FLNG ve Buzdağı Çarpışma Modellemesi Üzerine Bir Çalışma

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Özet

Kutup bölgelerinde deniz seferlerilerinin artmasıyla bu bölgelerdeki buz dağları ile gemilerin çarpışma riski de artmaktadır. Bu nedenle, deniz yapılarına etki edecek dizayn yüklerini belirlemek için çarpışma hasarının doğru değerlendirilmesi bir zorunluluk haline gelmiştir. Bu çalışmada, buz mekaniğini etkileyen parametreleri içeren KOSORI buz modeli kullanılarak gemi - buzdağı çarpışma senaryolarının uygulamalarına odaklanılmıştır ve elde edilen sonuçlar rijit buz modeli ile kıyaslanmıştır. KOSORI ve rijit buz modelleri kullanılarak oluşturulan buzdağı modeli ile FLNG gemisinin çarpışma durumu incelenmiştir.

Anahtar kelimeler: Buz malzemesi, Malzeme modellemesi, FLNG çatışması, Çatışma simülasyonu

A Study on FLNG and Iceberg Collision Modelling

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Abstract

Marine operations increase in the arctic, therefore collision risk of ships with ice bergs in the regions is higher and so the accurate assessment of the collision damage has become a necessity to estimate loads for the design of ship structures. This paper focuses on applications of ship – iceberg collision scenarios by using the KOSORI ice model which takes into account ice mechanic in terms of influencing parameters and, comparing results with rigid ice model. A case of collision of an iceberg with FLNG structure is studied by using the KOSORI ice model as well as the rigid body model for iceberg.

Keywords: Ice Material, Material Modelling, FLNG Collision, Collision Simulation

1. Introduction

Due to the global warming, the last few decades have seen the accelerated melting of huge icebergs and glaciers. This situation gets new opportunities such as the exploration of oil and natural gas industry in the arctic regions and shorter routes for transportations. Accordingly, with continuing increase in the marine operations, the risk of collision of floating structures such as offshore platforms or ships with icebergs is high and so the accurate assessment of the collision damage has become a necessity to estimate loads for the design of floating structures.

The iceberg - ship collision event has two major parts which are external and internal mechanics as shown at Figure 1. External mechanics of the collision include added mass effect, wave damping restoring forces, etc. Although the external mechanics of the collision between ship and iceberg are really important, there is not enough study of them. Therefore, in this study those are neglected. The internal mechanic is examined. Ice and steel materials behaviours change extremely under low temperature or other environmental conditions such as the highly random nature associated with the iceberg. There are usually three different approaches used for numerical simulation of ice and steel interaction, strength design, ductile design and shared energy design (Liu et al., 2011; Norsok, 2013). Major part of collision energy is absorbed by iceberg in the strength design. In some studies ice is assumed as a rigid material for the collision (Sato et al., 2013). Thus, all collision energy is absorbed by steel structure that is the ductile design. In reality, steel is much stronger than ice and the collision energy is shared by both colliding bodies. This approximation is named as shared energy method. The material models of both steels and ice materials should be characterised for numerical computations as the collision impact energy is dissipated for the two colliding as deformation in the bodies.

