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Comparative Study on Collision Strength of LNG Carriers

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Abstract

The collision energy absorbing characteristics of side structure of the LNG carriers which have the cargo containment systems of the spherical and the membrane types are compared. A failure mechanism of the double hull side structures of 130,000 m^3 class LNG carriers under sideways collision event has been simulated by using the detailed finite element calculations. In ship collision analysis, the finite element method based on explicit time integration has been used with much success. Finite element modeling techniques for detail description of structural members and ship motion regarding the dynamic behavior allowed to investigate the effect of bow shape and the initial contact position on side shell of collided ship. In the numerical simulations of the ship-to-ship sideways collision, the effect of the colliding bow shapes and the change of the colliding ship draft are investigated. The critical collision energy which is absorbed by a side structure of a collided ship until the fore-end of colliding ship arrives at the boundary of the cargo tank is calculated. The critical speed of specified colliding ships which can not penetrate the boundary of the LNG cargo tank of the collided ship under collision accident is evaluated.

Keywords: sideways collision of LNG carrier, finite element collision modeling, critical speed

1 Introduction

Analysis of ship collision strength has attracted attentions in order to prevent a large scale environmental disaster in sea. Some of ship collision accidents in the past remain instructive records in losses of human lives and properties and environmental damage. The research activities of ship collision have been focused on the nuclear powered ships and large oil tankers which may cause serious environmental pollution. The LNG carrier is also one of the dangerous vessel which contains the most hazardous cargo. Special considerations are needed in structural design and operation of the ship.

The collision mechanics of the ship structure is complicate and highly nonlinear phenomena. However it is important to establish a reliable analysis procedure of the hull structure collapse under collision accident. In the past years, much research activities have been focused on behavior of the structural component of ship structure. A number of simple expressions between the colliding obstacles and the collided structures have been derived analytically or empirically.

A simplified method which describes the structural response under collision has contributed to a practical design up to present.

On other hand, the finite element method with explicit time integration algorithm has been widely used in the analysis of the dynamic non-linear structural response of the industrial products with much success. The application of numerical simulations are also tried to the analysis of the ship structure to investigate whether the cargo tank boundary can protect the hazardous or polluting cargo from the colliding obstacles.

The reliability of the non-linear finite element simulations has been confirmed by various laboratory experiments and real ship collision tests. The numerical simulation allowed designers to investigate the structural behavior of a ship during collision process. The yielding, bucking, tearing of material and the share of the collision energy for each structural member can be observed and it provides useful information for safe operation of the ship and optimum design of the hull structure. Shipbuilding authorities and leading shipyards are also making their own studies on the numerical analysis of the ship collision.

The ISSC1997(International Ship and Offshore Structures Congress) have reviewed the literature and its applicability for predicting the crushing and damage of ships in collision and grounding. A detailed numerical simulation with explicit time integration algorithm in ship-to-ship collision was applied and confirmed in the full scale collision experiment by Lenslink(1992).

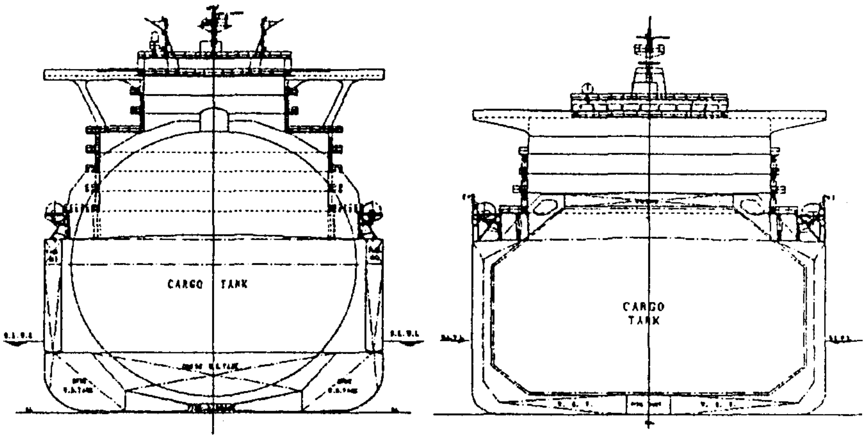
In this work, the energy absorbing capabilities of double hull LNG carriers are evaluated to get useful information in structural design and operation of ship. The arrangements of the side structures in LNG carriers are different according to the LNG tank systems of the spherical type tank or the membrane type tank. The energy absorbing capabilities also varies according to the structural members within local area of the initial contact position of the collision. The investigations are made with change of the initial contact position of two ships and the bow shape of the colliding ship.

