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Ice Collision Analyses for Membrane Tank Type LNG Carrier

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Abstract

As arctic energy resource is attracting public attention, arctic shipping market will also be growing in large as expected to increase in LNG trade from Arctic area to the western countries by shipping. During the voyages through such routes, collision with icebergs may be possible. In the present report, ice collision analyses are carried out from a practical point of view to verify the safety of hull structural strength of LNG carriers equipped with GTT MKIII™ membrane type cargo containment system. From the results of collision analyses and the operation-friendly design concept of no-repairing of cargo containment system, a safe operating envelope against ice collision is proposed for LNG carriers of membrane type cargo containment system. Based on the currently proposed safety criteria, it is concluded that LNG carriers with membrane tank type can operate safely with regard to the integrity of CCS in regions where collision between LNG carrier and iceberg is expected.
Keywords: ice-collision scenario, ice-collision analysis, membrane-type LNG carrier

1 Introduction

Recently, as arctic energy resource is attracting public attention, arctic shipping market is expected to grow. For example, there is expected an increase in LNG export from Murmansk to the US market with traditional LNG carriers. A possible collision scenario between an LNG carrier and iceberg on the route between Murmansk and Gulf of Mexico were looked into in Ref. (Mejlaelander-Larsen and Hysing 2006).

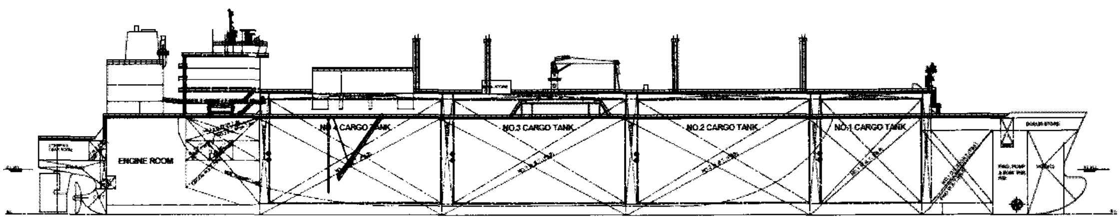
In the present paper, ice collision analyses are carried out from a practical point of view to verify the safety of a conventional 155,000 m^3 LNG carrier of GTT MKIII™ membrane type cargo containment system (M-LNGC hereinafter). The collision scenarios are selected as the most typical cases according to the above reference (Mejlaelander-Larsen and Hysing 2006). MSC.DYTRAN is used as an explicit FEM code for the analysis of the collision between the iceberg and the hull structure (Han et al. 2007). For the collision analysis, icebergs are modeled basically as rigid bodies. Comparative study is also carried out for a crushable iceberg in a specified scenario. Maximum deformation depths are checked to investigate whether the integrity of cargo containment system (CCS hereinafter) is damaged or not.

From the collision analysis results and the operation-friendly design concept of no-repairing of cargo containment system, a safe operating envelope against ice collision is proposed for LNG carriers of membrane type cargo containment system. Finally, based on the proposed safety criteria, the safe operating speed can be derived for different iceberg weights to give the guidance for the ship operators to keep the integrity of LNGC CCS.

2 Ice collision scenario

2.1 Collided ship

A 155,000m^3 M-LNGC is investigated. General arrangement and midship section are shown in Figure 1. Only full load condition is considered, where the draught is 11.5m and the displacement is 106,000 tons.



LBP x B x D = 274 m x 43.4 m x 26.0 m

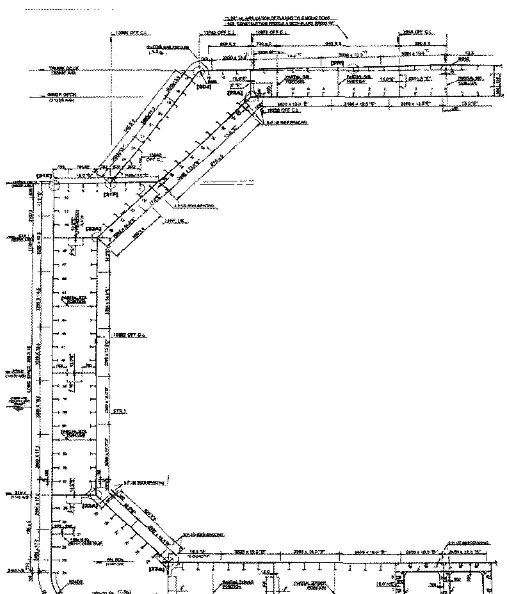
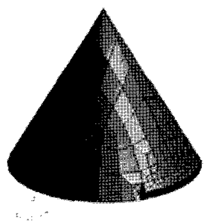
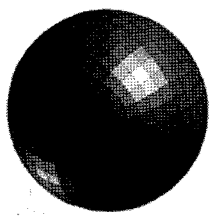
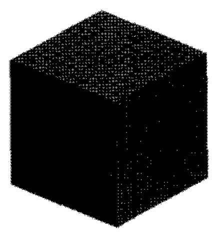


