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INTERNAL MECHANICS OF SHIP COLLISIONS

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Abstract: *This paper is part of a procedure which analyses ships collisions, addressing to all types of ships and damage scenarios. The analysis of a ship-ship collision is usually separated into two classes. These are external and internal mechanics. Large plastic deformation of the shell plating subjected to various loadings is developed. Folding and crushing of frames are studied and analysis of denting and crushing of intersections is performed.*
Key words: *collision mechanics, damage analysis, super-element method, forces and deformation*

1. INTRODUCTION

The nowadays vessels have an integrated passive safety based on damage stability regulations, which is build on either modern probabilistic approach or on traditional methods. All relevant compartment damages, in the usual deterministic procedure, must be analysed. For ships with a standard distribution of compartments, this may be reasonable, but may lead to either too unsafe or too conservative ship designs (Brown, 2002). A solution for all this could be the probabilistic approach, where all possible damages are considered and weighed with regard to survivability.

The International Maritime Organization (IMO) is currently seeking to harmonise the damage stability regulation for all types of vessels using the probabilistic damage stability concept. In parallel with the activity within IMO, an European research program entitled HARDER, "Harmonization of Rules and Design Rationale", was initiated. The project, which begun in 2000, is investigating systematically the validity, robustness, consistency and impact of all aspects of the harmonized probabilistic damage stability regulations (Lutzen, 2001).

2. COLLISION MECHANICS

The process involved in collision is complicated. The analysis of a ship-ship collision is usually separated into two classes. These are external and internal mechanics.

External mechanics is concerned with the rigid body motion of the two ships involved in the collision. The two ships are referred to as the struck and striking ships. Thus, external mechanics deals with the kinetic energy of the struck and striking ships, including an allowance for the added masses of water (Pedersen, 1993).

Internal mechanics is concerned with the response of the struck and the striking vessels to collision. This specifically means the relationship between force and deformation of the two vessels (Pedersen, 1993).

The methods used to assess collision are often simplified due to its complexity. When the duration of impact is short compared to the natural periods of vibrations of the system, then the collision event is essentially dynamic. However, if the duration of impact is long compared to the natural periods, as is normally the case, the impact can be treated as quasi-static (Minorsky, 1959).

3. LATERAL LOADING OF PLATES

The model for the internal mechanics is based on a set of so-called super elements. Each element represents an assembly of structural components and contains solutions for the structural behaviour of this assembly under deep collapse. From all super elements, we will discuss about deflection and rupture caused by lateral loading of plates.

Plates are structural elements at the ship's side, the longitudinal bulkheads or the longitudinal floors. The horizontal boundary of a plate can be weather deck, mid-decks, inner bottom, and bottom or stringer decks. If stiffeners are attached to the plate they will form a boundary until they are in contact with the striking ship. After contact smaller stiffeners will be smeared out, and the plate will be considered orthotropic. Larger stiffeners will be considered as beams (Abramowicz, 1994). Consider a rectangular plate deformed by a point load, where the distances from the point of loading to the four edges of the plate are noted R_1, R_2, R_3, R_4, as in Figure 1. The plate is subjected to an increasing deflection ω_0 at the point of loading. Large deflections are considered, which implies that the bending resistance can be neglected. The purpose of the analysis is to find out the force, P, necessary to deform the plate (Lutzen, 2001).

The plate is divided into 4 triangular parts, which extend from the point of impact to the corners of the plate. The deformation mode considered, which contents the boundary condition, is as follows:

$$w = w_0 \frac{xy}{R_1 R_2} \tag{1}$$

The Langranian strain sensor $\varepsilon_{\alpha\beta}$ is defined by

$$\varepsilon_{\alpha\beta} = \frac{1}{2}\left(u_{\alpha,\beta} + u_{\beta,\alpha}\right) + \frac{1}{2} w_{,\alpha} w_{,\beta} \tag{2}$$

where u is the component of the in-plane displacement, and w denotes the out-of-plane displacement. The non-linear strain and strain rate can be expressed as

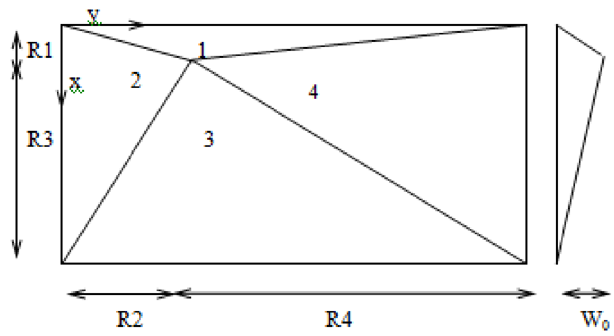

Fig.1 Deformation pattern for a rectangular plate

$$\varepsilon_{xx} = \frac{1}{2}\left(\frac{dw}{dx}\right)^2 = \frac{1}{2}\frac{w_0^2 y^2}{(R_1R_2)^2} \qquad \dot{\varepsilon}_{xx} = \frac{w_0\,\dot{w}_0\,y^2}{(R_1R_2)^2}$$

$$\varepsilon_{yy} = \frac{1}{2}\left(\frac{dw}{dy}\right)^2 = \frac{1}{2}\frac{w_0^2 x^2}{(R_1R_2)^2} \qquad \dot{\varepsilon}_{yy} = \frac{w_0\,\dot{w}_0\,x^2}{(R_1R_2)^2} \qquad (3)$$

$$\varepsilon_{xy} = \frac{1}{2}\frac{dw}{dx}\frac{dw}{dy} = \frac{1}{2}\frac{w_0^2 xy}{(R_1R_2)^2} \qquad \dot{\varepsilon}_{xy} = \frac{w_0\,\dot{w}_0\,xy}{(R_1R_2)^2}$$

