lifetime. This will cause a high investment cost at the construction phase but no repair cost during the design life. Another possibility is to allow some local plasticity requiring repair work at specified nominal frequencies during the ships' lifetime, which causes smaller investments, but higher maintenance costs. The optimum between these two extremes is searched in this paper and the procedure on how to identify such concept will be described.

KEY WORDS: ships; ice strengthening; limit states; ice loads, economic design

170-RF ***Investigation of the Propeller Blade Failure Load and the Associated Spindle Torque - JIP BlaFex***

Andreas Junglewitz, Claas Fischer, Wolfgang Fricke, and Wolfgang Koch

The IACS Polar Class Rules define the maximum propeller blade / ice interaction loads to be expected once in a life time of a ship. Beside the ice loads used for the scantlings of propeller blade, the ultimate blade failure load is also defined in order to check the connection between the blade and the hub and the pitching system. However, controllable pitch propeller makers claim that the failure load generates too high spindle torques and results in one or two hub sizes larger propellers being against their long term experience with existing designs and rising costs for new projects. Hence, IACS initiated a common Joint Industry Project (JIP) with different propeller makers called "BlaFex". The main goal is an experimental validation of the blade failure load and the associated spindle torque calculation. At present, two blades have been tested in elastic and plastic range using different points of load application. In advance and parallel, numerical simulations have been performed and their results will be given and compared with the measurements. In this paper the obtained test results are presented and conclusions are drawn with respect to the next tests and numerical simulations.

KEY WORDS: propeller blade; ice load; ultimate strength test; FEA

2. Structures in Ice

2(a) General

Day 1, Room B, 1100-1200

138-RF ***Detailed Ice Ridge Loading Events on the Norströmsgrund Lighthouse***

Louis Poirier, Denise Sudom, and Robert Frederking

Three ridged ice loading events have been analyzed from the Norströmsgrund lighthouse, off the Swedish coast. Ice load data from 1999 and 2000 were collected as part of the LOLEIF project. The three events described in this paper occurred in March and April 2000. The ridges were relatively small, with maximum keels of less than 5 m depth and sails of less than 0.5 m height.

KEY WORDS: Consolidated layer; ice load; keel; ridge.

154-RF ***Challenges Implementing ISO 19906 for Probabilistic Assessment of Multi-year Sea Ice Loads on Sloping Structures***

Mark Fuglem, Martin Richard, and Jan Thijssen

The ISO standard ISO 19906:2010 provides guidance for determining design loads for offshore structures in arctic and sub-arctic regions, using both deterministic and probabilistic approaches. References are provided for models of both first and multi-year ice loads on both vertically-faced and sloping structures. ISO 19906 indicates that consideration should be given to limit stresses at the ice structure interface based on the dominating ice failure mechanisms, limit forces associated with the available driving force that can act on the interacting ice floe due to wind, currents and surrounding ice, and the kinetic energy of the impacting feature. Analyses show that the kinetic energy of an impacting multi-year floe driven by surrounding ice will result in larger loads than those from driving forces alone. In order to determine penetrations and maximum loads, it is then necessary to consider the variation in load with penetration during an impact.

In the case of multi-year ice loads on sloping structures, full-scale data to properly validate models is lacking. Several models are available that estimate maximum loads for level ice interactions with sloping structures. These models can partially account for rubble forming on the structure during the interaction thereby increasing loads, though the ability to estimate rubble heights for different structure shapes and ice conditions at present is limited. In the case of multi-year ridges, several models are available that estimate the maximum load during the interaction of a prismatic beam shaped ridge contacting a conical structure. Data and model for loads from more realistic multi-year ridge shapes are lacking. Additionally, the influence of rubble existing on the structure at the time the ridge impacts is not explicitly considered. This paper examines issues in determining probabilistic design loads for multi-year interactions with sloping structures and presents sensitivity results for key assumptions and parameters. The analyses were carried out using the Sea Ice Loads Software (SILS) developed by C-CORE as part of a Joint Industry Project (JIP) to implement ice load models referenced in ISO 19906 within a probabilistic framework for the purpose of determining design loads. Interpretation was required where ISO 19906 does not provide explicit details on the models and probabilistic implementation. Monte-Carlo simulation was selected for carrying out probabilistic calculations of design loads as this approach is robust.

KEY WORDS: multi-year sea ice; sloping structures; design loads; probabilistic approach.

153-RF ***Challenges in Determining Design Iceberg Impact Loads for Offshore Structures***

Paul Stuckey and Mark Fuglem

Designing offshore structures for iceberg loads in arctic and subarctic regions presents unique challenges. The ISO 19906 standard provides guidance for the calculation of design ice loads using both deterministic and probabilistic approaches. C-CORE has developed and applied a software package, the Iceberg Load Software, for determining global and local design loads associated with iceberg impacts. Using this software, a number of issues related to design global and local iceberg impact loads for fixed structures are examined. This paper highlights these issues, including iceberg and structure shape, global ice crushing pressure, low iceberg impact frequency, ice management influences and variation in design loads and moments with impact location on structure.

KEY WORDS: icebergs; design loads, probabilistic approach

2(b) Ice Loads

Day 1, Room B, 1350-1450

167-RF ***Uncertainty in 100 and 10,000 Year Ice Loads on Offshore Structures***

Richard McKenna, Mark Fuglem, and Greg Crocker

The ISO 19906 arctic structures standard specifies that ice loads be calculated at the extreme level (100 year return period) for verifying ultimate limit states and at the abnormal level (10,000 years) for accidental/abnormal limit states. Since ice load measurements on structures have only been made over much shorter time periods, concerns are often expressed about the accuracy to which 10,000 year values can be estimated.

In this paper, the uncertainties in 100 and 10,000 year loads are considered through examples based on experience with calculations of loads on structures in different iceberg and sea ice environments. For icebergs, it is necessary to consider the size distribution of icebergs (including the potential presence of extremely large icebergs and ice islands) as well as drift velocities and shapes that can govern highreturn- period loads for fixed structures. With sea ice, abnormal-level loads can be governed either by the presence and geometrical properties of large discrete features (e.g. first-year ridges and stamukhi, or in the arctic, multi-year floes with thick ridges), or by very thick ice as a result of thermal growth. It is demonstrated how errors in key contributing ice parameters can influence extreme-level loads,

