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SELECTION OF SUITABLE ICE CLASS FOR ANTARCTIC OPERATION BASED ON FULL SCALE MEASUREMENTS OF THE HULL STRUCTURE

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ABSTRACT

Shipping in ice covered waters is increasing and new ice classed ships are built to replace older ice strengthened fleet. Selection of suitable ice class for ships operation is an important but not simple task. The ice classes assigned by the classification standards are providing limited guidance in characterizing the ships operational limits and corresponding structural strength for actual ice operational modes in ice. In addition, the actual structural redundancy and safety when operating in ice conditions which may be considered beyond what is assumed as basis for the ice class is generally unknown. The process of selecting an appropriate ice class is of high importance both from a safety as well as an economical perspective, but the selection process is still based on accumulated experience and traditions within the areas of existing operations. The increased exploitation of the Polar waters, both wrt. seasonal periods and geographical areas, as well as the introduction of new international design standards, reduces the relevancy of using existing experience as basis for the selection, and new methods and knowledge have to be developed.

Based on full scale measurements of ice loads from two consecutive seasons in the Antarctica, the structural strength of the South African research vessel S.A. Agulhas II has been evaluated to assess the suitability of the chosen ice class of the vessel. The structural suitability of the chosen ice class will be evaluated based on non-linear analysis of the bow structure. The response of the recorded loads and forecasted lifetime loads which are assumed to be representative for the operational profile of the vessel is evaluated against the assumed design point and the subsequent residual capacity of the structure until failure. The impact of choosing a lower/higher ice class will also be considered.

INTRODUCTION

Navigating ships in cold areas and in ice pose additional risk elements and challenges beyond what the shipping industry are used to from world-wide operation. The risk elements related to general world-wide operation are well known based on several hundred years of experience. The experience from Polar navigation is generally limited to dedicated (summer) expeditions with purpose-built icebreakers, except from the experience gained through winter navigation in the Baltic, the Russian Arctic and North America. The anticipated increase in commercial shipping will pose and unique set of new risks and challenges, related to operational areas, type of operation, ship types and sizes, experience of crew etc.

The most obvious risk comes of course from the increased loading on the ship hull and the machinery system due to ice impacts, giving additional requirements to the design of the hull and machinery and the appendices attached to the vessel. In addition, the low ambient temperature put extra demands on the material quality of the hull and the functionality of all the components on board related to the ship operation and safety.

Typical risk mitigating measures can for example be the ice class of the vessel defining the strengthening of the hull and the machinery system necessary to withstand the ice loads. Winterization notations may take into account risks related to operability and functionality of equipment, material qualities and other issues related to safety of cargo, life and property in low temperatures. The introduction of double hull requirements, compartmentalization of hull, in addition to requirements for the location of fuel tanks reduce the risk of sinking and major oil spills in ice covered waters, together with oil combating equipment specially designed for use in ice conditions.

One of the main challenges when operating vessels in ice covered waters is to ensure that the vessel is operated within capabilities of the vessel. In the future, full scale measurements in combination with various types of decision support tools will be an important factor to gather information about the actual conditions the vessel is operating in and to evaluate the conditions against the capabilities of the vessel.

For operators it is important that ice class selected for operation is suitable. Ships structure should be strong enough for operation and ice conditions that it does not get damaged. On the other hand structure should not be too heavy so that capital costs do not increase and that ship’s cargo carrying capacity is not reduced too much. Selected ice class needs to have suitable strength for normal operations and residual strength after the damage has occurred.

International Maritime Organisation (IMO) is bringing new regulations for the polar shipping. International Code for Ships Operating in Polar Waters (Polar Code) (IMO, 2015) will become in force in two years’ time. The goal of the code is “to provide for safe ship operation and the protection of the polar environment by addressing risks present in polar waters and not adequately mitigated by other instruments of the Organization” The code requires that ships are designed for operation in polar waters. In the Polar Code ships are divided into three categories A, B and C based on their design for ice operations. The Polar Code refers to the IACS URI Requirements concerning Polar Class (IACS, 2007) when defining the categories. For the selection of the ice class for new ships or in estimation of the category of the existing ship the presented method can used for proofing that the ship’s structure fulfils the Polar Code requirement once suitable local ice load data is available. This can be gained from measurements on board the ship or from similar ships in similar operations.