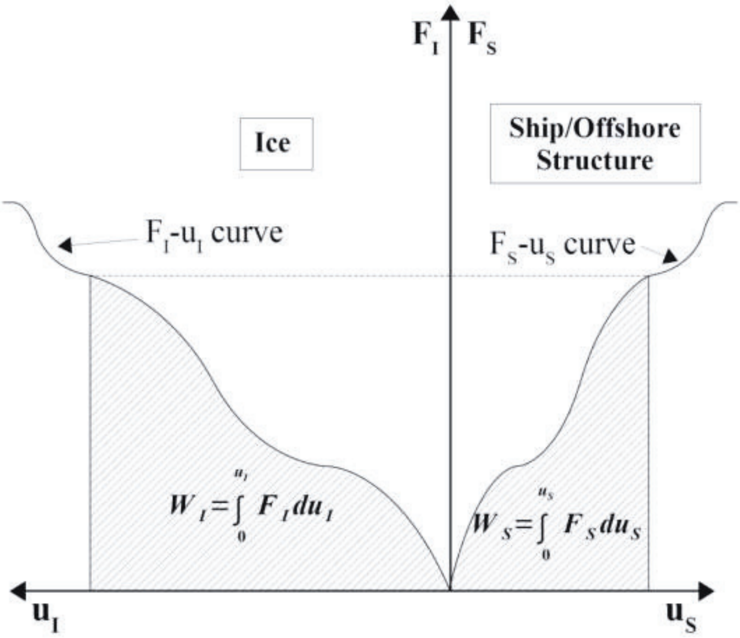


Fig. 1. Energy components absorbed by ice and marine structure.

Even though steel is the main material for ship structure design, ice material responses are important for shared energy design. Ince et al. (2017 a) developed the KOSORI ice model which includes a constitutive equation and a fracture model for ice structural mechanic (Ince et al., 2017 a).Then the model is implemented as a finite element subroutine and validated by ice drop experiment on steel plate (Ince et al., 2017 b). It is the comprehensive model which considers effect of influencing parameters such as strain rate, temperature and salinity based on experimental results. The ice strength and fracture behaviour in the KOSORI model are combined with the traditional metal strength model to implement as a user defined material model (UMAT) into nonlinear finite element program to solve ice-steel interaction problem. An experiment is conducted on interaction of steel plate and ice to validate the developed methods. Additionally, a rigid body drop test is performed for similar conditions with ice drop test to show difference between considering ice as rigid and as deformable. The motivation of this paper is coming from need of application of the model to the realistic collision scenarios. Thus, two examples of marine structure – iceberg collision scenarios are performed in this study.

2. Site-Specific Metocean Effects

The term metocean comes from the abbreviation of the words meteorology and oceanography. It is used in the offshore industry to describe the environment near the offshore structure. Metocean data are essential for the design of ships and offshore structures destined for ice-infested seas. The design of these structures requires practical knowledge of the physical changes occurring in the properties of ice throughout the year and depending on the temperature and salinity. Due to the environmental conditions, the properties of ice in different seas differ from each another. Same way, ice formation in Arctic area is very different from the ice, which freezing in inland seas (Pashin et al., 2011). Thus, ice types are as diverse as region itself. The cold regions are home to huge variations in their geography, resources and environmental conditions, creating a variety of highly complex ice structure. It is necessary that simplify the complexity and to put more reasonable solution for ice behaviour in terms of impact engineering.

Each sea has different metocean properties at different times of the year. For example, Leppäranta et al., (1992) studied the structural behaviour of first-year ice in the Baltic sea and found that the ice salinity rate was 0.05% and the density of the ice was 0.9 g/cm3 in that region, while Urabe et al., (1988) studied the Antarctic sea ice, finding the salinity of ice to be between 0.01–0.025%, the density to be between 0.75–0.9 g/cm3 and the root brine volume to be between 0.025–0.05% (Leppäranta et al., 1992). The salinity of ice also changes with time. Sammonds et al., (1998) gathered data on first- year sea ice from Tuktoyaktuk and Prudhoe Bay and multi-year sea ice from Buckingham Island (Sammonds et al., 1998)The salinity of ice from Tuktoyaktuk and Buckingham Island was between 1– 3 ppm, while that of Prudhoe Bay was between 4–7 ppm. Although Tuktoyaktuk ice was first-year ice, its salinity was the same as Buckingham Island multi-year ice. Therefore, instead of first-year and old ice separation, site-specific ice examination can give better idea about ice strength. Salinity and temperature parameters were used in the KOSORI model to define the ice mechanics for specific location.

2.1. Weather changes over year

As known, temperature in the Arctic region changes strongly in a day from daytime to night as well as yearly. Temperature changing over years from 1979 is shown in the Figure 2 for 70°N and 70°S obtained by satellite. Especially after 1993, average temperature is increasing in the Arctic regions as a result of global warming. Because of that, instead of big massive ice bergs, the amount of icebergs increases in some regions. On the other hand, in a year sharply temperature change is seen in the graph, therefore it affects ice making process highly. Unfortunately, this change effect is unpr edictable.

