

Improved Collision Safety of Ships by an Intrusion -Tolerant Inner Side Shell

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ABSTRACT:

This paper presents a conceptual deformable inner barrier design with the aim of improving the collision safety during a collision into the side of a ship by facilitation of a deep intrusion before penetration. Validation of the conceptual design was made using finite element simulations in a comparative study of the original "reference" structure. The analysis shows that the amount of absorbed energy can be increased by up to several 100% at the same time as the stakeholder's interests are fulfilled.

KEYWORDS: Hull, Collision, Double side shell, Inner Barrier, Finite Element Method

INTRODUCTION:

The potentially costly consequences of a lost ship in the form of fatalities, property, cargo, and related industries, as well as pollution of the environment in the form of oil spills, and so forth, and in public view are the driving force for developing more collision-resistant ships. Different approaches have been used to improve the collision safety. A variety of attempts to vary the structural arrangements and scantlings of double side shells have been made in order to improve the energy-absorption capabilities in collisions. The improvements of varying the structural arrangements are generally small. A common belief is that if the steel mass is not increased or the steel grade is not upgraded, the increase of the energy-absorption capability is limited. This is especially true when the penetration depth is less than the width of the double side.

Statistics of collision damage:

In the IMO project Harmonization of Rules and Design Rationale (HARDER), International Maritime organization (IMO) damage statistics have been updated with more recent collisions, comprising more than 2900 casualties, of which 1851 were collisions, 930 groundings, and 165 other incidents. The data concerning collision were analyzed, regarding the damage Location along the ship length, the longitudinal damage extent, and the intrusion depth

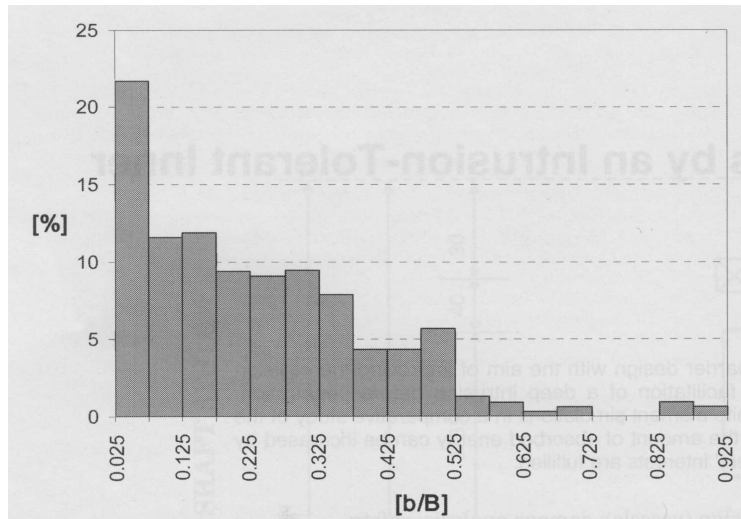


Figure shows a distribution of the intrusion depths based on the statistics from 570 collision events; the intrusion depth, b , is normalized by the ships, breadth, B , as b/B . The statistics do not distinguish between intrusions above or below the waterline. The mean intrusion depth is $0.15 \times B$. In general, a double side shell is approximately 0.05 to $0.1 \times B$. This indicates that most ships are penetrated in a- collision, even if they have a double side shell.

Another 216 damage records contain data for the upper most vertical extent of damage. The damage height ranges from 9 m below to 15 m above the sea still-water level. More than 20% of the uppermost vertical damage is below the waterline.

Collision mechanisms:

The mechanisms involved in a collision can be classified into external and internal collision mechanisms. The external mechanism deals with the rigid-body global motion of the ships and the hydrodynamic forces. The parameters of the external mechanism consist of the mass of the striking and the struck ship, the velocities of the striking and the struck ship, the collision location, the collision angle, and the hydrodynamic forces. This mechanism determines the amount of kinetic energy dispersed into the structures in the collision.

