Structural design of mega LNG carrier

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Abstract

Design of ship is a spiral of stages which highly effected by each others, where every step forward must be reviewed by previous stages to make the best combinations between requirements in all design stages and results. The initial design stage for ship depend on its mission and service, this functions determine the main characteristic and dimensions for the owner and shipyard. The final design should be arrived at taking into account not only present economic consideration but also those likely to develop within the ship life. This is especially for some trading like LNG where the ship will do the same work for all its working life.

While spherical storage tanks are widely used in LNG carrier, this thesis aim to make hull structural design of mega LNG ship with spherical tanks type B, perform structural analysis based on the functional requirement of typical LNG carriers providing its main particulars, hull form as well as the general arrangements. The design is developed according to the GL rules integrated in Poseidon software.

This work start by defining the structural concept of LNG carrier type B, where the spherical tank, which uniquely used in LNG ships, highly effect on the ship design, in way of providing enough space for huge tanks and ensure the hull rigidity. The second part is concerning the material selection for this kind of ships. To evaluate the scantling of structural members, Poseidon software was used to built numerical model, two approaches were considered, the first one analytical, where dimensioning of the structural elements has to confirm the requirements of the GL rules. The structural weight was estimated, section modulus, moment of inertia, was also calculated. In the second approach direct calculations were carried out with the use of the finite element method to verify that the stress level and buckling capability of primary structures under the applied load cases are within the acceptable limits.

The 3D-FE model analysis and applied loading is to evaluate the loads and responses of all primary structural items including hull structure supporting the cargo containment system; inner and outer hull plating and associated structure; double bottom structures; cargo tank covers and their connections to upper deck. A buckling analysis is to consider the maximum construction tolerances.
# Table of contents

List of table .......................................................................................................................... 9
List of figures .......................................................................................................................... 11
List of symbols ....................................................................................................................... 15
List of acronyms .................................................................................................................... 17
List of abbreviations ............................................................................................................. 18
Declaration of Authorship ..................................................................................................... 21
Introduction ........................................................................................................................... 23
  1.1. Background .................................................................................................................. 23
  1.2. Information provided by design .................................................................................. 24
  2. Liquefied natural gas ....................................................................................................... 27
    2.1. LNG history & features .............................................................................................. 27
    2.2. LNG market ............................................................................................................... 28
    2.3. Key points of development of LNG market in the world .......................................... 28
  3. LNG terminal in Świnoujście .......................................................................................... 31
    3.1. Importance of LNG terminals .................................................................................. 31
    3.2. Status and plans for the north European LNG terminals .......................................... 31
    3.3. Maximum parameters for port of Świnoujście ......................................................... 33
  4. Design aspects of gas carriers hull structure .................................................................. 35
    4.1. Features and capabilities ......................................................................................... 35
    4.2. Types and general arrangement of gas carriers ....................................................... 36
    4.3. General arrangement and type of LNG carriers ...................................................... 40
       4.3.1 Generalities ......................................................................................................... 40
       4.3.2. Type A tanks .................................................................................................... 41
       4.3.3. Membrane tanks ............................................................................................ 42
       4.3.4. Type C tanks .................................................................................................. 44
4.3.5. Type B tanks

4.4. Materials of Construction and Insulation

4.4.1 Construction Materials

4.4.2 Tank Insulation

4.5. Information about loading process for LNG carriers

4.6. Conclusion

5. Concept of the hull structure, material, topology and numerical modeling in Poseidon

5.1. General assumptions and design philosophy

5.2. Material selection of the hull structure

5.3. Hull structural modelling using Poseidon software

5.4. Framing system

5.5. Structural topology selection

5.6. Transverse bulkheads structure

5.7. Double bottom structure

5.8. Deck structure

5.9. Double side shell structure

5.10. Foundation deck

5.11. Midship section concept sketch

5.12. Conclusion

6. Hull structure scantling according to GL rules

6.1. Generality

6.2. Design criteria loads

6.2.1. Tank load

6.2.2. Stillwater bending moments, shear forces and torsion moment

6.3. Scantling of longitudinal and transversal plates and its stiffeners

6.3.1. Scantling of transversal plate

6.3.2. Scantling of bulkheads structural elements

Master Thesis developed at West Pomeranian University of Technology, Szczecin
6.3.3. Transversal and longitudinal hull strength ............................................................... 80
6.3.3.1. Transverse members ......................................................................................... 80
6.3.3.2. Longitudinal members ..................................................................................... 80
6.4. Hull steel mass estimation ......................................................................................... 84
6.5. Conclusion .................................................................................................................. 86

7. Strength analysis using finite element method ............................................................... 87
7.1. Objectives and structural modelling ......................................................................... 87
7.2. Description of the model .......................................................................................... 88
7.3. Boundary condition ................................................................................................. 89
7.4. Loads specifications ................................................................................................... 91
7.4.1. Generality ............................................................................................................ 91
7.4.2. External loads ........................................................................................................ 91
7.4.3. Tank loads ............................................................................................................ 93
7.5. Selected load cases ................................................................................................... 94
7.6. Global load adjustment ............................................................................................. 98
7.7. Results evaluation ...................................................................................................... 99
7.8. Buckling .................................................................................................................... 111
7.9. Conclusion ................................................................................................................ 112
7.10. Technical description ............................................................................................... 113

8. Technology of hull construction ..................................................................................... 115
8.1. Manufacturing of the shell ....................................................................................... 115
8.2. Prefabrication of sections ......................................................................................... 116
8.3. Procedure of hull assembly ....................................................................................... 116
8.3.1. Determination of blokes ...................................................................................... 116
8.3.2. Succession of assembly ....................................................................................... 117
8.3.2.1. Installation of the bottom .................................................................................. 118
8.3.2.2. Installation of bulkheads .................................................................................. 118
8.3.2.3. Installation of shell ................................................................. 118
8.3.2.4. Installation of the upper deck .................................................. 119
8.3.2.5. Installation of LNG tanks ......................................................... 119
9. Conclusion general ................................................................. 120
Acknowledgements ...................................................................... 121
List of references ....................................................................... 122
APPENDIX .................................................................................. 124
List of table

Table 2.1 Physical properties of LNG……………………………………………………………27
Table 3.1 Maximum dimensions for ships types in Świnoujście port……………………33
Table 4.1 Main characteristics of Abdlakadr LNG ship................................................43
Table 4.2 Main characteristics of Alhamra LNG ship.....................................................48
Table 5.1 Main characteristics of studied ship.................................................................53
Table 5.2 Material selected for hull structure.................................................................56
Table 6.1 Arrangement of ballast tanks with compartments method............................70
Table 6.2 Arrangement of cargo tanks with compartments method...............................71
Table 6.3 Scantling for all longitudinal members and its stiffener.................................77
Table 6.4 Transversal plat sizing....................................................................................78
Table 6.5 Claculation of bulkheads plating........................................................................79
Table 6.6 Load cases according to GL rules for Normal stress verification................82
Table 6.7 Load cases according to GL rules for Shear stress verification.......................83
Table 6.8 Calculation of cargo holds weight.................................................................85
Table 7.1 Description of boundary condition...............................................................90
Table 7.2 Selected load cases.........................................................................................94
Table 7.3 Load case 1 description...................................................................................95
Table 7.4 Load case 2 description...................................................................................96
Table 7.5 Total subjected bending moment.................................................................98
Table 7.6 Allowable stresses..........................................................................................98
Table 7.7 Maximum deflection of the studied ship under considered load cases........108
Table 7.8 Bulking results...............................................................................................111
Table 7.9 Maximum recorded stresses for selected load cases........................................112
List of figures