Figure 1: GA and midship ordinary section view for 155,000m^3 M-LNGC

2.2 Colliding object

Airborne radar monitoring systems are capable of identifying icebergs with a length greater than 15m. This means that smaller icebergs such as bergy bits and growlers are not identified (Mejlaelander-Larsen and Hysing 2006). It is also considered that bergy bits with the height above the water less than 2m are difficult to be detected by onboard radars. Thus, bergy bits or fairly small icebergs with the height of 2 m are considered as the colliding objects in the present study. Ice features of conical, spherical and cubical shapes of typical bergy bit are chosen, to have possibility to collide with LNG carriers operating in the course from Murmansk to the US coast (Mejlaelander-Larsen and Hysing 2006). These colliding objects are summarized in Table 1.

Table 1: Summary of bergy bit iceberg features

Conical	Spherical	Cubic
		
• Cone angle with horizontal plane = 60 deg. • radius at base = 2.5 m • radius at water surface = 1.15 m • Height = 4.3 m • volume = 28 m^3 • mass = 25 tones	• radius = 5.1 m • radius at water surface = 4.05 m • volume = 555 m^3 • mass = 500 tones	• height = 20 m • length at water surface = 20 m • volume = 8000 m^3 • mass = 8000 tones

2.3 Colliding scenario

Figure 2 shows various collision scenarios which can be expected. Among these collision scenarios, the collision in turning maneuver is selected in this report, because it is considered as the most probable case and dangerous for LNGC (Mejlaelander-Larsen and Hysing 2006). The collision scenario is summarized as follows.

- Impact location: ship side
- Load condition: Fully loaded
- Iceberg shapes: conical, spherical and cubic
- Impact speed: transverse ship speed (10% of ship speed due to turning) + Iceberg drift speed (=1.0 m/sec)
- Iceberg strength assumption: rigid for all iceberg shapes and crushable for spherical shape only

If no operational speed limit in ice-infested waters is given, the open water service speed should be assumed for the impacts against the bow side. For the potential impact during turning maneuvers, 10% of the ship speed before turning is assumed as a transverse ship speed.

