CONSTANTA MARITIME UNIVERSITY
Doctoral School: Mechanical Engineering and Mechatronics

EPITOME PHD THESIS

SAFETY INCREASE CONTRIBUTIONS IN CONTAINER SHIP'S OPERATION IN CASE OF EXPLOSION AND GROUNDING MARITIME ACCIDENTS

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INTRODUCTION

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1. **Current aspects of the evolution of maritime transport and the importance of containerized maritime transport**

The development of the world economy has been based throughout all its history on transport, maritime transport being the most important link, both through the way in which it has managed to connect all the remote regions of the world, and by continually increasing the capacity and diversity of goods transported

The actuality of the theme addressed in the thesis derives from the analysis of the container ship exploitation from the safety point of view, a sector that does not have an equally long tradition compared to the other branches of maritime transport.

Containerisation means, for example, 1.72 billion tonnes of freight carried by container ships in 2016, continuing a trend that began spectacularly in the 2000s, and with regard to the transport capacity of this type of ship, after a historic maximum 1.68 million TEUs for ships delivered in 2015, it still reached 904 thousand TEUs in 2016, according to statistics. [1][3]

An important feature for the last years is the increase in the individual ship load capacity, measured by container ship economies of scale.

2. **Container vessel accidents and the need to assess the safety of their operation**

Motivating the choice of the theme for the thesis consists in the need to know the issues that affect the operational safety of the container ships and the research of the effects that the implementation of some measures may have, in preserving the structural resistance of the container ship.

There is a direct relationship between the number of accidents and the degree of maritime transport safety and EMSA's[1] annual report shows for the year 2016, 1484 ships involved in major accidents or maritime incidents, of which 33% were general cargo ships, 17% container ship and 16% bulk carrier ships to list first places in a generic ranking. [6]

The **goal** of the thesis is to assess the risks associated with container ships and to find solutions and specific measures that can be taken to increase the safety of container ships.

The objectives of the thesis are:

- highlight technical issues, current theoretical and practical approaches to the safety of container ships,
- identify factors that may lead to the loss of their operational capacity as a result of accidents caused by explosions and grounding,
- to develop specific measures that can be taken in the operation of container ships, in order to avoid certain critical situations, taking into account the risk factors involved in this segment of maritime transport.

The grounding of the container ships presents some specific elements, highlighted in the present paper, and may affect the structural strength of the ship introducing bending moments or additional shearing forces, but also the occurrence of cracks in the bottom plates, emphazing the effects of fatigue or stressing certain components of structure beyond the ultimate limit.

The computerized simulations of grounding-related phenomena are the way in which measures can be developed for those interested in enhancing the operational safety of the container ships, which is subject to various demands in the resilience structure, and a set of proposals for specific measures has been developed in this thesis.

Using computational tools such as the OCTOPUS program or Finite Element Method (FEM), are analysed for the purpose of the research:

[1] EMSA – European Maritime Safety Agency

- the study of ship oscillations and how to avoid dangerous phenomena such as parametric roll, surf riding and broaching-to;
- studying strains in the ship's strength structure in grounding of the ship, using the NX / Siemens software suite;
- analysis of how to initiate and develop cracks in the bottom panel or bilge plating area as a result of a grounding of the ship, using the ABAQUS program;

Another aspect addressed in the thesis is to identify the possible risks associated with fires and explosions that may occur on board container ships and the measures that can be taken to eliminate or mitigate these risks, but also measures to mitigate the consequences for ship, crew or cargo, in maritime accidents caused by fire or explosion.

Since the on-board security systems of the container ships have not kept up with the size of the ships and the number of containers that can be transported, there is increasing concern about the crew's ability to extinguish a fire at such a vessel.

In particular, the measures associated with the fire or explosion hazard on board container ships refer to:

- preventive measures in legislation, company management or equipment for the detection or monitoring of goods during transport at sea
- measures to improve procedures for dangerous goods or the use of fire prevention and fire-fighting equipment
- fire control measures and limitation of damage caused by explosion and introducing and using more efficient equipment and devices.

In the thesis, the impact of a fire (whether or not generated by an explosion) on board a container ship in terms of developed temperatures, has been assessed on the structure of the sea container, which can affect the strength of the entire container stack on deck.

An assessment of the temperature resistance of the container was simulated by the FEM using the Abaqus program to confirm research into how explosions and fires in maritime accidents can have catastrophic consequences for the ship and the environment, and drawing conclusions that may be the basis for future measures to combat these consequences.

Keywords: ship's oscillations, containership's grounding, fire and explosion on board containerships, dangerous goods transport.

CHAPTER 1. STAGE OF KNOWLEDGE IN THE FIELD OF CONTAINER SHIP'S SAFETY

Over the past 40 years, any limit set as the maximum size of the container ship, was shortly overtaken, the economies of scale remaining the crucial factor in increasing the load capacity of the vessel.

The classification societies establish, from the design stage, the requirements that the ship must meet in terms of structural strength, during the entire lifetime under normal load conditions. [11]

In Fig. 1.1 it can be seen how the ship is subject to head arches as a result of excessive buoyancy in the mid-section and lack of this buoyancy in the bow and aft extremities, at the passage of the ship over the wave crest, in which case, the bending moment is conventionally positive and known as *hogging*.

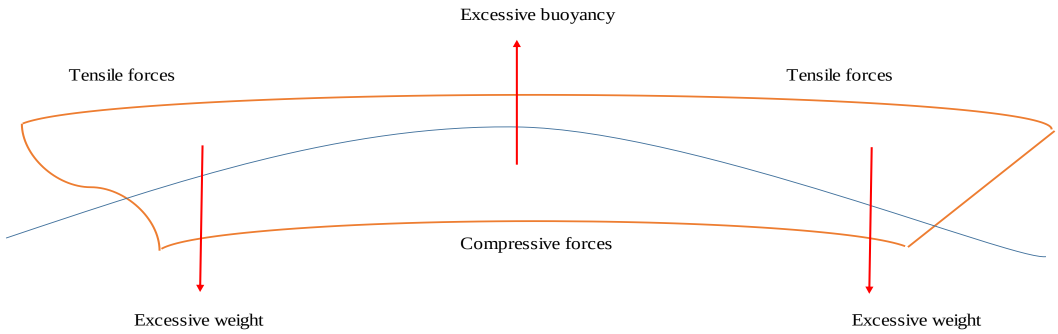

Fig. 1.1 – Ship's hogging due to the waves

Bending moment is negative - *sagging* - when the bow and stern of the ship have excessive buoyancy and the midship is affected by the weight of the cargo, and manifestly when the ship passes over the wave trough.