Figure 1.1 Design spiral.................................................................................................................. 25
Figure 3.1 LNG terminal in Świnoujście and north Europe............................................................. 32
Figure 3.2 Wave breaking construction of Świnoujście LNG terminal.............................................. 32
Figure 4.1 Fully pressurized carrier midsection.............................................................................. 37
Figure 4.2 General arrangement of semi pressured carrier............................................................. 38
Figure 4.3 General arrangement of Ethylene carrier....................................................................... 39
Figure 4.4 Midship section of fully refrigerated LPG carrier............................................................ 39
Figure 4.5 Self supported-type A tanks........................................................................................ 41
Figure 4.6 Gaz trasport membrane (large LNG), Abdelkadr membrane ship................................. 43
Figure 4.7 Construction of Technigaz membrane........................................................................... 44
Figure 4.8 Self supported – fully and semi pressured LNG tanks type C........................................ 45
Figure 4.9 Self supported-spherical type B tanks.......................................................................... 46
Figure 4.10 General arrangement of Alhamra LNG ship............................................................... 47
Figure 4.11 Tank layer and isolation............................................................................................... 49
Figure 4.12 Containment systems used in LNG carriers............................................................... 50
Figure 5.1 Midship section drawing for studied LNG ship............................................................. 54
Figure 5.2 General arrangement of studied LNG carrier............................................................... 54
Figure 5.3 Selected part for modelling in Poseidon........................................................................... 57
Figure 5.4 Moulding in Poseidon using functional elements......................................................... 57
Figure 5.5 Frame spacing along the ship....................................................................................... 59
Figure 5.6 First sketch of cargo hull structure and cargo hold space............................................ 59
Figure 5.7 Bulkheads of LNG carrier............................................................................................ 60
Figure 5.8 Bulkheads and water ballast........................................................................................ 61
Figure 5.9 Double bottom structural element arrangements in the transverse direction.............. 62
Figure 5.10 3D view of the bottom structure.................................................................................. 62
Figure 5.11 Main deck of LNG carrier............................................................................................ 63
Figure 5.12 Double side shell and foundation deck....................................................................... 64
Figure 5.13 3D model of double side shell..................................................................................... 64
Figure 5.14 Foundation of spherical tank........................................................................................ 65
Figure 5.15 Skirt of spherical tank over foundation deck............................................................... 65
Figure 5.16 Amidships section....................................................................................................... 66
Figure 5.17 Progress of modelling in Poseidon software............................................................... 67
Figure 5.18 The ship hull structural model developed in Poseidon software

Figure 6.1 Location of compartment and ballast tank in different region

Figure 6.2 Cargo tank location

Figure 6.3 Ballast and cargo tank distribution

Figure 6.4 Content of compartment in Poseidon software

Figure 6.5 Still water bending moment

Figure 6.6 Scantling algorithms using in Poseidon, Germanischer Lloyd, 2012

Figure 6.7 Results of check command in frame 75

Figure 6.8 Deck region sizing

Figure 6.9 Bilge region sizing

Figure 6.10 Bottom region sizing

Figure 6.11 Scantling results according to GL rules

Figure 6.12 Calculation of permissible still water stresses

Figure 6.13 Permissible bending moment and share force

Figure 6.14 Von Mises stress distribution

Figure 6.15 Distribution of hull member’s weight

Figure 7.1 Algorithm of stress evaluation by GL rules

Figure 7.2 Full FE model

Figure 7.3 Mesh tolerance for studied part

Figure 7.4 Boundary condition table

Figure 7.5 Applied boundary condition on FEM model

Figure 7.6 Definition of draught margin and wave number

Figure 7.7 Hogging wave definition

Figure 7.8 Sagging wave definition

Figure 7.9 Tank loads in Poseidon

Figure 7.10 External and tanks static loads

Figure 7.11 Load case1

Figure 7.12. FE model of load case1

Figure 7.13 FE model of load case2

Figure 7.14 Global loads adjustment in Poseidon

Figure 7.15. Von Mises stress results for load case1

Figure 7.16 Von Mises stress results in shell and bottom for load case1

Figure 7.17 Result of Von Mises stress of load case2

Figure 7.18 Von Mises stress results in shell and bottom for load case2
Figure 7.19 Stress distribution from natural axes .......................................................... 102
Figure 7.20 Distribution of the Von Mises stresses in the transverse members
For load case 1 & load case 2 .......................................................................................... 103
Figure 7.21 Distribution of the normal stresses in the model, used scale up to 180 MPa .......... 104
Figure 7.22 Normal stress distribution for load case 2, scale up to 300 MPa .......................... 105
Figure 7.23 Shear stress distributions for load case 1 ....................................................... 106
Figure 7.24 Shear stress distributions for load case 2 ....................................................... 107
Figure 7.25 Model deformations under selected load cases, scale 60 .................................. 109
Figure 7.26 Von Mises stress & model deflection ........................................................... 110
Figure 7.27 Final technical description of midship section .......................................... 113
Figure 8.1 Hull welding sections .................................................................................... 115
Figure 8.2 Manufacturing process .................................................................................. 116
Figure 8.3 Hull assembly using cranes ........................................................................... 117
Figure 8.4 Positioning of bottom .................................................................................... 118
Figure 8.5 Shell assembly .............................................................................................. 119
Figure 8.6 Spherical tank installations ........................................................................... 119
### List of symbols

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Entity</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>m</td>
<td>Moulded breath of the ship</td>
</tr>
<tr>
<td>CB</td>
<td>-</td>
<td>Block coefficient of the ship</td>
</tr>
<tr>
<td>D</td>
<td>m</td>
<td>Depth of the ship</td>
</tr>
<tr>
<td>g</td>
<td>m/s²</td>
<td>Gravitational acceleration</td>
</tr>
<tr>
<td>fF</td>
<td>-</td>
<td>Weighting factor for the simultaneousness of global and local loads</td>
</tr>
<tr>
<td>k</td>
<td>-</td>
<td>Material factor</td>
</tr>
<tr>
<td>LOA</td>
<td>m</td>
<td>Length over all of the ship</td>
</tr>
<tr>
<td>LPP</td>
<td>m</td>
<td>Length between perpendicular of the ship</td>
</tr>
<tr>
<td>M_{ST}</td>
<td>N·m</td>
<td>Static torsional moment</td>
</tr>
<tr>
<td>M_{WT}</td>
<td>N·m</td>
<td>Torsional moment coming from wave</td>
</tr>
<tr>
<td>M_{SW}</td>
<td>N·m</td>
<td>Still water vertical bending moment</td>
</tr>
<tr>
<td>M_{WV}</td>
<td>N·m</td>
<td>Vertical bending moment coming from wave</td>
</tr>
<tr>
<td>M_{WH}</td>
<td>N·m</td>
<td>Horizontal bending moment coming from wave</td>
</tr>
<tr>
<td>M_{ZZ}</td>
<td>N·m</td>
<td>Torsional moment around the X-axis</td>
</tr>
<tr>
<td>M_{YY}</td>
<td>N·m</td>
<td>Bending moments around the Y-axis</td>
</tr>
<tr>
<td>M_{ZZ}</td>
<td>m/s²</td>
<td>Bending moments around the Z-axis</td>
</tr>
<tr>
<td>R_{eH}</td>
<td>N/mm²</td>
<td>Yield stress</td>
</tr>
<tr>
<td>t</td>
<td>mm</td>
<td>Thickness</td>
</tr>
<tr>
<td>T</td>
<td>m</td>
<td>Draught scantling</td>
</tr>
<tr>
<td>V</td>
<td>m/s</td>
<td>Service speed</td>
</tr>
<tr>
<td>W</td>
<td>m³</td>
<td>Section modulus</td>
</tr>
<tr>
<td>τ_{L}</td>
<td>N/mm²</td>
<td>Shear stress</td>
</tr>
<tr>
<td>σ_{L}</td>
<td>N/mm²</td>
<td>Normal stress</td>
</tr>
<tr>
<td>σ_{V}</td>
<td>N/mm²</td>
<td>Von Mises stress</td>
</tr>
<tr>
<td>σ_{Y}</td>
<td>N/mm²</td>
<td>Normal stress component in the transversal direction</td>
</tr>
<tr>
<td>σ_{X}</td>
<td>N/mm²</td>
<td>Normal stress component in the longitudinal direction</td>
</tr>
</tbody>
</table>
# List of acronyms

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>GL</td>
<td>Germanischer Lloyd</td>
</tr>
<tr>
<td>LNG</td>
<td>Liquefied natural gas</td>
</tr>
<tr>
<td>LPG</td>
<td>Liquefied petroleum gas</td>
</tr>
<tr>
<td>IGC Code</td>
<td>International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk</td>
</tr>
<tr>
<td>ABS</td>
<td>American Bureau of Shipping</td>
</tr>
<tr>
<td>IACS</td>
<td>International Association of Classification Societies</td>
</tr>
<tr>
<td>IMO</td>
<td>International Maritime Organization</td>
</tr>
<tr>
<td>ISO</td>
<td>International Organization for Standardization</td>
</tr>
<tr>
<td>NKK</td>
<td>Nippon Kaiji Kyokai</td>
</tr>
<tr>
<td>SOLAS</td>
<td>IMO convention for Safety Of Life At Sea</td>
</tr>
<tr>
<td>SPB</td>
<td>LNG Carrier Type B Tanks Prismatic</td>
</tr>
<tr>
<td>IHI</td>
<td>Ishikawajima-Harima Heavy Industries</td>
</tr>
<tr>
<td>CH4</td>
<td>Methane</td>
</tr>
<tr>
<td>GERG</td>
<td>European Gas Research Group</td>
</tr>
<tr>
<td>GIE</td>
<td>Gas Infrastructure Europe</td>
</tr>
<tr>
<td>IGU</td>
<td>International Gas Union</td>
</tr>
<tr>
<td>SIUTT</td>
<td>Society of International Gas tanker &amp; terminal</td>
</tr>
<tr>
<td>GIIGNL</td>
<td>The International Group of Liquefied Natural Gas Importers</td>
</tr>
<tr>
<td>CS1</td>
<td>Membrane System for LNG Integrated Tanks</td>
</tr>
</tbody>
</table>
List of abbreviations