The internal mechanism deals with the way the kinetic energy is absorbed in the structures through buckling, crushing, tearing, shearing, and friction. The internal mechanism depends on the striking bow geometry and its structural arrangement, the structural arrangement of the struck ship, the material properties, and the failure mode. The cargo inside the struck ship can also be a part in the energy distribution and absorption. This can greatly affect the intrusion depth of a ship. In all, these two mechanisms will determine the damage in a collision.

Reference ship and side shell structure:

In the finite element simulations a ship developed in the European project Intermodeship was used as the reference vessel, see Fig. 2. The "Intermodeship" is a coastal RO/RO cargo vessel with the task of transporting trailers between ports in Lake Vanern, Sweden, and Duisburg, Germany. The vessel was chosen because it has a typical type of side shell structure, at the same time as there is a small distance between the inner and outer side shells, making her sensitive for

collision damage. The vessel has a length overall (LOA) of 88 m, breadth (molded) of 13.3 m and a design draught of 4 m. She has three RO/RO decks one on the tanktop, one on the main deck, which also constitutes the freeboard deck, and one outdoors on the upper deck (Fig. 2). The ship has ice class IC, and her total cargo capacity is 48 trailers, or 1700 DWT.

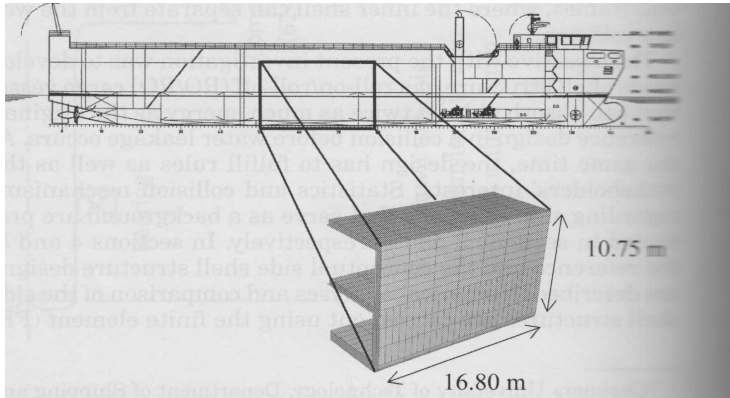


Fig.2 Reference vessel “Intermodeship” and midship section

The reference ship has a longitudinally stiffened single side shell above the main deck and a transversely stiffened double side shell, with a horizontal depth of 0.825 m, between the main deck and the tanktop. The longitudinally stiffened double bottom has a height of 0.9 m. The deck beams, with a spacing of 2.4 m, are continued from the upper deck as vertical webs down through the double side shell to the double bottom, where they meet the floors.

Conceptual design of the deformable inner barrier:

In order for a new type of double side shell design to become a commercial success, there are several stakeholders' interests that have to be considered. The major stakeholders are: the ship owners, the classification societies and maritime authorities, the shipyards, insurance companies, and the cargo owner. The main requirements for a new double side shell design were then:

- A 100% increase of the energy-absorption capability of the side shell structure
- A cost increase of a maximum of 1.5% of the ship's total cost.
- A weight increase of a maximum of 1.5% of the ship's total lightweight
- An unchanged cargo and ballast volume
- Normal structural strength according to the rules
- Access for inspection and maintenance
- Not "too complicated" design to construct.

Today, the majority of large ships are equipped with bulbous bows. If a ship with a bulbous bow collides into the side of another ship, two holes might be struck: one above the waterline by the stem and one below the waterline by the bulb. To reduce the risk of water intrusion, a double side shell beneath the surface is required. A double side shell will reduce the risk of penetration, but only in lighter collisions/contacts.

In a collision into the side of a ship, the amount of absorbed energy increases considerably with the intrusion depth. This occurs partly because of the accumulated absorbed energy but, especially, because of the increasing contact area of the stem that is pushed into the side of the

collided ship, as the width of the colliding ship's stem increases aftward. The basic idea of the conceptual design is to make a deep intrusion possible before the inner barrier is penetrated and leaking cracks arise. This will greatly increase the energy absorption capability and thereby the collision safety of a ship. The result will be ships that can survive a side collision, without water intrusion, by a ship with a much higher mass and speed.