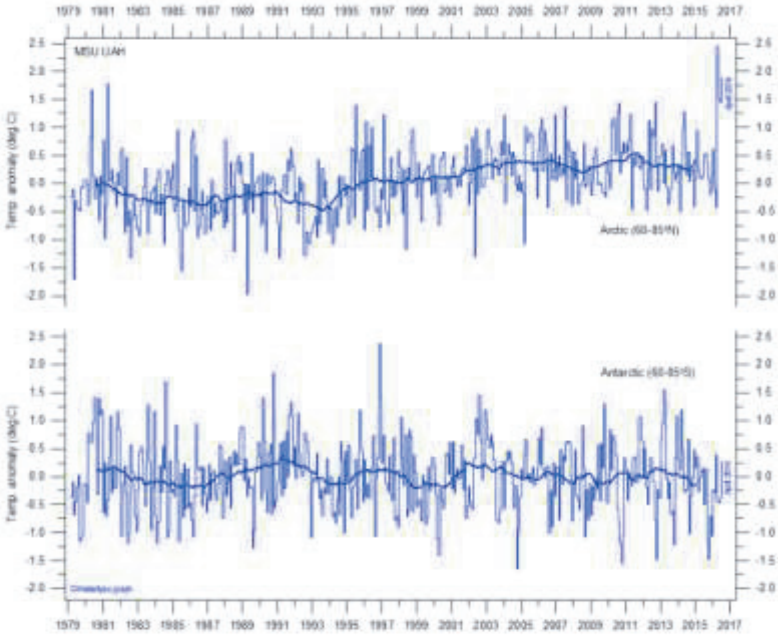


Fig. 2. Temperature changes over years from 1979 to April 2016 for Arctic and Antarctic (Spencer et al., 2016).

Temperature is really effective material properties of steel and ice. Even though, sea water temperature cannot go less than –1.9 °C, air temperature is going –40 °C at night time in some regions. Therefore, both ship and icebergs parts which is under water will be around –2 °C but superstructures will be in – 40 °C, because of this temperature difference both materials have pre-stress. Outer layer temperature of the icebergs which also contact with marine structures is highly effecting water or weather temperature changes. But the inside temperature of icebergs is isolated by an outer layer. The KOSORI model has temperature parameters. Thus, Ice can be model for different temperatures by the model.

2.2. Ocean properties changes over year

Not only temperature, but also winds, currents and waves are important to ice making process and ice crushing itself process. But the effects of them are hard to predict.

The icebergs and icebergs are also moved by the ocean condition. It can cause the collision between the offshore platforms and icebergs or ridges. As an example, Table 1 shows the iceberg velocities for Bransfied Strait (Madejski et al., 1990). Possible collision risks should calculate for specification of the location.

Table 1. Bransfied Strait iceberg velocities

Term	Mean Range (m/s)	Absolute Range (m/s)
February–April	0.6–0.8	0.2–0.9
May–July	0.1–0.2	0.0–0.3
August–October	0.4–0.6	0.1–1.0
November–December	0.4–0.5	0.1–0.5

3. Applied Example

The KOSORI ice model which is implemented in a finite element computer program as a subroutine is used for an example of FLNG – iceberg collision. The KOSORI ice model and rigid model of iceberg cases are compared.

The model helps us to put all of these parameters together into one governing equation. The constitutive material model can adequately represent a wide range of strain rates, temperatures and salinity levels. Equation 1 is constitutive equation of the KOSORI model.

$$\sigma = A \underbrace{\left[1 + B\ln\left(\frac{\dot{\varepsilon}}{\dot{\varepsilon}_o}\right)\right]}_{\substack{\text{Strain rate} \\ \text{Parameter}}} \underbrace{\left[C\left(\frac{T}{T_o}\right)\right]}_{\substack{\text{Temperature} \\ \text{parameter}}} \underbrace{\left[D\ln\left(\sqrt{\frac{v_b}{v_{bo}}}\right)\right]}_{\substack{\text{Salinity} \\ \text{Parameter}}} \quad \text{[MPa]} \qquad (1)$$

where $\dot{\varepsilon}$ is strain rate, $\dot{\varepsilon_O}$ is reference strain rate, T is temperature, T_o is reference temperature, is the brine volume and is the reference brine volume and *A, B, C,* and *D* are the test coefficients of material. Additionally, the model has fracture model which base cohesive zone model. Unlike classical cohesive zone model, it is fracture opening speed depended cohesive model. Equation 2 shows the relation between dynamic strain energy release rate and fracture opening speed of the model.