Upper deck high 27000 mm ......................................................................................... DK1
Second deck high 23200 mm ....................................................................................... DK2
Double side shell Y = 22000 mm .................................................................................... IH
Stringer high 20550 mm ............................................................................................... STR6
Foundation deck high 10000 mm .................................................................................... STR18
Inner bottom high 1600 mm ............................................................................................. IB
Longitudinal girder N°1, at the centre line ...................................................................... LG0
Longitudinal girder N°2, at Y5 = 4800 mm ...................................................................... LG1
Longitudinal girder N°3, at Y9 = 8400 mm ...................................................................... LG2
Longitudinal girder N°4, at Y13 = 12000 mm ................................................................. LG3
Outer shell ...................................................................................................................... Shell
Outer bottom .................................................................................................................. Bottom
Plate of the floor limited by LG0, shell, LG1 and IB ....................................................... F97A
Plate of the floor limited by LG1, shell, LG2 and IB ....................................................... F97B
Plate of the floor limited by LG2, shell, LG3 and IB ....................................................... F97C
Plate of web frame limited by LG3, shell, and z26 ......................................................... BP97A
Plate of web frame limited by y18, z26, shell and z23 ..................................................... BP97B
Plate of web frame limited by z23, shell, STR18, and slop ............................................. BP97C
Plate of web frame limited by slop, y18 and z26 .......................................................... BP97D
Plate of web frame limited by STR18, shell, STR6 and IH .............................................. W97A
Plate of web frame limited by STR6, shell, DK2 and IH ................................................ W97B
Plate of web frame limited by DK2, shell, DK1 and IH .................................................. W97H
Plate watertight bulkhead 1 ............................................................................................ BB72A
Plate watertight bulkhead 2 ............................................................................................ BB72C
Plate watertight bulkhead 3 ............................................................................................ WT72A
Plate watertight bulkhead 4 ............................................................................................ WT72B
Non watertight bulkhead 5 ............................................................................................ C88A
Shell plat in bottom from Y1-Y5 .................................................................................... B1
Shell plat in bottom from Y5-Y14 ................................................................................... B2
Shell plat in bottom from Y14-Y23 .................................................................................. B3
Side shell plat from bilge to Z22 .................................................................................... SH1
Side shell plat from Z22 to Z17 ..................................................................................... SH2
Side shell plat from Z17 to SD.................................................................SH3
Side shell plat from SD to Z2..................................................................SH4
Side shell plat from Z2 to MD..................................................................SH5
Inner hull plat from second deck to main deck .........................................IH1
Inner hull plat from Z5 to MD.................................................................IH2
Inner hull plat from Z8 to Z5.................................................................IH2
Inner hull plat from Z16 to Z8.................................................................IH2
Inner hull plat from FD to Z16.................................................................IH2
Declaration of Authorship

I declare that this thesis and the work presented in it are my own and have been generated by me as the result of my own original research.
Where I have consulted the published work of others, this is always clearly attributed.
Where I have quoted from the work of others, the source is always given. With the exception of such quotations, this thesis is entirely my own work.
I have acknowledged all main sources of help.
Where the thesis is based on work done by myself jointly with others, I have made clear exactly what was done by others and what I have contributed myself.
This thesis contains no material that has been submitted previously, in whole or in part, for the award of any other academic degree or diploma.
I cede copyright of the thesis in favour of the West Pomeranian University of Technology, Szczecin.

Date 15/01/2013
Introduction

1.1. Background

The primary aim of all structural design is to ensure that the structure will perform satisfactorily during its design life. Specifically, the designer must check that the structure is capable of carrying the loads safely and that it will not deform excessively due to the applied loads. This requires the designer to make realistic estimates of the strengths of the materials composing the structure and the loading to which it may be subject during its design life, furthermore, the designer will need a basic understanding of structural behaviour.

According to the new requirements of the world market and high value cargo, ships must offer good response with this needs, this requirement put ship designer in course of challenge to reach high speed, good stability, high propulsive efficiency and navigational limitations draft and beam, all this requirements should be achieved taking by consideration the most important conditions on the ship body and structure to resist all loads effect while ship sailing in the sea, this loads come from sea waves as bending moments and the shear forces, and also there is the loads which comes from cargo on board of ship.

The present trend in shipbuilding is to build larger ships, and the demand for higher safety standards is also continuously growing. Furthermore, the emergence of large scale ships has brought about the demand for new standards in ship structure design and safety assessment. In the conventional shipbuilding method, structural analysis is applied to only major parts of a ship. But in the modern method, most of the time, structural analysis is applied to the whole ship. Ship design process is composed of three major stages: basic design stage, detail design stage and production design stage. In the basic design stage, hull form design for designation of outer shape of ship, basic calculation for evaluation of the cargo containment capacity and the stability of ship and initial structure design for designation of typical structural part of ship such as mid ship section.

There are basically two schools to perform analysis and design of ship structure. The first one, the oldest, is called rule based design. It is mainly based on the rules defined by the classification societies. In the past, ship structural design has been largely empirical, based on accumulated experience and ship performance, and expressed in the form of structural design codes or rules published by the various ship classification societies. These rules concern the loads, the strength and the design criteria and provide simplified and easy to use formulas for the structural dimensions, or “scantlings” of a ship. This approach saves time in the design
office and, since the ship must obtain the approval of a classification society, it also saves time in the approval process.

The second school is the Rationally Based Structural Design; it is based on direct analysis, Hughes, who could be considered as a father of this methodology [7].

Even if direct calculation has always been performed, design based on direct analysis only became popular when numerical analysis methods became available and were certified. Direct analysis has become the standard procedure in aerospace, civil engineering and partly in offshore industries.

In ship design, classification societies preferred to offer updated rules resulting from numerical analysis calibration. For the designer, even if the rules were continuously changing. With the aid of computers it is possible to make a study of a large number of varying design parameters and to arrive at a ship design which is not only technically feasible but, more importantly, is the most economically efficient, so the analysis using the finite element method allows knowing the deflections and the distribution of the stresses over the hull structure which may verified against the permissible stresses. Hence, at this stage changes in the material used and the sizing of the structural elements can be made in certain structural regions which need to be more strengthened.

The structural design is an iterative process; the analysis can be proceeding until reach satisfactory scantling which fulfils the design criteria. Therefore the structure is ready for the final design and can be presented for the fabrication and the construction.

1.2. Information provided by design

The initial ship design information is defined by the design information available at the basic ship design stage such as:

- dimensions, \((L_{oa}, L_{pp}, B, C, \text{ and } T)\),
- displacement (lightship + dead weight),
- stability (GZ + hydrostatic curves),
- propulsive characteristics and hull form (engine power and resistance),
- preliminary general arrangement,
- principal structural details.

These main stages which design of ship goes through are showing in Figure 1.1, where it’s clear that ship design is spiral and every stage is highly affected by another stages during design progress.
Each item of information may be considered in more detail, together with any restraints placed on these items by the ship’s service or other factors outside the designer’s control.

The main dimensions of the most ships are primarily influenced by the cargo, carrying capacity of the vessel, taking by consideration that increasing of the length of the vessel produces higher longitudinal stresses required additional strengthening and a greater displacement for the same cargo weight, where the breadth related more to statical stability in order to ensure that this is sufficient in all possible conditions for loading.

Displacement is made up of light weight plus deadweight, and there is reversible relation between the light weight and deadweight capacity, like in case of carrying high density cargoes its desirable to keep the light weight as small as possible. The general arrangement is prepared in cooperation with the owner, allowing for standards of accommodation particular to that company. Adequate propulsive performance will ensure that the vessel attains the required speeds. The hull form is such that economically it offers a minimum resistance to motion so that a minimum power is required.

Almost all vessels will be built to the requirements of classification societies such as Germanischer Lloyd. The standard of classification specified will determine the structural scantlings and these will be taken out by the shipbuilder. The determination of the minimum hull structural scantling can be carried out by means of computer programs made for
shipyards by classification societies. Owners may specify thicknesses and material requirements in excess of those required by the classification societies and special structural features.
2. Liquefied natural gas

2.1. LNG history & features

Thousands of years ago, it was noticed that natural gas “seeps” ignited when hit by lightening and created burning springs. In Persia, Greece and India, people built temples around these eternal flames for religious practices. The energy value of natural gas was not recognized by these people; however, it was recognized in China in this respect around 900 BC. The first known gas well was dug by the Chinese in 211 B.C [8].