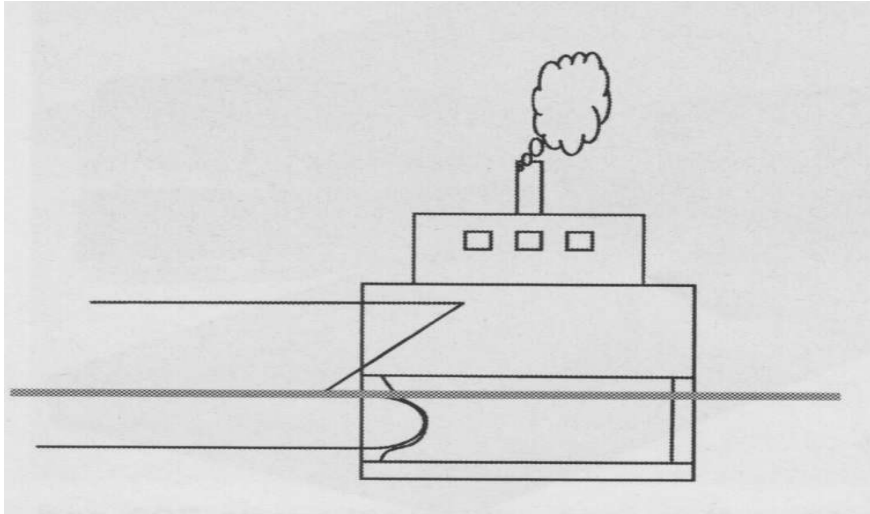


Fig. 3 Deformable inner barrier

One can consider the hull as a two-barrier system, the first (outer) barrier consisting of the outer side shell and the bottom and the second (inner) barrier consisting of the inner side shell and the tanktop. The two barriers are connected via the web frames, the margin plate, the side girder, and the bottom floors. In order for the second inner barrier to deform, or buckle in, without fracturing in a collision, the second inner barrier has to disconnect from the outer barrier at extreme loads. To facilitate a deeper intrusion without the inner side shell being penetrated, the inner side shell is here corrugated. This will allow the inner side shell to unfold at the extreme loads of a collision.

Finite element models and calculation procedures:

The FE simulations were carried out by Ulf B. Karlsson using the commercial FE software ABAQUS/Explicit version 6.5 on a computer with an Intel Xeon DP 3.2 GHz 800/1M processor with a 1 GB DDR333 internal memory. For the FE simulations, a midship section of the reference ship was used, with a length of 16.8 m between the weather deck and the tanktop and with a depth into the centerline. The section was constrained in all degrees of freedom along all outer free edges. A sensitivity analysis showed that this length was adequate, since the stress at the boundaries was within the elastic region and the amount of absorbed energy by the structure for a longer section was marginal.

The characteristics of the two materials used in the FE simulations, a normal strength steel with a yield stress of 240 MPa and a high strength steel with a yield stress of 700 MPa, were established by uniaxial tensile tests and recalculated into true stress and strain. For both materials, Young's modulus E , was 206 GPa, Poisson's ratio, ν , was 0.3 and the density, ρ , was 7,850 kg/m³.

A bulbous bow from a coastal product and chemical tanker, scaled down 1:2 in order to better fit this midship section, was made to collide into the structure in Fig 4. In the FE simulations, the bow acts as a rigid body, that is, undeformable. The bulb was given a thickness of 10 mm, a very high density ($\rho = 1 \times 10^4 \text{ kg/m}^3$) and high Young's modulus ($E = 206 \times 10^3 \text{ GPa}$) to force it to remain undeformed, acting as a rigid body. Hence, the amount of elastic energy it absorbed was negligible in contrast to the energy absorption in the structure. The bulb was seeded with an element size of 200 mm (4,366 elements); that is, the size of the elements that formed the mesh of the bulb was 200 mm, in order to maintain its geometric shape. From the results presented in Karlsson et al. (2009), it was suggested that a velocity of 10 m/s or less be used in the FE simulations to obtain adequate accuracy and resolution in results together with reasonable computation times.

