CONSTANTA MARITIME UNIVERSITY
Doctoral School: Mechanical Engineering and Mechatronics

EPITOME PHD THESIS

CONTRIBUTIONS TO THE STUDY OF THE INTERACTION BETWEEN MOTION OF FREE FLUID SURFACES AND SHIP MOTIONS IN MARINE WAVE ENVIRONMENT FOR BULK CARRIERS

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CONTENT

Thesis necessity and opportunity

This scientific research presents very important aspects of the liquefying process of bulk cargo carried on board merchant ship which may lead to loss of the intact stability of bulk carriers, with serious consequences for the safety of ships and their crew.[146]

Besides the practical methods for evaluation on board ships of the possible liquefying state of bulk cargo, recommended by the International Maritime Codes for cargo transportation, regulating carriage of cargo, this thesis presents a possible method of determining the listing moment of the ship due to cargo liquefying, and also the possibility of cargo shifting during the liquefying process.[147][149]

In the last years, an increased number of ships lost their intact stability due to cargo liquefying. Some of them developed large listing angles while others, unfortunately, capsized.[45][144][151][152]

In the field of analysing the „sloshing" phenomenon, there are many papers researching this subject especially in the maritime field. One of the main concerns generated by this phenomenon is the impulse type loading given by the large volumes of liquid flowing from the holds/tanks of the ships over the structure of the ship which may lead to structural deformations over their walls. Such structural deformations due to „sloshing" have been reported especially in case of oil tankers and LNGs. [19][25][26] [36][66][67][75][149][152][153]

In the 1950-1960's experimental studies and analytical ones have been pursued for space ships of the rocket type, and in the 1970-1980's this issue was addressed in the case of LNGs. Starting with 1980 once the finite elements analysis methods arose, these phenomena started to be studied by researchers.

This thesis is meant to continue this trend of involving the finite elements analysis in this damaging phenomenon analysis over the structure of a bulk carrier.

Thesis objectives

From the objectives point of view the thesis aims:

- To present the actual state regarding maritime transportation of bulk cargo.
- Simulation of the dynamic behavior of a type bulk carrier vessels under the influence of external factors marine environment.
- To generate the geometry of cargo holds on a bulk carrier using SolidWorks.
- To simulate the behaviour of five cargo holds using ANSYS and the two previous elements, under different loading scenarios and for different fluids (cargo or sea water).

Organizing the thesis

The PhD Thesis ,,**Contributions to the Study of the Interaction between Motion of Free Fluid Surfaces and Ship Motions in Marine Wave Environment for Bulk Carriers**" is organized as follows: the documentary stage, experimental research, numerical modelling which is also the objective of the thesis, and in order to reach the targeted goals the thesis was structured in 6 chapters, emphasising the value of each stage of the scientific research.

The first part represents approximately one third of the thesis included in two chapters: the first chapter introducing to the reader the subject of the thesis, and then the actual study in the maritime transportation of cargo in bulk, detailing the evolution of maritime transportation of cargo in bulk, the structural and ship building elements for bulk carriers, exploitation characteristics of bulk carriers designated for carrying cargo in bulk and future tendencies in building bulk carriers.

The second part includes experimental research as in numerical simulation of the effect of free liquid surfaces on board – stage 1 – geometrical modelling (CAD) and numerical analysis with ANSYS CFX and stage 2- numerical simulation of the effect of free liquid surfaces on board the ship, resulting in three different scenarios. In establishing the parameters used for the simulation, the fact that during the sloshing phenomenon the bulk carrier's holds are ballasted or loaded at different levels was also considered. Qualitative validation of models and CFD versus Tests on diminished models, and for experimental validation of the modelling technique and of the numerical model, a model tank in 3D was used having the dimensions of: 5x4,5x3m. Numerical simulation was performed by using the ANSYS Fluent. Results of the experimental simulation results revealed that sloshing is a dynamic phenomenon that can be studied using dynamic simulations of CFD ANSYS Fluent package, proving the power of CFD to accurately simulate the evolution of sloshing phenomenon in tanks or cargo holds of the bulk carrier vessel type and deformations of tank and bulk carrier structures, undergone sloshing phenomenon, were recorded using ANSYS and some partial conclusions. Final conclusions are next and also personal contributions and recommendations for future research are part of the last chapter.

Personal contributions are represented by analytical modelling, modal analysis and finite elements analysis applied in the hydrodynamics of the ship in the water environment, when realising a complex model 3D of the ship's bulkheads by modelling with finite volumes with the purpose of emphasising these walls' behaviour when on board the bulk carrier there is a sloshing effect due to free liquid surfaces in the ship's cargo holds and I also performed a complex study regarding the structural answer of transverse bulkheads of the cargo holds due to the impact of free liquid surfaces, and this study represent two thirds of the thesis.

The thesis ends with the studied bibliography.

Numerical Analysis of a Cargo Vessel Motion

A modern ship design procedure can be seen as an iterative process where requirements, regulations and rules including, amongst others, analysis of seakeeping and intact stability criteria issued by the International Maritime

Organization and ship design solutions are compared in order to achieve an optimum solution. The combination of the ever growing population together with high demand for goods and increasing oil prices have resulted in the design of merchant ships that are optimized for minimum resistance and maximum load capacity.

Certainly, prediction of ship motion can be done in many different ways. Testing several full scale ships would unquestionably give the best estimate, but would of course be too costly and practically impossible.

Another way of analysing ship motion is by testing ship models in wave basins. Although a better option than testing full scale ships, it is often time consuming and costly. A third option is the prediction of ship motion by computer simulation. Computer simulations are done with respect to simplified models. These models represent physical reality to a degree that depends on the simplifications and assumptions made.

During the last decades, several unified models describing ship motion due to maneuvering in waves have been developed. A nonlinear unified state-space model for ship manoeuvring and control in seaway, where the unified model is obtained by superimposing a maneuvering and seakeeping model.

The potential and viscous damping terms in the model established by Fossen are presented by a so called state-space approach where instead of using the convolution integral which is used to derive the damping forces in classic theory a linear reduced-order state-space model is used to approximate the damping forces. Thus, achieving the standard representation used in feedback systems.

Regarding the wave excitation forces, they include the Froude-Krylov and diffraction forces (1 order wave loads) as well as the wave drift force (2 order wave loads). Hua and Palmquist describe a time domain ship motion simulation program (SMS) where two mathematical models, a wave induced model and a manoeuvrability model, are incorporated into a unified model.

The unification of the models is obtained by assuming that no interference between the turning motion introduced by ship maneuvers and the velocity potential, diffraction or radiation waves is attained, thus making it possible to superimpose the given models.

The damping forces, in contrast to the method described in Fossen are derived to the time domain through the convolution integral. As to the wave exciting forces, only the Froude-Krylov and diffraction (first and second order wave loads) are included, where the Froude-Krylov force is treated nonlinearly.

Furthermore, Min-Guk and Yonghwan introduced a unified model for ship maneuvering in waves where the interaction between the manoeuvring and seakeeping model is done similar to the unified models presented above. That is, the seakeeping and manoeuvring problems are coupled and solved simultaneously.

The emphasis of the program is on the 2^{nd} order wave drift obtained by using a direct pressure calculation method which is seen as an important factor in the ship trajectory calculations.