It is considered that the bow shape and the fore-end of the colliding ship which depend on the colliding ship type and size could be one of the major parameter which decides the absorbed collision energy in a side shell structure of collided ship. The free floating condition and the moored condition of the collided ship are also considered in the analysis.

2 Collision scenario

A failure of nautical equipment on a ship and/or human error in ship operation could be a potential source of ship-to-ship collision in seaway. Moreover, the rise of amount in marine transportation increases the risk of collision in a sea way or in a port. Because the most serious collision mode of a ship-to-ship collision may be ship bow to ship side collision, the analysis takes scenarios of sideways collision on full load condition of LNG carriers. In order to simulate the medium scale of collision energy which may cause the damage range of a double side structure of the LNG carriers, the same size of LNG carriers and 300,000 TDW class VLCC are taken as the colliding ships.

Because the distance of the LNG cargo tank from the side shell is different according to the cargo containment system, the cargo containment systems of the spherical type and the membrane type are introduced in the analysis. Also the change of the initial contact position is considered in the collision scenario, because the penetrating depth of the colliding ship from the initial contact to the boundary of the LNG cargo tank varies according to the fore-end shape of the colliding



(a) Spherical type (b) Membrane type

Figure 1: Configuration of LNG Carrier

Table 1: Loading condition of colliding ship

Colliding Ship	Speed (Knots)	Displacement(ton)		
		Light Load	Medium Load	Full Load
LNG Carrier	11.25	34,000	66,000	98,000
VLCC	14.5	41,800	192,000	343,000

ship and the contact position of two ships. The bulbous bow under the sea water level or/and the fore-end shape of the colliding ship decide the initial contact position of two ships and may affect the absorbed energy in the side structure of the collided ship.

The mid-ship sections of 130,000 m^3 class LNG carriers which are the subject collided ships in this work are shown in Figure 1. Selective shapes of the bulbous bow and fore-end shape of a 130,000 m^3 LNG carrier and a 300,000 TDW VLCC with different draft conditions are described in Figure 2. The loading condition of the colliding ships are described in Table 1 and the descriptive name of each collision scenario are shown in Table 2.

Table 2: Collision scenario name

Colliding Ship	Collided Ship Type	Loading Condition of Collided Ship		
		Light Load	Medium Load	Full Load
LNG Carrier	Spherical	SS-L	SS-M	SS-F
	Membrane	MM-L	MM-M	MM-F
VLCC	Spherical	VS-L	VS-M	VS-F
	Membrane	VM-L	VM-M	VM-F

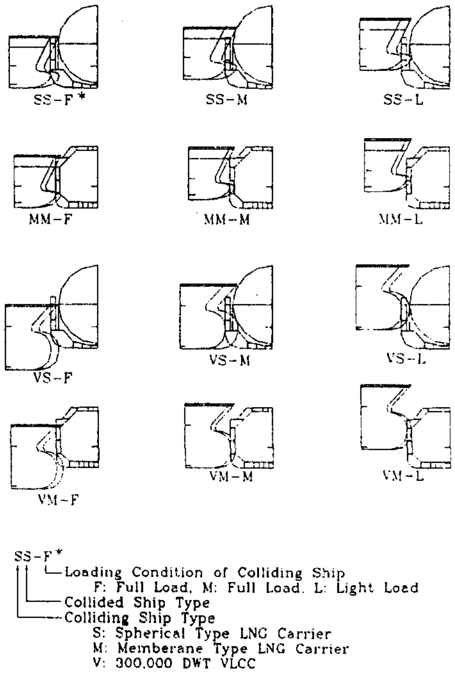


Figure 2: Collision scenario

3 Transformation of collision energy

During a ship-to-ship sideways collision process, the initial kinetic energy of the colliding ship is to be transformed into the strain energy of the structural members and the rigid body motion of two ships after collision.