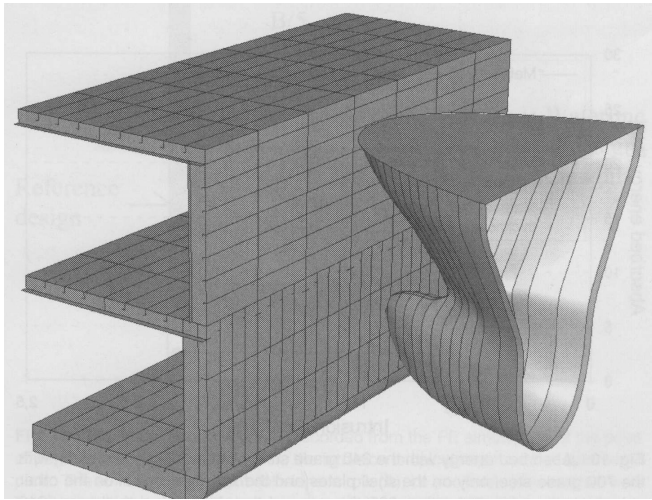
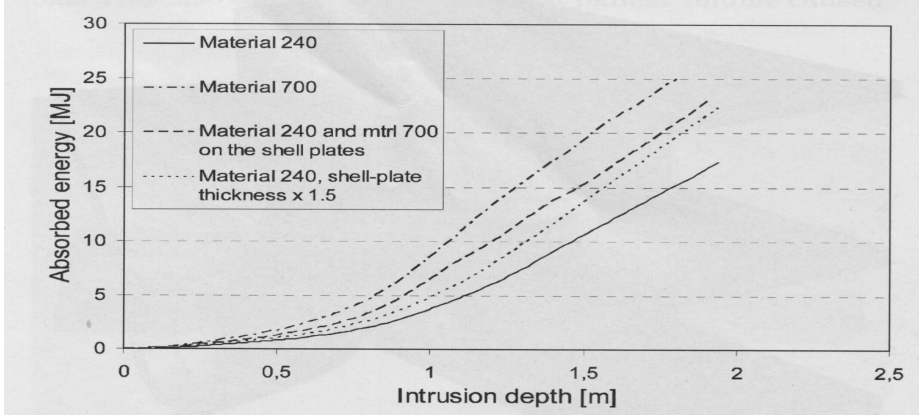


Fig. 4 Reference structure and the bow.

FE analysis of reference structure: material, shell-plate thickness, and energy absorption:

In this section, the FE analyses of the reference side shell structure are presented where the structural arrangement was kept unchanged and only the material characteristics and thickness dimensions were altered. The absorbed energy is the total energy = the internal energy + the friction energy absorbed by the collided structure.

In order to analyze the effect of using a higher strength steel, high strength steel with a yield stress of 700 MPa was applied for the whole reference structure. The amount of absorbed energy by the structure was compared with the reference material, which is a typical normal ship-steel grade with a yield stress of 240 MPa. In the simulation, the fore point of the bulb strikes between two web plates in the middle between the main deck and the tanktop at collision.



The absorbed energy versus the intrusion depth until fracture of the inner plate occurs is shown in Fig. 5. In comparison with the reference 240 grade steel, the energy absorption was increased from 17.3 to 24.9 MJ, or with 44%. If applying the high strength steel only to the side shell plates, keeping the normal grade steel for the other structural members, we find the increase of the absorbed energy to be 33% (Fig. 5).

Comparison between the reference design and the deformable inner barrier designs :

The collision resistance and energy absorption of the reference and the conceptual design with the deformable inner barrier were compared by simulating 10 collision events. The bow collided at an angle of 90 deg with the fore tip of the bulb striking either (A) between two web frames, or (B) into a web frame, at five different levels. The five collision levels were: (1) into the tanktop, (2) 1200 mm above the tanktop, (3) in the middle between the main deck and the tanktop, (4) 1200 mm beneath the main deck, and (5) into the main deck.