The aim of this paper is to determine via numerical methods with Ansys CFX the motion of a Cargo vessel involving modeling the ship seakeeping for 2 DOF.

CAD and Finite Volume Analisys (FVA) Model of the Ship

In order to achieve the goal stated above, the ship under consideration is the one given in the Fig.1 having the following characteristics:

- Length = 290 m
- Breadth = 32 m
- Draught = 11.1 m
- Deadweight = 57.700 t
- Engine type MAN B&W 6S50MC = 8.200 kw
- Thickness of the steel plate = 22 mm
- Steel density = 7800 kg/m^3

The geometry of the ship is developed by using the software SolidWorks 2015 as seen below:

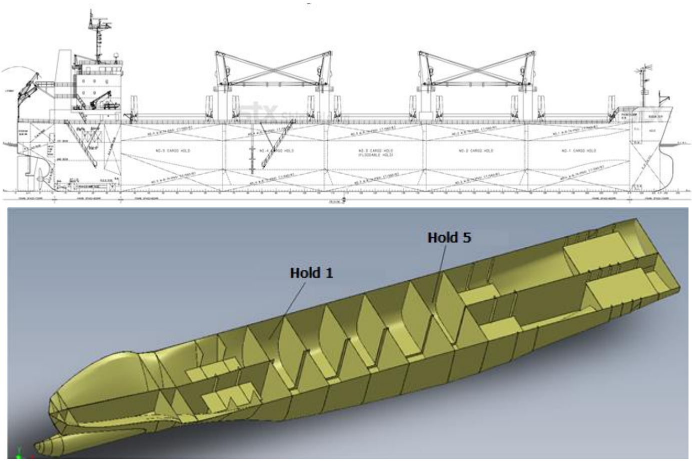


Fig. 1 Cargo vessel under consideration

After the generation of the geometry some geometrical properties are to be automatically calculated:

- Ship mass = 29212771.5516 kg
- Ship body volume = 3745.2271 m^3
- Ship area = 102516.6000 m^2
- Center of mass coordinates [m] including the freight:
    - X = 155.3927
    - Y = 17.6088
    - Z = -11.9597
- Calculated moments of inertia [kg/m^3]:
    - Ixx = 16830893681.8206
    - Ixy = 155000920198.2467
    - Ixz = -104240912271.1265
    - Iyx = 155000920198.2467
    - Iyy = 2751913141157.2334
    - Iyz = -6430523122.9927

- Izx = -104240912271.1265
- Izy = -6430523122.9927
- Izz = 2756311538962.6108

The ship is having 5 storage tanks carrying alumina inside the tanks 1, 3 and 5 filled 50%.

The strategy of ship modeling is that the body will be treated as a rigid body with the entire mass concentrated inside the center of gravity following with the study of the ship motion as heave (Oz axis) and pitch (around Oy axis).

The action and reaction of the sea upon the ship will be carried out using the Fluid Structure Interaction (FSI) of the fluid and the vessel body.

Inside ANSYS CFX software module the Beta option will be activated allowing the direct calculation of the ship motion. The rigid body is encompassing a fluid domain to which the OZ motion (Oz) and pitch motions are permitted.

The Beta option of the software is supposing that the ship is not changing the shape during its evolution inside the fluid domain and this is a simplified case of FSI with the benefit of tremendously reducing the computing power needed for solving the numerical problem. In this approach all the forces and moments are supposed to act only upon the center of mass of the structure and as per the Charles theory the entire motion of the body will be described only by the center of mass motions.

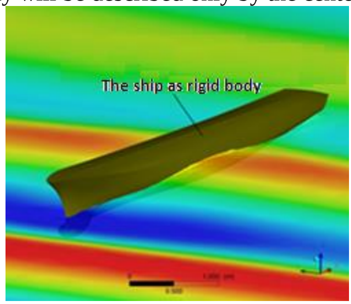


Fig. 2 The ship seen as a rigid body

In order to simulate the air above the sea, the sea itself and their interface the multiphasic option of the fluid will be activated. When using the multiphasic option of the fluid model there are a sum of phenomenon which are interacting as the buoyancy, the impulse and momentum exchange in between phases, mass exchange, superficial tension etc. that are involved. In our case the interface is separating two distinct phases, the gaseous one (air) and the liquid one (sea water). At that interface both phases are moving with the same speed and the flow is free. The mass fractions inside any fluid or gaseous phases is equal to 1 but the interface is defined by the mass fraction of 0.5.

In order to generate the waves inside the fluid domain we'll simulate a moving wall or Flapper. The fluid domain is parallelipipedic (like a testing hydrodynamic tank) providing enough space ahead and behind the ship in order the waves to develop like in the figure below:

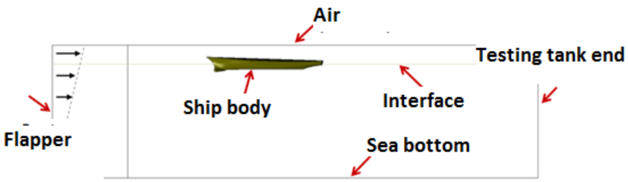


Fig. 3 Fluid domain

Once this strategy established the CFX model is generated like in the figure below (along with the boundary conditions):

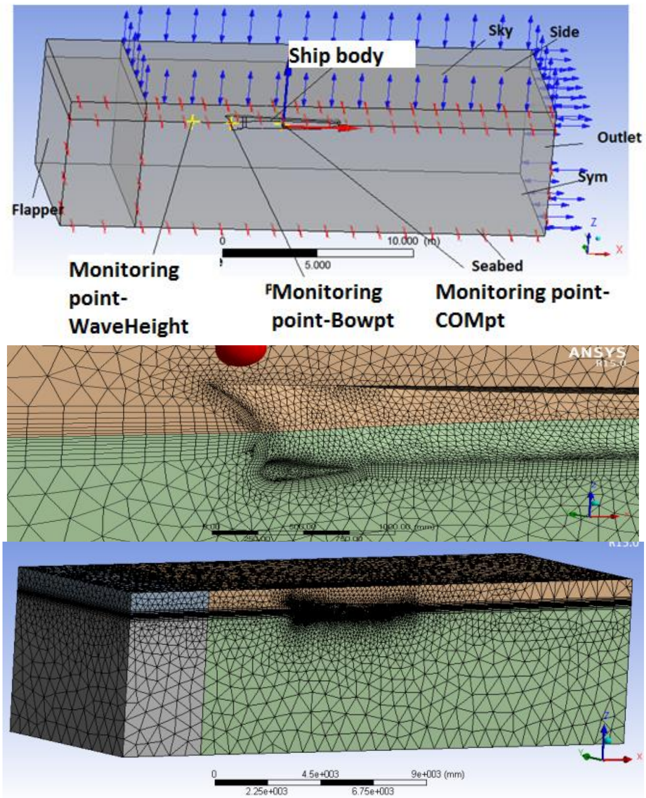


Fig. 4 CFX Model and the boundary conditions

There are established three monitoring points in order to have the at the end of the simulation the graphs for ship motions:

- WaveHeight is placed ahead of the ship body and is measuring the wave height impacting the ship

- Bowpt is monitoring the vertical displacement of the ship
- COMpt is monitoring the vertical displacement of the center of mass of the ship

The pitch is calculated from geometrical considerations and displacements of points Bowpt and COMpt with a new variable defined in Ansys as follows: appxPitch=atan2(probe(Total Mesh Displacement Z)@Bowpt -probe(Total Mesh Displacement Z)@COMpt,2.49[m])

The simulation is done as transient with steps of 0.1 sec within an interval of 10 seconds.