	and the relationship between level/rafted ice loads at the abnormal level and the factored (1.35) extreme-level values, and how these uncertainties might be considered in the design process. **KEY WORDS:** sea ice loads, iceberg loads; structural design, probabilistic approach, parameter uncertainty
135-RF	***First-Year Ice Ridge Loads on Norströmsgrund Lighthouse in 2002 and 2003*** Denise Sudom and Robert Frederking The lighthouse Norströmsgrund in the northern Baltic Sea was well instrumented to measure ice forces and ice thickness in the years 1999 to 2003. Load panel and tilt meter data have been analysed to assess global force on the lighthouse during several ice ridge or hummock field interaction events in 2002 and 2003. The size of the ridges, type of interaction, and level ice load are examined, and an attempt is made to assess keel load. The methods of the ISO 19906 Standard are applied to determine the range of ridge forces that may be predicted at the site. **KEY WORDS:** first-year ice ridge; hummock; ice force; cylindrical structure; Norströmsgrund lighthouse
134-RF	***Updated Temperature, Salinity and Strength Distributions for Old Ice*** Michelle Johnston and Robert Frederking This paper presents updated distributions of the temperatures, salinities and borehole strengths of old ice, as a function of time of year. Thousands of measurements are compiled from old ice floes across the Arctic. Probability of exceedance curves are used to show the more 'extreme' values that can occur at various depths in the ice. Properties over the full thickness are obtained from the means of sample populations and by depth-averaging measurements from the same borehole. The mean salinity of old ice varies little over the course of a year, whereas ice temperature and borehole strength do. Ice temperature and ice borehole strength are shown to be inversely proportional. Temperatures colder than approximately -38°C have not been measured in old ice in the marine environment, even during the three coldest months of the year (Dec, Jan, Feb). Borehole strengths upwards of 40MPa have been measured in old ice, but such high strengths are not representative of the mean strength over the full thickness of ice. The analysis focuses upon the ice temperature range from 0 to -20°C, which captures the mean temperature of the full ice thickness in all seasons. The commonly-used equation for calculating the flexural strength of first-year ice produces acceptable results for old ice with a mean salinity of 1.8‰, despite the limited physical basis for applying the equation to old ice. Normalized values of the mean borehole strength and the calculated flexural strength exhibit nearly identical trends of decreasing strength with increasing ice temperature. Relative to the maximum winter strength of old ice (at -20°C), the mean ice strength decreases to approximately 85%, 70% and 30% at ice temperatures of -10°C, -5°C and 0°C respectively. Mean borehole strengths of old ice are, on average, 31 times higher than the calculated flexural strength over the temperature range -1°C to -20°C. **KEY WORDS:** old ice; ice temperature; salinity; borehole strength; flexural strength; probability of exceedance.

3. Climate Change

Day 1, Room B, 1020-1100

119-RF	***Ice Road Operation and Climate Change*** Allan Strandberg, Ruixue Wang, Paul Spencer, and George Strandberg Changes in air temperatures from 1970 to 2013 due to climate change in the Northern regions can have a serious effect on the construction and use of ice roads. The construction of ice roads in the early winter season is dependent on the ability of the area weather to freeze a working surface for the use of heavy equipment. A safe thickness of frozen ground and/or floating ice sheet is required. Late winter season weather governs the last date that the ice road system can be used. This paper uses weather patterns over the 43 year period from 1970 to 2013 to determine trends that may be present in the geographical areas of Prudhoe Bay (USA), the Mackenzie Delta (Canada) and the Yamal Peninsula (Russia). In addition, the effect of these changes in the weather on ice construction procedures in these three geographical locations are discussed and summarized. **KEY WORDS:** Ice road; Prudhoe Bay; Mackenzie Delta; Yamal Peninsula; Climate change.
144-RF	***Nuclear Power Supply of Oil and Gas Resources Development of the Arctic Shelf*** Nidzhat Isakov, Evgeny Velikhov, Vyatcheslav Kuznetsov, and Dilizhan Mirzoev This paper validates the use of nuclear power (NP) to the energy supply the offshore production of oil and gas in ice conditions of the Russian Arctic shelf. Justification of the choice of nuclear energy as the most adequate for ice conditions of the Arctic shelf conducted on the basis of evaluation of quantitative and temporal parameters of the required energy, comparison of nuclear and alternative energy from an environmental perspective, the risks and taking into account the current state of relevant technologies. Assumed atomic energy supply based on innovative small nuclear power plants (power up to 300 MW (el.)) (SNPP), which differ from the traditional nuclear power plants (NPP) significantly greater degree of safety. **KEY WORDS:** Arctic shelf; atomic energy supply, safety, underwater-underice technology, development of oil and gas fields

4. Operations in Ice

4(a) General

Day 1, Room A, 1100-1200

117-RF ***A Case Study of ice Management for Exploration Floating Drilling***

Jed Hamilton, Curtis Holub, Svetlana Shafrova, Joshua Blunt, Raymond Foltz, and Ron Ritch

Oil and gas exploration in high-Arctic offshore locations may require floating drilling capability in the presence of sea ice due to the limited open water season and the potential for temporary pack ice intrusions during the nominal open water season. To aid in the evaluation of efficacy and reliability of potential operations in ice, ExxonMobil has focused on documentation of ice interaction scenarios based on observed historical data, against which ice management strategies can be tested and evaluated. The objective is to help to manage risk during the actual drilling by identifying ahead of time, the needed suite of tools required for ice management including monitoring, forecasting, maintaining situational awareness, icebreaker fleet deployment and operational decision-making. This paper presents an actual, welldocumented Beaufort Sea mid-summer ice intrusion scenario against which we evaluated different aspects of ice management support for floating drilling operations.

KEY WORDS: Arctic drilling; ice management; ice drift forecasting; common operational picture

150-RF ***Arctic Past Experience - How to Gather and Utilize It?***

G. Abdel Ghoneim and Merv Edgecombe

Considerable Arctic exploration and drilling experience exists that may be utilized while preparing for the upcoming wave of Arctic drilling and production activities. The many challenges with design and operation of Arctic E&P installations have been exhaustively discussed in the past. This paper will briefly summarize these challenges and show how a significant number of them have already been addressed. In the 1970s and early 1980s, Arctic activities such as the Arctic Pilot Project (APP), the Canadian Marine Drilling Limited (Canmar) icebreaker research program of full scale testing in the Beaufort Sea, the Tarsuit artificial island, and the Hans island ice load monitoring programs have resulted in a considerable Arctic related database that may be beneficial today. The Canadian Coast Guard development of the Canadian Arctic Shipping Pollution Prevention Regulations (CASPPR) was based on extensive Arctic R&D work performed in the late 1970s and early 1980s. This paper demonstrates how the available results from these projects may be gathered, analyzed, and applied to address Arctic challenges that still exist, particularly developing and updating current standards and regulations.

This paper will present specific ice load measuring systems developed in the early 1980s by the Canmar team. Sample ice load signal measured in full-scale tests will be re-analyzed and compared to recent ISO 19906:2010 and IACS predictions. The applicability of these results to the hull structures of newly proposed E&P structural concepts is also discussed. The paper references the available past experience both in the public and corporate domains. The paper also proposes an approach to reach out to experienced Arctic professionals to assess the ranking of Arctic challenges and evaluate the risks and mitigation efforts needed to assure the zero tolerance philosophy for this frontier.