In the analysis, it is assumed that the colliding ship approaches to the middle of the collided ship. There may be no yawing motion of the ship. Therefore, the motion can be described by an uncoupled one dimensional equation. It is also assumed that the drifting velocity of two ships by the initial kinetic energy after collision is same. The amount of dissipated energy by the structural damage is calculated from the conservation principle of the kinetic energy of two ships before and after collision process.

The dissipation of the lost initial kinetic energy is simulated by the dynamic elasto-plastic finite element model.

3.1 Simplified collision mechanics of freely floating ship

The drifting velocity of the colliding and collided ship induced by the initial kinetic energy of the colliding ship is calculated from the conservation principle of the momentum during collision process as shown below:

$$(M_1 + m_1)u_1 \sin\theta = (M_1 + m_1 + M_2 + m_2)U \qquad (1)$$

where

M_1: mass of colliding ship
m_1: added mass of colliding ship
M_2: mass of collided ship
m_2: added mass of collided ship
u_1: velocity of colliding ship
U: velocity of colliding and collided ship after collision
θ: angle between course of colliding ship and collided ship

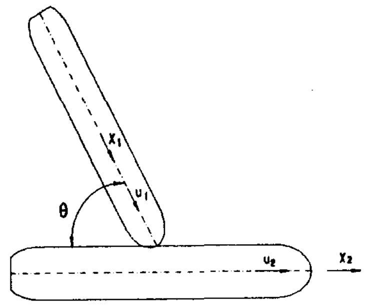


Figure 3: Course angle

In ship-to-ship sideways collision accident, the normal course of the colliding ship to the collided ship is the most serious. However, the effect of offset angle from the normal direction of colliding ship is accounted by taking the velocity component in the normal direction.

The change of kinetic energy of two ships during collision process is described by using the following equation:

$$\Delta E = 1/2(M_1 + m_1)(u1 \sin\theta)^2 - 1/2(M_1 + m_1 + M_2 + m_2)U^2 \tag{2}$$

Combining equation (1) and (2), we can find:

$$\Delta E = [(M_1 + m_1)(M_2 + m_2)/2(M_1 + m_1 + M_2 + m_2)]\,(u_1 \sin\theta)^2 \tag{3}$$

The calculated lost kinetic energy, ΔE is to be dissipated into the strain energy of the structural members, work done by the friction force and the inertia force of the structural members. The work done by the restoring heeling moment of the ships also shares the calculated ΔE.

3.2 Simplified collision mechanics of mooring ship

In the mooring condition of the collided ship, a finite rolling motion of the collided ship in the initial stage of the collision is allowed. But the translation of two ships after collision process is constrained. All the initial kinetic energy of the colliding ship is to be dissipated during the collision process. The initial kinetic energy of the colliding ship can be described by the following equation:

$$\Delta E = 1/2(M_1 + m_1)(u_1 \sin\theta)^2 \tag{4}$$

4 Finite element model

It can be expected that the extent of structural damage on the side structure of collided ship is localized and has symmetric nature in a center plane of the cargo hold length. Therefore, the detailed finite elements are arranged in a half length of one cargo hold with symmetric constraints on the center plane. The initial contact positions of two ships are also arranged in the center of the

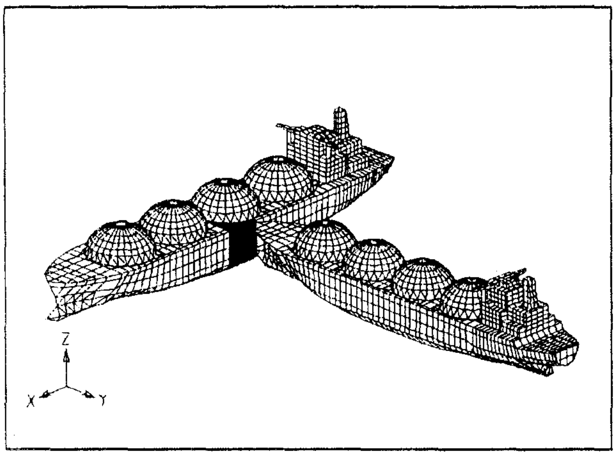


Figure 4: Typical finite element model

cargo hold length. The structural members far away from the collision area are idealized by using the rigid finite elements.