Natural gas became one of the principal source of energy in the 21th century, this gas is mainly composed of methane, weak concentration of another hydrocarbons, water, dioxide of carbon, azotes and oxygen, more information about LNG proprieties [8], are shown in Table 2.1, in the end of year 2005 natural gas represent 23.5% of the primary energy in the world, occupied the 3th position after petrol (36.4 %) and the carbons (27.8%). Great Britain discovered natural gas in 1659, but was only commercialized in 1790. In the United States, residents of Fredonia observed in 1821 gas bubbles rising to the surface from a creek. America’s father of natural gas “William Hart” dug the first natural gas well in Fredonia, which was 8 metres deep. It was initially used for street lighting and was put to industrial use two decades later.

<table>
<thead>
<tr>
<th>Symbol of LNG</th>
<th>CH4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carriage Temperature</td>
<td>-161° C</td>
</tr>
<tr>
<td>Cargo Pressure</td>
<td>1.04kg/cm²</td>
</tr>
<tr>
<td>Specific Gravity</td>
<td>470 kg/m³</td>
</tr>
<tr>
<td>Flash Point</td>
<td>-175° C</td>
</tr>
<tr>
<td>Ignition Temperature</td>
<td>595° C</td>
</tr>
</tbody>
</table>

*Table 2.1 Physical properties of LNG [8].*

Natural Gas is colorless, odorless, tasteless, shapeless and lighter than air. However for safety reasons a chemical odorant, Mercaptan, which smell like rotten eggs, is added in order to detect any leakage. For any temperature over minus 161°C it is in gaseous form. According to Eurogas², Natural Gas CO2 emissions are 40-50% less than coal and 25-30% less than oil.
2.2. LNG market

Natural gas becomes liquid when it is cooled to minus 162 °C. In this state, it occupies one six hundredth of its gaseous volume. This makes it possible to transport LNG by sea in ships. LNG is liquefied in the exporting country for transport and converted back to the gaseous state in the country of destination. It is transported to the consumers via pipelines. The seaborne transport of liquefied gases began in 1934 when a major international company put two combined oil/LPG tankers into operation. Natural gas and LNG are likely to continue to play a key role in the EU’s energy-mix in the coming decades. The total gas consumption in the SECA\(^1\) is forecasted to remain at today’s level in the period up to 2020. The total demand of LNG in the SECA is forecasted to increase by 140% over the period up to 2020, from 39 bcm to 93 bcm (29.5 million tonnes to 70.5 million tonnes) as gas production within the region declines [12].

2.3. Key points of development of LNG market in the world

Over the past few years, the use of natural gas is increasing popularity and becoming the fuel of the future because of depleting sources of commercial fuel, growing lobby against pollution of air and sea and the nuclear Fuel could not take off risks.

Natural gas provides approximately one-fifth of the world’s energy. The global gas market is segmented into two transportation sub categories: pipeline gas, which represents 70% of the market by volume, and vessel-transported liquefied natural gas (LNG), which holds a 30% share of the market. LNG exports grew at an annual rate of over 13% from 2000 to 2011, reaching 243 million tons per annum in 2011 [3].

There are an increasing number of countries that have either turned to importing LNG or plan to do so in the coming years. In Asia-Pacific, LNG demand has been growing steadily in China, India and Taiwan, while a number of countries just recently began importing LNG or have plans to do so soon. Even countries which have traditionally been LNG exporters, such as Malaysia, Indonesia and countries in the Middle East, are planning to import LNG. In South America, there are more countries importing LNG than exporting it.

Demand for liquefied natural gas (LNG) in the Asia Pacific region is forecasted to grow significantly to 2020 and beyond; by 2020, gas demand in Japan, Korea and China is

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\(^1\) SECA: Sulphur Emission Control Areas (SECA)
\(^2\) Eurogas: Europe Gas Association
forecasted to exceed secured supply by 49 million tons per annum, a volume that grows to 112 million tons per annum, by 2025. This gap creates a large opening for suppliers to sell LNG into this region.

The huge quantity of gas which can be transported by one ship make it so efficient from economical point of view, for example LNG tanker with Moss-Rosenberg spherical tanks for 138 000 m³ of LNG, its approximately 290 metres long and hold the annual consumption of a small city with 56 000 households [6].

As early as 2015, more than 400 LNG carriers are expected to be in operation. Counting extra crews for backup, sick leave or holidays, the LNG industry will need about 9000 additional skilled crew members at sea.

Several international organizations are involved in promoting and improving the LNG handling and operation. Some of them are shortly described below:

- International Gas Union (IGU) has a programme committee on LNG (PGC D, Liquefied Natural Gas LNG),
- Gas Infrastructure Europe (GIE) is a representative organization towards the European Institutions (European Commission, European Parliament, Council of the European Union),
- SIGTTO (Society of International Gas Tanker & Terminal Operators) is a world-wide organization,
- GIIGNL (The International Group of Liquefied Natural Gas Importers),
- GERG (European Gas Research Group). DGC is Danish member in GERG. A group for LNG has recently been formed [16].
3. LNG terminal in Świnoujście

3.1. Importance of LNG terminals

The availability of LNG as a marine fuel is imperative if it is to become a realistic compliance strategy for ship owners. The starting point for supplying LNG as a marine fuel within Northern Europe is large scale import terminals. In general, these terminals are built to import gas to national gas networks and they must be expanded to include facilities to load feeder ships or trucks. However, for a full network infrastructure, more LNG terminals or storage facilities will be needed. These small and medium sized intermediary terminals will be centred within ports, can be onshore in the form of tanks or offshore as vessels. Furthermore, small-scale LNG liquefaction plants fed from national gas grids could be seen as part of these intermediary LNG terminals [2].

Poland was caught up in a row between Russia and the Ukraine, which resulted in a reduction of gas supplies to Poland, Hungary and Austria. The Polish government is anxious to avoid a repeat of this and is building an LNG terminal and investigating the possibility of a pipeline from Norway, Ukraine, Denmark or Germany.

3.2. Status and plans for the north European LNG terminals

The port of Świnoujście, Poland, situated directly on the sea, is among the largest seaports in the Baltic Sea region, connecting Scandinavia with central and southern Europe, as shown in Figure 3.1. It is also located close to Berlin (140 km), and another relevant asset is the access to the European inland navigation system through the Oder-Havel Canal.
The construction of LNG Regasification Terminal and External Port in Świnoujście as shown in Figure 3.2 has been acknowledged by the Government of the Republic of Poland as a strategic investment project for the energy security of the country, enabling the off take of offshore natural gas from practically any point in the world. This is the first project of its kind not only in Poland, but also in the Central and Western Europe, as well as in the Baltic Sea region. The completion of the construction work and commissioning is scheduled for 30 June 2014 [5].
The project of constructing LNG Regasification Terminal and External Port in Świnoujście will significantly impact the diversification of gas supplies to Poland, thanks to this, importing the raw material from any point in the world will make Poland independent from single source gas supplies. It is for this reason that on 19 August 2008 the Polish Council of Ministers of the Republic of Poland adopted a resolution in which this investment project was recognized as being strategic for the energy security of the nation. During the first stage of the operations of the LNG terminal the off take of 5 bn m³ of natural gas annually will be possible. During the next stage, depending on the demand for the raw material, it will be possible to increase the regasification capacity up to 7.5 bn m³, which constitutes approx. 50% of the current annual demand for gas in Poland. The current consumption of Poland is approx. 14 bn m³ of gas annually.

### 3.3. Maximum parameters for port of Świnoujście

The new terminal in Świnoujście will be built to suit the evolution in the size of ships in terms of ship length, breadth, and draft; the maximum dimensions are given in Table 3.1.

<table>
<thead>
<tr>
<th>Bulk carriers</th>
<th>Ferry terminal</th>
<th>BalticMax</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length: 270 m</td>
<td>Length: 210 m</td>
<td>Length: 350 m</td>
</tr>
<tr>
<td>Draught: 13.2 m</td>
<td>Draught: 7.0 m</td>
<td>Draught: 18.5 m</td>
</tr>
</tbody>
</table>

**Table 3.1** Maximum dimensions for ships types in Świnoujście port [2].

In the first stage of operation, the LNG terminal will enable the re-gasification of 5 bn m³ of natural gas annually. In the next stages, depending on the increase of demand for gas, it will be possible to increase the dispatch capacity up to 7.5 bn m³, without the need to increase the area on which the terminal will be constructed. In the LNG terminal in Świnoujście, the construction of two standard-sized containers is planned, such as are used in other terminals around the world, namely, with a capacity of 160,000 m³.
4. Design aspects of hull structure of gas carriers

4.1. Features and capabilities

Due to the extra care in designing, maintaining, operating, and inspecting LNG carriers, they have an excellent safety record.