KEY WORDS: Arctic, ice; structure; interaction; development; cold climate; experience; safety; risk; reliability; monitoring.

166-RF ***A Short Review on Ice Navigation History***

Göran Wilkman

We have recently heard that our home, the Earth, was born some 100 million years ago, which is relatively recently as the big bang took place 13.8 billion years ago. The first humans are estimated to have inhabited the Earth some 8 million years ago. People have been sailing the seas at least some 5-10 thousand years. The first people, who crossed the Atlantic Ocean, as far as we know, were the Vikings, some 1200 years ago. They might have been the first who had any contact with ice. The serious business in trying to find the spice route through the north was over four hundred years ago started by Dutch Willem Barentz who started to sail the North East passage towards east, but he did not get very far. After mapping Spitsbergen and Frantz Josef land he stranded on Novaya Zemilya. Those days the ships were propelled by oars or sails, which did not work very well in ice. It took some two hundred fifty years until the ships were equipped with steam engines and the means to get the power into the water was either paddle-wheel or propeller. Steam power allowed the ships to be more flexible what comes to manoeuvring and the skipper was not so much dependent on wind or muscle power. The development of modern navigation in the icy waters started seriously during the second half of 19th century. People started truly to look for the passages both to the East and West through the North. The first icebreakers were built late 19th early 20th century. In those days icebreakers had just stronger hull structures and more power in the engine than the conventional ships. Traffic was limited in the north to summer period when the extent of ice was at minimum. In the Baltic and other sub-arctic waters icebreakers were really needed during the opening of the season in spring and lengthening the season at the autumn end. After the second World War, when people started to raise from the ashes the interest to ice navigation steamed up and during the last 60 years the development of technology has helped. This paper will talk about how navigation has taken steps during history and also look where we might be going to.

4(b) Ice Management

Day 1, Room B, 1510-1610

105-RF	***Winterization of Cold Climate and Arctic Offshore Operations***
	Ove Gudmestad and Eva Elisabeth Lund
	For oil and gas exploration and production projects in cold climate and Arctic environments, much attention has been paid to winterization of the facilities. Conferences with the theme "Vessel Winterization" are held regularly and standards like ISO 19906, Arctic Offshore Structures, are concerned with winterization of facilities. We will, however, highlight the need to winterize all aspects of the operation: - It is not sufficient that the vessel is winterized if the staff does not have competence to work in cold climate - It is not sufficient to ensure a good working environment if the staff is not prepared to work at the remote location - It is not sufficient to winterize the facilities if the personnel cannot be rescued in case of emergency - It is not sufficient to ensure safe operations if the oil spill equipment does not work at all in case of an oil spill during the cold period We could continue to list important aspects of oil and gas exploration and production projects in cold climate or Arctic environment that are not adequately robust even if the "facilities are winterized" and we will highlight the need to include all aspects of the operation planning in the preparation for winterization. Of particular importance is the involvement of the personnel when it comes to preparedness, health, and protection to ensure that the staff is adequately taken care of when working in cold climate and Arctic areas. The presentation will, therefore, also deal with practical aspects of health in cold climates, including pre-assignment health requirements, as well as competence and training with respect to "Winterization of Operations". The paper, thus, includes recommendations for health requirements, training and preparedness in order to prevent negative health impacts on the individual and on the operation. **KEY WORDS:** Health requirements, medical emergency preparedness, staff competence, rescue, vessel winterization, support operations.
129-RF	***Operating Experience of Sevmorput as a Basis for Future Nuclear Transport Ships***
	Vladimir Makarov, Vasily Ustinov, Vladimir Vorobiyov, and Stanislav Golovinskiy
	This paper: ▪ provides a brief analysis of the experience of construction and operation of *Sevmorput* nuclear lighter-aboard ship; ▪ lists the goals and tasks of *Sevmorput* construction; ▪ provides the description and technical parameters of the ship and its power plant; ▪ demonstrates the ship's compliance with the IMO *Code of safety for nuclear merchant ships*; ▪ describes the specific features of the lighter operation both on open water and in ice conditions; ▪ compares the lighter ship parameters with respective indicators of advanced ships designs intended for transit shipping in the Arctic. **KEYWORDS:** Arctic; Northern Sea Route; nuclear transport ships; nuclear lighter / container ship.
127-RF	***Simulation of Managed Sea Ice Loads on a Floating Offshore Platform using GPU-Event Mechanics***
	Claude Daley, Shadi Alawneh, Dennis Peters, Gary Blades, and Bruce Colbourne
	The paper describes a GPU-based event mechanics (GEM) model of the action of managed pack ice on a floating offshore structure. The ice cover is represented by a large number of discrete polygonal ice floes, of varying thickness. Each ice-structure contact is modeled, as is every ice-ice contact. Time histories of total platform force (net mooring force) and platform position are presented. Ice coverage, floe sizes and thickness are varied in the simulation set. The work represents a further exploration of the possibilities of GEM technology, which was previously used to explore both resistance and local structural loads for ships transiting pack ice. The work is part of a research project at Memorial University of Newfoundland called STePS2 (Sustainable Technology for Polar Ships and Structures). **KEY WORDS:** ice forces; pack ice; simulation; GPU, event mechanics GEM

4(c) Operations in Ice

Day 2, Room A, 1420-1520

137-RF	***Numerical Modeling of the Stationkeeping of Drillships in Ice***
	Mohamed Sayed, Ivana Kubat, Brian Wright, and James Millan
	Numerical simulations are carried out to examine the interaction of a managed ice cover with a drillship. Stationkeeping is maintained using a mooring system and Thruster-Assisted Mooring. The ice model is based on solving the momentum and constitutive equations, which determine the stresses and deformations of the ice cover. The drillship is modeled as rigid body of three degrees-of-freedom: surge, sway and yaw. A Base Case examines a managed ice cover consisting of floes with sizes ranging from 20 m to 50 m, and a uniform ice thickness of 1 m. The ice cover moves at 0.3 m/s along the surge direction. The drillship has a length of 130 m, beam of 42 m and a mass of 100,000 Mt. The resulting ice force shows peak values reaching 1.7 MN. Analysis of the ice force-time records gives probability distributions of the peak forces, the time required for the force to reach the peak (rise time to peak force), and the rate of force increase. The work includes a parametric study, which examines the effects of the size of the drillship, ice thickness variations, the existence of large ridge fragments in the ice cover, the presence of brash ice, patterns of icebreaking tracks, and thruster assistance to the mooring system. **KEY WORDS:** ice forces; stationkeeping; ice management; numerical simulations