The experience on Baltic and Russian ice classes and their capabilities makes the selection of suitable ice class for ships operation. The operational experience on the IACS Polar Classes (PC) is limited since the ships build with the class is limited and they are relatively new. Shown analysis can be used to gain information for IACS Polar Class for ships operating in the areas where the class notations have not been previously used. In addition, the local ice load measurement combined with detailed information on prevailing ice conditions and ships operation and structural analysis can be used in further development and calibration of the class rules. Other possibility is to use ice damages for the calibration of the class load levels and structural requirements but that requires detailed mapping of the damages and conditions they have occurred. This is difficult since many of the damages are observed much later they have occurred.

Analysis presented in this paper shows how local ice load measurements and structural analysis can be used to estimate load level for selected ice class during normal operation and structures capacity to carry the predicted life-time ice loads. Also, the structural analysis reveals the residual capacity of the structure after the damage has occurred.

SELECTION OF SUITABLE ICE CLASS BASED ON RECORDING OF LOADS

Significant structural reinforcement of the ship hull is normally necessary to withstand ice loads acting on the hull when operating in ice. The additional steel needed for ice strengthening may be a major contributor to the total steel weight, and will have impact on the newbuilding construction cost, as well as reduced cargo capacity, increased fuel consumption etc. accumulating during the lifetime of the vessel.

Adequate strengthening of the vessel is usually achieved by selecting an appropriate ice class based on the given requirements associated with the selected ice class. An ice class is a set of additional requirements to the parts of the ship structure which is exposed to potential ice loading. They are divided into different levels described by a set of characteristic ice parameters such as thickness, type, age etc. However, the nature of the ice class system leaves the selection of ice class often with a series of uncertainties, as they are generally established as a spectrum of capabilities, where the description of the capability of each ice class is deliberately very loose. Except for operation in the Canadian Arctic, the Russian Arctic, and the Baltic, where the minimum ice classes often are stipulated by the respective regulations, the choice of ice class will be a balance between foreseen ice conditions, operational requirements, and cost, and will depend on:

- Intended area and season of operation
- Intended operational profile
- Risk tolerance, including delays and minor structural damage

In most cases, the actual operational profile throughout the lifetime of the vessel will not be well defined at the design stage. In addition, the operational experience in Polar waters with higher ice classes are generally limited to a “handful” dedicated ships, mainly operating during summer periods in the harshest conditions. Hence, successful experience with year-round operation in Polar waters is pr date almost non-existent, and the actual capabilities associated with the ice classes are generally unknown for general operation in ice. As long as this is unknown, the uncertainties associated with a general risk assessment are significant, and the need for tools and methods for evaluating the actual conditions against the capability of the vessel is evident. Hence, full scale measurements and other decision support tools will be instrumental to ensure that the vessel is operating within its capability limits.

DESCRIPTION OF THE SHIP AND INSTRUMENTATION

The construction of PSRV S.A. Agulhas II was finalized in 2012. She was built to Polar ice class PC5 while the hull was built in accordance with DNV ICE-10. The main dimensions of the ship are 121.8 m, 21.7 m, and 7.65 m denoting length (bpp.), breadth (mould.), and draught (design), respectively. Three areas of the ship hull were instrumented with strain gauges during the construction – bow, bow shoulder, and stern shoulder, see Figure 1. The frames in these areas were instrumented with V-shaped gauges to measure shear strains, while one-directional strain gauges were mounted on the hull plating. The instrumentation at the bow consists of four V-shaped gauges (the frames #134+400 and #134) and two one-directional gauges mounted between the instrumented frames. For a detailed description of the instrumentation, see Suominen, et. al (2013).