In the analysis, the shape of a colliding ship is described by rigid finite elements and the initial velocity is applied on the mass of the ship. The structural members in the side structure of the collided ship are described by elasto-plastic finite elements.

The mass of the ship in the finite element model includes the added mass effect due to the sea water. The restoring force and the moment induced by the change of the draft and the heeling angle of the ship are simulated by supporting springs on the finite element model of the ship.

The material property of elasto-plastic stress-strain relation with strain hardening is assigned in the finite elements. The effect of strain rate sensitivity of the material is also taken into account by using the Copper-Simond's equation(3). The rupture of structural members is simulated by the failure of the finite element strength in which the element strain arrives at critical value of 20%.

The plate of the hull structure and the stiffeners are idealized by using the plate bending elements which include the in-plane stiffness. The detailed description of the panel and the stiffeners with several nodes allows the global and local deformation modes of the structural members. Therefore, the bending, buckling, folding of the structural members are to be simulated by the finite elements. By application of the contact surface in each structural member, the contact force between structural members is calculated.

A typical finite element model of the collision scenario is shown in Figure 4. In the work, the transient dynamic solution with the explicit time integration is done by using the MSC/DYTRAN.

5 Results of calculation

By application of the non-linear dynamic finite element method based on explicit time integration algorithm, a quite reasonable behavior of the side structure members has been obtained with the several specific collision scenarios.

A detailed failure mode of the structural members is described by the finite elements as shown in Figure 5. Yielding of the material and failure of the structural members are observed. It is also

Table 3: Calculated critical lost kinetic energy(MJ)

Colliding Ship	Collided Ship Type	Loading Condition of Col-lided Ship		
		Light Load	Medium Load	Full Load
LNG Carrier	Spherical	200[SS-L]*	480[SS-M]	480[SS-F]
	Membrane	28[MM-L]	36[MM-M]	96[MM-F]
VLCC	Spherical	400[VS-L]	1120[VS-M]	200[VS-F]
	Membrane	42[VM-L]	74[VM-M]	178[VM-F]

[ ]* : Scenario name

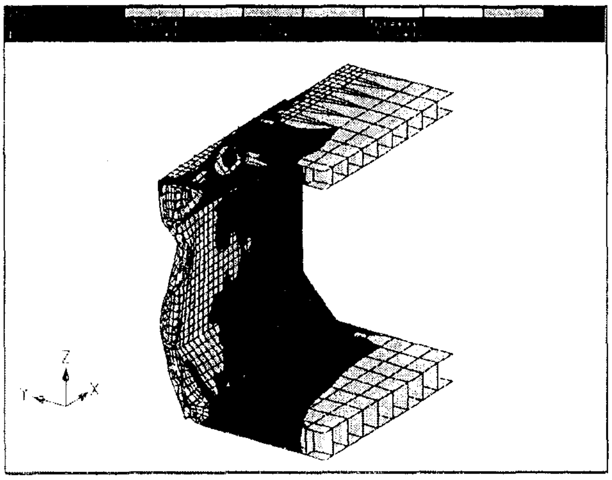


Figure 5: Deformed shape of collided ship(Membrane Type)

found that the range of the structural damage is localized and the shape of the colliding objects remains on the side structure of the collided ship.

The detailed finite element calculation provided the time history of the member force during collision process and the relation between the lost initial kinetic energy and the bow penetration distance. The typical relation is shown in Figure 6.

To ensure the safety of the cargo tank under collision accident, it is required that the colliding object does not penetrate the cargo tank boundary. If the side structure of collided ship can absorb the lost initial kinetic energy during collision process, the colliding object could not penetrate the cargo tank boundary. The lost initial kinetic energy until the fore-end of the colliding ship arrives at the cargo tank boundary is considered as the critical lost kinetic energy. From the relation between the lost of kinetic energy and the penetrating distance of the colliding ship, the critical lost kinetic energy is decided.