Any design or construction error that ignores the occurrence of a stress concentration, can lead to cracks (due to wear) sooner or later. A good example in this respect is the container ship MOL Comfort (8000 TEU - 316 m length), which suffered a fracture in the midship area, while passing the Indian Ocean from Singapore to Jeddah (Saudi Arabia) on June 17, 2013.

A causal link between the risk factors, most encountered in the operation of the container ships and the casualties of these ships can be structured, according to statistics. As highlighted in the thesis, some of the most common maritime accident situations result in variable damage to the structure of the ship.

1.5 **Phenomena associated with the grounding of container ships**

In the ship's grounding accidents, the current approaches go from the two grounding models, defined according to the response of the ship and the structural elements affected:

• soft grounding, when the forces induced by contact with the bottom of the sea affect the structure through the vertical component, until the vessel is stopped,

• powered grounding produced at relatively high speed when induced forces affect the structure of the ship in particular through the horizontal component.

Depending on the seabed typology, the ship may follow a sliding process (sand and mud sea-bed) or, when there are protrusions of the bottom, the ship's plates may be deformed by raking.

It is worth mentioning that the deformation of the bottom plates of the ship can also be carried out after another pattern, that of the fracture from the reinforcements and its folds before the indenter (rock) – *concertina* model. [28]

This situation is encountered when the radius of the rock that penetrates the ship's hull is large (the rock is uncut) and the penetration takes place in the initial vertical stage, followed by a horizontal motion.

1.6 Technical aspects of the evolution and consequences of explosions and fires on board container ships

The accidents suffered by container ships in recent years have shown the importance of limiting the fire, otherwise its development makes it impossible to fight fire, especially when mixing various dangerous goods on board. The first structure that can collapse under the action of fire induced heat is the stack of containers, especially if the fire comprises a container at the base. The collapse of the stack usually leads to fire and goods in containers whose integrity is destroyed and the separation of dangerous goods required by the IMDG Code can be compromised.

Real scale tests have been rare over time, the most well-known being carried out in 1977 by the US Department of Transportation [37].

The conclusion of the research carried out so far is that the resistance of the steel under the influence of high temperatures is strongly affected and the parameters that actually vary with the temperature are the elastic modulus of material and the yield limit.

- Elastic modulus at 600^0 C is reduced by 70%,
- Yield limit at 600^0 C is reduced by about 50%.

Considering the danger that fires or explosions may pose to the integrity of the ship, the safety concerns have materialized through specific regulations for fire prevention and firefighting on board ships such as SOLAS Convention, IMDG Code, FSS Code or FSA Code.

CHAPTER 2. DESCRIPTION OF THE RESEARCHES CARRIED OUT FOR THE ASSESSMENT OF RISKS ASSOCIATED WITH THE CONTAINER SHIPS EXPLOITATION

2.1 **Study of the containership's oscillations in extreme conditions**

Container ships, especially those of the latest generation, have a specific hull form, with thin and elongated shapes at the bow and stern and the rectangular main deck over almost the entire length, to allow the loading of as many units as possible on the deck. The number of containers that can be loaded on the deck is at least equal to the one loaded in the ship's stores. [52]

The particular aspect that the current thesis addresses is related to the dangerous oscillatory phenomena the container ships can encounter, such as the parametric roll or the oscillations of the ship in the following waves, which have been studied only in recent years, with the occurrence reporting of these phenomena in the operation of such a vessels.

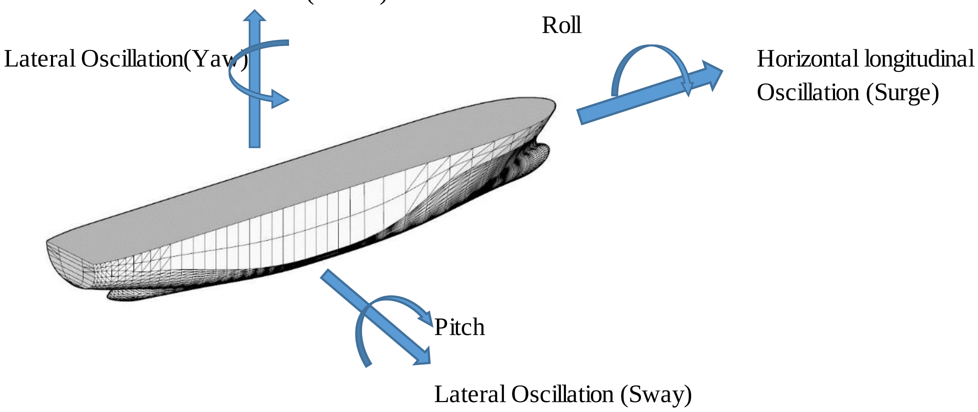

Fig. 2.1 Oscillatory motions of the ship - 6 degrees of freedom

The complete study of ship oscillations on all 6 degrees of freedom is very difficult and therefore research is generally simplified in coupled motions, as can be seen in Fig. 2.1.

The occurrence and develop of the parametric roll is caused by the change of the ship stability in encountered waves with a well-defined frequency - twice the natural transverse oscillation frequency of the ship. The theoretical study is based on the phenomenon of resonance in wave oscillations. [61]

Transverse or roll oscillations are considered periodic rotation motions, that the ship considered a rigid body, performs around the central inertial longitudinal axis of its mass.

The differential equation of the oscillations amortized on still water is obtained from the equilibrium condition at time t i.e. the sum of moments M acting on the vessel is 0:

$$\sum \vec{M} = 0 \quad (2.1)$$

Or:

$$(I_x + A_x)\ddot{\phi} + B_x\dot{\phi} + \Delta\overline{GM}\phi = 0 \quad (2.3)$$

Representing the differential equation of motion, which is a second order homogeneous equation with constant coefficients

As has been shown previously, *GM* (metacentric height) varies over time at waves passing (very close to a sinusoid), so:

$$GM(t) = GM_m + GM_a cos(\omega_e t) \quad (2.4)$$

Where ϖ_e is encountered waves frequency, GM_m is medium metacentric height and GM_a is the amplitude of metacentric height.