$$= G_0[5 - \alpha\, ln(\delta_m)] \quad [N/mm] \qquad (2)$$

Where G_d is the dynamic strain energy release rate, G_0 is the reference energy release rate, α is the coefficient, δ_m is $\dot{\delta}/\ \dot{\delta}_0$, $\dot{\delta}$ is the fracture opening speed and δ_0 is the reference fracture opening speed.

For numerical simulations first step is meshing process. Finite element programs run on the mesh model of the design. Therefore, high quality mesh is required to take good results from computer simulations. In the literature a lot of studies are focused mesh qualities and mesh size. It is not the target of this thesis, but simply will explain the mesh technic and will study mesh size to get better results.

In the explicit finite element analysis, time step size is calculated by using minimum mesh size. Therefore, mesh size should be uniform to get faster simulation. After creating a mesh model of the structure, mesh qualities should check and impact area and critical areas (intersection of the two or more bodies, around holes or edges etc.) should model out of triangular element. Because linear triangular element shape function is not allowed to show stress changes in element and it gives the mean stress everywhere in the element.

3.1. Iceberg – FLNG collision

Floating liquefied natural gas (FLNG) ship has the facility which produces, liquefies, stores and transfers LNG. It is useful due to the operational capability and processing, LNG on the ship. Additionally, they have some challenges due to the huge LNG storing tanks. Possible colissions can be catastrophic.

3.1.1. Numerical modelling

In this collision scenario,2500 tonnes iceberg collides with middle of the FLNG tank at 0.5 m/s speed under effect of wind and current. FLNG main dimensions and other details of the scenario are given in the Table 2. Figure 3 shows the CAD geometry of the collision. Iceberg is defined as a rigid body and the KOSORI ice model for two cases.

Table 2. Iceberg – FLNG collision details

LOA	396 meters
LWL	387 meters
B	45 meters
T	25.3 meters
D	16 meters
DWT	260 000 tonnes
Iceberg Mass	2 500 tonnes
Iceberg Velocity	0.5 m/s