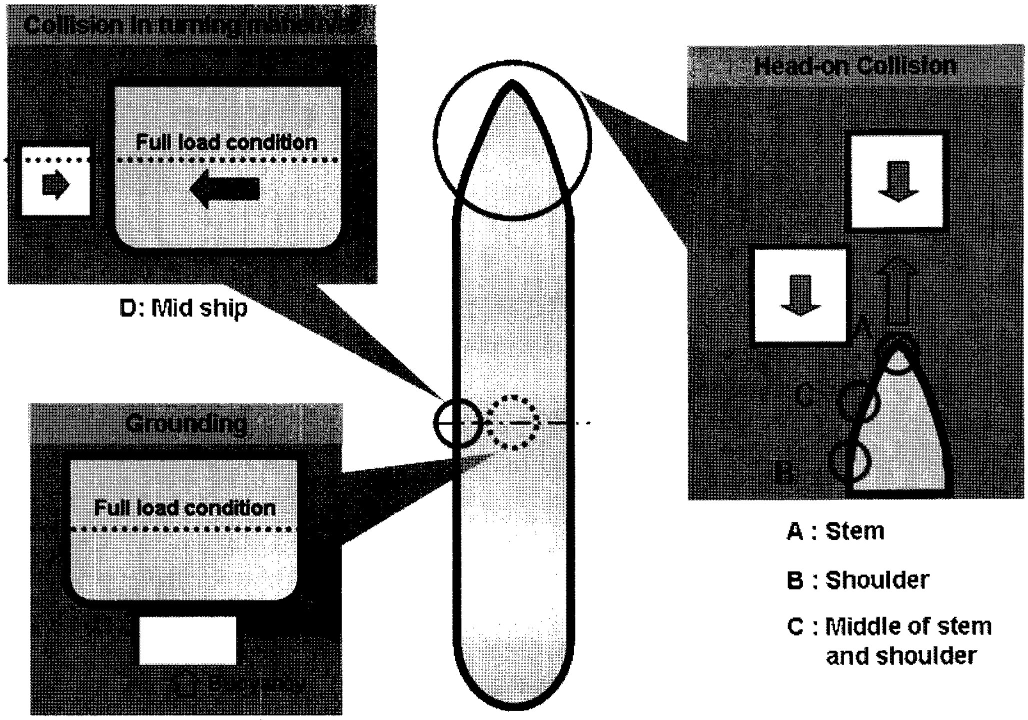
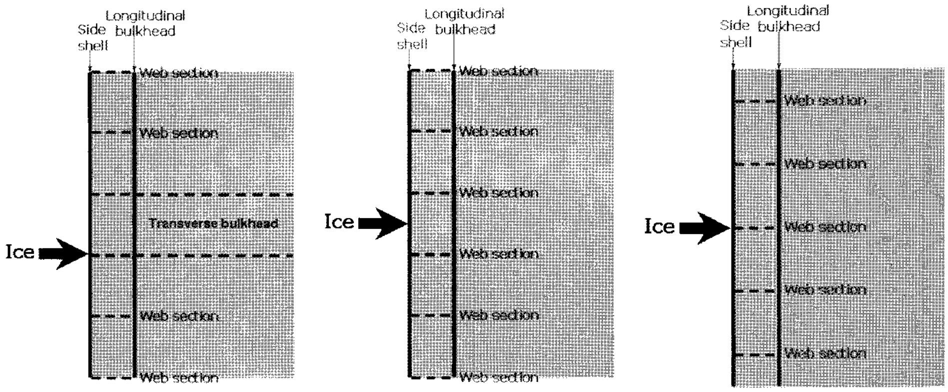


Figure 2: Summary of general ice collision scenarios

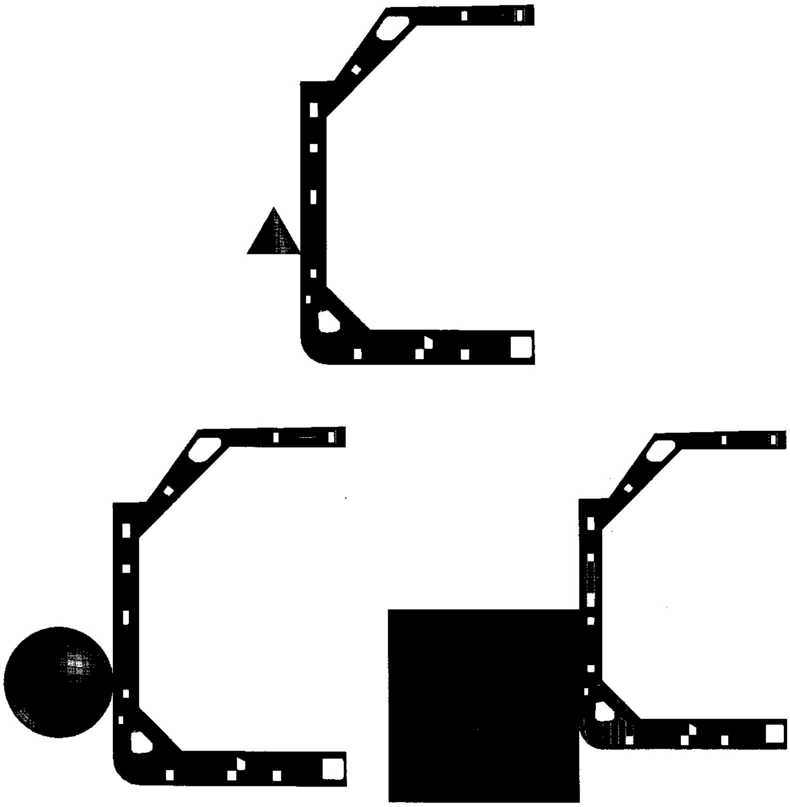
2.4 Impact location

The three kinds of impact location are categorized as shown in Figure 3, and the collision at a transverse web frame is selected as a typical case. Vertical location is adjusted to the floating condition of the icebergs and the full loaded LNGC as shown in Figure 4.