By rewriting the equation and substituting terms, we can obtain the final form of the transversal oscillation equation, which is a Mathieu equation:

$$\frac{d^2x}{d\tau^2} + \left(p + q\cos(\tau)\right) \cdot x = 0 \quad (2.13)$$

Where:

$$p = \left(\overline{\omega}_m^2 - \mu^2\right);\ q = \overline{\omega}_a^2 \quad (2.14)$$

Mathieu's equation is a linear differential equation with variable coefficients, whose solutions cannot be expressed with elementary functions.

As is well known, the Mathieu equation can have two types of solutions, some of which have been interpreted by some researchers to develop new stability criteria as requested by the IMO [62]:

- Bounded or stable,
- Unbounded or unstable, depending on the combination of coefficients p and q.

Since q shows the level of *GM* variation in waves, by the square of the frequency ratio according to equations (2.8), (2.11), (2.14), this parameter can be considered as the amplitude of the parametric excitation.

The first instability zone, for $p = 0.25$ and frequency ratio *2,* means that the area corresponds to a double excitation frequency relative to the natural ship's roll and this is the main parametric resonance zone.

2.2 **Analysis of ship's hull behaviour in case of grounding**

While preserving the overall design framework of this type of maritime accident, a division of the ship's grounding into two major categories, given the nature of the seabed, which has direct consequences on the results, would be:

- *Soft* bottom grounding – sand, mud, small gravel – which produces relatively little damage to the shell of the ship's hull but, very importantly, can induce bending and shearing moments, which may lead to weakening or fracture to some of the ship's framing elements;
- *Hard* bottom grounding – rocks – more or less homogeneous, which causes the breaking of hull plates and the destruction or weakening of the framing members and which can also induce shear moments, in addition to the flooding of the ship's compartments.

There is a relatively common approach to the mechanics of grounding over the last twenty years. Starting from the interaction of the soil (seabed) on the ship's hull, Pedersen made in 1995 a separation of the phenomena that took place during the grounding, in the external mechanics (dynamics) and internal mechanics.

The external mechanics of the accident refers to the ship's hull motions generated by the grounding and the hydrodynamic pressures acting on it, and the internal mechanics assess the response of the ship's shell platings and structure during the grounding.

Simplified analysis methods use theoretical formulations and take into account the processes that occur during structural damage. These methods are working tools for designers and give insight into local and global processes that take place, ensuring their prediction with a high degree of accuracy. Several patterns have been studied that relate to the behaviour of the bottom plate and ship's framing elements in boundary situations, such as: deforming and tearing the plates, cutting, bending or folding, this type of assessment being used in recent years for the analysis of naval accidents by researchers (Wang et al).[83]

If the structure is rigid-plastic, such as the container ship, no elastic energy is stored and the power of the external loads is dissipated by plastic deformations, ruptures or friction effects on the surface of the structure, so according to the method validated by Simonsen:[84]

$$F_H V = \dot{E}_p + \dot{E}_r + \dot{E}_f = F_P V + \int p\mu V_{rel}\, dS \qquad (2.24)$$

Where,

F_H horizontal force of structure resistance in *V* direction;
V relative speed between ship and rock;
$\dot{E}_p$ rate of plastic energy dissipation;
$\dot{E}_r$ rate of energy dissipation in the rupture area;
$\dot{E}_f$ rate of energy dissipation by frictional forces on the surface of the structure;
F_P plastic resistance that includes both plasticity and rupture;
μ Coulomb friction coefficient;
p normal rock pressure given by the plate element *dS;*
V_{rel} relative speed between the rock and the plate element.

To study the damage caused by the penetration of the ship's body over a certain length and with a certain depth of penetration, simplified formulas proposed by Zang, Samuelides et all. [79] [85]

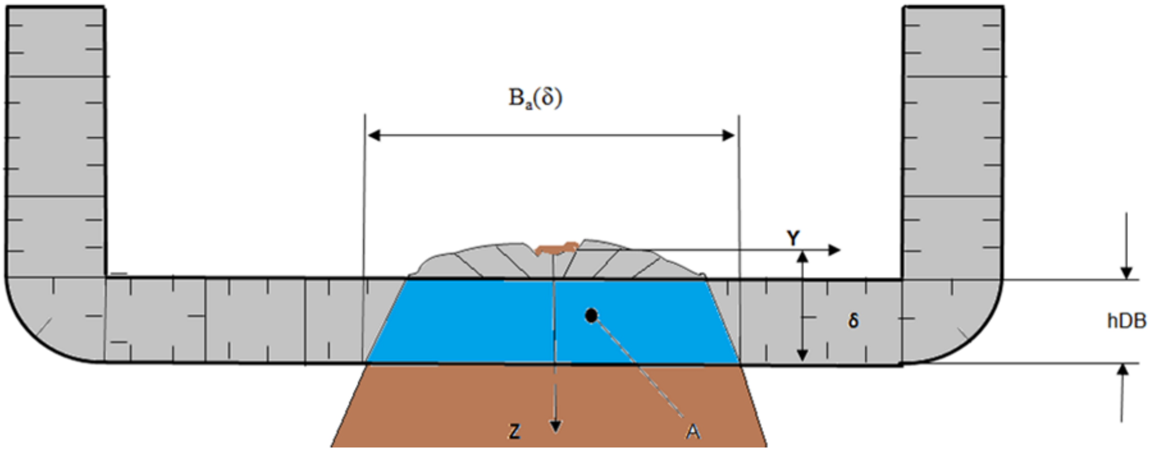

Fig. 2.22 Transverse section of grounded ship on rock

The contact pressure between the ship and the rock at *a* depth of penetration δ can be obtained with the expression:

$$p(a, \delta, h_{DB}) = \frac{F_H}{A} \qquad (2.26)$$

Where F_H is the horizontal force of grounding and *A* is the contact area that depends on the depth of penetration:

$$A(a, \delta, h_{DB}) = \begin{cases} \frac{4}{3}\sqrt{a}\,\delta^{\left(\frac{3}{2}\right)} & pentru\ \delta \le h_{DB} \\ \frac{4}{3}\sqrt{a}\left[\delta^{\left(\frac{3}{2}\right)} - (\delta - h_{DB})^{\left(\frac{3}{2}\right)}\right] & pentru\ \delta > h_{DB} \end{cases} \qquad (2.27)$$

The analysis of internal mechanics by finite element method (FEM) is constantly developed, due to its ease of application in relation to the theoretical models and the amount of information it is working with. There are already packages of programs that analyse the strength of plates or framing elements in the case of a wide range of plastic deformations, based on structural damage models. Such a program is NASTRAN used by NX Siemens to simulate and analyse the results of a failure, presented in the next chapter.