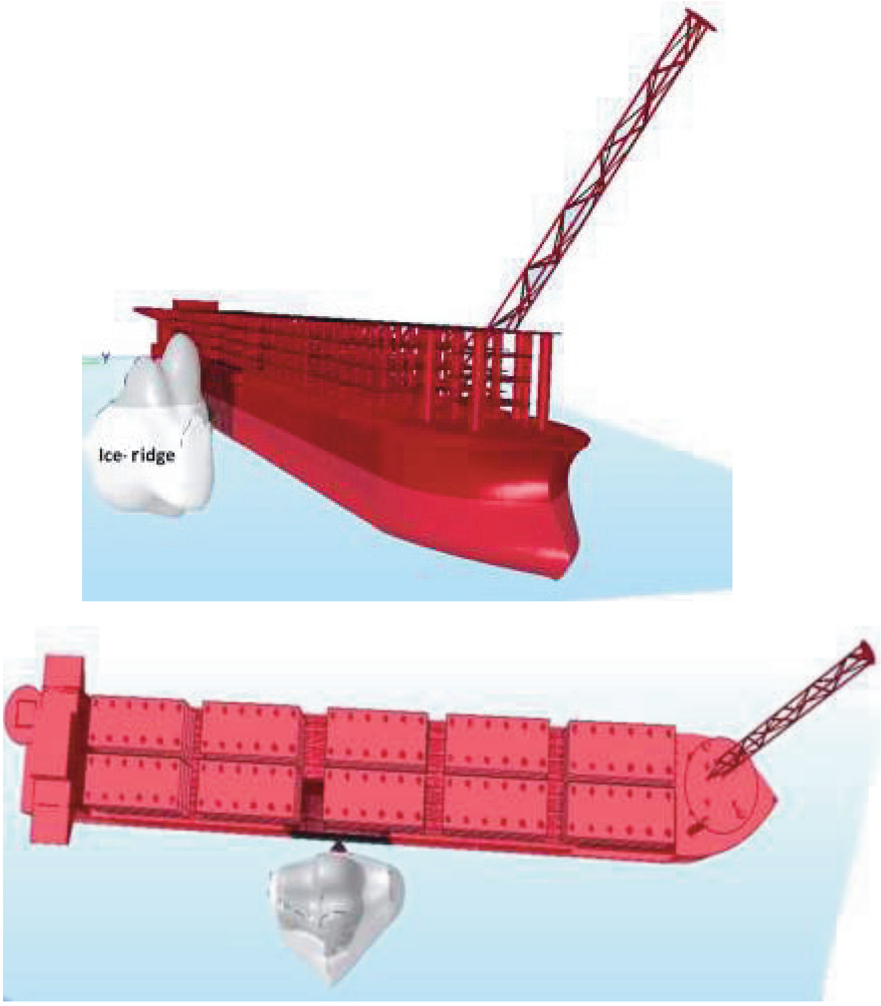


Fig. 3. CAD geometry of the FLNG – iceberg collision.

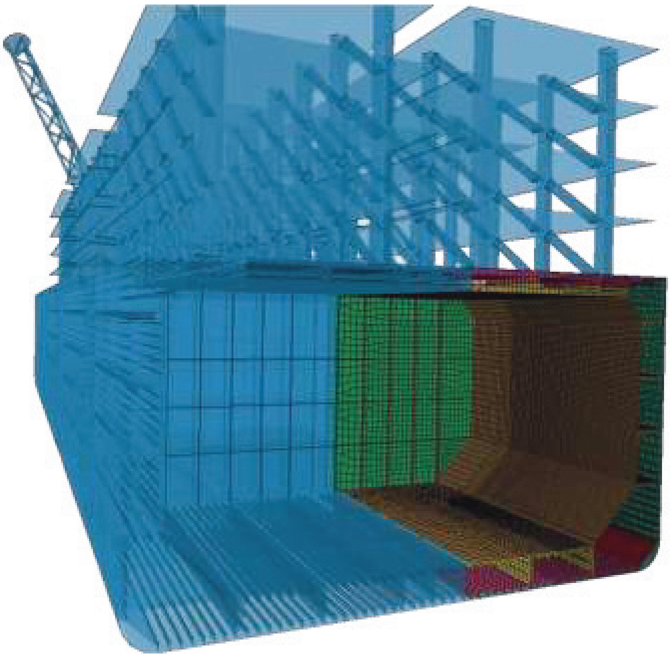


Fig. 4. Mesh model of the FLNG.

In the Figure 4, FE meshes of the FLNG are shown. Thicknesses and other important local dimensions are given in the Table 3.

Table 3. Details of the collision area structure

Outer hull thickness	18 mm
Inner hull thickness	14 mm
Longitudinal frame thickness	14 mm
Transverse girder thickness	14 mm
Longitudinal girder thickness	14 mm
Distance between hulls	2.85

3.1.2. Results and discussion

FLNG – iceberg collision simulations are performed by using KOSORI ice model and rigid body ice model. Figure 5 illustrates the FLNG side structure deformation after collision. Ice elements are separated during collision, therefore the impact contact area is enlarged. Thus, the pressure is decreasing on the contrary the rigid assumption as seen in Figure 6.