145-RF	***Motion Control of Underwater Vehicle Floating in Space Under Ice Cover***
	Sergei Karlinskiy and Alexandr Iurkanskii
	The subject of the paper is a control of vertical motion of the underwater vehicle operation under ice cover. Underwater vehicles are usually controlled by planes and/or by water ballasting using a compensating tank. But, taking into account a very low allowed operation speed of underwater vehicles near ice cover, ballasting remains the mostly effective way of control. The vertical motion is influenced by the vehicle residual buoyancy which depends on two variables: (1) a pressure hull volume reduction depth-wise, (2) sea water density variation depth-wise, as well as (3) a vertical force impulse induced by an unexpected contact with ice cover. The control of vertical motion of the vehicle may be done better by use of seawater density current information, that enhances the reliability and controllability of underwater vehicle maneuvering. Also the information on a vertical distance to ice cover and a corresponding vertical velocity shall be used for reduction of the vehicle vertical speed, i.e. for diminution of ice contact force impulse. So, the instrumentation for the underwater vehicle for seawater density metering and also for measuring of vertical distance to ice cover is very useful for effective motion control of underwater vehicle The contol laws for the compensating tank ballast control are developed in the paper. To demonstrate the advantages of the developed control method, computer simulation of underwater vehicle vertical maneuvers under ice cover is performed.
	KEY WORDS Research underwater vehicle (RUV); motion control; seawater density; compensating tank (CT), ice cover.
172-RF	***A Mathematical Model of Icebreaking for Safe Speed Assessment***
	Mahmud Sazidy, Claude Daley, and Bruce Colbourne
	This paper presents numerical and mathematical models of ship-ice breaking. Two ship-ice breaking scenarios are considered, ice wedge breaking and level ice breaking. Numerical models of both breaking scenarios account for ice crushing, ice flexure and water foundation effect. For ice wedges, the effect of ship speed on the ice breaking process is investigated for different ship angles, ice wedge angles and ice thicknesses. The level ice breaking is investigated with and without radial cracks. The mathematical model is developed based on validated numerical results. Both models can be useful for safe speed evaluation, ice management and ship design.
	KEY WORDS: ship-ice breaking; bending failure; dynamic ice load; radial crack; LS-DYNA model.

5. EER and Risk

5(a) EER and Risk 1

Day 1, Room A, 1350-1450

121-RF	***Design Considerations in the Arctic: Ensuring Vessels are Capable of and Suitably Prepared for Operations in Cold Climates through Application of Advanced Design and Operations Studies to Improve Safety, Reliability and Risk Management***
	William Cowardin Jr and Roderick Allan
	World consumption of hydrocarbons continues to increase as developing nations join the developed world. Yet, easily accessible energy sources are becoming increasingly rare. This supply and demand dynamic is leading to exploration for oil and gas in increasingly challenging environments, particularly within the Arctic Circle. The challenges of operating in the Arctic are significantly different than elsewhere and society demands that companies take every step possible to insure that operations are conducted in a safe, reliable, and low risk manner - for both the crew and the environment. Within this paper the authors discuss some of the challenges of operating in the Arctic, the influence of these challenges on Arctic exploration and production vessel design, and how the design and subsequent operation of these vessels must manage potential deteriorations in functionality as a result of the cold climate operations.
	KEY WORDS: Drillship Design, Integrated Barrier Analysis, Safety, Emergency Response.
123-RF	***Current Offshore Oil Spill Statistics***
	Frank Bercha, Caryn Smith, and Heather Crowley
	Probabilistic oil-spill occurrence estimates are used by the United States Department of the Interior (USDOI), Bureau of Ocean Energy Management (BOEM) to support the development of National Environmental Policy Act assessments for hypothetical exploration and development scenarios in the U.S. Chukchi and Beaufort seas. Due to the limited offshore oil development in this region, it was not feasible to base these oil-spill occurrence estimates on empirical data from that region alone. Rather, statistically significant non-Arctic empirical data on oil spills of 50 bbl or more from the U.S. Outer Continental Shelf (OCS) including the Gulf of Mexico (GOM) and Pacific (PAC) OCS, together with their variance, are used as a starting point, to be adjusted using fault and event tree methodologies to emulate Arctic conditions. This paper, however, addresses the base statistical data for U.S. GOM and PAC OCS oil spills as well as world wide data on well control incidents including oil and gas blowouts. The first database contains information on crude, condensate and refined petroleum oil spills reported to the Bureau of Safety and Environmental Enforcement (BSEE), primarily from the GOM. As reports on this database up to 2008 were published earlier by the authors, this paper focuses on more recent updates to 2012, giving oil spill statistics for subsea oil pipelines, platforms, and wells in the U.S. OCS. A preliminary assessment of loss of well control incidents is also reported based on both BSEE and SINTEF data. The paper discusses the results of the U.S. statistical updates and the world wide well control preliminary statistics developed under current contracts of the first author's company with BOEM. Conclusions summarizing the status and applicability of the statistics presented are given, and avenues for future work are identified.
	KEY WORDS: Oil spill, loss of well control, blowout, arctic, Alaska OCS, fault tree, oil spill probability, Monte Carlo.

169-RF	***Assessing the Risks of Icebergs Impacting the Topsides of a Gravity Based Structure*** Paul Stuckey, Adel Younan, Jonathon Bruce, and Mark Fuglem One of the governing design aspects of a bottom founded structure on the Grand Banks is the impact of icebergs. A Gravity Base Structure (GBS) caisson will be designed to withstand iceberg impacts, but the platform topsides are not designed to withstand iceberg impacts. Therefore, the topsides structure must be designed in a manner such that the specified target safety levels set by ISO 19906:2010 are met. This paper presents an analytical model to estimate the probability of an iceberg impacting the topsides based on a three-dimensional model of the GBS caisson and topsides, including the extent of topsides overhang relative to the caisson and the caisson size. The impact model is implemented using a Monte Carlo simulation to ensure the risk of icebergs impacting the topsides satisfies ISO 19906:2010 requirements. **KEY WORDS:** iceberg; topsides; impact; probability; model