CHAPTER 3. OWN CONTRIBUTIONS TO THE DEVELOPMENT OF METHODS OF ASSESSING THE SAFETY OF CONTAINERSHIP IN CRITICAL SITUATIONS

3.1 **Analysis of container ship's behaviour in critical situations using OCTOPUS program**

The OCTOPUS program is one of the programs that validates the theoretical analysis of the ship's oscillatory behaviour in waves. The ship's response to dynamic behaviour may serve as a criterion for static or dynamic stability conditions of the ship by taking precautionary measures prior to voyage, but also as a subject of analysis for the effects this behaviour exerts on the structure, and ship's cargo.

The main operational parameters, represented by the speed and track of the ship, as highlighted in the previous chapter, have a strong effect on the ship's response to a certain state of the sea. To study the motions of the ship due to waves, is used the transfer function, operator called "amplitude response operator"- RAO. [92]

RAO has values based on the movement it describes and can be linear, in *m*, for the translational motions (surge, sway or heave) or angular, in *degrees*, for the rotation (roll, pitch, yaw). To exemplify the ship's behaviour analysis using the OCTOPUS program, a Panamax vessel was selected with the following characteristics:

L_{WL} = 285 m; B = 32,2 m; T_{max} = 12,5 m; C_B = 0.691; GM = 3m;

Case 1 M_1 = 82760 to (Loading condition 1)

Case 2 M_2 = 42760 to (Loading conditions 2 - ballast)

The voyage chosen to study the behaviour of the ship was on the route Hamburg – Baltimore, through North Atlantic, in two loading conditions.

The main response, which is of maximum interest for the dynamic stability of the ship, is represented in Fig. 3.5 and shows the amplitude of the roll for different wave angles at 19.2 Nd in the two ship loading conditions, left for the loaded ship and right for the ship in the ballast.

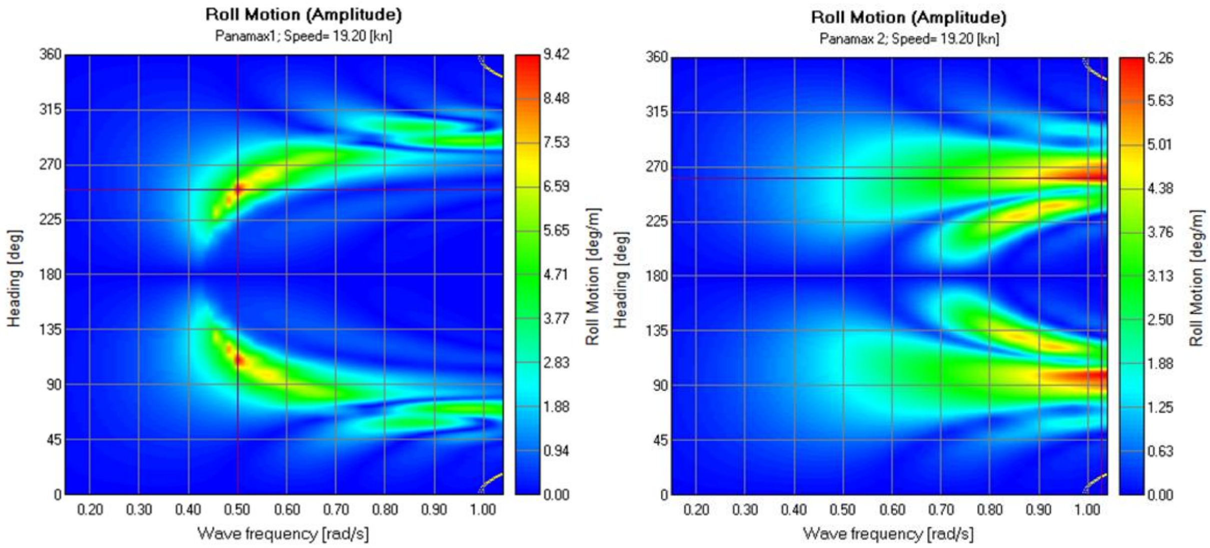

Fig. 3.5 Roll diagram for speed of 19,2 for *Case 1* – left and *Case 2* – right (RAO)

The maximum values can be reached in the case of a beam waves (slightly towards the bow) for both sides. The maximum roll angle the ship can reach are easily viewed in the comparative diagram for different encountered wave's angles, as shown in Fig. 3.6.

Short-term sea statistics are further reproduced for different vessel responses and the Most Probable Extreme (MPE) chosen operator.

The polar chart for the ship's roll movements, shown in Fig. 3.6, is the most accurate the maximums that the ship can develop, depending on the state of the sea, in addition to the parameters previously presented.

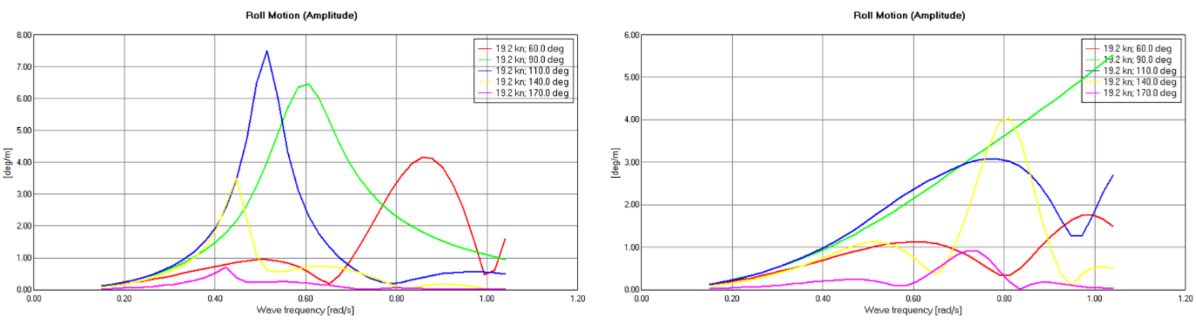

Fig. 3.6 Comparative roll diagram for different wave directions

The chart model is also used by other programs on board ships (ex Arrow) and complies with the requirements of the 2008 Stability Code. [94]