(i) at transverse bulkhead (ii) between web frames (iii) at a transverse web frame

Figure 3: Schematic views of Impact locations for LNGC hull structures



a. conical iceberg b. spherical iceberg c. cubical iceberg

Figure 4: Section views showing icebergs colliding against the hull ship for different iceberg shapes

3 Analysis of ice collision

For the collision analysis, MSC.DYTRAN is used (Han et al. 2007). It is an explicit FEM code capable of analyzing short, transient dynamic events that involve large deformations, material nonlinearity and interactions between fluids and structures in time-domain simultaneously (MSC Dytran Manual 2005).

As a conservative approach, icebergs are modeled basically as rigid bodies. In the case of spherical iceberg, crushable model is also developed. The strength of the ice may vary significantly with the operational season, i.e. summer and winter. For the winter season a nominal ice crushing strength of 4~5 MPa is adopted (Mejlaelander-Larsen and Hysing 2006). Figure 5 shows the FE model of the crushable spherical iceberg. Shell elements are used to model rigid icebergs and solid elements are used for crushable iceberg. For the spherical iceberg collision case, the element size of the model is refined at the contacting area to simulate properly. The strength of ice is assumed to be independent of the contact or load area.

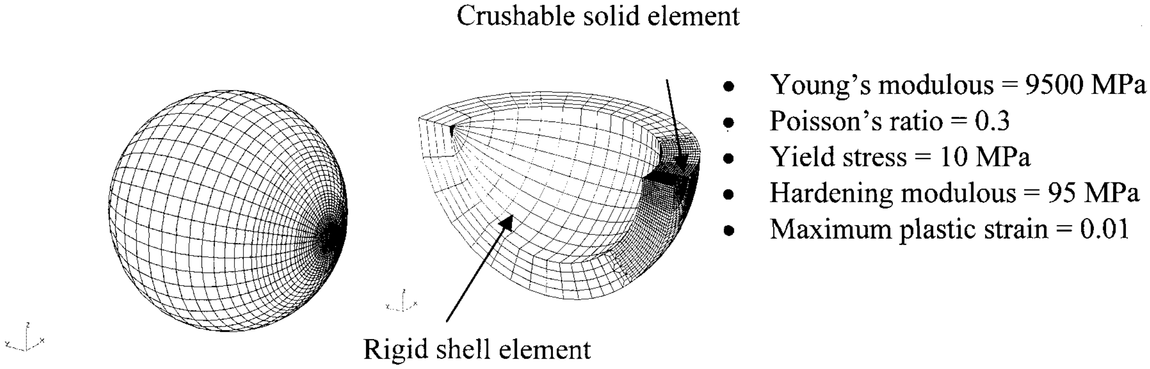


Figure 5: Crushable ice model of spherical iceberg feature (Jang et al. 1997)

As collision affects the structure locally close to impact area (Koehler 1985), the proper size of hull structure, which can show the sufficient structural response due to collision, is modeled as shown in Figures 6. The ship and icebergs are not comparable in the sizes and weight, therefore, collision is simulated in such a way that the iceberg collides against the hull structure which is fixed along the edges. This means the kinetic energy due to the rigid body motion of the ship and additional fluid motion around the ship which are raised during collision process is ignored, and this treatment gives conservative results. Shell elements and bar elements are used to form the hull structure, and normal element mesh sizes are around 800mm×800mm and refined element mesh sizes are around 200mm×200mm. Only the structural damping due to the plastic deformation is considered since the deformation model adopts the elastic-perfectly plastic theory and the Cowper-Simonds equation.