CFD Simulation Results

After 500 iterations the software is automatically calculating the ship motion as below. There are two zones: the first one corresponds to transitory behavior of the forming waves somehow stochastic, and a second stabilized zone where the waves get their shape and the ship motion is stabilized.

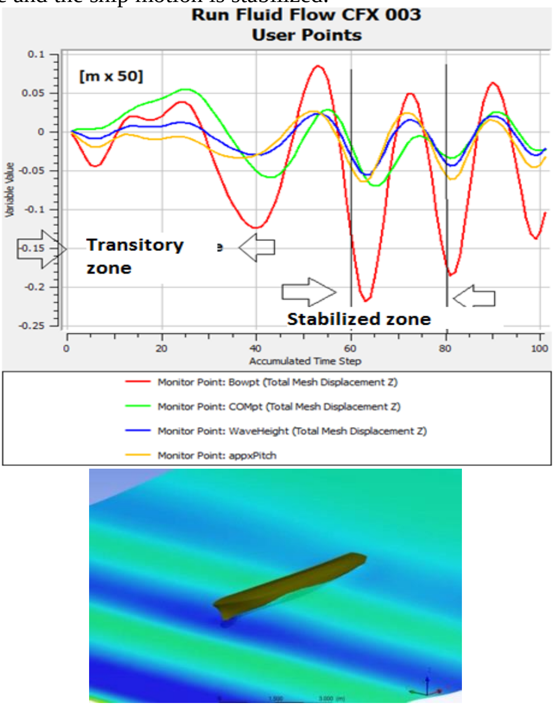


Fig. 5 Motion curves and the seakeeping ship

For the final time step (10 sec) there are some other calculated parameters of interest to be shown.

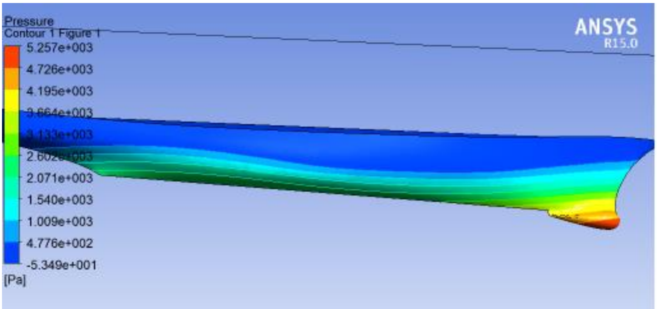


Fig. 6 Pressure fields distribution on the ship body

The pressure distribution fields as seen above, is revealing an maximum value of 5257 Pa at the bowsprit.

Below is shown the sea water velocity along to the ship vessel with a maximum of 0.25 m/s in the same bowsprit region.

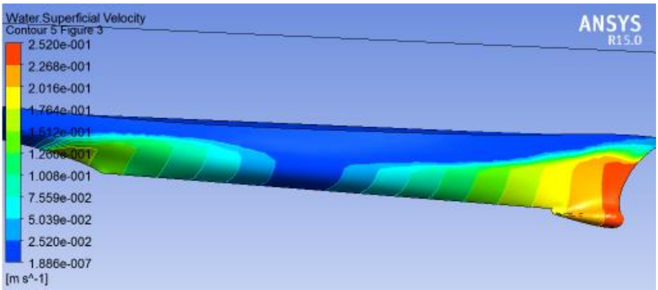


Fig. 7 Water velocity fields distribution on the ship body

The water buoyancy force (BForce) is almost constantly distributed along the body with an average of 9766 kg/(m^2s^2).

On the other hand the flow parameters of the fkuid domain were calculated as well.

For instance the pressure distribution onside the fluid is like in the figure below:

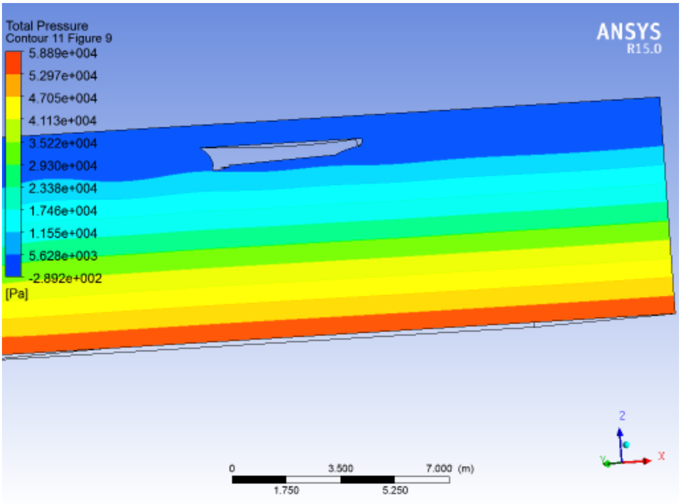


Fig. 8 Pressure distribution inside the fluid domain

The maximum pressure of 5.88e4 Pa is placed on the bottom of the sea due to the hydrostatic pressure.

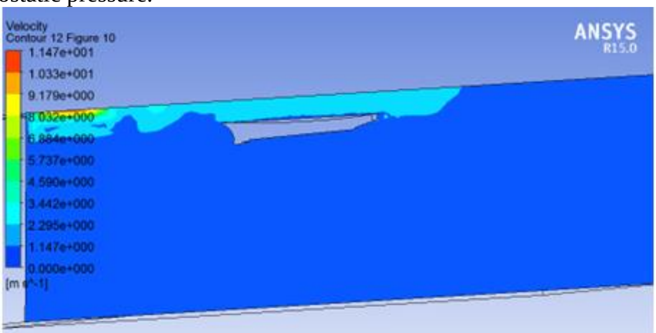


Fig. 9 Fluid velocity distribution inside the fluid domain

The air velocity is having the maximum value of 11.4 m/s above the ship.

The interface parameters are calculated as well. For instance the wave velocity is to be seen below.

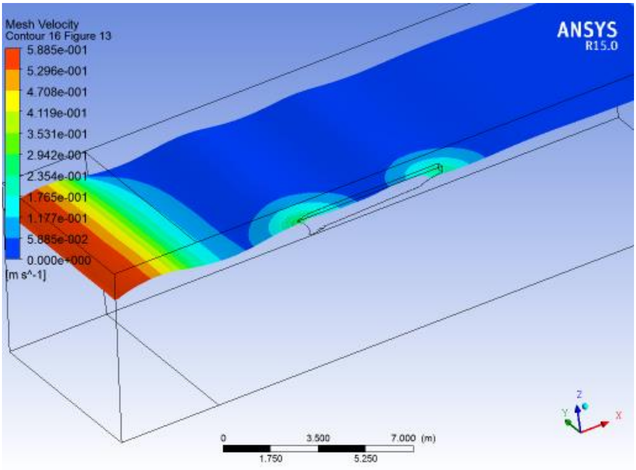


Fig. 10 FE Mesh velocity

The maximum Finite Elements mesh velocity is to be recorded near the Flapper with its maximum of 58.8 m/s.