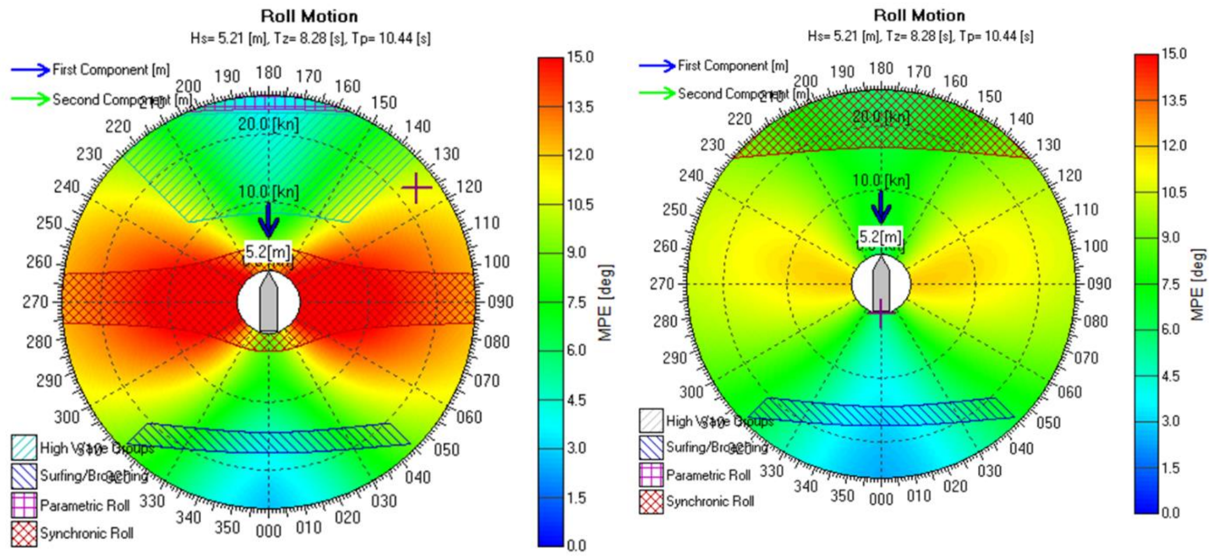

Fig. 3.6 Polar diagram for roll motion Case 1 - left and Case 2 - right

As can be seen in Fig.3.6, polar diagrams clearly define areas where dangerous phenomena may occur for loss of stability. The occurrence of dangerous dangerous phenomena can be avoided by altering certain parameters listed above - ship speed and ship's course - but also by modifying metacentric height *GM* by ballasting or de-ballasting the ship (when possible). A model to avoid dangerous phenomena was proposed by using the OCTOPUS program and studying the polar chart as a basis for the decision to change the speed or the ship's way in bad weather conditions. [95]

In conclusion, we can assert that the introduction of the OCTOPUS program in the stability assessment procedure can be considered a good measure of safety to avoid the dangerous oscillations of the containe ship, oscillations which can lead to the loss of containers, but also the subjecting of the vessel's structural resistance to considerable efforts.

3.2 **Using the finite element method in assessing the structural strength of the container ship in case of grounding**

In order to assess the structural resistance of the container ship in grounding, the finite element method was chosen by simulating the loads and analysing the structural responses of the ship framing elements. [97]

One of the most simple ways to evaluate material deformations is to check the stresses (e.g. von Mises, normal or tangential) and compare them to the boundary - yielding or fracture condition, and this has been highlighted below.

The chosen model was a Panamax vessel (230 m), and similar plans were made to those made by NOWA Design Office in Szczecin Poland for the Hamburg shipyard in Germany, the ship being schematically represented in Fig.3.16.

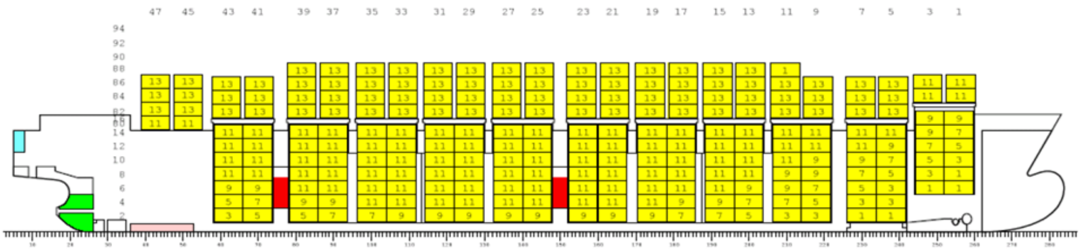

Fig. 3.16 Container ship – side view

I. For the proposed study, I was represented the hull of a ship that has grounded on a soft bottom (sand, mud, mud) over its entire breadth. For the first evaluation, an area of the double bottom area was chosen, and for the second, one of the spine area, both of which studied the tensions that occurred in case of failure.

After finishing the meshing, the first study area was embedded and then oblique pressure applied to the CSYS Global direction using the following pressure values: P_x = -500 MPa, P_y = 400 MPa and Pz = 600 MPa.

In order to study the behaviour of the first area under pressure, the behaviour of the material was observed in several steps (depending on time), and for each type of stresses, 6 steps were chosen.

The variance of von Mises stress is represented in Appendix 2 Fig. 5, and the maximum and minimum values according to Fig. 3.24 are

$\sigma_{v\,min}$ = 0 MPa and $\sigma_{v\,max}$ = 1539,083 MPa.