By comparing the lost kinetic energy calculated from the (3) or (4) and the critical lost kinetic energy, we can evaluate that the cargo tank will be protected or not under collision accident.

From the finite element calculations, the critical lost kinetic energy which could not yield damage on the cargo tank in each scenario are provides as listed in Table 3.

6 Evaluation

It is found that the non-linear dynamic finite element method applied in this work requires large amount of machine calculations but provides elaborate failure modes of the structural members, detailed time history of the collision force and the energy dissipation.

Based on the calculated critical lost kinetic energy, the critical speed of the colliding ship is calculated from the right hand side of the (3) or (4). If the colliding ship keeps the critical speed in vicinity of the LNG carrier, the colliding ship could not penetrate the LNG cargo tank under the sideways collision accident. The critical speed of the voyage in a port or in an entrance of strait on navigation route of the LNG cargo could be a guidance to avoid a serious accident of the LNG cargo tank damage.

The calculated critical speeds of specific colliding ships in each scenario are summarized in Figure 6 and Figure 7. It is found that the critical speed of colliding ship depends on the LNG cargo containment system of the collided ship and the draft condition of colliding ship. From the calculated critical speed, the following characteristics are found.

- Relatively higher collision speed is allowed on the side shell of the spherical LNG cargo containment system.
- The calculated critical speeds resulted in quite different values according to the initial contact position on the side shell of the spherical LNG cargo containment system.
- The critical colliding speed of the moored condition resulted in lower values than that of the freely float condition.

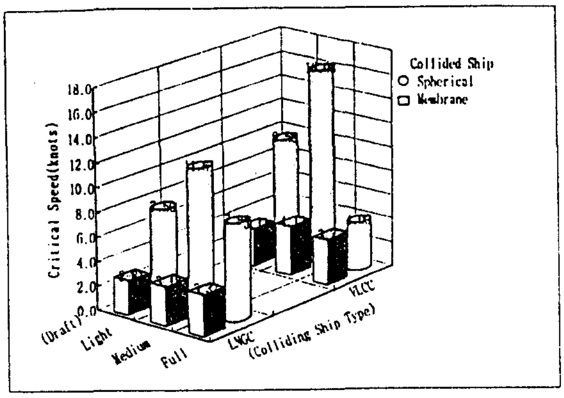


Figure 6: Critical colliding speed for free float condition

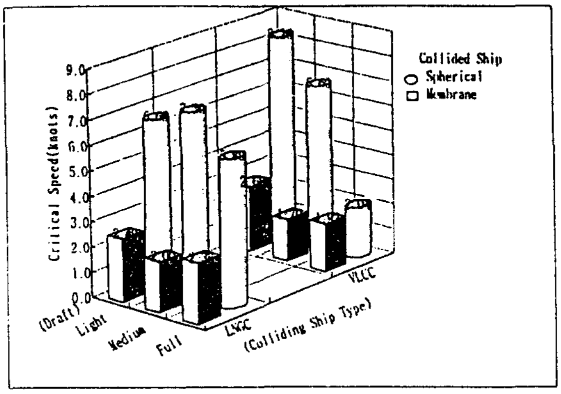


Figure 7: Critical colliding speed for moored condition

7 Conclusion

The energy absorbing capabilities of the side structure of the LNG carriers under the hypothetical collision accident are evaluated. It is difficult to make a general description of the collision characteristics of the LNG carriers. However, from the calculated results with the specified collision scenario, the energy collision characteristics of the double side structures of the ships are described.

- The side structure of the spherical type LNG carrier can absorb relatively more collision energy than the membrane type LNG carriers.
- It is observed that the critical lost kinetic energy depends on the initial contact position of two ships and the bow shape of colliding ship.
- It could be recommended that the operation speed of a ship around a floating spherical type LNG carrier should be less than 4.0 Knots and the operation speed of a ship around moored one should be less than 2.0 Knots.
- It could be recommended that the operation speed of a ship around the floating membrane type LNG carrier should be less than 2.8 Knots and the operation speed of a ship around moored one should be less than 1.7 Knots.

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