The waves are exerting a certain pressure as below with an maximum of 319 Pa due to the wave height:

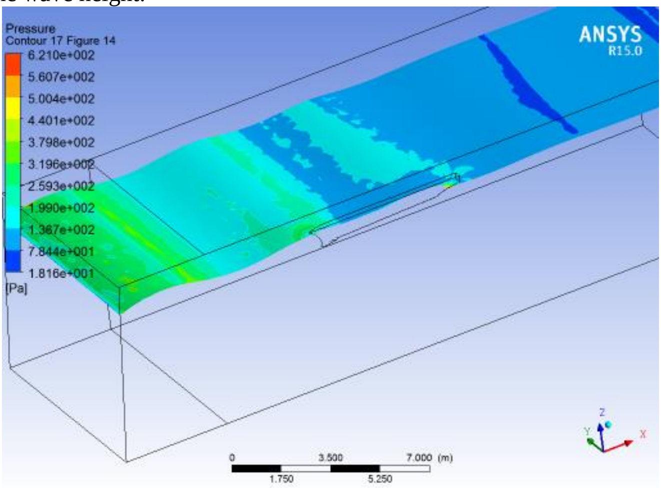


Fig. 11 Wave pressure

Thus the water velocity will be max. 1.59 m/s due to the interaction to the structure.

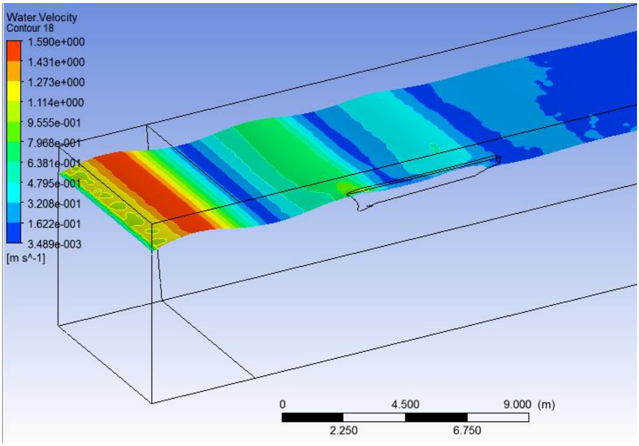


Fig. 12 Water velocity

Conclusions

The target of this paper was to show how, by using advanced numerical simulation techniques, one may describe accurately the ship motion due to the marine environment conditions like waves and wind.

This simulation was done in order to have the input data for further studies like the sloshing effects of liquid freight inside the tanks of the cargo ship, study to be described inside some subsequent articles.

As the sloshing effect take place, the structure of the ship is loaded and in some points of the structure the stress may become critical.

By using the motion curves calculated and given in Fig.5, all these intricate simulations may be successfully developed.

Numerical Analysis of the Sloshing Effect of a Pulverous Freight inside a Cargo Vessel

Sloshing can be defined as any movement of the free liquid surface inside other object. This motion can be caused by disturbance to partially filled liquid containers. For sloshing, the liquid must have a free surface to constitute a slosh dynamic problem, where the dynamics of liquid can interact with container to alter the system dynamic significantly.

Sloshing behavior of liquids within containers represents thus one of the most fundamental fluid-structure interactions (FSI). The movement of liquid having a free surface is important in varios engineering disciplines such as propellant slosh in spacecraft tanks and rockets, **cargo slosh in ships** and trucks transporting liquid (for example oil and gasoline), oil oscillation in large tanks, water oscillation in a reservoir due to earthquake, sloshing in pressure-suppression pools of boiling water reactors and several others.

The dynamic behavior of a free liquid surface depends on the excitation type and its frequency, container shape, liquid motion. The excitation to the tank can be periodic, impulsive, sinusoidal and random. It can create lateral, planar, non-planar, rotational, irregular beating, parametric, symmetric, asymmetric, pitching/yaw or combinational effects. In lateral harmonic excitation, the liquid surface display non-linearity of two types. First is large amplitude response and the second involves different forms of liquid behavior produced by coupling or instabilities of various sloshing modes.

Liquid sloshing and free surface motion is a common problem affecting not only the dynamics of flow inside the container, but also the container itself. The containers carrying the liquids, tanks used to store liquids have to withstand the complex dynamics of the transportation system, different ground motions which they are serving. This unavoidable motion of the container and the forces associated on the liquid inside it results in mostly violent and disordered movement of the liquid/gas (mostly air or vapor) interface or free surface.

Containers having liquid with a free surface should be moved with proper attention to avoid spilling and other damages. Whenever there is free surface of liquid, oscillations or liquid sloshing will be induced by acceleration of the container walls. Liquid sloshing problem involves the estimation of pressure distribution in the tank, moments and forces developed by fluid motion, and natural frequencies of the free surfaces of the liquid inside container. These above parameters can directly affect the dynamic stability and performance of moving containers.

Generally, estimation of hydrodynamic pressure in moving rigid containers two distinct components. First one is caused by moving fluid with same tank velocity and is directly proportional to the acceleration of the tank. The second component represents free-surface-liquid motion and known as convective pressure.

In this paper the behavior of a liquid-like substance (Pulverous alumina) is to be studied in regard of the sloshing effect, inside a Cargo Vessel, by using Ansys CFX.

CAD and Finite Volume Analisys (FVA) Model of the Ship

In order to achieve the goal stated above, the ship under consideration is the one given in the Fig. 13 having the following characteristics:

- Length = 290 m
- Breadth = 32 m
- Draught =11.1 m
- Deadweight = 57.700 t
- Engine type MAN B&W 6S50MC = 8.200 kw
- Thickness of the steel plate = 22 mm
- Steel density = 7800 kg/m^3

The geometry of the ship is developed by using the software SolidWorks 2015 as seen below:

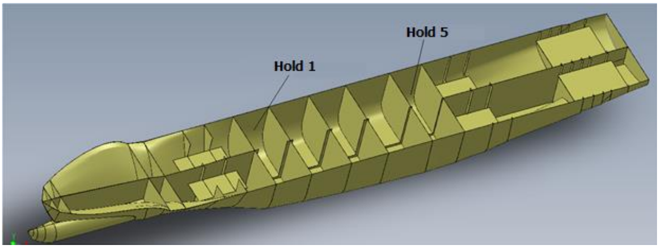


Fig. 13 Cargo vessel under consideration

From this ship structure only the Tanks 1…5 region is selected as follows:

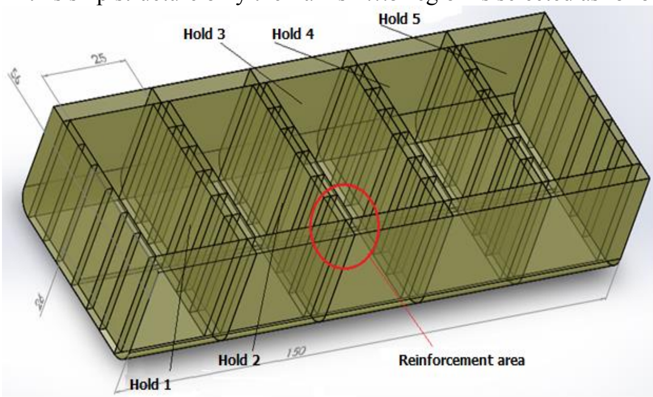


Fig. 14 Hold zone to be simulated

The strategy to solve the numerical problem is to use the so called One Way FSI, meaning that firstly the behavior of the fluid inside the Tanks is modeled in response to the marine environment excitation and then the fluid is acting upon the structure by loading and deforming it.