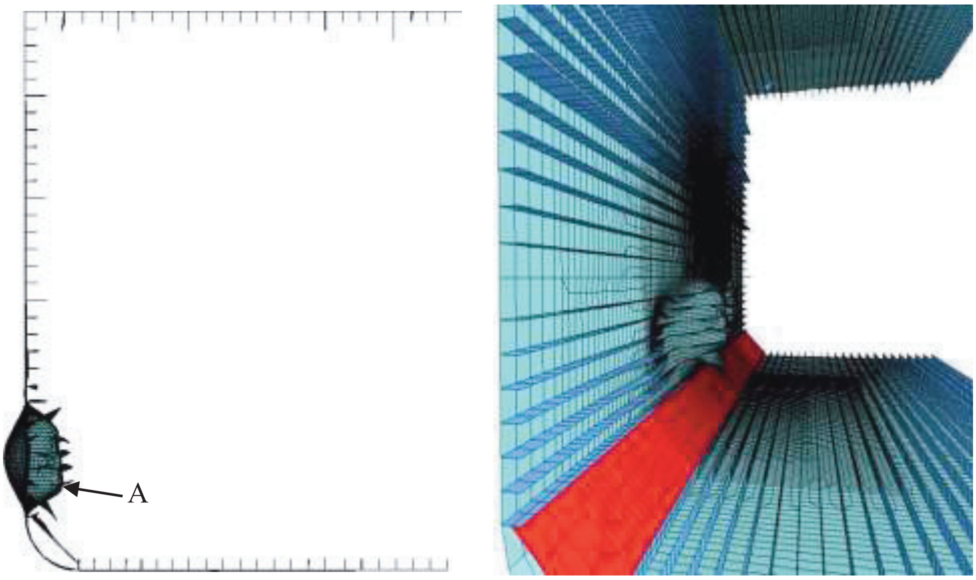
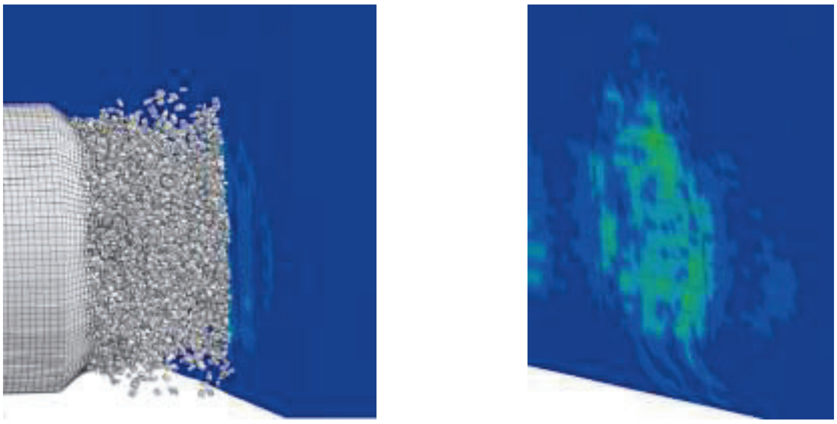
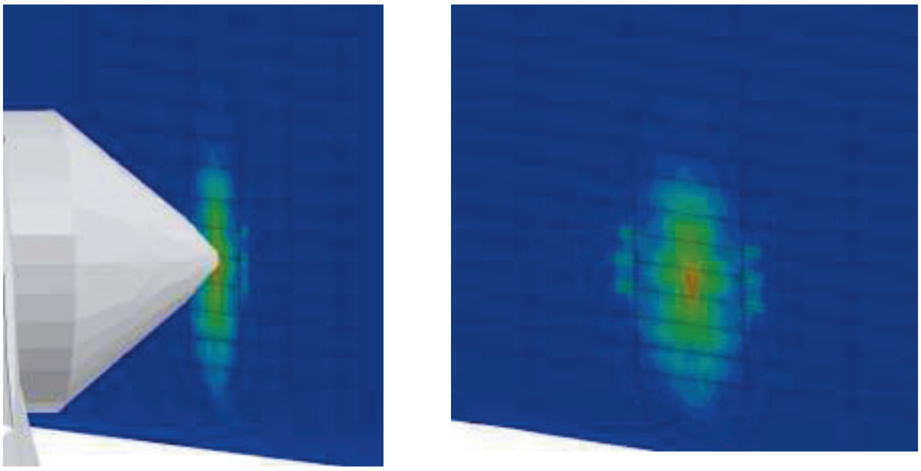


Fig. 5. FLNG side structure deformation after collision by magnification of 50.