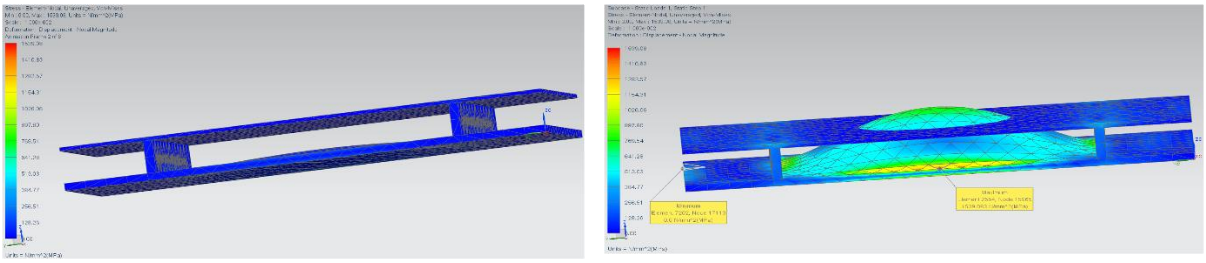

Fig. 3.24 Step 1 – left and step 5 – right in von Mises stress variation

II. The second stress test induced by the ship's grounding was performed for the behaviour of the ship's hull in the bilge area, bounded by frames 123-133 (Figure 3.27 – area of study II)

As a result of the mesh, 8582 elements and 16834 nodes, the final results being represented in Fig. 3.28 (shear stress) and Fig. 3.29 (von Mises stress), and the extreme values are: shear stress τ_{max} = 1187,34 MPa and τ_{min} = 0 MPa,

von Mises stress $\sigma_{v\,max}$ = 1434,46 MPa and $\sigma_{v\,min}$ = 4,23 MPa

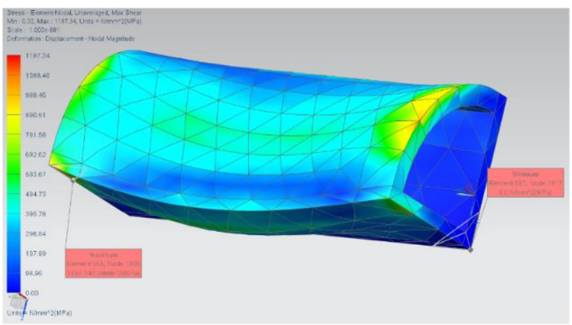

Fig. 3.28 Shear stress area II

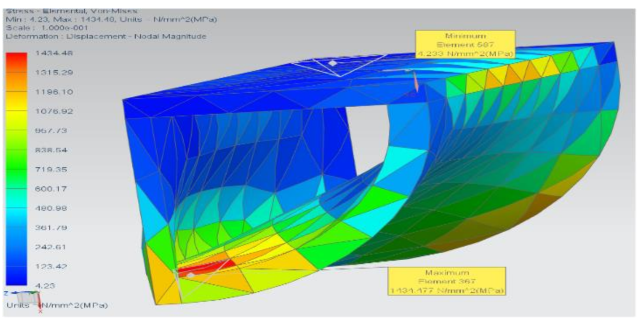

Fig. 3.29 von Mises stress area II

Such research are useful for port authorities, who are encouraged to carry out such analyses to assess limit situations. Such a study was carried out by the Panama Canal Authority, which simulated the grounding of a container ship in the area of a Canal Bridge, and proposed measures on the slope in the area close to the foot of the bridge to be avoided a collision with it. [104]

For the FEM study of cracks in the bottom of the grounded ship was used the Abaqus / CAE program created by Dassault Systemes, by modelling a 1m x 0.5m portion (sample) of a container ship, with a capacity of 13.300 TEU.

The applied simulation will refer to the crack of the table its entire thickness (0.02m) in the bottom area of the ship. [106]

It was chosen to simulate a circular hole in the area of the double bottom of the ship and analysed with SIMULIA, part of the Abaqus Unified FEA program of Dassault Systeme and the scenario involves simulation by FEM of the occurrence and propagation in the area of the bottom plate of the crack at the edge of a circular shape hole which may be the consequence of a soft grounding of the container ship.

The crack propagation pattern near the hole confirms the theory and is shown in Fig. 3.37, and in Fig. 3.38 it can be seen that the maximum normal stresses are concentrated at the tip of the crack.

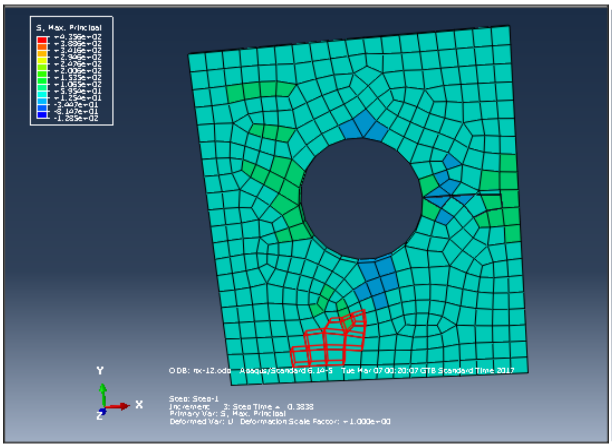

Fig. 3.37 Normal stresses σ_{max} before deformation (left)

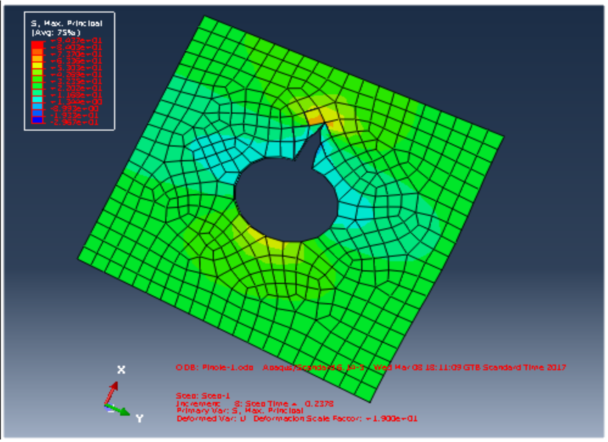

Fig. 3.38 Normal stresses σ_{max} after deformation (right)

It has been studied through the FEM, the crack propagation mode, if the hole from which propagation begins is elliptical, closer to the actual consequences of such damage to the bottom plates of the ship. When the crack is positioned in the extension of the long axis of the ellipse, according to the pattern used at the circular hole, the maximum values of von Mises (σ_v) stress are as expected at the crack tip and the opposite end of the large axis of the ellipse, similar to the stress σ_{11} (Fig. 3.41).