In this paper only the fluid response to excitation is studied, the structure response is left for a subsequent article.

The excitation for the ship was calculated inside a previous article and looks like in the figure below. There are two zones: the first one corresponds to transitory behavior of the forming waves somehow stochastic, and a second stabilized zone where the waves get their shape and the ship motion is stabilized. Only the motion of the fluid for the stabilized zone is taken into account.

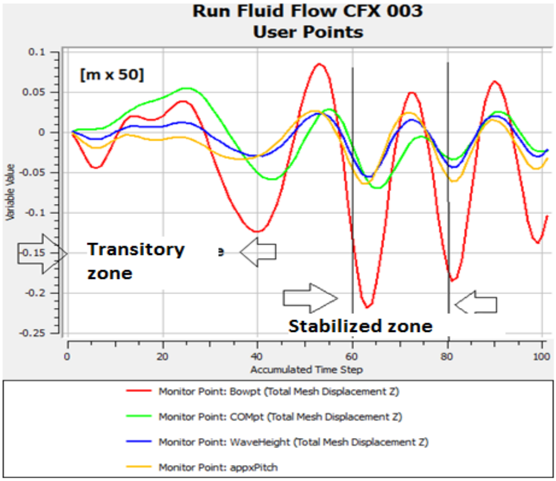


Fig. 15 Fluid excitation due to the marine environment

Taking the "negative" of the cargo tanks we may define the fluid domains as below:

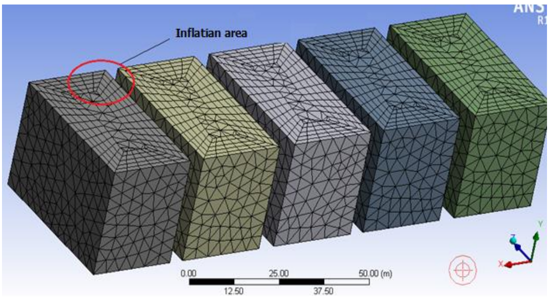


Fig. 16 The fluid domains of the tanks in CFX

In order to retrieve more accurately the behavior of the fluid near the structure walls, an inflation FE zone was established in Ansys CFX.

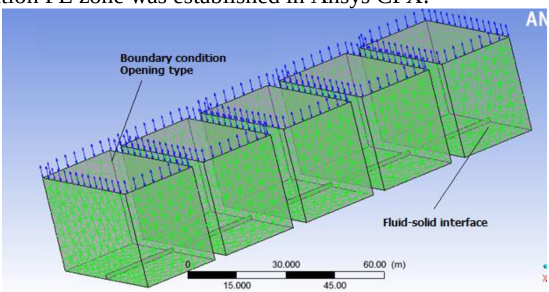


Fig. 17 Boundary conditions and fluid-solid interface in CFX

The boundary conditions are of Opening type to the upper part of the tanks and the wall are of Wall type.

After studying the curves in Fig.3 two displacements are imposed to the center of mass (of the ship) as follows (given as CFX variables):

Dispy =5[m]*sin(0.32*t/1[s])

Rotz = 3[rad]*sin(0.32*t/1[s]-0.5)

The above curves are approximately describing the motion of the ship subjected to the marine environmental loads (waves and wind).

The freight is the pulverous alumina with the density of 3.2e3 kg/m^3 and kinematic viscosity of 11.7 cSt.

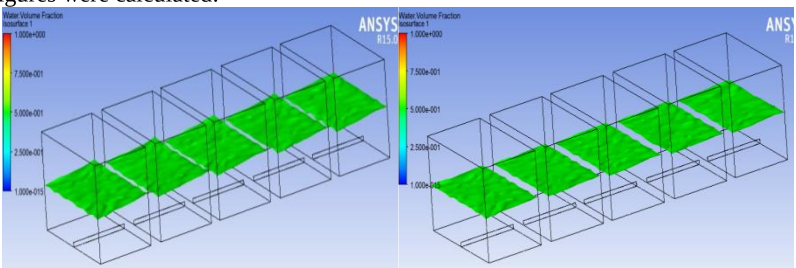
The approach is Multiphasic meaning that inside the tanks 1-3-5 is 50% alumina and the rest is air.

The simulation is covering 20 seconds in transient conditions.

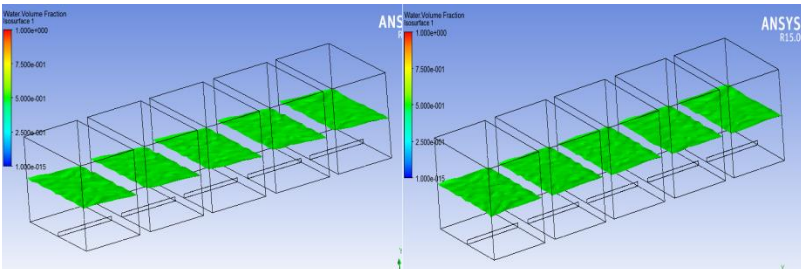
CFD Simulation Results

- **Free surface evolution in time**

In order to visualize the alumina free surface evolution in time the below figures were calculated:



Second 5 Second 10



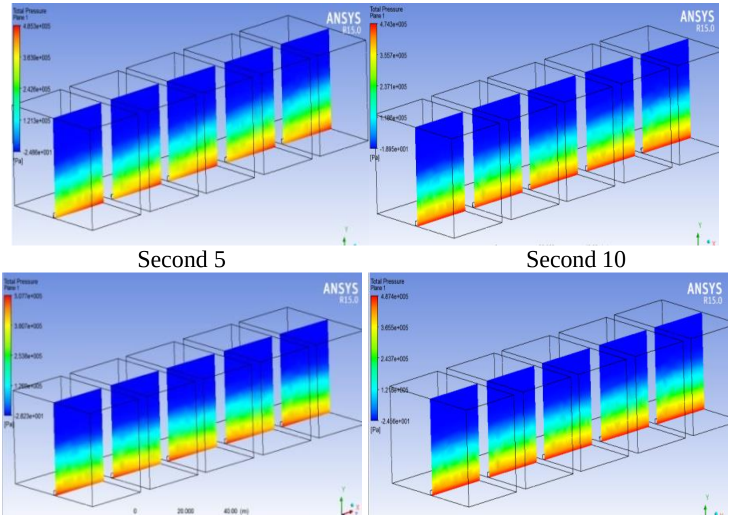
Second 15 Second 20

Fig. 18 Free surface of alumina evolution in time

Following the excitation imposed by wall movement, an internal alumina wave is developing inside the tanks.