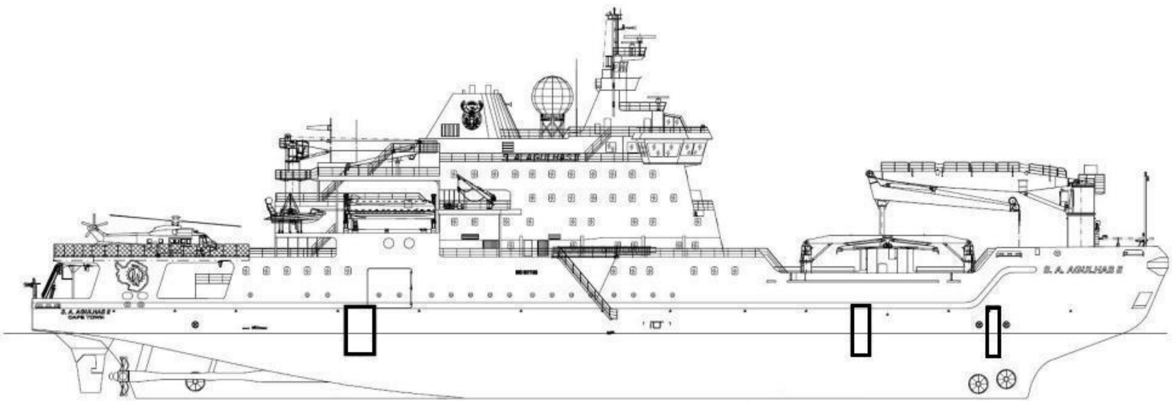

Figure 1. The instrumented areas indicated with black squares.

The ice-induced loads acting on the hull are determined from the difference in shear strains between the upper and lower part of the frame (measured with V-shaped gauges). The conversion from shear strains into shear loads (i.e. ice-induced loads) is conducted by introducing an influence coefficient matrix, which was determined for the bow frames with a FEM model (Suominen, et. al, 2013).

THE MEASURED AND PREDICTED MAXIMUM ICE-INDUCED LOADS

The first voyage to the Southern Ocean was conducted between Dec 2012 and Feb 2013, which was followed by the second voyage between Dec 2013 and Feb 2014. The load measurements were continuous during the voyages. The measured one hour maximum loads on the frames #134+400 and #134 (the bow frames) during the voyages are presented in Figure 2. The data presented in Figure 2 includes open water periods in addition to the operations in ice conditions. As the focus is on ice-induced loads, only the one hour maximum loads exceeding 50 kN are considered in the study. This threshold was exceeded in 835 cases on the frame #134+400 and in 842 cases on the frame #134 when both voyages are accounted. Thus, the ship was operating approximately 35 days in ice conditions during the two voyages.

The measured maxima were organized into histograms having 10 kN bin size. The probability of the measured maximum loads was determined using the Weibull plotting positions

$$p_e = \frac{m}{N+1} \qquad (1)$$

where m is the cumulative number of maxima on the bin and N is the total number of maxima. As the Gumbel I asymptotic distribution has been shown to give a good fit to the data, see e.g. Kujala (1994), and the extreme values of the exponential type distributions approach the Gumbel I distribution (Gumbel, 1958), it is used in estimating the return period of maximum ice-induced loads. The cumulative distribution function of the Gumbel I asymptotic distribution is given as

$$G(x) = e^{-e^{-\beta(x-u)}} \qquad (2)$$

where β and u are parameters of the distribution. The parameters are defined from the standard deviation and the mean value of the sample, σ and μ, and the Euler-Mascheroni constant, $\gamma_{E\text{-}M}$, equals 0.5772, as

$$\beta = \frac{\pi}{\sigma\sqrt{6}}, \quad u = \mu - \gamma_{E-M}\beta^{-1} \qquad (3)$$

The load range is incomplete due to the threshold. Thus, a truncated cumulative function, $G_t(x)$, for Gumbel I distribution, G(x), is derived

$$G_t(x) = \frac{G(x) - G(x_t)}{1 - G(x_t)}, x_t \leq x \tag{4}$$

where x_t is the threshold. The return period of time, T(x), can now be determined from the cumulative distribution, F(x),

$$T(x) = \frac{1}{1 - F(x)} \tag{5}$$

Following the presented approach, the return period of the measured maxima is calculated with Equations (1) and (5) and the maxima are predicted with Equations (2)-(5), see Figure 3. The mean value and standard deviation of the sample data and the values of the Gumbel I parameters are presented in Table 1.