The double hull feature of LNG carriers and many LPG ships is a required safety feature and the tanks of LPG ships which do not have this feature are required to be a minimum distance inboard of the shell. Fore end and aft end structure is similar to that for other ships. The cargo section is transversely or longitudinally framed depending primarily on size and distribution of loads in the same manner as other cargo ships, the inner hull receiving special consideration where it is required to support the containment system. All gas ships have spaces around the tanks which are monitored for gas leaks and in many ships these spaces are also inerted, an inert gas system being fitted aboard the ship. Liquid gas cargoes are carried under positive pressure at all times so that no air can enter the tanks and create a flammable mixture. The ballast tanks and its volume are very important, it will be impossible to fill the cargo tanks with water, during return journey in addition the density of the products, (LNG) is relatively low, which give great heights to hold a large freeboard and a relatively weak draft. Steel of hull ship of LNG ships is subjected to low temperature and embrittlement of steels at low temperature causes structural damage. For this reason, low-temperature service materials are selected according to the service temperature, tanks are sufficiently heat insulated, and secondary barriers are provided around the tanks as necessary to prevent the temperatures of the principal structural hull members from becoming excessively low in the event of gas leakage from the tanks.

Furthermore all gas carriers utilize closed cargo systems when loading or discharging, with no venting of vapor being allowed to the atmosphere.

In a small liquefied gas carrier with a length of less than 90 m, the single-hull/bottom construction is common, and in larger carriers, the construction of double bottom/single hull or double hull is employed, as necessary.
4.2. Types and general arrangement of gas carriers

Before go deep inside the ship construction of gas carriers its necessary to highlight the codes which control industry of LNG carriers, this gas codes was developed by International Maritime Organization apply to all gas carriers regardless of size. There are three gas codes and these are described below:

The code which applies to new gas carriers (built after 30 June 1986) is the International code for the construction and equipment of ships carrying liquefied gases in bulk. In brief, this code is known as the IGC code. The IGC code [8], under amendments to international convention for the safety of life at sea, (SOLAS), is mandatory for all new ships. As proof that a ship complies with the code, an international certificate of fitness for the carriage of liquefied gases in bulk should be on board. In 1993, the IGC code was amended and the new rules came into effect on 1 July 1994. Ships on which construction started on or after 1 October 1994 should apply the amended version of the code but ships built earlier may comply with previous editions of the IGC code.

Gas carriers built between 1976 and 1986, the regulations covering gas carriers built after 1976 but before July 1986 are included in the code for the construction and equipment of ships carrying liquefied gases in bulk. It is known as the gas carrier code or IGC code in short. Since 1975, International Maritime Organization IMO has approved four sets of amendments to the IGC code. The latest was adopted in June 1993 [8]. All amendments are not necessarily agreed by every government. Although this code is not mandatory, many countries have implemented it into national law.

Gas carriers built before 1977 (The existing ship code). The regulations covering gas carriers built before 1977 are contained in the code for existing ships carrying liquefied gases in bulk. Its content is similar to the IGC code, though less extensive. The existing ship code was completed in 1976 after the IGC code had been written. It therefore summarises current shipbuilding practice at that time [8].

Gas carriers must comply with the standards set by the Gas Codes or national rules, and with all safety and pollution requirements common to other tankers. The safety features inherent in the tanker design requirements have helped considerably in the safety of these tankers. Equipment requirements for gas carriers include temperature and pressure monitoring, gas detection and cargo tank liquid level indicators, all of which are provided with alarms and ancillary instrumentation. The variation of equipment as fitted can make the gas carrier one of the most sophisticated tankers afloat today.
There is considerable variation in the design, construction and operation of gas carriers due to the variety of cargoes carried and the number of cargo containment systems utilised. Gas carriers can be grouped into five different categories according to the cargo carried and the carriage condition [3]. These are as follows:

1- Fully pressurised carriers
These are generally the smallest type of gas carrier afloat (up to about 5,000 cubic meters), and carry products at ambient temperatures in cylindrical or spherical steel pressure vessels designed to withstand pressures up to 20 bars. They are not fitted with reliquefaction plant and represent a simple cost-effective means of transporting LPGs and chemical gases to the smaller gas terminals. Today, most fully pressurized LPG carriers are fitted with two or three horizontal, cylindrical or spherical cargo tanks, as shown in Figure 4.1. However, in recent years a number of larger capacity fully-pressurized ships have been built with spherical tanks.

![Figure 4.1 Fully pressurized carrier midsection, (double hull & single hull).](http://www.liquefiedgascarrier.com/fully-pressurized-ships.html)[Access 20 Nov, 2012].

2- Semi-pressurised carriers
With the development of metals suitable for containment of liquefied gases at low temperatures, semi-pressurized tankers were developed, by installing a reliquefaction plant, insulating the cargo tanks and making use of special steels, the thickness of the pressure vessels, and hence their weight, could be reduced. These carriers, incorporating tanks either cylindrical, as shown in Figure 4.2, spherical or bi-lobed in shape, are able to load or discharge gas cargoes at both refrigerated and pressurized storage facilities [8].
Those tanks are usually constructed by expert manufactures and the sizes are rather small due to the restriction coming from the design concept. Therefore those pressurized gas carriers are usually constructed by small shipyards. Material and constructions of conventional ships, though high tensile Steel having comparatively high yield point are used for cargo tank.

3- Ethylene carriers

Ethylene carriers are the most sophisticated of the gas tankers and have the ability to carry not only most other liquefied gas cargoes but also ethylene at its atmospheric boiling point of \(-104°C\). These ships feature cylindrical, insulated, Stainless Steel cargo tanks able to accommodate cargoes up to a maximum specific gravity of 1.8 at temperatures ranging from a minimum of \(-104°C\) to a maximum of \(+80°C\) and at a maximum tank pressure of 4 bars [8]. The general arrangement of this kind of ship is presented in Figure 4.3.
4- fully refrigerated LPG carriers

They are built to carry liquefied gases at low temperature and atmospheric pressure between terminals equipped with fully refrigerated storage tanks, as shown in Figure 4.4. However, discharge through a booster pump and cargo heater makes it possible to discharge to pressurized tanks too. The first purpose-built, fully refrigerated LPG carrier was constructed by a Japanese shipyard, to a United States design, in 1962. Prismatic tanks enabled the ship's cargo carrying capacity to be maximized, thus making fully refrigerated ships highly suitable for carrying large volumes of cargo such as LPG, ammonia and vinyl chloride over long distances. Today, fully refrigerated ships range in capacity from 20,000 to 100,000 m$^3$. 

Figure 4.3 General arrangement of Ethylene carrier.  

Figure 4.4 Midship section of fully refrigerated LPG carrier. 
5- LNG ships
LNG ships are specialized types of gas carriers built to transport large volumes of LNG at its atmospheric boiling point of about -162°C. These ships are now typically of between 125 000 and 150 000 m³ capacity and are normally dedicated to specific project. They often remain for their entire contract life, which may be between 20-25 years or more. The types of tank construction are: independent tank type, membrane tank type and semi-membrane tank type. LNG carriers normally have a double-hull/double-bottom construction, and secondary barriers, which are provided separately from the hull and used for a specific period (normally 15 days) to prevent the temperatures of hull structures from becoming excessively low due to liquid leakage from cargo tanks. There are currently three types of LNG vessels, each classified according to tanks fabrication technique
- gas transport membrane (tanks integrated with ship hull)
- Moss Rosenberg System (tanks independent of ship hull)
- IHI SPB tank-prismatic (Ishikawajima-Harima Heavy Industries has developed the self-supporting prismatic type B (SPB) tank. Only two vessels currently have the SPB containment system)

Also there is other two types of membranes was developed by a French company, Gas Transport and Technogaz. The third system (CS1) was done but it had little success. The next section 4.3 will provide more information about LNG carriers.