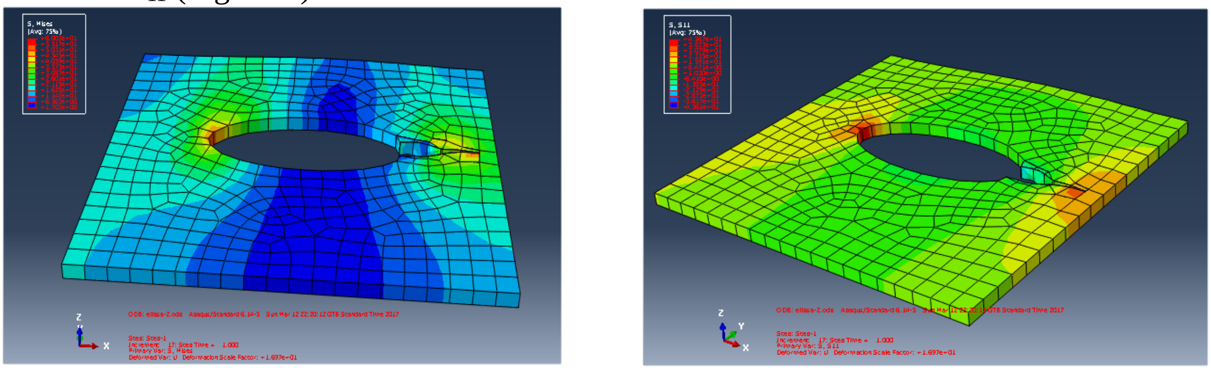

Fig. 3.41 Von Mises stress (left) and σ_{11} (right) crack in long axis of the ellipse

We can conclude that if there is a crack due to an elliptical hole in the bottom of the ship, both crack propagation and tearing occur faster and with less effort if the crack is in the extension of the axis large hole, than in the case of the crack positioned in the elongation of the small axis of the elliptical hole.

The paper highlights the fact that the FEM can be used successfully in naval fracture mechanics not only for the design phase but also for later phases of ship operation in order to develop safety measures based on a deep knowledge of all processes which is carried out in the field of naval accidents.

3.3 **Comparative study on the assessment of sea container strength at high temperature**

The shipping container is a very efficient way of transporting a wide variety of goods, which allows easy and fast handling and, through its regular specific form, a very good stacking as both efficient and durable under transport conditions on the ship.

The design of the container requires the use of appropriate materials and rigorous tests carried out by classification societies in the production phase. However, there may be situations when resistance limits can be overcome in unforeseen circumstances and whose impact cannot be accurately defined, such as fire.

The variety of goods that can be containerized makes it unnecessary to test through the tests, the effects of flames generated by various materials on the stack of containers.

When the shipping containers are stacked and the total weight of the stack, the height of which can reach 9-12 rows, directly affects a container at the base, this weight can reach 200,000 kg (9 rows mean 8 overlapping x 24 000 kg = 192 000 kg above the base), and the weight used in container standardization tests. [109]

The present simulation shows the mode of showing stresses within the corner posts of the sea container at the base of a stack when changing the temperature of the material as explained above.

The conditions for reaching and exceeding resistance limits can be met in the case of the development of temperatures above 500^0 C, which is common in the case of fires, which directly affect a container.

The simulation has been simplified by loading with a force corresponding to the weight of the stack, acting as a compressive force in the vertical corner frame parts of the container.

The steel used in simulation has the characteristics according to the ISO standard [108]:

Steel type JIS: SPA-H OR EQUIVALENT,
Density 7850 kg/m^3,
Dimensions: 60 mm x 60 mm x 3 mm,
YP= 35 kg/mm^2,
TS= 49 kg/mm^2,
E= 22%.
Poisson ratio $\nu = 0{,}33$.

The simulation showed that, in the case of material heating, the yield limit and strength of steel change as described in the previous chapter so that the von Mises values change in the corner post, depending on the temperature, for the same load at the end of the stand.

Thus, if at ambient temperature (20° C), as can be seen in Fig. 3.48, they reach a maximum of 1.44×10^2 N / mm^2, with temperature changes due to flames caused by a fire at values reaching 600^0 C in the material, the stresses reach the maximum value of $3{,}143 \times 10^2$ N / mm^2 (see Figure 3.49).

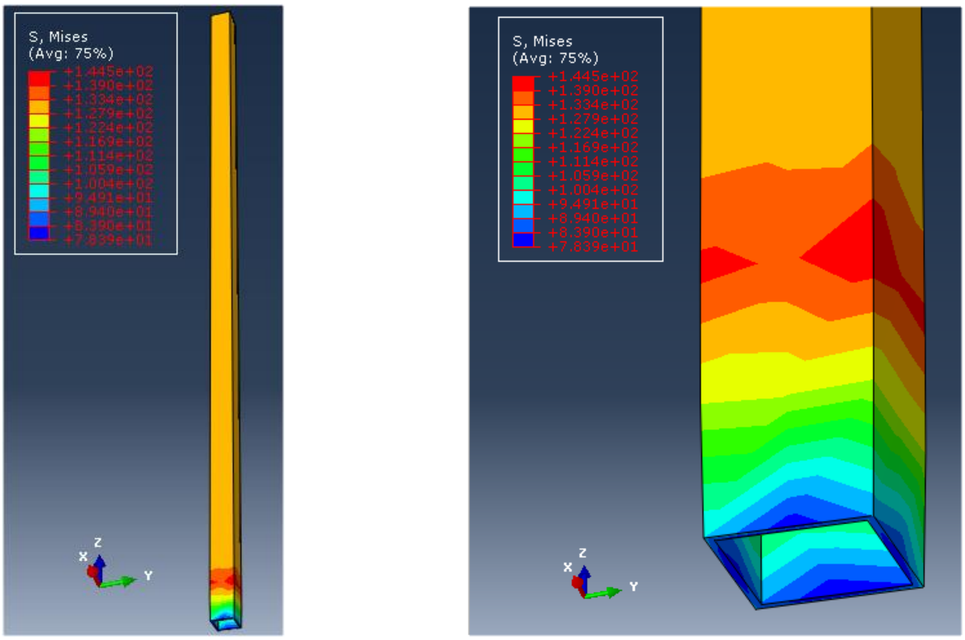

Fig. 3.48 Corner post at ambient temperature (20^0 C)

If the temperature rises, the phenomenon of weakening of the steel strength is amplified, with von Mises values reaching 5.82 x 10^2 N / mm^2 at 800^0 C, obviously exceeding the steel yield point, even if the compressive force remains constant.