Assuming the two voyages together represent average voyages, the ship will operate approximately 440 days in ice conditions during 25 annual voyages. Therefore, the expected maximum ice-induced load on the frame #134+400 is 2060 kN and 1730 kN on the frame #134.

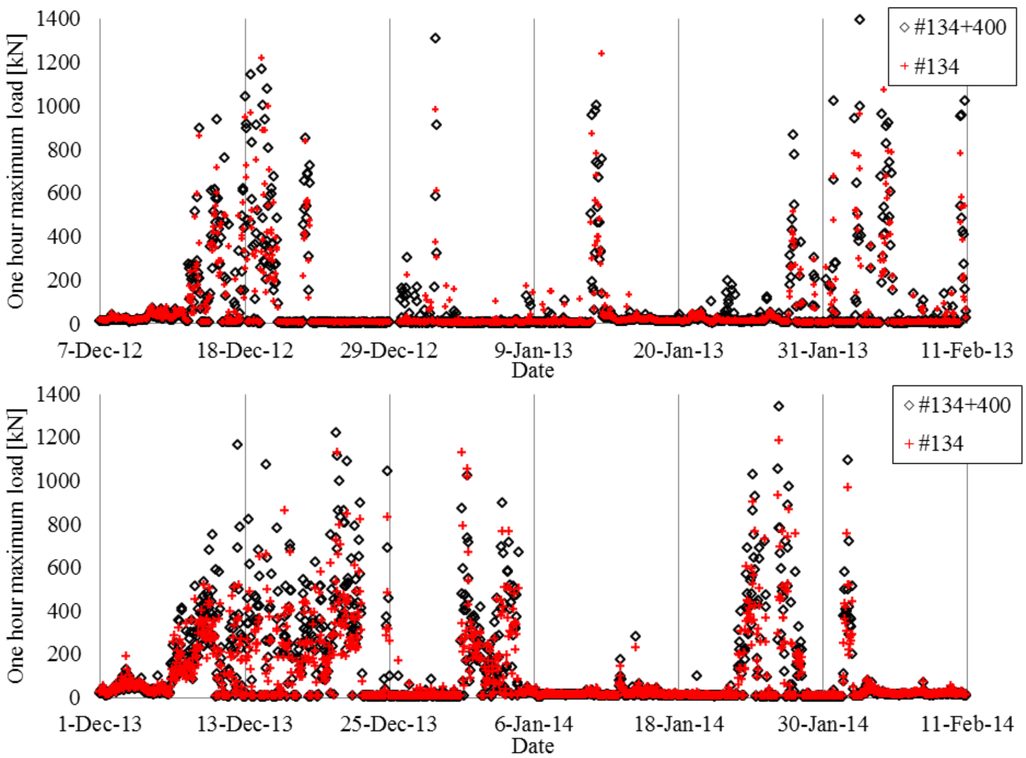

Figure 2. The measured one hour maximum ice-induced loads on the frames #134+400 and #134 during the Antarctic voyages 2012-2013 and 2013-2014.