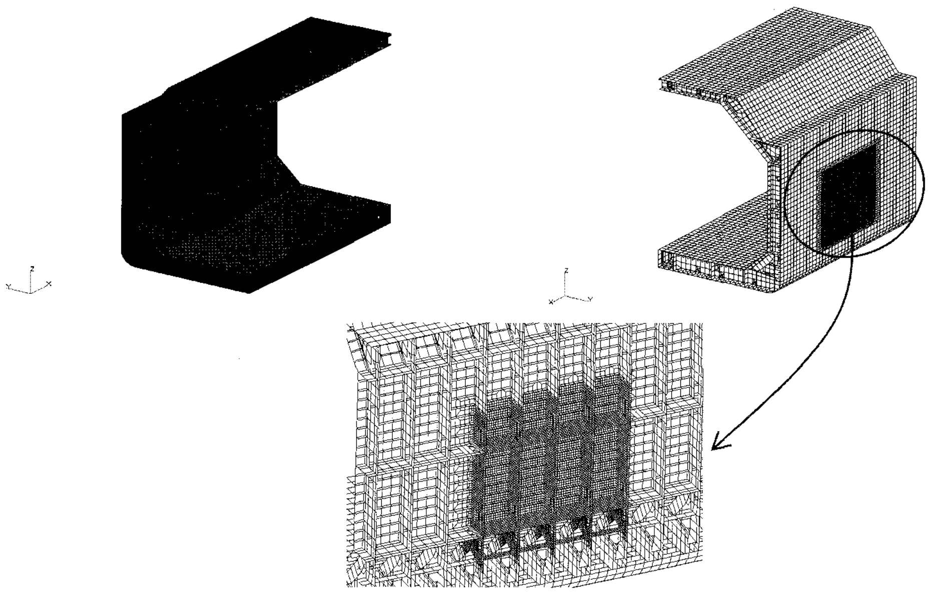


Figure 6: Finite element models for M-LNGC hull structure

4 Calculation results

The results are mainly examined for the inner longitudinal bulkhead deformations to see whether it damages the LNG CCS system. Figure 7 shows deformation behaviors of M-LNGC for rigid iceberg collision in each shape at chosen times. Based on the calculated results, the maximum deformation depths for all the cases are summarized in Table 2.

The maximum deformation depth of the inner longitudinal bulkhead of M-LNGC is less than 30 mm for conical and spherical icebergs from Table 2 and the deformation of the inner longitudinal bulkhead due to the collision of conical and spherical icebergs does not cause any serious damage to CCS of GTT MKIII™. Therefore, it is concluded that the LNG CCS need not to be repaired for the integrity even in the present design of normal LNG carrier and this "no-repairing of CCS" concept is used as the safety criteria for the collision analysis in the current paper.

For cubical iceberg, the loss of tightness for the CCS is not expected in spite of the deformation depth of 128 mm, considering the result (about 2500mm) of large deformation tests from GTT (GTT 1983) which verified the tightness of the insulation system until about 2500mm deformation. In addition, the present M-LNGC is not designed for ice-strengthening. Therefore, the vessel will have more safety margin if the hull structure is strengthened for arctic service.

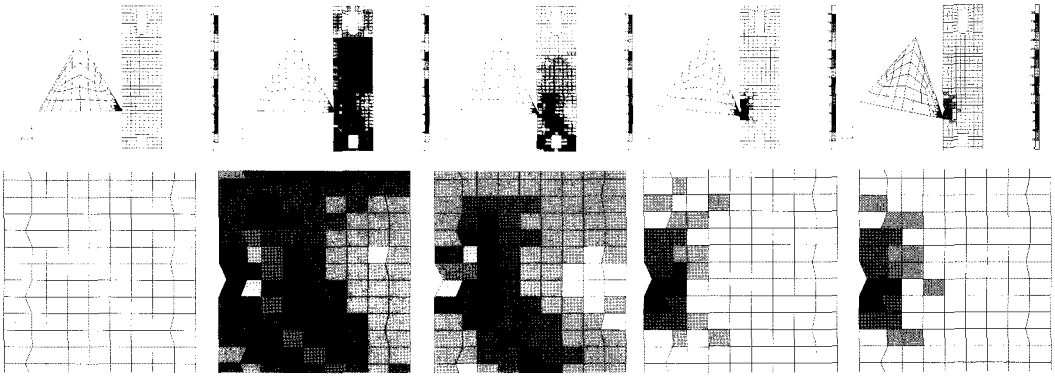
For the case of spherical iceberg collision, a crushable ice model from Figure 5 is applied to the collision analysis to investigate the effect of ice crushing to the results.

The motion of a spherical iceberg and the deformation depth of inner longitudinal bulkhead of M-LNGC are compared in Figure 8 and 9 for the rigid model and the crushable model. Although the rigid iceberg model is moving toward the hull structure about three times more than the crushable iceberg model, the deformation depth of the rigid model is only about 50 % of the crushable model, as shown in Figure 9. Since the results are considerably dependent upon the material properties and element size, however, the analytical results using the crushable ice model can not be used confidently as data for the evaluation of the design of M-LNGC. This comparison makes sure that the usage of rigid iceberg model is more conservative for the ice collision analysis.

