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The Effect of Low Temperatures on Energy Dissipation in Accidental Collisions on Marine Structures

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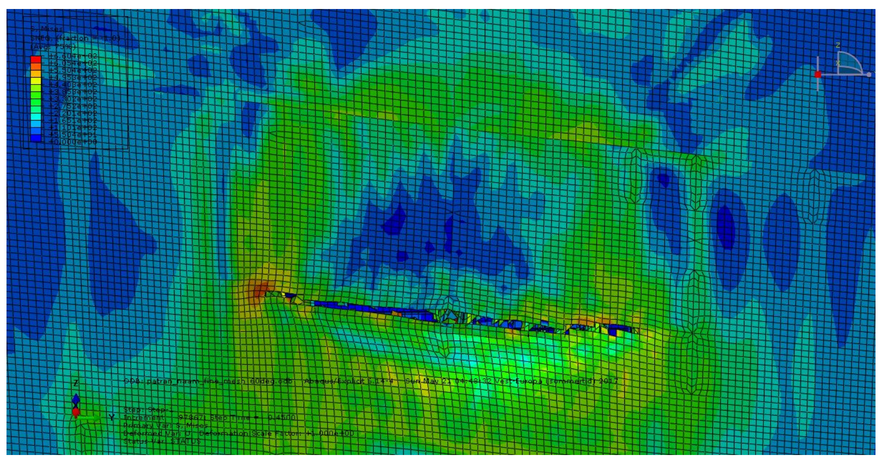

Figure 1: The damage of the ship side after a -60°C impact

Abstract

A material model for brittle fracture in large scale shell elements has been tested and the effect of low temperatures in accidental collision with a ship side has been investigated. The analysis shows that lower temperatures leads to larger damage of the ship side. However, the material model is only calibrated for -60°C, -100°C and -140°C and further studies will be needed to properly test other temperatures.

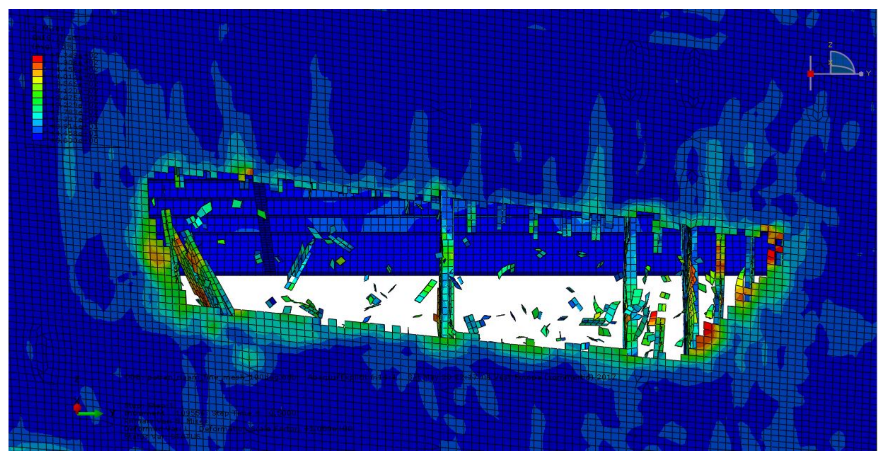

Figure 2: The damage of the ship side after a -100°C impact

DNVGL expects about 480 annual trans-arctic voyages for container ships by the year 2030 (DNVGL, 2010). For ships sailing in the Arctic, sub-zero temperatures will be a frequent occurrence. These temperatures might drop below the ductile to brittle transition temperature for the steel used in the hull. The purpose of this thesis is to do an initial investigation on how the low temperature effects the damages of an accidental collision on a marine structure.

Introduction

Several classification societies have rules and recommendations which takes ice action into account, however the effect of sub-zero temperatures and the embrittlement of steel is not properly taken into account by these rules.

Woonshik Nam is currently working on a material model for modelling brittle fracture in large scale shell elements. The model combines the extended BWH-criteria proposed by Storheim and the critical shear energy density (SED) criteria. This model will be tested in this thesis.

Method

By finite element analysis in Abaqus, two models have been analysed. In 2016 Kim et al published an experimental and numerical impact study on a plate at room temperature and at -60°C. This analysis has been replicated in Abaqus. The impact study was done on a 1200 mm by 1200 mm plate, with a thickness of 6 mm. Two plates was tested, one unstiffened plate and one plate stiffened by two 150 mm flat stiffeners with a thickness of 6 mm. The plate was then impacted at the centre of the plate by a cone shaped striker dropped from 3 m height at room temperature and 5 m height at -60°C. This analysis was replicated twice for each plate, once using the material code supplied by Woongshik Nam and once using material parameters given in the report by Kim et al.