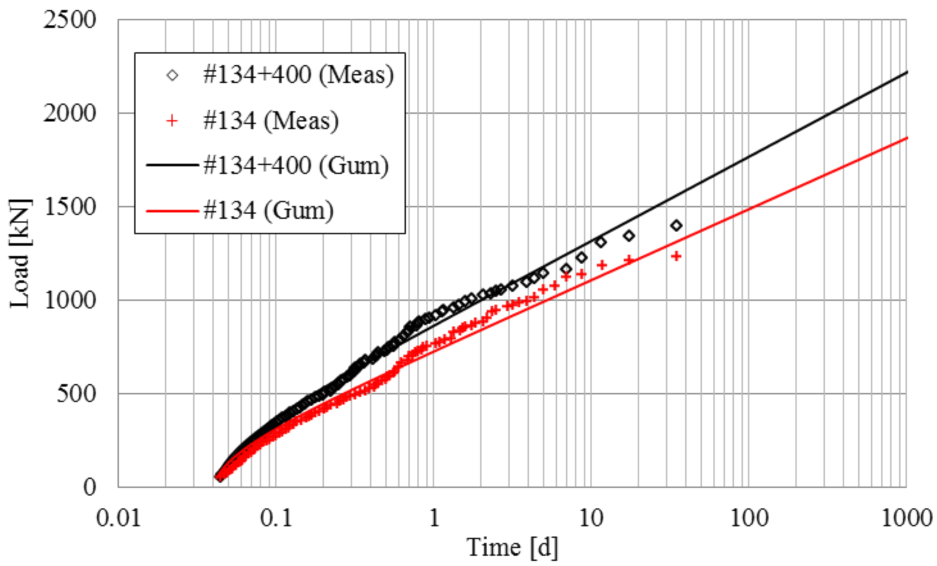

Figure 3. The return period of time of the measured and predicted ice-induced loads.

Table 1. Determined parameters.

	#134+400	#134
Mean value, μ, [kN]	344.3	285.5
Standard deviation, σ, [kN]	250.8	211.3
Gumbel parameter, β	0.005113	0.006070
Gumbel parameter, u	231.4	190.4

FEM analysis - DNV GL

CAPACITY ASSESSMENT OF HULL STRUCTURE

A finite element model of the bow structure including the instrumented frames has been developed, as shown in Figure 5. The model includes the adjacent ice frames as well as the supporting web frames and stringers between Deck 2 and Deck 3. The extent of the model is considered sufficient to represent the actual response in the structure when subject to ice loads.

The recorded loads from the measurements are considered to be the total loads acting between the upper and lower strain sensor, but the distribution within this area is unknown. In the capacity assessment, different load patches have therefore been considered, in order to evaluate the effect the load patch has on the response and capacity of the frames. The width of the load patches was set equal to the frame spacing as this is considered representative for the the loads recorded from the measurements.
In the vertical direction, three different patches have been considered as shown in Figure 5. The first load patch is a line load on the frame at the middle of the distance between strain gauges. The second load patch has a height of the half of the distance between strain gauges and it is located at the middle of the distance between strain gauges. The third load patch height is equal to the distance between strain gauges.

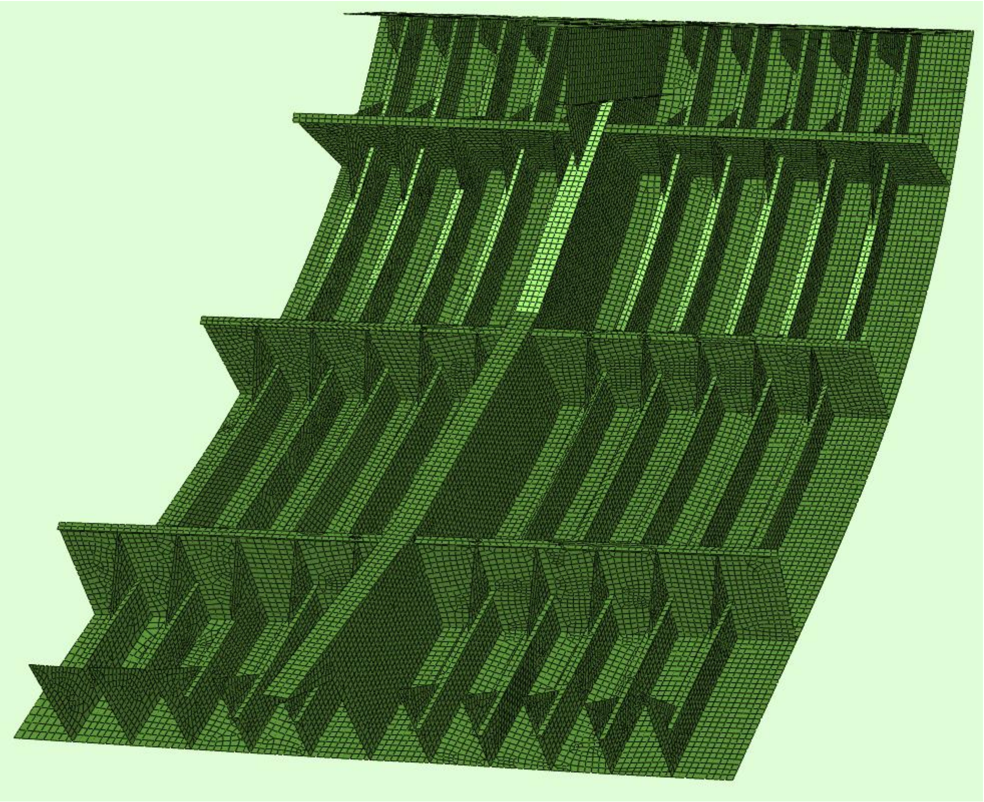

Figure 4. Modelled ship bow side structure.

