Ice induced loads on the Oblique icebreaker Baltika

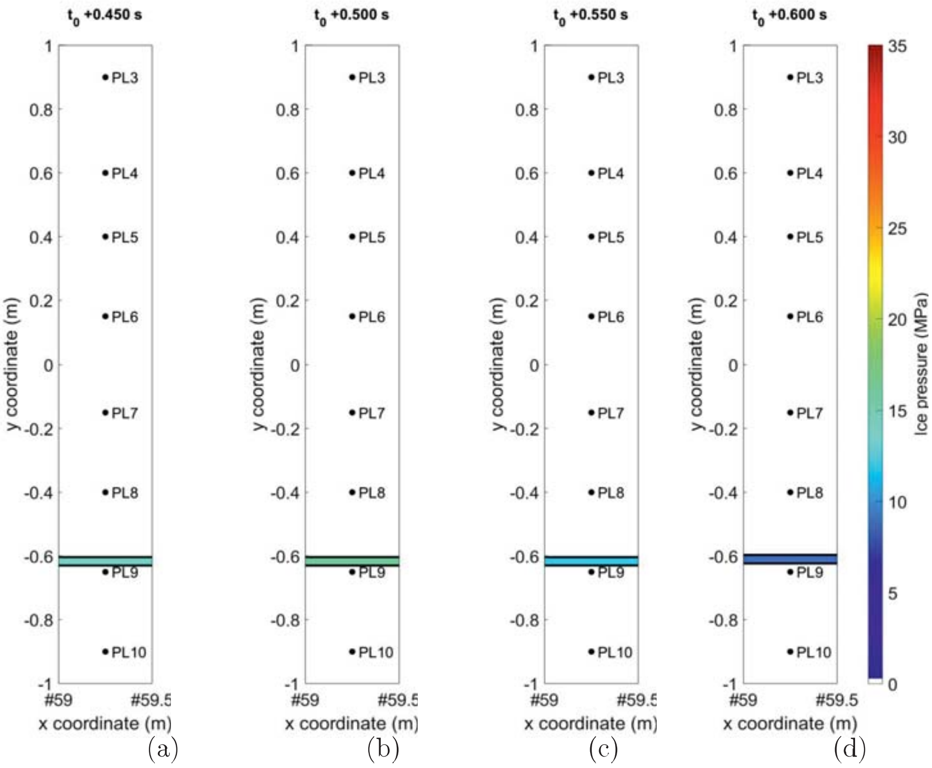
The oblique icebreaker *Baltika*, currently operating in the Gulf of Ob, is the first oblique icebreaker ever made. An ice load monitoring system was installed on the inclined side used in icebreaking operations during construction in order to gather information about the ice loads and learn more about the asymmetrical hull shape. The data has now been analysed with new scientific discoveries as a result.

Baltika has been operating in the Gulf of Ob for four years and has continuously been gathering data concerning the ice loads it experiences. There are 22 strain gauges used to measure the ice load. All of the sensors are located on the inclined side of the vessel and centred around the waterline. Maritime Engineering graduate Jillian Adams has analysed the first two years of data (May 2015 – May 2017) as the topic of her Master's thesis for Aalto University, with Naval Architect, Structural Designer Ville Valtonen from Aker Arctic acting as her advisor.

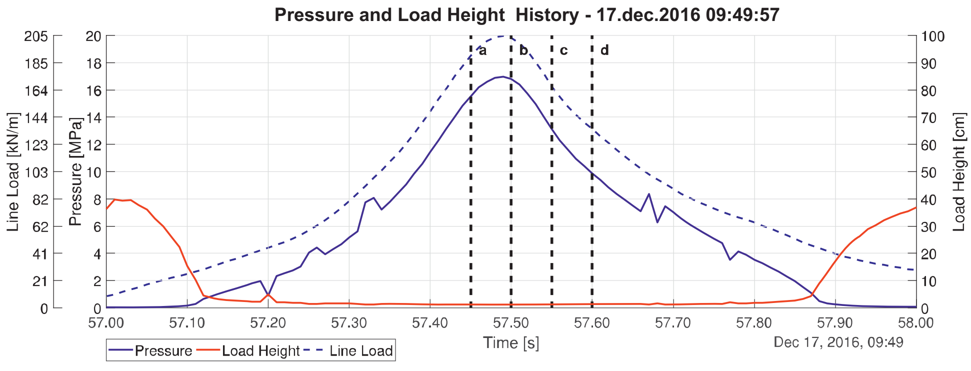
Inverse method

Adams further developed an inverse method, originally implemented by Teemu Ikonen for his Master's thesis at Aker Arctic in 2013 to analyse the full-scale strain measurements taken on board *Baltika*. Two discretisation patterns were used to estimate the pressure and load patch height induced by impact events between the ship and the surrounding sea ice.