Figure 7 shows force and penetration relationships for the KOSORI and rigid model. For both cases, similar maximum force is founded and the maximum deflections are 39 mm for KOSORI model used case and 131 mm for the rigid case.



(a) The KOSORI model



(b) Rigid model

Fig. 6. FLNG side structure deformation after collision.

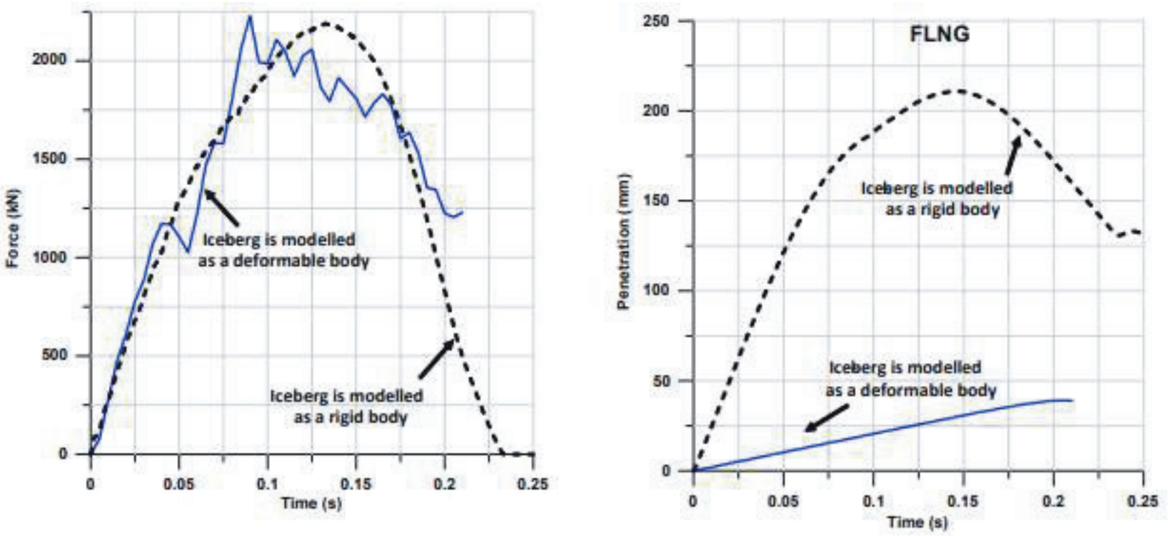


Fig. 7. Force and penetration responses of the collision between FLNG and iceberg for point A.

Force and penetration alteration for both, ice and FLNG side structure is shown Figure 8. In the KOSORI model case, the energy dissipated for deforming ice and FLNG on the contrary rigid model. It is clearly seen that, the energy mostly absorbed by ice structure.

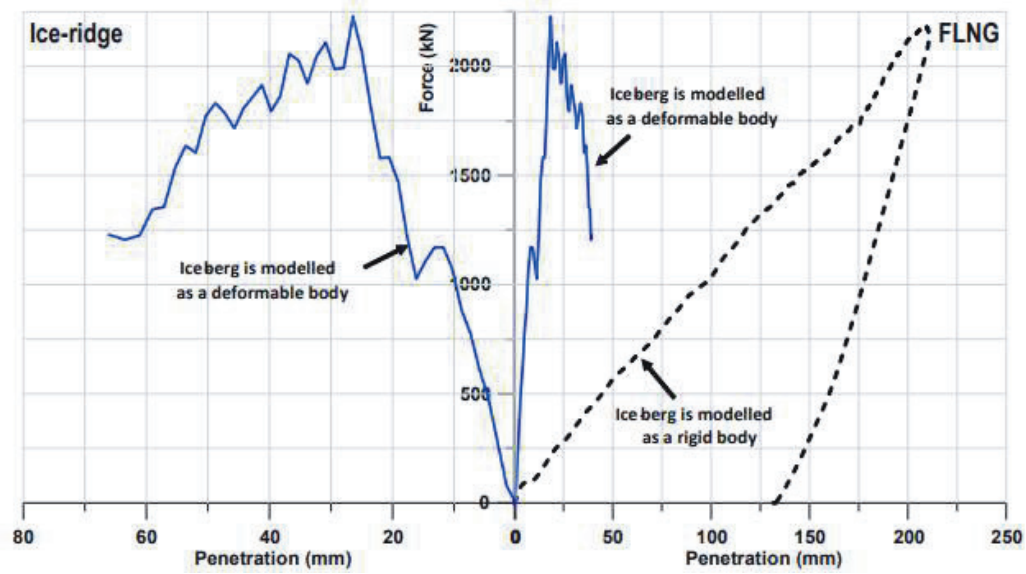


Fig. 8. Force and penetration relation of point A for both models.