Table 2: A comparison of deformation depth on the inner longitudinal bulkhead

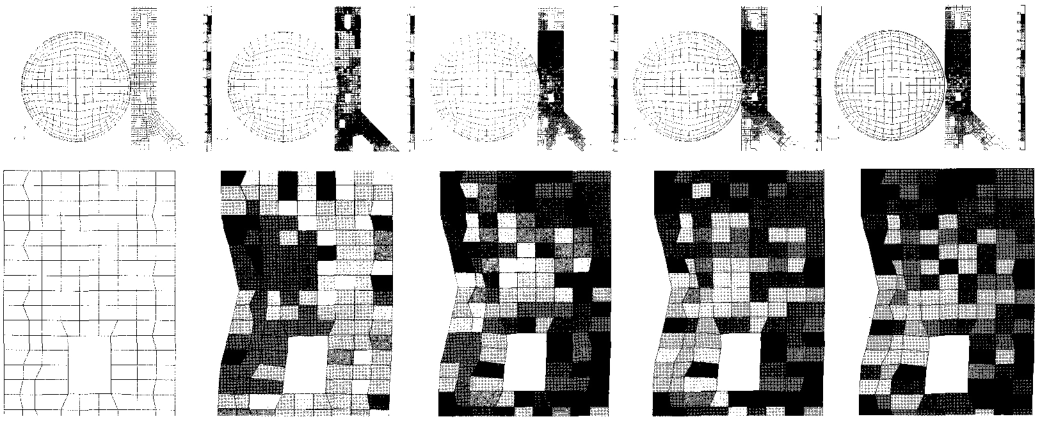
Iceberg shape	Conventional 155K M-LNGC	
	Deformation	Allowable depth
Conical (25 ton)	4 mm	50mm*
Spherical(500 tons)	29 mm	
Cubic (8000 tons)	128 mm	

Remark *) Elastic deformation limit of inner longitudinal bulkhead
But GTT test result shows that about 2500mm deformation of inner longitudinal bulkhead doesn't have the loss of membrane tightness



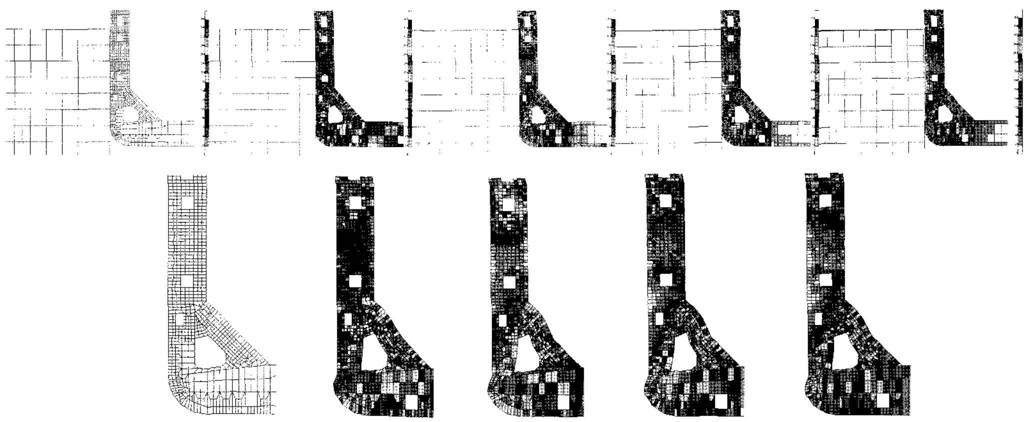
0.0sec 0.01sec 0.02sec 0.03sec 0.04sec

(i) Conical iceberg



0.0sec 0.08sec 0.16sec 0.24sec 0.32sec

(ii) Spherical iceberg



0.0sec 0.1sec 0.2sec 0.3sec 0.4sec

(iii) Cubic iceberg

Figure 7: Ice collision with M-LNGC

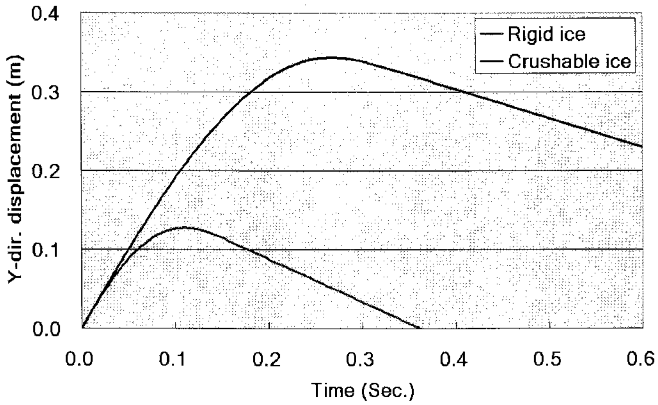


Figure 8: Comparison of motion of iceberg for different material properties in the case of spherical iceberg