4.3. General arrangement and type of LNG carriers

4.3.1 Generalities

Today there are four containment systems in use for new build LNG carriers. Two of the designs are of the self-supporting type, while the other two are of the membrane type. There is a trend towards the use of the two different membrane types instead of the self supporting storage systems. This is most likely because prismatic membrane tanks utilize the hull shape more efficiently and thus have less void space between the cargo-tanks and ballast tanks. As a result of this, Moss type design compared to a membrane design of equal capacity will be far more expensive to transit the Suez Canal. However, self-supporting tanks are more robust and have greater resistance to sloshing forces, and will possibly be considered in the future for offshore storage where bad weather will be a significant factor. Every type of LNG carriers will be more detailed in second subsection 4.3.2.
4.3.2. Type A tanks

Type A tanks are constructed primarily of flat surfaces as shown in Figure 4.5. The maximum allowable tank design pressure in the vapour space for this type of system is 0.7 bars; this means cargoes must be carried in a fully refrigerated condition at or near atmospheric pressure.

![Figure 4.5 Self supported-type A tanks.](http://mh-mechanicalengineering.blogspot.com/2012/06/gas-carriers-ship.html)[Access 25 Nov 2012].

The material used for Type 'A' tanks is not crack propagation resistant. Therefore, in order to ensure safety, in the unlikely event of cargo tank leakage, a secondary containment system is required. This secondary containment system is known as a secondary barrier and is a feature of all tankers with Type 'A' tanks capable of carrying cargoes below -10°C.

For a fully refrigerated LPG carrier (which will not carry cargoes below -55°C) the secondary barrier must be a complete barrier capable of containing the whole tank volume at a defined angle of heel and may form part of the tanker's hull. In general, it is this design approach which is adopted. By this means appropriate parts of the tanker's hull are constructed of special steel capable of withstanding low temperatures. The alternative is to build a separate secondary barrier around each cargo tank.

The IGC Code stipulates that a secondary barrier must be able to contain tank leakage for a period of 15 days. On such tankers, the space between the cargo tank (sometimes referred to as the primary barrier) and the secondary barrier is known as the hold space. When flammable...
4.3.3. Membrane tanks

A liquefied gas tank design where the cargo is contained by a thin Stainless Steel or Nickel alloy flexible membrane. There are two membrane systems in use. In both cases the insulation is fitted directly into the inner hull and the primary barrier consists of a thin metal membrane less than one millimeter thick [15].

The gas transport system uses two such membranes constructed of ‘Invar’ (36% nickel-iron low expansion alloy). One acts as the primary barrier and the other the secondary barrier and they are separated by plywood boxes of perlite insulation. Similar boxes are fitted between the secondary barrier and the inner hull. Loading is transmitted through the insulation to the ship structure. No centerline division is possible in this type of tank, as shown in Figure 4.6. The other system, developed by Technigaz, has a stainless steel membrane as the primary barrier while the secondary barrier is included in the insulation, which consists of load bearing balsa and mineral woods.
Figure 4.6 Gas transport membrane (large LNG), Abdelkader membrane ship. (http://www.aukevisser.nl/supertankers/gas/id663.htm)[Access 28 Nov 2012].

The main characteristics of the ship in the Figure 4.6 are given in Table 4.1:

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Deadweight</td>
<td>87194 ton</td>
</tr>
<tr>
<td>Overall Length</td>
<td>298.43 m</td>
</tr>
<tr>
<td>LPP</td>
<td>285 m</td>
</tr>
<tr>
<td>Breadth</td>
<td>46 m</td>
</tr>
<tr>
<td>Depth</td>
<td>26.8 m</td>
</tr>
<tr>
<td>Draught</td>
<td>13 m</td>
</tr>
<tr>
<td>Freeboard</td>
<td>4.393 m</td>
</tr>
</tbody>
</table>

Table 4.1 Main characteristics of Abdllakadr LNG ship. (http://www.aukevisser.nl/supertankers/gas/id663.htm)[Access 28 Nov, 2012].

“EMSHIP” Erasmus Mundus Master Course, period of study September 2011– February 2013
The hull structure supports the membranes which is composited of following layers:

- Built with Invar (36% nickel iron alloy),
- 0.7 mm thick membrane, but corners are 1.5 mm thick,
- Primary and secondary membrane are the same,
- Insulation is of perlite with a total thickness of 540mm,
- Membranes are connected to hull hence they are prone to fatigue (max 120 N/m²).

Figure 4.7 Construction of Technigaz membrane.

4.3.4. Type C tanks

Type C tanks are normally spherical or cylindrical pressure vessels having design pressures higher than 2 bars. The cylindrical vessels may be vertically or horizontally mounted as shown in Figure 4.8. This type of containment system is always used for semi-pressured and fully pressurised gas carriers. In the case of the semi pressurised ships it can also be used for fully refrigerated carriage. Type C tanks are designed and built to conventional pressure vessel codes and as results, can be subjected to accurate stress analysis.
4.3.5. Type B tanks

Type B tanks can be constructed of flat surfaces or they may be of the spherical type. This type of containment system is the subject of much more detailed stress analysis compared to type A systems, these controls must include an investigation of fatigue life and crack propagation analysis.

This design is owned by the Norwegian company Moss Maritime and it is a spherical tank. This is to have from four to six tanks all along the centre line of the vessel. Surrounding the tanks is a combination of ballast tanks, cofferdams and voids. These areas give the vessel a double-hull type design. The outside of the tank has a thick layer of foam insulation that is either fitted in panels or in more modern designs wound round the tank. Over this insulation is a thin layer of "tinfoil" which allows the insulation to be kept dry with a nitrogen atmosphere. This atmosphere is constantly checked for any methane that would indicate a leak of the tank. Also the outside of the tank is regularly checked at a roughly 3 month interval for any cold spots that would indicate breakdown in the insulation [8].

Because of the enhanced design factors, a type 'B' tank requires only a partial secondary barrier in the form of a drip tray. The hold space in this design is normally filled with dry inert gas. However, when adopting modern practice, it may be filled with dry air provided that inverting of the space can be achieved if the vapor detection system shows cargo leakage. A protective steel dome covers the primary barrier above deck level and insulation is applied to
the outside of the tank. The type 'B' spherical tank is almost exclusively applied to LNG tankers; seldom featuring in the LPG trade.

The tank is supported around its circumference by the equatorial ring which is supported by a large circular skirt which takes the weight of the tank down to the ships structure as shown in Figure 4.9. This skirt allows the tank to expand and contract during cool down and warm up operations. During cool down or warm up the tank can expand or contract about 2 feet. Because of this expansion and contraction all piping into the tank comes in via the top and is connected to the ships lines via flexible bellows. Inside each tank there is a set of spray heads. These heads are mounted around the equatorial ring and are used to spray liquid LNG onto the tank walls to reduce the temperature. It is normal practice to keep onboard 5% to 10% of the cargo after discharge in one tank. This is referred to as the heel and this is used to cool down the remaining tanks that have no heel before loading. This must be done gradually otherwise you will cold shock the tanks if you load directly into warm tanks. Cool down can take roughly 36 hours on a Moss vessel so carrying a heel allows cool down to be done before the vessel reaches port giving a significant time saving.

![Figure 4.9 Self supported-spherical type B tanks.](http://mh-mechanicalengineering.blogspot.com/2012/06/gas-carriers-ship.html)[Access 28 Nov 2012].
This technology does have its advantages, while a membrane carrier has to remain at the fitting out pier for tank installation for a long time, spherical tanks can be manufactured simultaneously therefore spherical tank vessel takes much less time to complete. But there is a catch, spherical tanks are very heavy. Few shipyards have cranes strong enough to hoist these behemoths into the ships. And apart from that, the sleek membrane carriers are more fuel efficient. The type B spherical tank is almost exclusively applied to LNG carriers.

Figure 4.10 General arrangement of Alhamra LNG ship. (http://www.aukevisser.nl/supertankers/gas/id550.htm)[Access 28 Nov 2012].
The main characteristics of the ship in the Figure 4.10 are given in the Table 4.2.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length Overall</td>
<td>290.10 m</td>
</tr>
<tr>
<td>Length between Perpendiculars</td>
<td>275.00 m</td>
</tr>
<tr>
<td>Breadth (moulded)</td>
<td>48.10 m</td>
</tr>
<tr>
<td>Depth (moulded)</td>
<td>27.00 m</td>
</tr>
<tr>
<td>Design Draft (moulded)</td>
<td>11.30 m</td>
</tr>
<tr>
<td>Summer Draft (moulded)</td>
<td>11.767 m</td>
</tr>
<tr>
<td>Air draft</td>
<td>59.70 m</td>
</tr>
</tbody>
</table>

**Table 4.2 Main characteristics of Alhamra LNG ship.**


Spherical tank advantages:

1. Robust, flexible, and reliable,
2. Maintenance-free cargo tank structure,
3. Easy and quick stripping of tank,
4. Emergency pressure discharge in case of pump failure,
5. Within the tank hold space there is easy visual inspection of the insulation and the inner hull.