5(b) EER and Risk 2

Day 1, Room A, 1510-1610

104-RF	***Probabilistic Analysis of Local Ice Loads on a Lifeboat*** Md Samsur Rahman, Rocky Taylor, Antonio Simões Ré, Allison Kennedy, Jungyong Wang, and Brian Veitch Lifeboats are a ubiquitous means of evacuation fitted to offshore petroleum installations and marine vessels. For lifeboats operating in ice environments, the magnitude of local ice loads and the structural integrity of these crafts under ice loading are not well understood. To address these gaps, full-scale measurements relating to lifeboat-ice interactions were collected during a field campaign carried out in 2013. During this trial, the local ice loads on the hull of a Totally Enclosed Motor Propelled Survival Craft (TEMPSC) operating in pack ice conditions were measured using instrumented load panels. This full-scale field data provides the foundation for risk-based design load estimation and has been analyzed using the event-maximum method of local ice pressure analysis. This approach is based on probabilistic methods developed for the analysis of ice loads measured on icebreakers, which have been adapted for ice interaction scenarios involving small vessels. Results from this work provide improved insight into the nature of loads on lifeboats operating in ice-covered waters and help to inform design methodology for these vessels. **KEY WORDS:** Probabilistic methods; lifeboat; ice loads; local pressure; ship-ice interaction.
130-RF	***CPR Propulsor Development for Arctic Vessels*** Hannu Jukola and Markus Niemi Contra-rotating propellers (CRP) are used in various types of ships due to their superior efficiency and fuel economy. Azimuth propulsors have become the norm for ice-breaking vessels due to the maneuverability and operational versatility they provide. The ICE CRP propulsor possesses the high efficiency of CRP and the great maneuverability of an azimuth propulsors. Equipped with both pushing and pulling propellers, it also provides good ice-milling capabilities with the pulling propeller and enhanced ice-management ability with the unique propeller flow of a CRP propulsor. Steerprop has conducted a series of ice model tests at the Aker Arctic ice laboratory to study the effects of CRP propulsors propeller flow with varying installation angles and steering angles on the ice management and ice-going capability of ice-breaking vessels. **KEY WORDS:** Azimuth propulsor; CRP; Ice model tests; Ice management.
132-RF	***Characterization of the Iceberg Scour Regime on the Makkovik Bank, Labrador Shelf*** Tony King and Gary Sonnichsen The Bjarni Development Study (Petro-Canada, 1983) indicated a very high iceberg scour risk for gas export pipelines from the Makkovik Bank to landfall on the Labrador coast. Re-analysis of the available data identified conservative elements in the 1983 work (King, 2002). Subsequent seabed surveys conducted to define the iceberg scour regime have resulted in over 5,800 km2 of high resolution multibeam on, or near, the Makkovik Bank. This data set contains more than 27,000 analyzed scour features with depth and geometry measurements at over 260,000 cross-sections. Limited repetitive mapping to estimate the iceberg scour formation rate has also been performed. **KEY WORDS:** iceberg; scour; risk; pipeline; Labrador

6. Ice

6(a) Properties and Measurements - 1

Day 2, Room A, 1020-1120

124-RF ***Tracking Icebergs with Remotely Monitored GNSS Satellite Telemetry Ice Drift Beacons***

Juan Acevedo, Chris Ulan-Kvitberg, Scott Tiffin, Roger Pilkington, Logan Cooper, Eric Soulis, and Dave Hannah

TRACKING icebergs provides information on their drift characteristics for iceberg drift research, iceberg drift model development and for keeping track of the icebergs during field operations. The paper provides details of a bi-directional GPS/Iridium satellite telemetry ice tracking drift beacon with flexible data transmission that has been used successfully to track pack ice and extreme ice features and a modified version, which could be deployed by a UAV. The paper also presents various ideas for attaching beacons to icebergs and a gripping mechanism designed to allow a beacon to adhere to inclined ice surfaces. Suggestions are provided to accommodate rolling and decay of the iceberg.

KEY WORDS: Tracking icebergs and sea ice; GPS; bidirectional Iridium communication; UAV; adherence to incline ice surfaces.

107-RF ***Forecasting Pack Ice Blockage Events at St John's Harbour, Newfoundland: An Empirical Approach and Development of Ship Alert and Advisory Tables***

Ian Turnbull, Richard McKenna, Rocky Taylor, and Robert Sarracino

Supply vessels for the Grand Banks oil and gas industry have faced 25 ice blockage events entering St. John's Harbour, Newfoundland from 1979-2005. We propose an empirical approach to forecasting the occurrence of 8-10/10ths total ice concentration at the harbour, and tables for alerting and advising ship personnel on the likelihood of such an event based on offshore winds, surface ocean currents, and ice conditions. These events are primarily controlled by the strength and character of an ocean current gyre and the ice conditions over a large area offshore St. John's Harbour.

KEY WORDS: ice blockage; empirical ice forecasting; St. John's Harbour; probabilistic ice forecasting; vessel alert and advisory.

102-RF ***Identification of Extreme Ice Features in the Canadian Arctic***

Igor Zakharov, Pradeep Bobby, Sherry Warren, and Desmond Power

Research on automatic detecting, tracking and characterizing extreme ice features in the Arctic is based on analyzing and processing satellite synthetic aperture radar (SAR) and optical images. Algorithms to identify ridges from very high resolution optical data have an accuracy of 86.4% when compared to manual extraction and ridge height has been estimated from shadow. SAR signatures of various ice features have been analyzed and the results indicate that it is possible to identify rubble fields from other ice types.

KEY WORDS: extreme ice features; ridges; icebergs and ice islands; satellite; remote sensing; radar; optical.

6(b) Properties and Measurements - 2

Day 2, Room A, 1120-1220

158-RF ***The Detection of Multi-Year Ice Using Upward Looking Sonar Data***

David Fissel, Edward Ross, Louis Sadova, Alex Slonimer, Dawn Sadowy, and Todd Mudge

Upward looking sonar (ULS) instruments on year-long sub-surface moorings are widely used in support of oil and gas exploration programs. The analysis results are used to provide key inputs to the engineering of offshore platform design and ship-based ice management. Detection of the older and harder multi-year sea ice is particularly important for engineering and ice management applications. Here, we analyze multi-year ULS measurements of sea ice in the Beaufort Sea and off Northeast Greenland. The detectability and characterization of multi-year ice is derived from two independent analysis methods. The first method uses the backscattered acoustic pulse shape received by the sonar instrument while the second method involves the degree of the smoothness of the underside of the ice keels away from the leading and trailing edges. Both methods demonstrate skill in detecting multi-year sea ice as distinct from first year sea ice. The two methods are shown to be complementary in that some multiyear ice floes cannot always be clearly categorized by one method alone.

KEY WORDS: sonars; sea ice, multi-year ice; acoustic; backscatter

157-RF ***The Measurement of Shallow Ocean Currents Beneath Deformed Mobile Sea Ice Using Upward Looking Sonar Instruments***

Todd Mudge, David Fissel, Keath Borg, Nikola Milutinovic, and Ed Ross

The under ice ocean currents are critical in the understanding of the boundary layer between the sea ice and the ocean, involving determination of the drag forces that sea-ice exerts on the upper water column and the related turbulence and mixing levels. A semi-automated algorithm has been developed, which accounts for the changes in sea ice drafts, to determine the nearest surface ocean current measurement level. Using long-term measurements from upward looking sonar datasets in the Chukchi and Beaufort Seas, the algorithm and its extensions to all current bins is investigated.

KEY WORDS: Sea Ice, Ocean Currents, Boundary Layer, Chukchi Sea, Beaufort Sea.