Analysis revealed low magnitude yielding incidents due to higher ice loads than the vessel was designed for. *Baltika* was originally designed for Baltic Sea ice but was taken, shortly after her delivery, for ice trials in the Arctic. There she surpassed the required performance targets even though the ice conditions are much harsher than the ones she was designed to operate in. She has now successfully served as an ice management vessel at the Arctic Gate oil

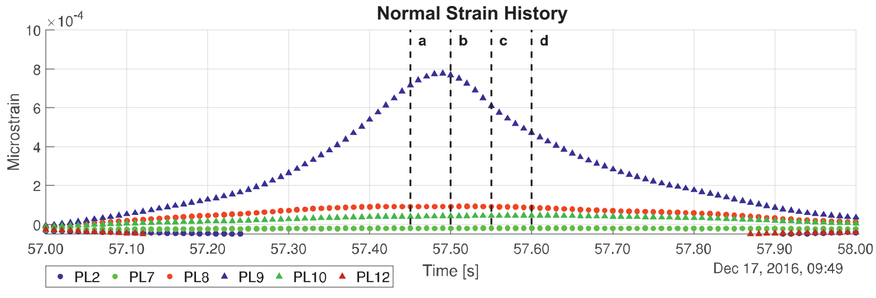


The four figures show how the load patch and pressure load develops over time. The figures are captures from a video of the full impact event. In this case, the ice load is concentrated on one sensor for the full duration of the event.
a) High pressure due to crushing; just before the ice breaks
b) Peak pressure of approximately 17 MPa as the ice breaks
c/d) As the load disengages from the ship and the pressure decreases



The development of the line load, the pressure and the load height are shown for a full impact event. It shows a textbook impact event where the pressure (solid blue) grows gradually until a single peak occurs. The ice breaks at the point of maximum pressure. The pressure then decreases as the load disengages and loses contact with the hull.

The important part of the figure is the fact that the load height (red line) is very narrow. It is only 1-3 cm and it is constant throughout almost the entire impact event.



This details the strain history of the event. Here only one sensor measures significant strain (PL9 in blue). This is reflected by the load patch location shown in the top figure. The next closest sensors experience smaller magnitude strains.

terminal assisting oil tanker operations together with nuclear-powered icebreaker *Vaygach* and the icebreaking supply vessel *Vladislav Strizhov*.

“The data shows that *Baltika* has been used in oblique angles of mainly 30 to 50 degrees for significant amounts of time,” Adams says.

“*Baltika* can break ice in a 90 degrees angle, but the thick arctic ice sets some limitations,” Valtonen adds. “It was however interesting that during the ice trials *Baltika* was compared to two other icebreakers with double the power and all three performed equally well.”

Research on ice loads

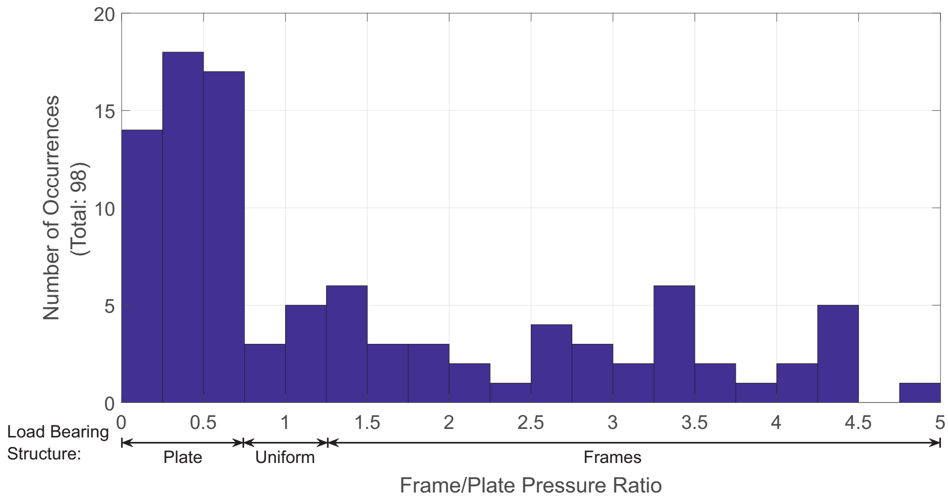
In her research Adams used finite element analysis to create an influence coefficient matrix that describes the strain response of the hull structures to an applied load. The inverse method was applied to the strain measurements from 250 impact events for the general analysis of maximum ice-induced loads and 98 events were selected to analyse the details of the full impact event.