Although the first carriers had storage tanks that were made of 9% Nickel-Steel, that technology was quickly replaced by Aluminium tanks. Aluminium storage tanks proved to be more resistant to mechanical stress, rupture, and it was easier to correctly form them into a sphere. The main characteristic of the spherical tanks is the equatorial ring on which the tank “hangs”. The greatest mechanical and thermal stresses are precisely on the “equator”. That part of the ship’s structure must be able to absorb the deflections of the ship’s hull on one hand and the thermal and mechanical strains of the tank on the other hand.

As a resume the structure of the independent spherical tank type B can be divided to:

1. Outer skin of tank which is layer of Stainless Steel as shown in Figure 4.11, insulated by a layer of polyurethane or polystyrene foam, protects the inner Aluminium shell. This prevents the LNG from warming up, expanding and generating too much pressure. The maximum pressure is 0.7 bars, as shown bellow [6].
2. Central column which is a pipe tower with filling and discharging pipes, measuring lines and access ladder. It can be up to 40 meters high. The cargo pump is located at its base. The deck pipe system runs into the tank dome at the top [6].

3. Tank skirt which an equatorial ring part of the spherical tank, which is thus self supporting rests on foundations in the ship. A thermal brake, which prevents temperatures in the tank system from rising, is an important component here. The tank support skirt compensates for expansion or contraction of the spherical tank.

Type B tank however need not be spherical. There are type B tanks of prismatic (SPB) shape in LNG service as shown in Figure 4.12. The prismatic type B tank has the benefit of maximizing ship hull volumetric efficiency and having the entire cargo tank placed beneath the main deck. Where the prismatic shape is used, the maximum design vapour pressure is as for type A tanks limited to 0.7 bars.
4.4. Materials of Construction and Insulation

4.4.1 Construction Materials

The choice of cargo tank materials is dictated by the minimum service temperature and, to a lesser degree, by compatibility with the cargoes carried. The most important property to consider in the selection of cargo tank materials is the low-temperature toughness. This consideration is vital as most metals and alloys (except Aluminium) become brittle below a certain temperature.

Treatment of structural carbon steels can be used to achieve low-temperature characteristics and the Gas Codes specify low-temperature limits for varying grades of Steel down to -55°C. Reference should be made to the Gas Codes and classification society rules for details on the various grades of Steel.

According to the Gas Codes, tankers carrying fully refrigerated LPG cargoes may have tanks capable of withstanding temperatures down to -55°C. Usually, the final temperature is chosen by the ship owner, depending on the cargoes expected to be carried.
This is often determined by the boiling point of liquid propane at atmospheric pressure and, hence, cargo tank temperature limitations are frequently set at about -46°C. To achieve this service temperature, Steels such as fully killed, fine-grain, carbon-manganese steel, sometimes alloyed with 0.5 per cent Nickel, are used.

Where a tanker has been designed specifically to carry fully refrigerated ethylene (with a boiling point at atmospheric pressure of -104°C) or LNG (atmospheric boiling point -162°C), Nickel alloyed Steels, Stainless Steels (such as Invar) or Aluminium must be used for the material of tank construction.

### 4.4.2 Tank Insulation

Thermal insulation must be fitted to refrigerated cargo tanks for the following reasons:
- to minimise heat flow into cargo tanks, thus reducing boil-off,
- to protect the hull structure around the cargo tanks from the effects of low temperature.

Insulation materials for use on gas carriers should possess the following main characteristics:
- low thermal conductivity,
- ability to bear loads,
- ability to withstand mechanical damage,
- light weight,
- unaffected by cargo liquid or vapour.

The vapour sealing property of the insulation system, to prevent ingress of water or water vapour, is important. Not only can ingress of moisture result in loss of insulation efficiency but progressive condensation and freezing can cause extensive damage to the insulation. Humidity conditions must, therefore, be kept as low as possible in hold spaces.

One method to protect the insulation is to provide a foil skin acting as a vapour barrier to surround the system [21].

### 4.5. Information about loading process for LNG carriers

A typical cargo cycle starts with the tanks in a "gas free" condition, meaning the tanks are full of air, which allows maintenance on the tank and pumps. Cargo cannot be loaded directly into
the tank, as the presence of oxygen means one would encounter explosive atmospheric conditions within the tank. Also, the temperature difference could cause damage to the tanks. First, the tank must be inerted by using the inert gas plant, which burns diesel in air to remove the oxygen and replace it with carbon dioxide (CO₂). This is blown into the tanks until it reaches below 4% oxygen and a dry atmosphere. This removes the risk of an explosive atmosphere in the tanks.

Next, the vessel goes into port to "gas-up" and "cool-down", as one still cannot load directly into the tank: The CO₂ will freeze and damage the pumps and the cold shock could damage the tank's pump column.

Liquid LNG is brought onto the vessel and taken along the spray line to the main vaporizer, which boils off the liquid into gas. This is then warmed up to roughly 20°C in the gas heaters and then blown into the tanks to displace the "inert gas". This continues until all the CO₂ is removed from the tanks. Initially, the IG (inert gas) is vented to atmosphere. Once the hydrocarbon content reaches 5% (lower flammability range of methane) the inert gas is redirected to shore via a pipeline and manifold connection by the HD (high duty) compressors. Shore terminal then burns this vapor to avoid the dangers of having large amounts of hydrocarbons around which may explode.

Now the vessel is gassed up and warm. The tanks are still at ambient temperature and are full of methane [17].

4.6. Conclusion

The cargo containment systems will generally be either, type B LNG Carriers - Membrane systems (Gaz Transport / Technigaz) previously described. A full secondary barrier with inerted spaces is required for the membrane system. This system has a primary and secondary barrier that is constructed of a thin material and an insulation layer. Type B (Moss Rosenberg) this Type with spherical tank requires only a partial secondary barrier, a full double-bottom and side tank ballast system is fitted to all LNG ships.
5. Concept of the hull structure, material, topology and numerical modeling in Poseidon

5.1. General assumptions and design philosophy

The majority of LNG carriers are between 125 000 and 150 000 m$^3$ in capacity, big part of this ships are with spherical tank for liquefied natural gas which have been praised for their tank system, this system provide a reliable configuration and sloshing resistance, making it appropriate for use in areas with severe environmental conditions such as the North Sea and areas near the Baltic [4]. According to the information provided in pervious section about the LNG carriers design, and different type of construction, taken in account that my study will focus on the concept design of mega LNG carrier, convenient for new LNG terminal in Świnoujście Poland, and its environment conditions which make type B the best for this region, ship type and dimensions are chosen in Table 5.1.

<table>
<thead>
<tr>
<th>Mega LNG carrier type B</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>L$_{oa}$</td>
<td>293 m</td>
</tr>
<tr>
<td>B</td>
<td>49 m</td>
</tr>
<tr>
<td>T</td>
<td>12 m</td>
</tr>
<tr>
<td>D</td>
<td>27 m</td>
</tr>
</tbody>
</table>

Table 5.1 Main characteristics of studied ship [18].

This section is focused on the structural concept of the ship hull structure, starting by the defining the main characteristics of the ship, selection of the material, defining of structural topology, using Poseidon software. According to typical general arrangement and midship section for LNG ships type B given in Figure 4.9, and Figure 4.10, the first drawing of the ship is in Figure 5.1. Starting from the midship section of typical LNG carrier type B, cargo hold, ballast tanks locations, inner hull, double bottom, foundation deck, main deck and tank location which will be repeated along the mid part of the ship, where the fore end and aft end will be the same to other tankers, which actually mainly related to CB value, resistance, and ship speed.
The final general arrangement drawing for studied ship is always selected according to general arrangement of typical LNG carrier type B, as shown in Figure 5.2.

Figure 5.1 midship sections drawing for studied LNG ship [18].

Figure 5.2 General arrangement of studied LNG carrier [18].
5.2. Material selection of the hull structure

A popular philosophy in material selection is to assure that the material will behave at least as well as assumed in design calculation, this put the structural designer in challenge to continuously strive for lighter and more efficient structures, and as a result of marine life experience Steel became the marine construction material of choice in the late of 1800's due to its stiffness, strength and damage tolerance.

For a ship structure, structural design consists of two distinct levels: the preliminary design and the detailed design.

The preliminary determines the location, spacing, and scantlings of the principal structural members. The detailed design determines the geometry and scantlings of local structure (brackets, connections, cut-outs, reinforcements, etc).

Preliminary design has the greatest influence on the structure design and hence is the phase that offers very large potential savings. This does not mean that detail design is less important than preliminary design. Each level is equally important for obtaining an efficient, safe and reliable ship.