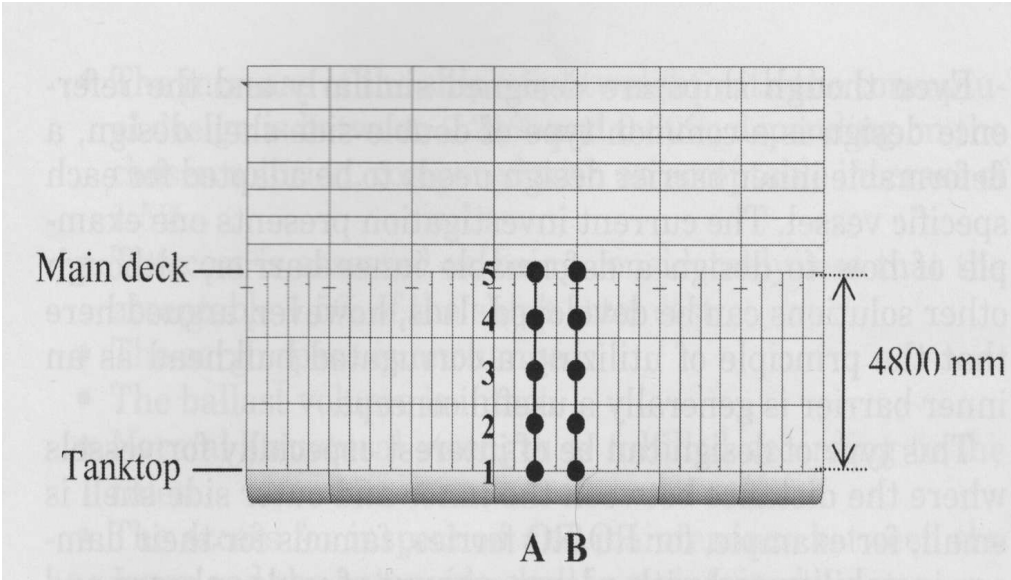


Fig.6 Collision points referring to where the bulb of the bow strikes.

The results show that the fore point of the bulb strikes between two web plates (A) in the middle between the main deck and the tanktop (3). The intrusion depth, calculated from the outer

shell plate, is presented for both the reference and the conceptual design. The intrusion depth for the reference design was 1.94 m, while it was increased to 3.46 m for the deformable inner barrier design. Hence, the increase in energy absorption using the deformable inner barrier design was from 17.3 to 59.2 MJ, or 242%. The increase occurs when the corrugated inner side shell disconnects from the web plates and unfolds.

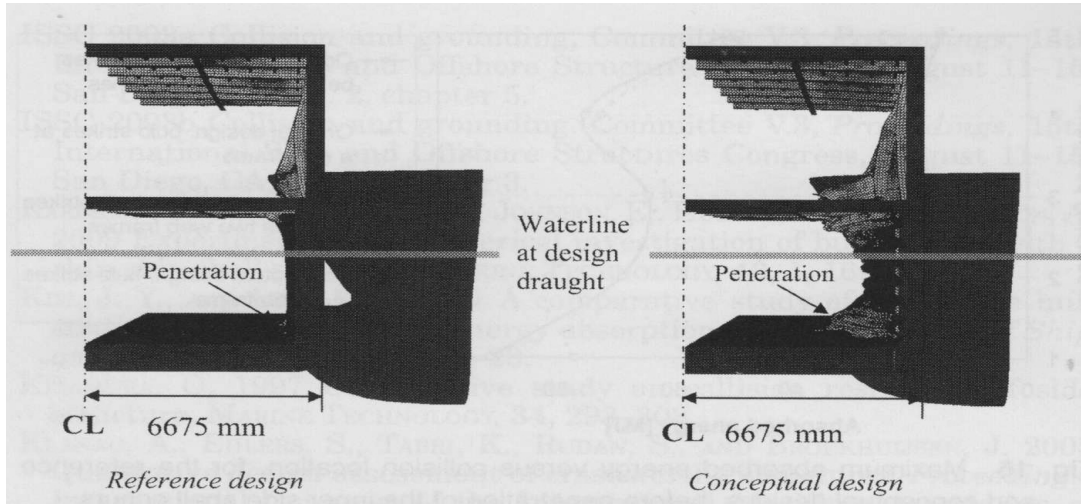


Fig.7 Collision Event A1

The result from FE simulations of collision event A1, as the intrusion depth until the inner shell is penetrated below the main deck for the reference and the conceptual designs. The intrusion depth increases from 1.74 m for the reference design to 3.52 m with the deformable inner barrier design, resulting in an increase of the absorbed energy from 24.1 to 91.2MJ, or 278%. The large increase occurs as a result of the corrugated inner side shell and the tanktop disconnecting from the web plates, the margin plate, the side girder, and the bottom floors, facilitating a deeper intrusion.