In addition, a model of the fore part of a DNVGL ICE-1A classed vessel was supplied by Suyu Wang. This model was impacted with a rigid ice body modelled as a disc with a diameter of 10 m and a thickness of 1.2 m. The rigid body had a mass of 1000 tonnes and initial velocity of 6 m/s. This impact was simulated at several different temperatures, ranging from room temperature to -100°C. The material model supplied by Nam had predefined criteria for -60°C, -100°C and -140°C. An interpolation has been carried out on these three criteria to cover for other temperatures.

Results

The study of the impacted plate shows that the behaviour of the material code supplied by Woongshik Nam corresponds well to the normal material and the experimental behaviour of the stiffened plate. Figure 3 shows the absorbed energy of the stiffened plate as a function of time.

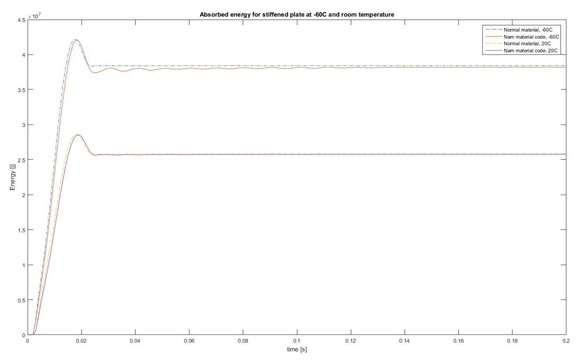

Figure 3: The absorbed energy as a function of time for the stiffened plate

The impact of the ship side shows a clear correlation between the temperature of the steel and the damage. The ship side shows larger damage for lower temperatures, as seen from Figure 1 and 2, which shows the damage to the ship side after impact at -60°C and -100°C respectively. Figure 4 shows the absorbed energy of the ship side after 0.5 s. As can be seen from the figure, less energy has been absorbed at the end of the simulation for -100°C compared to higher temperatures. In addition, it is seen that the absorbed energy peaks later for the lower temperatures.

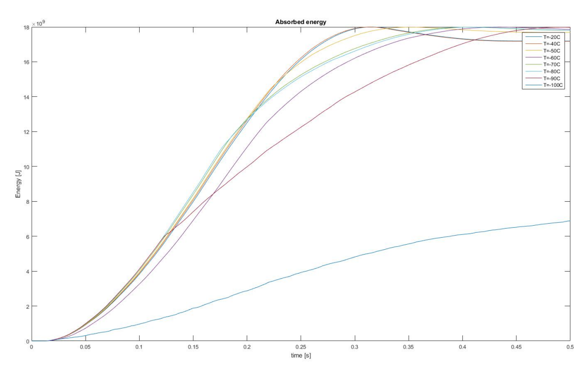

Figure 4: The absorbed energy as a function of time for the ship side

To get a overview of the extent of damage, the eroded mass has been plotted in Figure 5.

The figure shows that the amount of damage significantly increases between -40°C and -50 °C. In addition, a new increase of damage can be seen after -80°C.

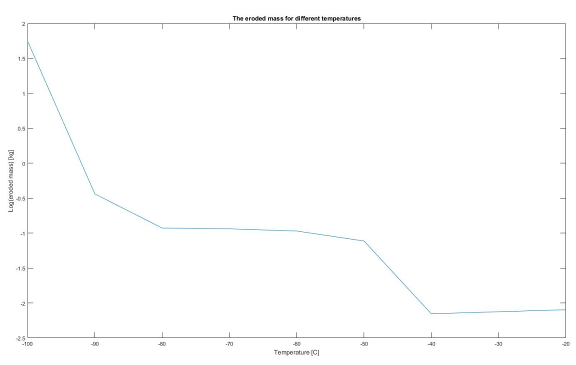

Figure 5: The logarithm of the eroded mass over different temperatures

Discussion

The unstiffened plate does not show the same displacement pattern for the two material models. The normal material does not show the same spring-back phenomenon as the Nam material code, and has a smaller displacement than the Nam material code. The reason for this is not known at the current time. In addition, the interpolation done on the critical strain energy density criteria is a possible source of error. The real values for the SED will have to be determined experimentally. The exponential interpolation done in this thesis is unlikely to reflect the exact critical SED values, but should be close enough to show the phenomenon.

Acknowledgement

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Sources

DNVGL. (2010) Shipping across the arctic ocean, a feasible option in 2030-2050 as a result of global warming?