- **Total pressure evolution in time**

In order to visualize the alumina total pressure evolution in time the below figures were calculated:

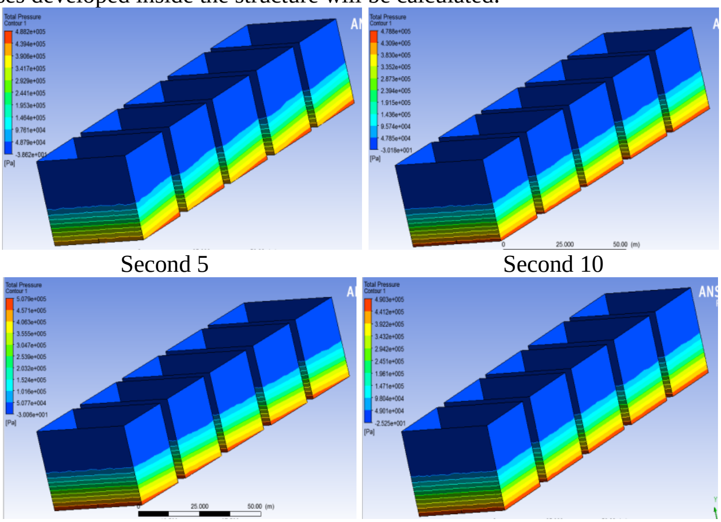


Second 5 Second 10

Second 15 Second 20

Fig. 19 Total pressure of alumina evolution in time

As seen above the maximum pressure due to the weight of the freight is acting upon the bottom walls and has the value of 5.1 e5 Pa. In order to use the calculated results for loading the ship structure the fluid pressure acting on walls is calculated as below. This pressure will load the structure walls and the deformations and stresses developed inside the structure will be calculated.



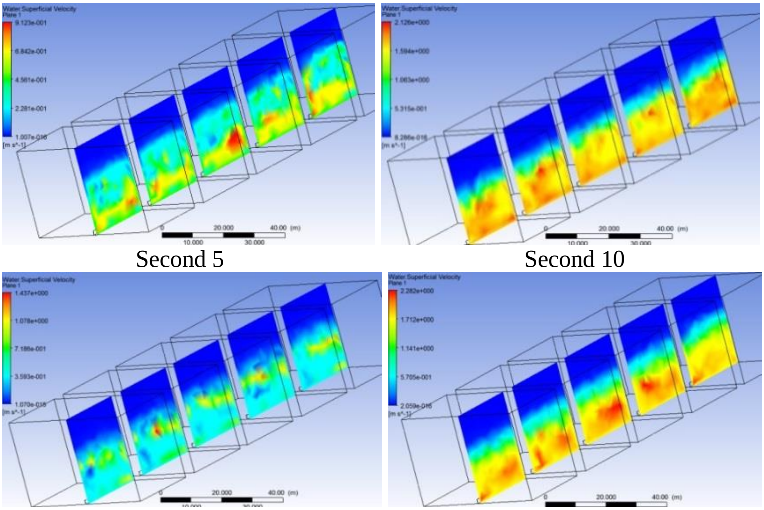
Second 5 Second 10

Second 15 Second 20

Fig. 20 Wall pressure of alumina evolution in time

- **Alumina internal wave velocity**

As expected due to the wall motion an alumina wave is borne with a maximum value of 2.2 m/s as seen below:



Second 5 Second 10

Second 15 Second 20

Fig. 21 Internal wave velocity of alumina evolution in time

Conclusions

The target of this paper was to show how, by using advances numerical simulation techniques, one may describe accurately the alumina internal waves due to ship motion.

This simulation was done in order to have the input data for further studies like the sloshing effects of liquid freight inside the tanks of the cargo ship, study to be described inside some subsequent article.

As the sloshing effect take place, the structure of the ship is loaded and in some points of the structure the stress may become critical.

By using pressures calculated and given in Fig. 20, all these intricate simulations may be successfully developed.

Numerical Analysis of the Sloshing Effect of a Pulverous Freight upon the Tank Walls of a Cargo Vessel

Mobile tanks are used from decades to transport various goods, from liquid to goods in bulk and even cryogenic liquid. They were a subject of a lot of research work what lead to provide adequate standards depending on tank assignment. All of them define design requirements and strength requirements that shall be fulfilled.

For example standard and specified detailed requirement for various tank design but they have one common requirement: tank structure shall resist specified load defined by lateral, vertical or longitudinal acceleration. Both standards define this acceleration as 2g in vertical and longitudinal direction and 1g in lateral direction. Nowadays mobile tanks are subjected not only for one liquid but the whole family, which may vary in density and due to the limit in total weight it may happen that tank is not filled to its nominal capacity. In such cases tank has to be provided with swash plates to eliminate unfavorable dynamic load of sloshing liquid on tank structure. Therefore swashing plates as well as tank structure has to resist these dynamic loads arising from liquid motion. Standards define the load from sloshing liquid as an equivalent pressure that should acts on swash plates as well as tank walls. This is very conservative approach and sometimes do not allow to investigate phenomena caused by sloshing liquid in a correct way. Available on the market design and simulation tools offer a rich possibilities but investigation of influence of liquid in motion on tanks is not easy task. There are few various approach for simulation of such problem. One of them is FSI (Fluid Structure Simulation) which combine phenomena of liquid motion with consideration tank structure. It can be performed using two independent codes (CFD and FEA) or one that have possibilities to use Eulerian-Lagrangian approach. Both of them have advantageous and disadvantageous. CAE systems supporting Eulerian-Lagrangrian elements avoid problems with exchanging data from fluid simulation to structure but offer less possibilities in flow simulation. Using independent CFD and FEA tools requires appropriate translators for exchanging data.

There are two types of FSI simulation: one way, when information from flow simulation is transferred into structure and two way simulation, where data are exchanged between both: fluid and structure. In this paper was presented using one way FSI simulation to investigate influence of liquid motion on typical, atmospheric tank on its structure. For this purpose Ansys Workbench environment was used.

In this paper the behavior of a liquid-like substance (Pulverous alumina) is to be studied in regard of the sloshing effect upon the tank walls a Cargo Vessel, by using Ansys.