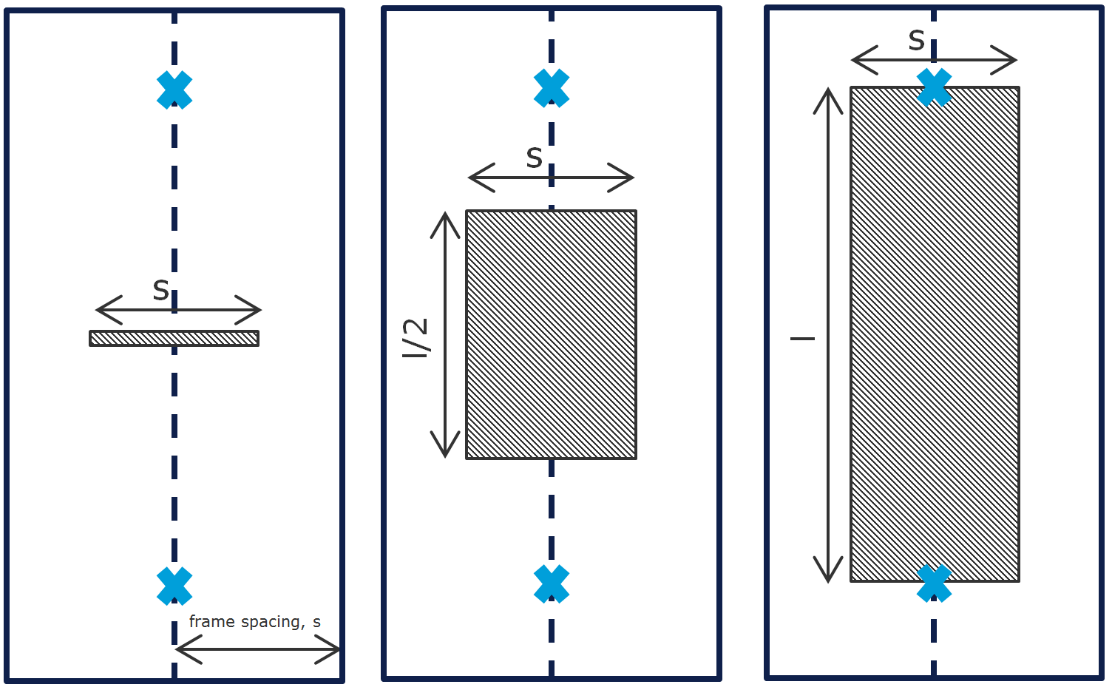

Figure 5. Illustration of the load patches applied on the frame

Nonlinear finite element modelling (FEM) was used in order to analyse the ultimate strength of the structure. The load was incrementally increased on the structure and continued beyond the point where yielding and large deformations occurred in the structures. Figure 6 shows the capacity curves for the structure for the different load patches applied on the frame # 134+400. For a narrow patch load, it is seen that the stiffness of the fames is significantly reduced at a load level of approximately 4 – 5 MN. When the load is further increased, a combination of massive yielding and loss of stability (buckling) develop, and the capability of the frame to carry higher loads is significantly reduced. This means that the residual strength of the frame beyond design point in this case is very limited.

For more uniform patch loads (i.e. reduced pressure over a larger area), the capacity of the frame is increased with a factor of approximately two. The lack of residual strength is however the same as for the case with the narrow load.