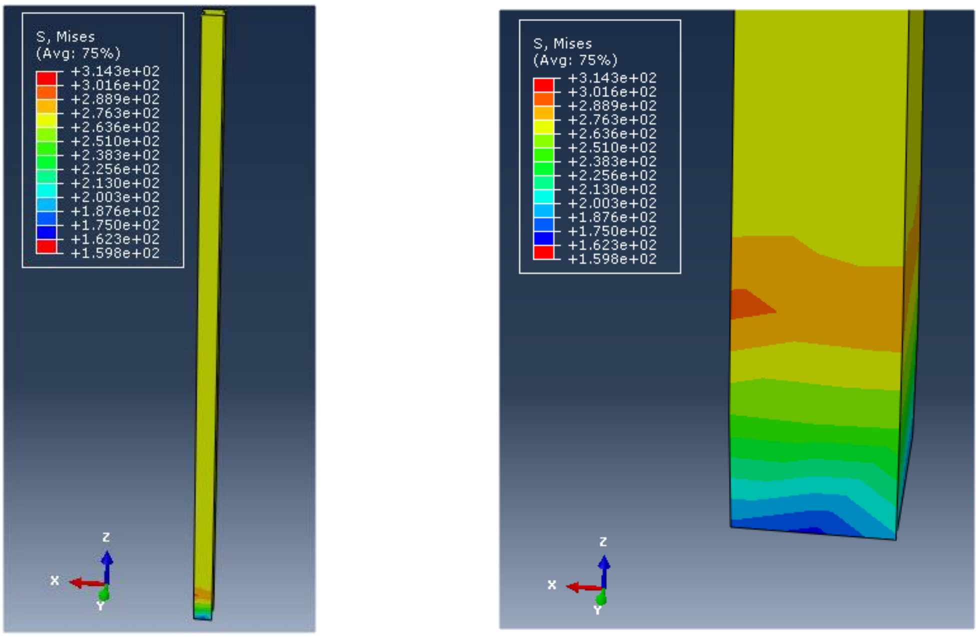

Fig. 3.49 Corner post at high temperature (600^0 C)

The conclusion that can be drawn is that the strength of the container is affected by the increase of the temperature in case of fire, which can lead, under certain conditions, to the collapse of the entire stack of containers, thus causing the generalization of the fire.

Tests carried out in recent years, and the analysis of accidents resulting in fires or explosions on board container ships, undoubtedly suggest that the *first and standing measure is to cool the area affected by the fire*.

CHAPTER 4. PROPOSED MEASURES TO INCREASE THE SAFETY OF THE CONTAINER SHIPS

The interpretation of the data and phenomena that have been highlighted for the container ship highlights proposals that can become measures to improve safety for marine casualties of grounding ships, such as:

• introduction of ship manoeuvring speeds specific in certain areas with high risk of grounding;

• performing complex simulations in different situations for each ship and brought to the attention of the captains so that critical decisions taken at critical times minimize the consequences of a grounding;

• increasing the slope of the navigable channel through proper dredging or hydrographic planning in order to avoid powered grounding that could lead to the stack of the fairway;

• the arrangement of hydro-technical constructions following comparative simulations between the effects of a hard grounding of a ship's on soft bottom and the effects of a collision at the same speed with a quay fitting, which can be provided with fenders or other means of damping;

Actions that can be taken to avoid the effects of fires and explosions on board container ships can be grouped according by two major objectives:

• preventing the occurrence of fires and explosions on board container ships,

• fire control and containment of the affected area, if the fire has already developed, whether or not associated with an explosion.

All assessments indicate that it is impossible to completely eliminate the risk of fire and explosion on board container ship by a applicable technical or procedural solution, but risk awareness and sharing experience gained from accidents that have taken place and measures taken individually, and have proven to be effective, can bring the level of risk to values that this transport sector deserves.

CONCLUSIONS

The thesis presents three critical aspects of container ship's operation, which may lead to the weakening of the structural strength of the ship, as demonstrated by the way in which some maritime accidents have been carried out, whose investigation reports have been studied and presented.

These refer to:

a) The way the container ship is affected in the rough sea, by studying oscillations on waves using the OCTOPUS program and measures that can be taken to avoid dangerous oscillatory phenomena,

b) Specific conditions in which the container ship may suffer a grounding and assess how the structure of the vessel is affected in such an event,

c) The impact of high temperatures in the event of an explosion on board container ship, both on the structure of the ship and the containers, the damage of which could lead to the collapse of the stack and the generalization of the fire with devastating effects for the ship and the crew.

The critical issues above were treated in steps during the study, by studying the current context and the theoretical elements underlying the phenomena that occur in the event of an accident, analysing some representative accidents, simulating situations in case studies and proposing measures to improve safety.

Own contributions

In the present thesis, the following studies, which constitute own contributions to the research of the safety of the container ships:

1. Comparative study of the dynamic response of the Panamax vessel under two loading conditions, on the route Hamburg – Baltimore, using the OCTOPUS Program. It has been shown how the program is used to make a decision on the stability of the container ship in bad weather conditions to avoid dangerous phenomena such as parameter roll or broaching to.

2. The FEM analysis of the deformation of the bottom tables of a container ship, in the case of a soft grounding, by studying the variation of normal, shear and von Mises stresses above the yield limit, in the sample selected in the bottom and bilge area of a vessel, using the NX program.

4. The FEM analysis of the way the cracks develop around a circular or elliptical hole in bottom table of a ship, by highlighting the variance of normal tensions and von Mises up to total sample fracture, using the Abaqus program.

5. Study on the strength of the shipping container stacked on board the container ship at high temperature due an explosion or fire, through the FEM using the Abaqus program.

6. Analyse processes in the flow of dangerous goods during container shipping to highlight the risks and develop measures to control the explosion risk on board the container ship.

Given the high degree of coverage of the type of ships operated by Romanian seafarers as well as the multitude of terminals serving the port of Constanta, the interest in increasing the safety specific to certain ships is fully justified and the research areas proposed, with a view to deepening the knowledge of maritime accidents are:

• The analysis of the factors affecting the safety of the oil tanker or LNG in the event of a maritime accident involving fire or explosion,

• Research into the behaviour of bulk or oil tankers in case of grounding,

• Research into ship behaviour in the event of a collision.

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