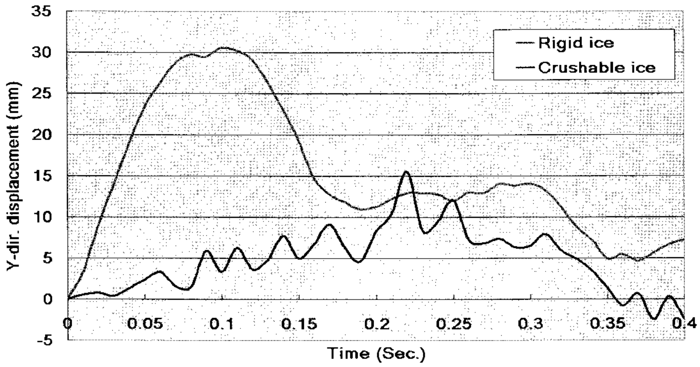


Figure 9: Comparison of deformation depth of inner longitudinal bulkhead for different material properties in the case of a spherical iceberg

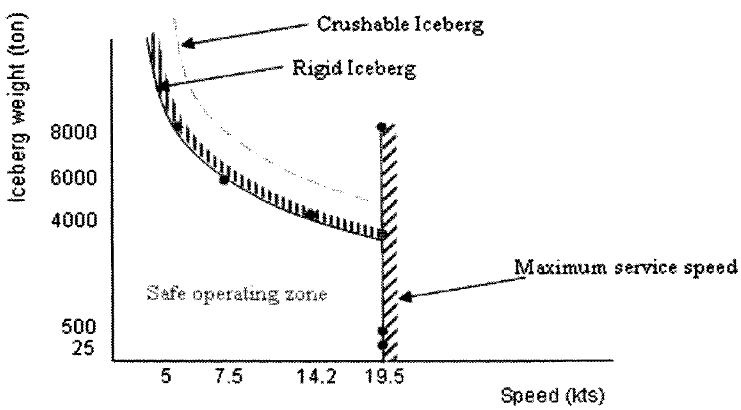


Figure 10: Safe operating envelope against ice collision for M-LNGC with the condition of no-repairing of CCS, the speed is calculated by 0.1×Vr (Vr = speed during turning), based on the assumption that the ship makes evasive maneuvers on detecting the iceberg

Safety vessel speed which seems not to require repairs of the CCS of M-LNGC with respect to different cubical iceberg weights up to 8,000 tons can be made as shown in Figure 10. Two more calculation results are added in Figure 10, i.e., 6,000 ton and 4,000 ton cubic icebergs. This curve is available as an operation guidance to minimize the risk of collision damage. Crushable iceberg curve is drawn to show that ice collisions will have more safety margin considering the rigidity of real icebergs.

5 Conclusions

Based on the collision scenarios, ice collision analyses are carried out to verify the safety of a conventional 155,000 m^3 LNG carriers of GTT MKIII™ membrane type.

The results are compared for different small iceberg shapes. Maximum deformation depths are investigated to evaluate the integrity of CCS following the iceberg collisions. From the collision analysis results and the operation-friendly design concept of no-repairing of cargo containment system, a safe operating envelope against ice collision is proposed for LNG carriers of membrane type cargo containment system. Then, based on the proposed safety criteria, the safety operating speed to sustain the integrity of CCS is derived for different iceberg weight to give the guidance for the ship operators.

From the results, the conventional 155,000 m^3 LNG carrier of GTT MKIII™ membrane type CCS need not to be repaired for the iceberg collisions with iceberg weights up to 500 tons at least. For even a cubical iceberg of 8,000 tons, the loss of tightness for the CCS may not be expected, since the deformation of inner hull structure is about 128mm and it is much lower than the deformation depth which was shown to be safe in large deformation tests carried by GTT.

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