Figure 9 shows absorbed energy comparison of the both model. At the end of the simulation, 7.42 kJ energy absorbed by the hull plate for using KOSORI ice model and 115 kJ energy absorbed in the rigid model case. All impact energy dissipated for deforming FLNG in the rigid model case. Therefore, it shows higher absorbed energy than the KOSORI model. The differences of the energy between rigid model and the KOSORI model case absorbed by iceberg.

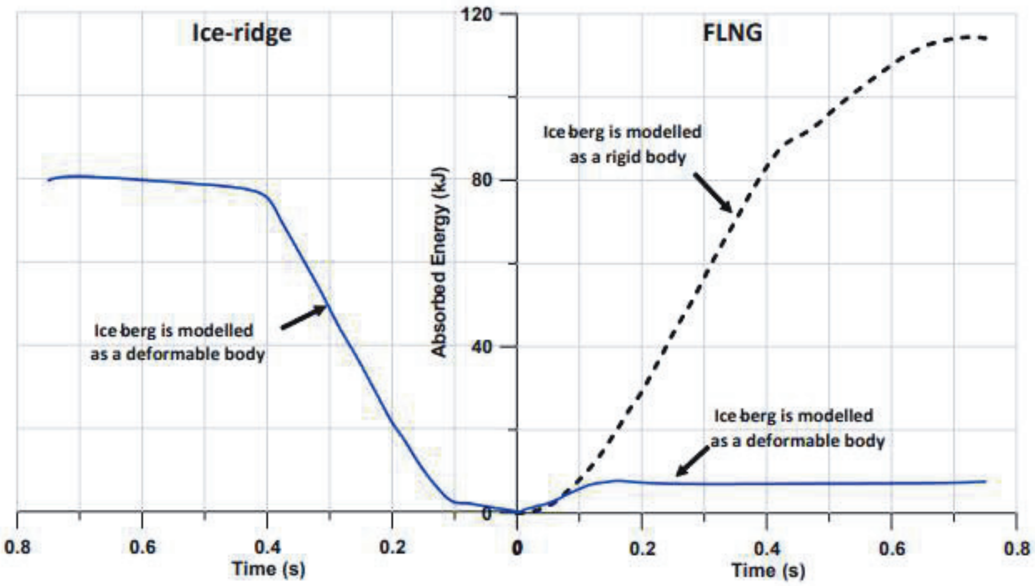


Fig. 9. Absorbed energy of the collision between FLNG and iceberg.

As a result, the penetration decreased more than four times by using realistic ice material model. Even though implementation of the rigid assumption is easy and simulation takes shorter time, it is quite pessimistic scenario for the collision between iceberg and marine structure.

4. Conclusion

The collision scenario is applied between a FLNG with iceberg for different ice model cases. Classical ice material as a rigid body assumption is compared with KOSORI ice model. In the simulation, following points are seen:

- Impact area is highly changing in the ship and iceberg collisions. Therefore, the discrete fracture capability of the KOSORI ice model was compensate impact area changes successfully. Rigid model case, the tip of the ice has been always sharp and it causes more damage.
- Even though force transfer from ice to ship structure during collision is similar in the KOSORI ice and rigid model cases, deflections are quite different.
- In the rigid model case, all impact energy absorbed by the marine structure. In the KOSORI ice model cases, the energy shared between ice and structure. The energy absorbed by structure in rigid ice model was really high comparatively the KOSORI ice model cases.
- The rigid ice model case, analysis is quite faster than the KOSORI ice model.

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