In this study one way Fluid Structure interaction was involved as seen in the figure:

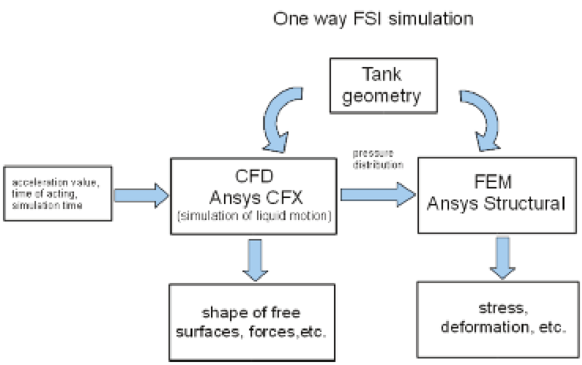


Fig. 22 One way FSI

CAD and Finite Volume Analisys (FVA) Model of the Ship

In order to achieve the goal stated above, the ship under consideration is the one given in the Fig. 23 having the following characteristics:

- Length = 290 m
- Breadth = 32 m
- Draught = 11.1 m
- Deadweight = 57.700 t
- Engine type MAN B&W 6S50MC = 8.200 kw
- Thickness of the steel plate = 22 mm
- Steel density = 7800 kg/m^3

The geometry of the ship is developed by using the software SolidWorks 2015 as seen below:

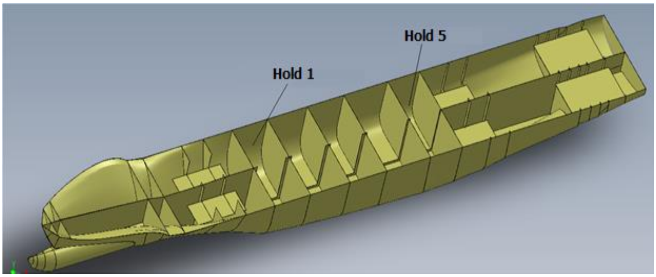


Fig. 23 Cargo vessel under consideration

From this ship structure only the Tanks 1…5 region is selected as follows:

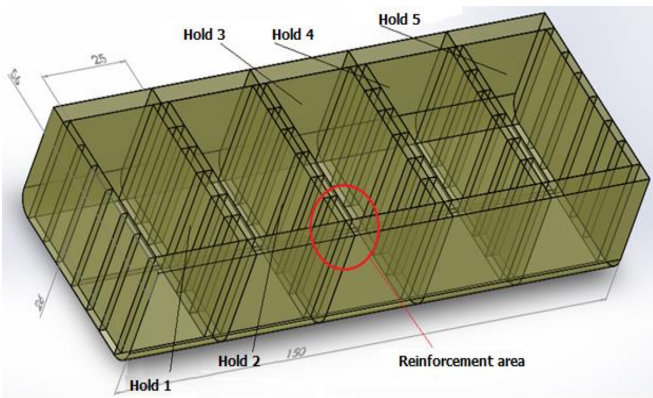
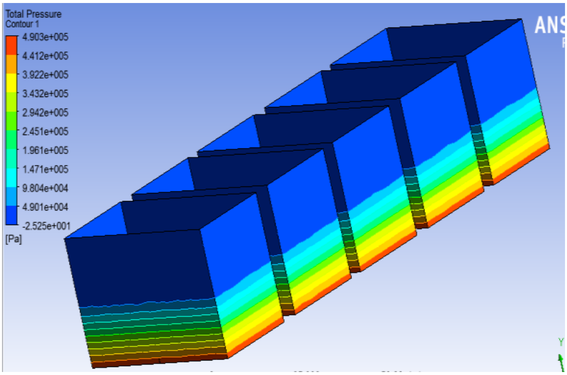


Fig. 24 Tanks zone to be simulated

The strategy to solve the numerical problem is to use the so called One Way FSI, meaning that firstly the behavior of the fluid inside the Tanks is modeled in response to the marine environment excitation and then the fluid is acting upon the structure by loading and deforming it.

In this paper only the fluid loading on the tanks walls will be studied, the liquid motion and pressure fields acting upon the walls was studied inside a previous paper.

The pressure of the fluid in sloshing was calculated inside a previous article and they looks like below:



Second 20

Fig. 25 Wall pressure of alumina to load the tank walls

The simulation is done only for second 20 of transient evolution of the fluid. The pressure is statically imported inside the structural static solving module of Ansys for tanks 1-3-5 which were 50% filled with alumina:

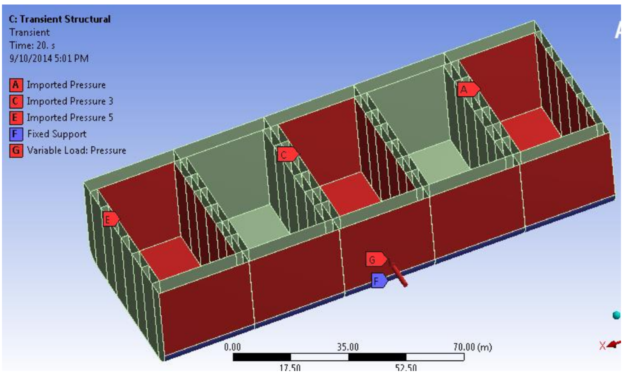


Fig. 26 Boundary conditions for structural analisys

Structural Simulation Results

- **Total deformation**

Since the Tanks 2 and 4 are empty, the sloshing pressure of the fluid will deform the walls of Tanks 1-3-5 as seen above, the maximum value being recorded inside the Tank 1, bottom, where 0.041 m=41 mm is a significant deformation.

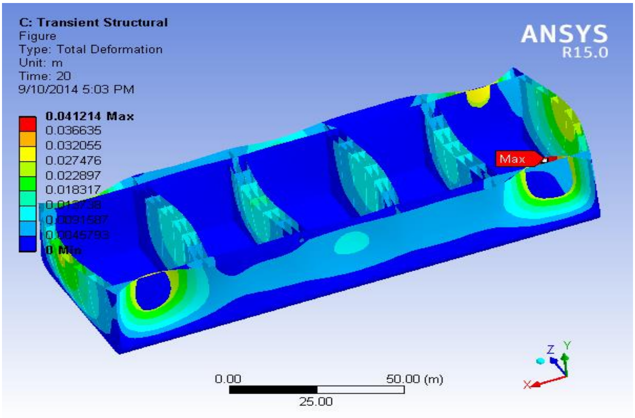


Fig. 27 Total deformation of the ship structure

- **Equivalent elastic strain**

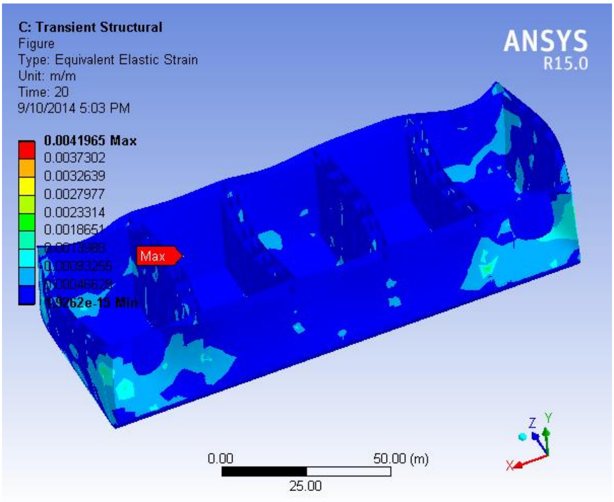
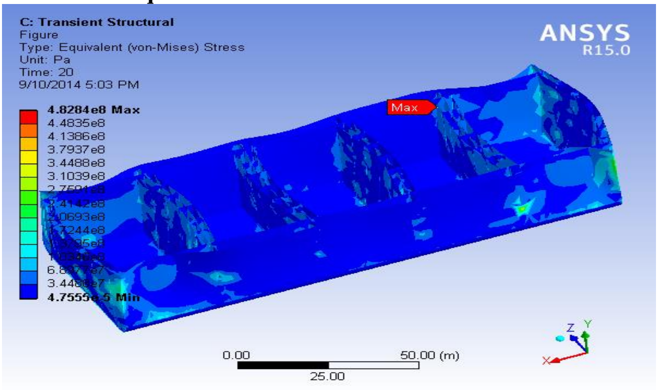


Fig. 28 Equivalent elastic strain of the ship structure

The maximum elastic strain is calculated for a point placed inside the Tank 4 where the value is 0.0041 or 0.41% which is very big. Therefore will be expected stresses above the yielding strength of the structure steel.