139-RF	***Iceberg Detection Using Simulated Radarsat Constellation Data***
	Michael Denbina and Michael Collins Iceberg monitoring, as well as maritime surveillance in general, is an important application of synthetic aperture radar (SAR), and is a stated objective of the Radarsat Constellation, the next generation of Canada's Radarsat satellites. In this paper, we simulate Radarsat Constellation data in a number of different imaging modes, using Radarsat-2 singlelook complex data covering a study area in the Labrador Sea. We test the iceberg detection performance of both linear dual-pol data as well as compact polarimetry, a novel SAR architecture that transmits circular polarization rather than the traditional horizontal or vertical polarizations. Compared to the linear data, the compact data missed fewer targets, and detected a greater number of pixels of detected targets, for most of the incidence angles and imaging modes tested. **KEY WORDS:** iceberg detection; synthetic aperture radar; compact polarimetry; circular polarization; Radarsat Constellation.

6(c) Properties and Measurements - 3

Day 3, Room A, 1000-1040

174-RP	***Modeling of Pressured Ice Interactions with Ships***
	Ivana Kubat, Mohamed Sayed, and Philippe Lamontagne Heavy ice conditions persisted over the Gulf of St. Lawrence and the Strait of Belle Isle during the winter of 20013-2014. Near full ice coverage and relatively large thicknesses caused difficult navigation conditions for most of the ice season. In addition, several episodes of ice compression triggered severe conditions, which led to besetting of vessels. The present paper will review ice conditions and the environmental forcing that led to the besetting episodes. Analysis of those besetting events is next presented. An ice dynamics model is used to hindcast ice drift and deformation over the Gulf of St. Lawrence and the Strait of Belle Isle. Analysis of ice deformation, convergence and stresses is conducted in the vicinity of the besetting incidents. The analysis quantifies the values of pertinent variables that correspond to besetting. Specifically, the results give critical values of the major principal compressive stress, mean normal compressive stress, convergence strain rate, and ridge thickness. Furthermore, the sensitivity of the risk of besetting to the proximity of the coastline and prevailing wind is examined. The present results are combined together with those from past investigations of besetting incidents in the Gulf of St. Lawrence and Frobisher Bay. The paper, thus, compiles the most comprehensive available account of besetting events in Canadian waters. Examination of those events and the results of the ice dynamics simulations gives the most reliable estimates, to date, of the critical conditions which correspond to besetting. The relatively large number of events also makes it possible to examine, albeit qualitatively, the effect of the type of vessel on the risk of besetting. Beyond the analysis of the specific besetting events, the paper provides a description of ice compression development over the Gulf of St. Lawrence and the Strait of Belle Isle. Regions which are prone to ice compression and the environmental conditions leading to heightened risk of compression are discussed.
115-RF	***A Method for Characterizing Uncertainty in Tactical Sea Ice Drift Forecasting***
	Joshua Blunt, Douglas Mitchell, and Adel Younan Hydrocarbon exploration in the high-Arctic offshore region may require enhanced station keeping capability in ice due to a limited open water summer season and/or the potential for temporary pack ice intrusions during a nominal open water season. Ice management systems have been employed as a means to improve station keeping ability in the presence of drifting sea ice, but accurate ice drift forecasting is central to improving the reliability of any ice management system. A rigorous approach to both (1) quantifying and (2) communicating the uncertainty associated with sea ice drift forecasting is proposed in this paper. **KEY WORDS:** ice management, icebreaking, sea ice drift forecasting, hindcasting, cone of uncertainty

7. Ice Mechanics

7(a) Ice Mechanics - 1

Day 2, Room B, 1020-1120

155-RF ***Analysis of Experimental Data and Quantifying Influence of Dimensionless Material Properties, Velocity and Aspect Ratio on Ice-induced Forces on Vertical Structures***

Aaruun Arunachalam

In this paper, the quantitative influence of aspect ratio (B/h), and dimensionless velocity or thickness Froude number [TFN = $u/\sqrt{(gh)}$] on dimensionless ice-induced pressures ($pe/\rho iu2$) is briefly reviewed and discussed. Since material properties of ice (E, σf, $K1c$) have not been reported for many data-sets, a strategy for generating appropriate material properties for ice is proposed. Two dimensionless terms for material properties of ice, $\{(E/\sigma f)\times[K1c/(\sigma f\sqrt{h})]\}$ and $\{[K1c/(\sigma fu)]\times\sqrt{[E/(\rho ih)]}\}$ were identified and their influence on $pe/\rho iu2$ is discussed. It was found that (1) $pe/\rho iu2$ on rigid vertical structures decreases with (a) increasing B/h at a rate of about 0.42, when $u/\sqrt{(gh)}$ and $\{[K1c/(\sigma fu)]\times\sqrt{[E/(\rho ih)]}\}$ remain constant; (b) pe/ρiu2 decreases with increasing $u/\sqrt{(gh)}$ at a rate of about 1.80 when $u/\sqrt{(gh)}$ is < about 6.0×10-3and at a rate of about 1.93 when $u/\sqrt{(gh)}$ is > about 6.0×10-3 when B/h and $\{[K1c/(\sigma fu)]\times\sqrt{[E/(\rho ih)]}\}$ remain constant. (2) Preliminary analyses of the datasets shows that $pe/\rho iu2$ decreases with increasing $\{(E/\sigma f)\times [K1c/(\sigma f\sqrt{h})]\}$ at a rate of 0.335 and 0.469 and that $pe/\rho iu2$ decreases with increasing $\{[K1c/(\sigma fu)]\times\sqrt{[E/(\rho ih)]}\}$ at a rate of 0.729 and 0.808. (3) It was also found that shapes of structures do not influence dimensionless ice-induced pressures on structures.

KEY WORDS: ice-loads on rigid vertical structures; dimensional analysis; aspect ratio; thickness Froude number; dimensionless material (ice) properties.

161-RF ***Characteristics of Field-scale High Pressure Zones during Non-simultaneous Failure of Thin First-year Sea Ice***

Rocky Taylor and Martin Richard

For temperate ice regions, the guidance provided by current design codes regarding ice load estimation for thin ice is unclear, particularly for local pressure estimation. During non-simultaneous failure of ice under compression, spalling fracture localizes contact into high pressure zones (*hpz*s), through which the majority of loads are transmitted. Much of our present understanding of *hpz*s comes from inferences made from the analysis of pressure panel data collected during medium-scale field tests or full-scale measurements on ships or structures. During medium-scale field indentation tests conducted by the Japan Ocean Industries Association (JOIA) from 1996-2000, tactile pressure sensors were also deployed. The JOIA dataset provide detailed information about pressure distributions at a sufficiently high resolution so as to allow for the identification and tracking of individual *hpz*s throughout an interaction. Given their importance in the transmission of loads during an ice-structure interaction, understanding the birth, evolution and death of individual *hpz*s is seen as being an important direction both for guiding fundamental studies of ice mechanics and also for guiding the development of new ice load models. Recent analysis of these tactile sensor data has led to the development of an empirical *hpz*-based model which can be applied to model local and global pressures for thin ice conditions (Taylor and Richard, 2014). From this analysis, new insights into the nature of *hpz*s for thin first year sea ice during non-simultaneous failure have resulted. In the present paper, an overview is provided of analysis techniques used to extract information about individual *hpz*s from the tactile sensor dataset, as well as the characteristics of these *hpz*s. Aspects discussed include spatial and temporal characteristics of high pressure zones, as well as pressure and geometric attributes. While observations of the shape of spatial distributions and total contact area covered by *hpz*s are consistent with previous observations (line-type distributions with total contact area on the order of 10% of the nominal interaction area), these results indicate that individual *hpz*s are smaller and more densely distributed than indicated by previous analyses based solely on pressure panel data. The implications of this finding in terms of scale effects and ice load modeling are discussed.