The rate of the external loading must be equal to the rate of energy dissipation in the plate. Using the von Mises yield criterion, this requirement is expressed by

$$P\dot{w}_0 = \frac{2}{\sqrt{3}}\sigma_0 t \int_A \sqrt{\dot{\varepsilon}_{xx}^2 + \dot{\varepsilon}_{yy}^2 + \dot{\varepsilon}_{xx}\dot{\varepsilon}_{yy} + \dot{\varepsilon}_{xy}^2}\, dA \qquad (4)$$

where P is the external load and A is the area of the plate.

Substituting the increments of equations (3) and (4) gives the following expression:

$$P_{1,left} = \frac{2}{\sqrt{3}}\sigma_0 t \frac{w_0}{(R_1R_2)^2}\int_0^{R_2}\int_0^{\frac{R_1}{R_2}y}\left(x^2 + y^2\right)dx\,dy =$$

$$= \frac{1}{6\sqrt{3}}\sigma_0 t w_0\left[\frac{R_1}{R_2} + 3\frac{R_2}{R_1}\right] \qquad (5)$$

The same procedure is used for the rest of the plate, and the forces are summed to give the total force acting on the plate.

$$P = \frac{2\sigma_0 t}{3\sqrt{3}} w_0 A\left[\frac{1}{R_1R_3} + \frac{1}{R_2R_4}\right] \qquad (6)$$

If the plate is orthotropic the force-deflection function can be expressed as

$$P = \frac{1}{6\sqrt{3}} w_0 A\left[\frac{3N_{0y} + N_{0x}}{R_1R_3} + \frac{3N_{0x} + N_{0y}}{R_2R_4}\right] \qquad (7)$$

where N_{0x} and N_{0y} are the membrane yield forces in the x and y direction, respectively.

After rupture, a special plate element is used, which takes into account that the plate may be intact with membrane tension or be fractured in the longitudinal, in the transverse or in both directions (Zhang, 1999).

If the boundary of the plate is touched by the striking bow, the part of the plate belonging to this boundary will be omitted. The rest of the plate will still be included until rupture. A new plate, found below or to the side, is now to be included. In Figure 2 the deformation pattern for a plate below the first plate of contact is shown. The resistance of this plate can now be calculated as

$$P_{new} = 0 \cdot P_1 + P_2 + \frac{1}{2}\cdot P_3 + \frac{1}{2}\cdot P_4$$

(8)

where P_1, P_2, P_3 and P_4 are the resistance of each of the four plate parts. The new distance for R_1, R_2, R_3 and R_4 are defined in Figure 2.

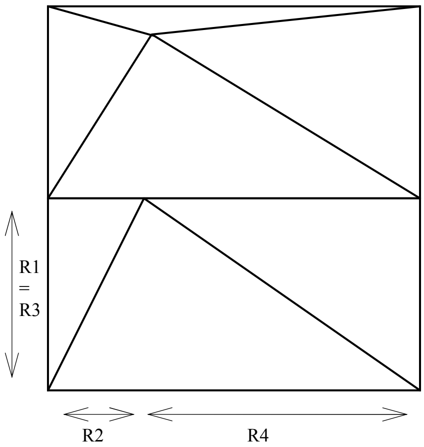

Fig.2 Deformation pattern for two plates. The first plate of contact and the plate below

If the striking ship has a bulbous bow, first a conventional ship without bulb is considered and all the plates in contact with the bow are found. If both the bow and the bulb touch the same plate, only the largest deflection is considered.

4. CONCLUSIONS

The presentation is part of a procedure which analyses ships collisions, addressing to all types of ships and damage scenarios.

The present theoretical model is based on the principle of splitting the collision problem into an external and an internal analysis. The method based on the super-element method, where the ship’s structure is separated into its structural elements like plates, beams, or plate intersections like X and T elements is a simplified but rational model for determining the internal mechanics.

An example of super element can be described as: the bow strikes between two transverse frames, first the side plating will deflect and later will fracture. After a certain penetration, the bow hits some deep stiffeners, which will deflect as beams. Later on the bow will come into contact with transverse bulkheads or frames. These intersections are modelled as T or X elements.

The use of super-element solution calls for adaptive or successive discretisation. By summing up the crushing force of each super-element, it’s possible to determine the total contact load between the two involved vessels and the total amount of absorbed energy.

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