The results of the study show that, for the analysed impact events, the peak pressure created by the ice is most often between 10 and 25 MPa. The load height at the time of maximum pressure is on the order of 1 to 3 cm, confirming that the ice-induced loads are line-like as suggested by earlier research. This implies that the main ice-induced pressure is concentrated on a smaller area than the load patches used in classification society rules.

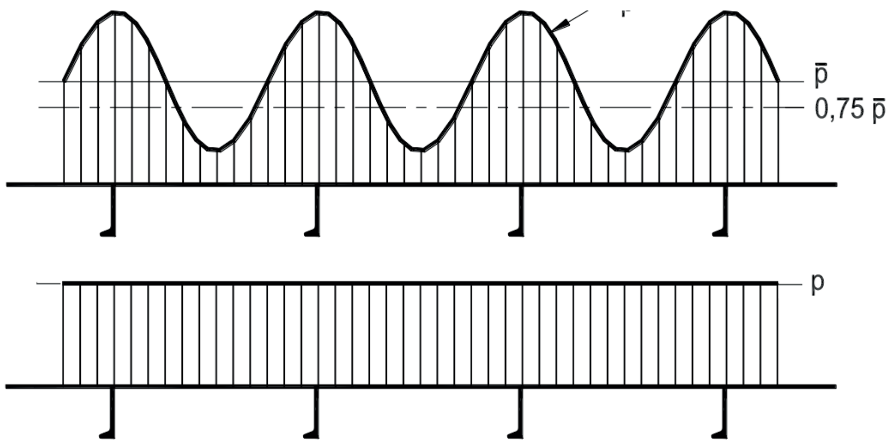
The detailed analysis revealed constant load patch heights over the duration of the individual impact events. Most high pressure impacts occurred in the area surrounding the design waterline. There were noticeably fewer large strains measured on the sensors immediately surrounding the large stringer located at the design waterline due the increased stiffness in that area. In most cases, the impact events are less than a second in duration and the full development of the pressure, from the crushing stage to the load disengagement, can be seen. A new discovery from this study is that the load height is markedly constant throughout the entire duration of the impact event, even though the location of the load varies throughout the loading event. The line load estimated using the inverse method follow the same trends as the loads estimated using more common methods based on shear strains.

Ice load is independent from structure

By dividing the frame spacing into three sections, Adams investigated the pressure distribution across the structural members. The results do not



The figure presents the distribution of the ratios calculated for each of the impact events. The summary of the results indicates that there is no significant trend towards either a uniform distribution of the pressure or a consistent sinusoidal distribution. The results imply that pressure distribution is random and independent of the ship's structures.



The first figure is the pressure distribution assumed by the FSICRs. The pressure distribution on the structures is assumed to follow a sinusoidal pattern where the frames experience a higher pressure than the plates.

The second figure in contrast assumes a uniform distribution of pressure across the ship's structures.

The results from the analysis of the Baltika data imply that pressure distribution is more random and does not consistently follow either of these patterns.

show a conclusive tendency for the frames to experience higher ice-induced pressures than the plates or for the distribution to be equal. For the impact events analysed, the distribution between events where the plates experience a higher pressure and where the frame experience a higher pressure is almost equal in the number of occurrences. The results indicate that the distribution of pressure across the structural members is more random and is independent of the supporting structures.

“This would mean that the ice load does not depend on the structure behind, which is currently the assumption in the Finnish-Swedish Ice Class Rules,” Adams explains.

“This topic has been discussed for decades and, with the longest continuous full-scale data now analysed, the results can be considered quite reliable,” Valtonen adds. “Based on this new scientific evidence, there seems to be room for development of the rules.”

Recommendations

Based on the results and conclusions of the thesis, Adams makes the following recommendations with the intention of improving structural design.

1. Structural design investigation
   The results of the general analysis indicate that the ice impacts create concentrated high-magnitude loads on the hull structures. The nature of the loaded area differs significantly from the load patches and design pressures used in design and classification rules and standards.

It is unclear at this time how the line-like ice loads would affect the dimensions of the ship's structures if more concentrated loads were used as the design scenario. Therefore, an investigation of the effects of the concentrated loads is recommended to determine their influence on the structural design, with the aim of improving safety and efficiency of ice-going ships.