KEY WORDS: tactile sensor data; empirical *hpz* database; local ice pressure; high pressure zones; probabilistic ice load model.

162-RF ***Use of Thermal Imagery to Assess Temperature Variation in Ice Collision Processes***

Jochen Tijsen, SE Bruneau, and Bruce Colbourne

The paper describes the exploratory use of thermal imagery on ice collisional processes. This way of measuring provides a new source of information which may lead to new insights and improvements of existing ice collision models. Results indicate significant internal temperature rises in both the crushing case and in the sliding (friction) case. The paper provides some observations, however the main purpose is to show the value of applying thermal imagery in studies of collisional processes. Nevertheless the reader may be interested in the observations originating from the experiments. The first is that the internal temperature increments during ice friction are shown to track the trends in the friction coefficient. The second is that internal temperature increments during ice crushing appear to be concentrated in specific areas of the contact zone and may indicate high pressure zones.

KEY WORDS: Collision, friction, crushing, temperature, heat

7(b) Ice Mechanics - 2

Day 2, Room B, 1120-1220

125-RF	***Fracture Analysis of a Steel Plate Loaded by Ice***
	Tayyebe Seif, Abdullah Jamaly, and Claude Daley
	There are several theories used to describe the fracture process including Linear Elastic Fracture Mechanics (LEFM), Elastic-Plastic Fracture Mechanics (EPFM), and Cohesive Zone Models (CZM), which allow for development of predictive capabilities. The main disadvantage of LEFM and EPFM techniques is that only structures with an initial crack can be modeled. Other drawbacks of these techniques are geometry dependence and validity limits. In contrast, CZM can simulate fractures in any structures, with or without a crack. CZM is not confined to a class of materials, but can be used for arbitrary materials. In this paper, the CZM is used to numerically simulate crack initiation and growth in a steel plate. Within the CZM, material separation (i.e. damage of the structure) is described by interface elements, which open irreversibly and lose their stiffness at failure, causing the continuum elements to be disconnected.
	KEY WORDS: fracture analysis; cohesive zone model; ductile material; ice pressure.
120-RF	***Impact Ice Loads on Spherical Geometries***
	Dan Oldford, Regina Sopper, and Claude Daley
	Laboratory experiments were conducted by crushing a spherical indenter into cylinders of ice. These experiments were aimed at proving the force estimates produced by a program called Direct Design for Polar Ships (DDePS). DDePS is a contact-geometry specific tool based on Popov type formulations. The ice crushing experiments were performed in open air at various impact speeds using a double pendulum impact apparatus. The ice was laboratory ice with properties close to that of multi-year ice. Values of impact speed, force and penetration were measured. This paper presents the results of these laboratory experiments which were in good agreement with DDePS.
	KEY WORDS: Double-Pendulum; Ice Loads; Azimuthing Propulsion; DDePS
111-RF	***Bond Enhancement in Curved Sandwich Shells***
	Peter Marshall, Vul Thang, Nicholas Brake, and Paul Corder
	As follow-up to recent papers by Marshall et al. (2010, 2012), research on steel-concrete-steel (SCS) sandwich shells for Arctic offshore structures continues at two universities. National University of Singapore is testing heavy transverse reinforcement which ties the outer steel plates together. Lamar University in Texas originally studied the composite ice wall concept in the late 1980s, and is now testing surface treatment with a size-tiered gradation of mini-studs, macro fibers (steel) and micro fibers (synthetic), intended to develop the full bulk properties of the Fiber Reinforced Concrete (FRC) core in radial tension and punching shear. Using ISO's design non-hydrostatic partial span loading on the Singapore Cone, radial bond stress at the inner steel plate is low and deemed attainable for both the stud enhanced bonding surface and the bulk concrete core. The steel shell serves as prefabricated permanent formwork, and the arched vaults resist external ice loading mainly by compression, provided the sandwich does not disintegrate in an unstable fashion.
	KEY WORDS: Arctic caissons; Sandwich shell; Concrete; Bond; Stud

7(c) Ice Mechanics - 3

Day 2, Room B, 1420-1520

118-RF	***Ice Crushing Pressures for Arctic Structure Design***
	Paul Spencer
	This paper describes a reanalysis of the data used to support the ISO 19906 deterministic pressure recommendations for Ice Loads on Arctic Structures. The reanalysis using quantile regression generated calibrated ice crushing pressure probability distributions. Using an interaction model based on High Pressure Zones, new recommendations are presented for Local and Global pressures for a wide range of ice thickness and width combinations.
	KEY WORDS: Ice load; ISO 19906; High Pressure Zones.
164-RF	***A Short History of Ice Model Tests in Finland***
	Göran Wilkman
	Ice navigation has been practiced on regular basis some 120 years and testing of ships in a model laboratory close to 60 years. In Finland the first laboratory was commenced only 45 years ago. Open water facilities have it much less complicated as they only need the water. In ice modeling the cornerstone is how to model ice, which in fact is just hard water. A lot of different materials have been used for ice modeling. Normally when you get some of the properties right, some go wrong. The ice modeling materials used during the short history goes from naturally grown saline ice through different chemicals mixed with water, wax and plastics towards ice that is actually built or constructed or the natural growth has been disturbed by using different methods to control the density. This paper discusses the development of model testing, its different features and how the development has taken place in Finland.
175-RF	***Behavior of Ice Covers Under Moving Loads - The Driving Mechanism***
	Michel Lanteigne and Gary Van Der Vinne
	Measurements of the response of a floating ice cover to a loaded vehicle travelling at various speeds indicate that the "deflection bowl" created under the weight of the vehicle behaves like a vessel which is carrying the vehicle over the water surface. Because the ice cover is flexible, the bowl changes shape as the forces acting on it change with speed. Results show that: 1) as vehicle speed increases towards "critical speed" the depth of the bowl increases from the effect of the Bernoulli principle; 2) the depth of the bowl diminishes above critical speed from dynamic lift; 3) critical speed is sensitive to water depth – which is predicted by the Bernoulli principle.
	KEY WORDS: Moving loads on ice covers; critical speed; deflection bowl; Bernoulli principle; water depth.