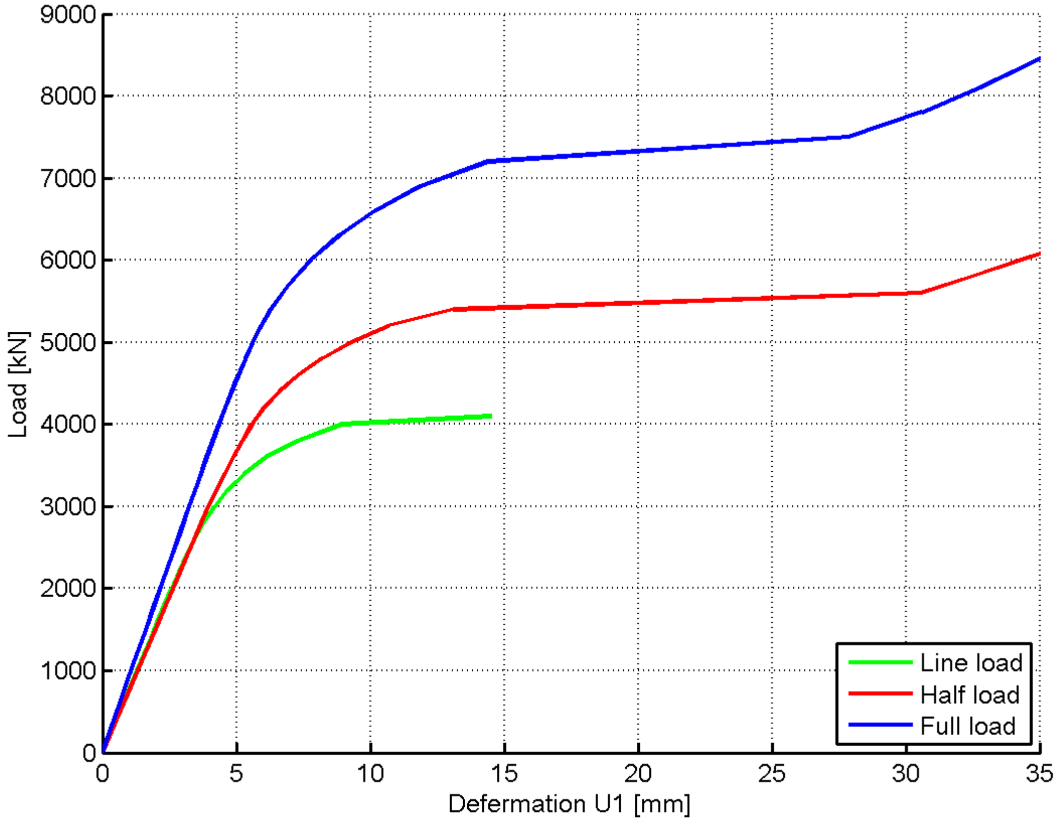

Figure 6 . Capacity curves for frames under different loading. Y-axis

SELECTION OF SUITABLE ICE CLASS BASED ON MEASURED LOADS

Based on the above, it may be concluded that the capacity of the considered frames at least are twice the maximum loads predicted from the measurements. Based on a simplified assessment, it may also be concluded that a reduction of the frame scantlings representing a lower ice class (one step down) would have sufficient margins as well. However, it is also seen that the residual strength of the framing system beyond the point where the frames start to undergo permanent deformation is small, which means that the capability of the adjacent frames and supporting web frames and stringers to carry overloading is limited. This lack of ductility and redundancy in the structure indicates a need for retaining a significant strength margin between the predicted maximum loads and the point where permanent deformations are initiated.

For a comprehensive assessment of the suitability of the vessel, the similar evaluations should be carried out for other parts of the vessel which may be considered critical.

CONCLUSIONS

The analysis presented in this paper shows how local ice load measurements and structural analysis can be used to evaluate the structures ability to carry the predicted life-time ice loads, and to ensure that the vessel is fit for operation in defined ice covered areas. Selection of suitable ice class, and a throughout understanding of the actual capabilities associated with each ice class, is instrumental in order to address risk and ensure safe operation in Polar waters. In this paper, the historic operational profile of the South African research vessel S.A. Agulhas II has been used as an example to evaluate the loads acting on the structure, and compare this with the initial capacity, the redundancy and the actual safety margins present

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