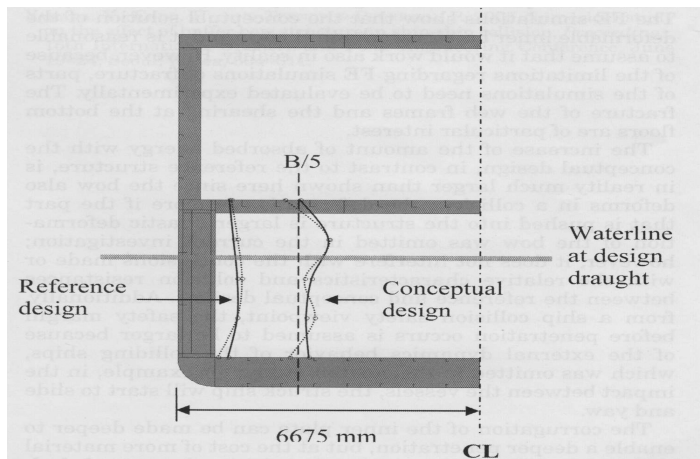


Fig.8 Intrusion depth recorded from the FE simulations

Ten collision events were simulated for the reference and the conceptual designs. Figure shows summary of the results from all the 20 FE simulations, here presented as the maximum intrusion depth recorded from each of the analyses at the point of penetration below the main deck the intrusion is calculated from the outer shell plate. The solid lines represent collision

between two web frames, while the dotted lines represent collision into a web frame. The intrusion depths calculated for the reference design varied between 1.50 and 2.04 m. With the deformable inner barrier design, the calculated intrusion depth was increased to between 2.98 and 3.96 m.

The deeper intrusions made possible with the deformable inner barrier, compared with the reference design, result in a large increase of the totally absorbed energy until the inner barrier is penetrated and water leakage occurs. Using the deformable inner barrier design instead of the reference design, the increase of the amount of absorbed energy is between 206% and 295%.

Conclusions:

Using the FE model of the reference double side shell design, the benefit of using a high strength steel with a yield stress of 700 MPa, instead of a typical normal ship-steel grade with a yield stress of 240 MPa, was studied together with the influence of an increased shell-plate thickness regarding increased energy absorption before penetration of the inner side shell occurred.

The FE simulations of the deformable inner barrier BY ULF B Karlsson (2009) showed that it can increase the energy absorption considerably more than the stipulated 100%, at the same time as the stakeholders interests are fulfilled. The intrusion depth of the reference design was 1.50 to 2.04 m. With the deformable inner barrier design, the intrusion depth is increased to 2.98 to 3.96 m. This corresponds to approximately B/5 of the ship's breadth. The deep intrusion made possible results in an increase of the amount of absorbed energy of between 206% and 295%.

The statistics of the intrusion depth that the reference design would cope with 18% to 29% of all collisions without penetration through the double side shell. With the deformable inner barrier, the corresponding figures are 48% to 60%. In addition, the interests of the stakeholders are fulfilled according to:

- The increase of ship's lightweight with the conceptual design between 0.21% and 0.60%, depending on the chosen solution, compared with an acceptable increase of 1.5%.
- The cost is assessed as being considerably less than the acceptable 1.5% of the ship's total cost.
- The cargo space is unchanged.
- The ballast volume is intact.
- Normal structural strength is fulfilled according to the rules.
- The access for inspection and maintenance between the inner and outer side shell is maintained.
- The design is not considered "too complicated" to construct at a normal shipyard.

Reference:

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