- **Von Mises equivalent stresses**



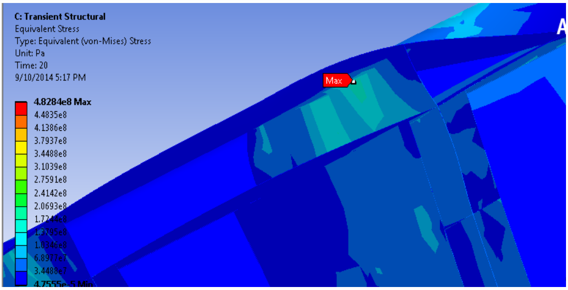


Fig. 29 Equivalent von Mises stresses of the ship structure

The maximum stress is supported by the Tank 1 where the maximum of 482 MPa is beyond the yielding strength of the steel, so that in this zone the designer ought to redesign in order to have some structural reinforcements.

- **Life**

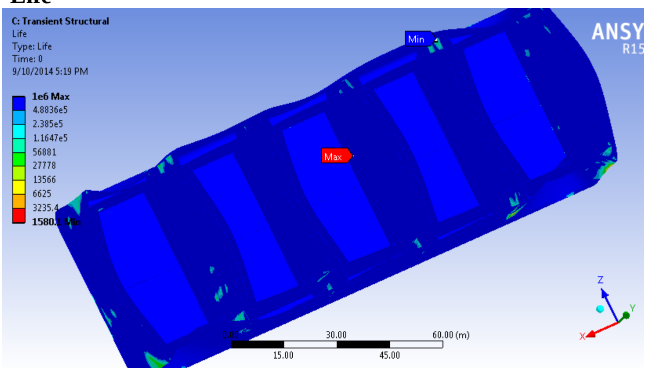


Fig. 30 Life of the ship structure

In order to pinpoint the conclusion, the life expectancy of the structure subjected to the internal sloshing waves was calculates resulting that the structure with the given design will resist only 1580 cycles so that it is mandatory the Tank walls to be redesigned.

Conclusions

The target of this paper was to show how, by using advances numerical simulation techniques, one may describe accurately the alumina internal waves due to ship motion and its impact upon the tank walls resistance.

This simulation was shown that the ship structure in the given arrangement is not upstanding the loading coming from the sloshing effects of alumina, and the tank walls need to be redesigned.

As the sloshing effect take place, the structure of the ship is loaded and in some points of the structure the stress may become critical.

Personal Contributions

In this PhD Thesis, the author developed a series of original elements which are his personal contributions:

1. Realising a study regarding the specific elements of the finite elements method applied in hydrodynamics. This study, being exhaustive due to the magnitude of the subject, reviews the main problems of the simulation with finite volumes of the behaviour of a bulk carrier's keel starting from generating the geometric model and ending with the results' analysis regarding the fluids' mechanics in different points of the keel. This first stage has as an explicit object positions' determination, speed and acceleration of the marine influential elements (waves and wind) on the ship's dynamics and kinematics. This calculated data shall be used in the second stage of simulation, more precisely simulation of the intern wave caused by sloshing with the ship's structure.

2. The complex study regarding the bulk carrier's behaviour in different loading conditions. Loading conditions may be different, and the solving manner may be adjusted for any imaginable scenarios, either concerning stimulation parameters coming from the marine environment or the loading degree of different holds, or as a type of researched fluid. What is actually important is that the described method may be used with minimum modifications for any scenario which the naval architect wishes to investigate.

3. Creating a 3D complex model of the bulk carriers' bulkheads by modelling with finite volume having as a purpose to emphasize the behaviour of these walls when on board the bulk carrier the sloshing effect appears due to free liquid surfaces in the ship's cargo holds. The resulted model uses an advanced software for 3D generating such as SolidWorks which was then imported in Ansys for a detailed analysis of the interaction phenomenon fluid structure.

4. Performing a complex study regarding the structural answer of transverse bulkheads of cargo holds due to free liquid surfaces.

4.1 The first stage of this study in represented by geometrical modelling (CAD) and numerical analysis with Ansys CFX. Just as in any research, the starting point is a real model without losing the generality degree of the ship. The chosen ship for our research is a bulk carrier with the following characteristics: Length over all = 290 m, Breadth = 32 m, Draught = 11,1 m, Deadweight = 57.700 t, Engine MAN B&W 6S50MC = 8.200 kw, Thickness of steel plates = 22 mm. Using the design of this bulk carrier and SolidWorks 2014 a geometrical model CAD was created for the bulk carrier.

4.2 The second stage of the study is represented by numerical simulation of the free liquid surfaces on board the ship, performing three scenarios with this purpose. Establishing parameters used for simulation, we considered the time of the sloshing phenomenon when the bulk carrier's holds are ballasted or loaded with different values. Simulation cases have been processed as it follows:

• Numbering the cargo holds from the bow (the front part) to the stern (aft part): 1-5
• Cargo: Bauxite, density = 3,2 t/m³; viscosity = 11,70 cSt
• Case 1
All cargo holds of the bulk carrier ballasted 50%.
• Case 2
Cargo in the bulk carriers holds:
- cargo holds: 2 and 4 = 65% loaded with bauxite
- cargo holds: 1, 3 and 5 = 50% loaded with bauxite

5. The study performed proved the effects of different factors influencing the bulk carrier's structure dynamic and its answer among which the degree of loading of cargo holds, bulk heads structure in thickness, material and configuration, stimulations coming from the marine environment and the effect of sloshing with the simulation and generation of the internal wave in the cargo holds. The end point of the research was the evaluation of these tensions in the structure and evaluations of their effects on the integrity of the structure and implicitly of the bulk carrier.

6. Validation of the modelling technique. The numerical model was compared with a container/cargo hold model with dimensions of 5x4,5x3m. Numerical simulation was obtained using ANSYS Fluent and ANSYS Structural software, with inputs from the output of CFD, in order to calculate the structural behavior of tank and cargo holds of the bulk carrier vessel type. Results of the experimental simulation results revealed that sloshing is a dynamic phenomenon that can be studied using dynamic simulations of CFD ANSYS Fluent package, proving the power of CFD to accurately simulate the evolution of sloshing phenomenon in tanks or cargo holds of the bulk carrier vessel type and deformations of tank and bulk carrier structures, undergone sloshing phenomenon, were recorded using ANSYS.

Recommendations for future research

This thesis opens a certain variety of possibilities related to possible studies and research which may be performed in the future starting from this thesis.

These recommendations are described below with no restrictions for exhaustively using them:

- Regarding the existent complex geometry at different types of bulk carriers, developing this study should be considered and performing simulations of the sloshing phenomenon as close to these new cases.
- Performing some studies for improving and refining building solutions of the hold's structure on board bulk carriers by defining and analysing the worst case scenario.
- A very important future research direction is the study and research of basin tests which would represent an imperious necessity.

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