2. Further application of the inverse method
There exist many full-scale data sets from numerous ships operating in different ice-covered waters. The inverse method developed in the thesis proved to be capable of identifying ice-induced pressures and load patches. Applying the method to additional data sets with different instrumentation layouts would be beneficial to determine the methods accuracy and allow for comparison of the results.

Measurements continue

Measurements will continue on *Baltika* for at least another set of two years, maybe even more.

"Our mission at Aker Arctic is to design icebreakers, but also to advance the field of icebreakers by conducting scientific work," Valtonen says. "Ice is such a complicated material and behaves in unexpected ways close to the melting point that the only way to get reliable information about ice loads is either instrumentation or studying damages on ships. In the past years, research has advanced remarkably because we have more sophisticated tools to analyse data accurately compared to twenty years ago." ■

Arctic Passion Seminar gathered experts from all over the world

This year, the 13th Arctic Passion Seminar focused on discussing new Arctic projects and the development of new polar vessels and technologies, including a model test demonstration of the world's first LNG-fuelled icebreaker, *Polaris.*

The opening speech was given by Mr. Petri Peltonen, Under-Secretary of State from the Ministry of Economic Affairs and Employment, Finland, who summarized the core policies in the country's upcoming EU presidency with four letters: A for the Arctic, B for bioeconomy, C for cleantech, and D for digitalization.

Aker Arctic's Managing Director Reko-Antti Suojanen gave an overview of the Arctic market, recent achievements and new tools for design and testing at Aker Arctic. Examples of recent achievements are the beginning of the first Arctic LNG project for Yamal LNG, the construction of the ice class PC 3 Chinese icebreaking research vessel, and the design of a LNG-fuelled, ice class PC2 polar icebreaking cruise vessel for PONANT.

Dan McGreer, from Vard Marine Inc., presented the Chilean Antarctic Vessel's design project, in which Aker Arctic supported Vard with the design of the hull form, model tests and some specific ice class design solutions.

Mikhail Grigoryev, from GECON, continued with forecasts on how freight traffic on the Northern Sea Route will grow according to two different scenarios. He also gave his view on how many new arctic cargo vessels need to be constructed in the future.

The French Polar Logistics Vessel, *L'Astrolabe*, successfully finished her first year delivering supplies to Antarctica and patrolling in the Indian Ocean. Jean-Luc Prime, from Piriou Shipyard, described the first winter's positive experiences and showed impressive pictures from loading and unloading cargo by the quayside, on ice floes and with helicopter.

Finnish and Swedish exports depend on efficient winter navigation on the Baltic Sea. With the introduction of EEDI (Energy Efficiency Design Index), which aims to lower CO_2 emissions a need arises to ensure that ships will continue to sail with feasible schedules. Arto Uuskallio, from Aker Arctic, gave an overview of the potential risks and what Aker Arctic is doing to prevent them from becoming reality.

In addition to seminar presentations, one of the highlights was the demonstration of an ice model test. This year, the icebreaking capability of the Finnish icebreaker *Polaris*, the world's first LNG-powered icebreaker, was demonstrated. The vessel is based on the Aker ARC 130 concept design and full-scale ice trials were carried out in 2017.

After lunch, Torkild Skjong, from Vard Group AS, presented Vard's different vessel construction projects along with the new luxury icebreaking expedition cruise vessel for Ponant, which Aker Arctic has designed in close cooperation with Stirling Design International.

Mikhail Belkin, from FSUE Atomflot, then talked about their icebreaking support for Arctic projects, their current fleet and the new generation icebreakers which will be the basis for year-round navigation along the Northern Sea Route.

Novatek is planning to further expand its LNG production on the Gydan peninsula. Maxim Minin, from PAO NOVATEK, gave insight into the project.

Search and rescue operations in the Arctic have been under development. Commander Tomi Kivenjuuri, from the Ministry of the Interior, Finland, explained what the Arctic Coast Guard Forum (ACGF) does as a cooperation of the eight Arctic member states.

Tuomas Korpela, from ICEYE, continued with presenting a new service for on-line ice data, based on SAR satellite images.

Alexey Fadeev, from Gazpromneft-Sakhalin LLC, described their offshore projects on the Russian shelf. Lastly Ilkka Rantanen, from STARKICE Ltd., presented experiences of intelligent de-icing on an 1A Super ice class bulk carrier in the Baltic.

We would like to thank all guest speakers and participants of this year's successful and interesting Arctic Passion Seminar! The seminar presentations have been uploaded to our website **www.akerarctic.fi.** ■