8. Regulations and Standards

Day 3, Room A, 1100-1200

147-RF	***Class Requirements and Practical Solutions to Winterisation*** Tony Vollmers and Rob Hindley Winterisation rules are currently used as a means to incorporate historic specification best practice for cold environment shipping into formal notation requirements to be specified for new designs. The background to the development and context of the winterisation rules is given and the transition between such owner led practices and class rule requirements is explored. Cases studies of real applications of the winterisation rules are used to identify practical solutions and key learning points. A review of the structure of winterisation rules in the context of the developing IMO Polar Code requirements is provided. A new approach to structuring and using winterisation rules based on functional requirements is outlined. **KEY WORDS:** Winterisation; Design Temperature; Classification
152-RF	***Arctic Standards and Regulations – Status and Update*** G. Abdel Ghoneim The existence of comprehensive Arctic regulatory regimes is paramount for ensuring the safety of Arctic field development when recovering the vast Arctic oil and gas resources (estimated at 25% of world reserves). Several Arctic coastal countries such as Canada, USA, and Russia have successfully undertaken year-round Arctic drilling. Companies such as Dome Petroleum's subsidiary, Canadian Marine Drilling Limited (CANMAR), Esso Resources Canada, and Gulf Canada have pioneered such Arctic operations since the early 1970s. With almost 70% of the world's Arctic reserves, Russia is presently leading Arctic drilling and production.. Russia has comprehensive Arctic regulations in place and has been cooperating with Norway resolving Arctic issues through venues such as the Barents 2020 project and the resolution of their dispute over Arctic territories in 2010. This paper presents the current state of the regulatory schemes of the five Arctic coastal countries. Additionally, the paper reviews the ISO Arctic standard ISO 19906:2010 for practical applicability and recommended safety factors (partial action and resistance). The paper identifies the necessary regulatory elements that regulators must address in the future.. The regulatory regimes are the laws used to govern Arctic offshore field development activities and the regulations that provide details on how to comply with these laws. The regulatory regime applies to environmental protection, safety, employment standards and worker safety, health protection, emergency planning, oil spill response, and liability for accidents. Arctic countries use either a prescriptive approach, specifying the methodology to be applied for achieving the goals of the regulator, or performance/goal-based approach, identifying the goals that must be achieved while allowing operators the flexibility to choose the methodology that fits their proposed technology. A mixed approach is also adopted by some countries. The objective is to demonstrate the need for guidance in the form of standards and regulations. **KEY WORDS:** Arctic, standards; structures; regulations; development; cold climate;; safety; risk; reliability; performance/goalbased; prescriptive.
106-RF	***Rock and a Hard Place: A Blowout in the Arctic*** Wylie Spicer The Arctic is one of the last frontiers. It is a potential source of abundant mineral resources. The consequences of a casualty caused by oil & gas exploration and exploitation are not internationally regulated. This paper considers how this situation has arisen and what may be done to remedy it.

9. Ships and Structures

Day 3, Room B, 1100-1220

149-RF	***Kits for the Enhancement of Surface Ship Operations in Cold Weather*** Heather Tomaszek and Christopher Bassler Because U.S. Navy (USN) surface ships are not specifically designed for conducting Arctic operations, a study was performed to examine and identify options to increase the operability of existing ships in extreme cold weather environments. Previous research about Arctic operations was performed by the USN in the 1980s, however, as platforms and systems have changed and anticipated missions have shifted, updates to that research are needed. Possible means to mitigate identified challenges are discussed, along with materiel solutions from commercially available equipment. Items for a deployable kit for the USN oilers for cold weather operations are identified as a case study for cold weather kits on USN ships. Options for delivering the kit to the ship from shore were examined. These deployable kits can provide a means for USN surface ships to better operate in extreme cold environments and carry out required missions. **KEY WORDS:** Arctic; Antarctic; cold weather; ship operations; mission effectiveness
126-RF	***Analytical Approach for Predicting Fracture in Structures Due to Lateral Ice Indentation*** Abdullah Jamaly, Tayyebe Sief, and Claude Daley The large deflection of a thin rectangular steel plate under laterally distributed pressure over a certain length of the plate span is investigated. Assuming "zero aspect ratio", plate ends are clamped and the other two edges are free. The plate behavior is analyzed considering membrane effect only, which is the dominant action in the large deflections of thin plates. The plastic strain criterion is used to predict the fracture point in the plate. Finite Element Analysis (FEA) is used to predict the fracture with the same criterion and the results compare well with theoretical formula. **KEY WORDS:** FEM; steel fracture; ice patch load; plate; membrane.

136-RF	***An Ice Failure Explanation of Dynamic Ice Loading Events on Molikpaq***
	Yan Qu
	This paper addresses an explanation to the ice failure process of the phase-locked dynamic ice loading events on Molikpaq in 1986. The ice failure is illustrated as a ductile damage-collapse process with the general features that the ice failure is a discrete ductile process that can be separated into damage and collapse phases; in the damage phase cracks propagate in the ice but the ice does not break and in the collapse phase the ice is pulverized into powder; the ice crushing is a ductile process with the typical simultaneously failure characteristic; the failure has a specific failure length which is related to displacement of the structure. The full-scale data show that the ductile damage collapse failure happens at the ice drift velocity lower than 0.1 m/s. The failure is simultaneous along ice-structure interface and induces high global ice load without width effect. It also induces saw teeth ice load and caused dynamic response of the platform. The response is not an oscillation process and is different to the lock-in vibration of the jacket platform and light house because the caisson is close to an over damped or critically damped system. The field measurement also shows that failure length of the ice is about 5 cm for those events. A simple analysis shows that displacement of the structures is approximately ½ to 1 times of the failure length.
	KEY WORDS: Phase-locked loading; vertical structures; ductile damage-collapse failure; saw teeth ice force; Simultaneous failure; failure length
141-RF	***A Semi-Empirical Method of Ice Resistance Prediction in Level Ice***
	Jeong Seong-Yeob, Kyungsik Choi, Seong-Rak Cho, Kuk-Jin Kang, and Chun-Ju Lee
	We introduce a semi-empirical model that can determine a ship's performance in level ice based on Lindqvist's model and develop a simple model for calculating ice resistance. This model assumes that contact between the ship and the ice is a case of symmetrical collision, and two contact cases are considered. Crushing and submersion forces are calculated via Lindqvist's formulas, and the breaking force is determined by a concept of energy consideration during ship and ice impact. The average difference between the predicted data and the model test data is about 4.6%, but the total resistance showed fairly close agreement with both. In addition, the friction coefficient may have considerable influence on breaking and submersion forces.
	KEY WORDS: Semi-empirical model; Ship performance; Level ice; Energy consideration; Ice resistance