Among the first steps (preliminary design) in the design process, it is very important to define the initial concept of the hull structure, this give the main characteristics of the ship, in LNG carrier it have longitudinal system of construction, so some areas in the structure such as deck, side shell and bottom structures, has thicker plates which are adopted to resist against the existing higher stresses in these regions. Therefore high tensile steel proposed to be used for such plates and profiles to reduce their thicknesses.

Steel has been adopted for the entire hull structure, where two categories have been selected to be considered in different structural regions of the hull structure, normal hull structural Steel grade, A32, D32 and high tensile hull structural steel grade D36, is used where there is normally high stress and some special geometry where we should reduce the thickness of plating and take the cost in consideration in all stages, this will be decided in the end of calculation.

The design of LNG ship hull structure is essentially influenced by type of tanks, which is type B, so there is no central longitudinal bulkhead and the transversal main bulkheads should be where there is no spherical tank, not like in case of membrane, also it should be governed by the IGC code, need to withstand temps as low as minus 162°C, so the material selected to be used as first assumption are listed in Table 5.2.
Steel grade | $R_{eh}$ N/mm² | Structural members                                                                                                                                 |
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>D36</td>
<td>355</td>
<td>Shell plating in region of upper deck, including keel, deck plates and longitudinal bulkhead strakes outer bottom and foundation deck, inner bottom</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Bottom longitudinal girders</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Tank steel structure</td>
</tr>
<tr>
<td>D32</td>
<td>315</td>
<td>Transverse members, including floors, web frames, and plates forming transverse bulkheads;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Longitudinal stringers in the side shell as well as transverse bulkheads structures;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>side plates</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Longitudinal stiffeners for the whole structure.</td>
</tr>
</tbody>
</table>

**Table 5.2** Material selected for hull structure.

5.3. Hull structural modelling using Poseidon software

General guidance on the modelling necessary for the structural analysis is that the structural model shall provide results suitable for performing buckling, yield, and fatigue, to ensure that all dimensioning loads are correctly included, also new classification societies software provide the possibility to calculate the ship scantling starting from the ship numerical model. Poseidon is a tool created to design and analysis of ship design, for shipyards, design offices owners and operators ships. It features a clear interface for fast work. Poseidon computer code is powerful software developed by GL company, where I did my inter ship and I had the opportunity to learn and work on it. Poseidon is a great a tool intended to reduce the cost of and minimize time of work on the model, because of modelling proceeding so we can divide the main members in Poseidon as follow:

**Longitudinal members:** all longitudinal elements which are extend over the ship length and contribute to the longitudinal strength, such as shell, inner bottom, decks, stringers, longitudinal bulkheads (inner skin), and longitudinal girders.

**Transverses members:** all elements which are not contribute to the longitudinal strength such as web frames, floors and, transverse bulkheads may be also considered as transverse
members. The model prepared is from the aft part (bulkheads of engine room) Fr.70, till the collision bulkhead Fr.108, as shown in Figure 5.3.

**Figure 5.3** Selected part for modelling in Poseidon.

Starting with creating model it can be using typical amidships section of tanker ship in wizards option, where the ship characteristics present input data to define the hull shape. There is the frame table in ship longitudinal direction and transversal direction where to define the location of main longitudinal and transversal member like (double side shell, double bottom, decks, frames and girders), as it shown in Figure 5.4.

**Figure 5.4** Moulding in Poseidon using functional elements.
5.4. Framing system

Frame is the special coordinate value to represent the position of the hull section, structure member and compartment arranged along the longitudinal direction of ship.

Framework play the role of a rib cage and the hull is like the skin. The ribs hold the hull in its place, not allowing it to flex. Because the hull curves produce the classic boat shape, every rib has a unique shape framing spacing is in longitudinal and transversal directions, marine architects and engineers vary the number and the spacing of the frames based on the requirements of the hull and construction system.

Frame spacing is necessary to know the location of all structural elements such as web frames, longitudinal girders, floors and longitudinal stiffeners. As shown in Figure 5.5. The spacing of the primary structural elements is based on the elementary framing spacing in the longitudinal direction and the stiffener spacing in the transversal direction. In the developed design the framing spacing in both longitudinal and transversal direction is selected as assumption as follow:

- The longitudinal framing spacing is taken equal to 800 mm, along the aft part up to from Fr.0 to Fr.65,
- The longitudinal framing spacing is taken equal to 900 mm from Fr.65 to Fr.70,
- The longitudinal framing spacing is taken equal to 5040 mm in the amidships part up to Fr.108,
- The longitudinal framing spacing is taken equal to 3000 mm in for part,
- The transversal stiffener spacing in the double bottom area is taken equal to 900 mm, in the double side shell area.

The selection of framing system shows the importance of transversal framing according to the distribution of ship and cargo weight. It is combination between transversal system in the aft part and longitudinal system in the mid and for part.
5.5. Structural topology selection

The selection of the structural topology of LNG carrier is based on the typical LNG ships spherical tanks type B. This selection should obey the classification rules in every part, therefore, an initial structural topology of one cargo hold is defined, starting by the identification of the arrangement of the primary structural members, the location of watertight barriers and bulkheads, besides of other construction notes such as the inner hull spaces, and the arrangement of the elements of each structure.
In Figure 5.6 represent the first sketch which is taking in consideration the importance of double side shell for ballast tank, the foundation of the spherical tank, double bottom, and the main bulkheads which define where the spherical tank will be located.

### 5.6. Transverse bulkheads structure

Bulkheads represent walls within the ship that separate the different rooms or compartments. Bulkheads are designed to block fire and water from going to other compartments; also it increases the structure rigidity of the vessel. From the definition and because in this kind of ship, which has special spherical tanks, the bulkheads will take place where there is no tank, and they will surround this tank, to provide more space to ballast tanks, this ship has 4 spherical tank, so it will has 5 main bulkheads in the amidships part of course including safety distance between the bulkheads and the tank. Bulkheads in this ship does not connect the ship from shell to shell, but it will follow the curve of the cargo tank, so it gives more space to ballast tank, which is very important for stability taking into account the light density of LNG, the main dimensions of the bulkheads are presented in Figure 5.7. all this requirement are considered during drawing but here this repeat for more details while the design is appear in 3D view in Poseidon so the idea goes more clear.

![Figure 5.7 Bulkheads of LNG carrier.](image)

The special cargo tank, which is spherical, need special connection with the ship hull which is skirt around the tank as mentioned before, this skirt need foundation follow the skirt and cargo tank, for this raison the girders which support the bulkheads play another role to support the skirt foundation as shown in the Figure 5.8.
Figure 5.8 Bulkheads and water ballast.

5.7. Double bottom structure

The double bottom of a ship is not only an important strength member of the bottom construction but also a principal structural member for longitudinal hull strength. Every part of the structure must serve its mission and support the rigidity of the ship body, even the double bottom, will follow the spherical tank in order to provide sufficient space to the ballast tanks and to facilitate the access during the fabrication process, inspection and in case of reparation. The double bottom occupies all void space under the spherical tank with sloped part make connection with the foundation deck. The mid part of double bottom has high assumed to be 1600 mm, after that this double bottom follow the tank curve to be higher and inclined to connect the slop part. The frame spacing must be doubled in the double bottom, because of the local pressure come from water and weight of the structure as shown in the Figure 5.9, and Figure 5.10.
**Figure 5.9** Double bottom structural element arrangement in the transverse direction.

**Figure 5.10** 3D view of the bottom structure.
5.8. Deck structure

Deck in LNG carrier with spherical tank will occupy all spaces around the tank in level of main deck to give the facilities for walking around tank, and in the same time support the rigidity of the ship because this deck follow the transversal bulkheads which located under the main deck between the tanks, also deck in LNG ships type B play another role as tank foundation to disturb the weight of the tank to the hull of ship by special structure named cover, which will make the connection of the tank and double shell in level of main deck, as shown in the Figure 5.11.

![Figure 5.11 Main deck of LNG carrier.](image)

Main deck is located far from natural axes of the ship, so it will be subjected to high stress, in addition to the tank weight come from cover structure, so this deck should be very rigid and has great plat thickness.

5.9. Double side shell structure

The structure of double side shell is limited by the shell and longitudinal bulkhead, the space lifted for this area is equal to 2500 mm, in order to provide sufficient space to the passage way. In this area, the arrangement of the web frames is coincided with the arrangement of floors in the double bottom structure. This double shell will be shifted in level of foundation deck to the slop part which makes the connection with the double bottom as mentioned
before, to be repeated in the other side to create the inner hull structure as shown in the Figure 5.12, and Figure 5.13.

**Figure 5.12** Double side shell and foundation deck.

**Figure 5.13** 3D model of double side shell.
5.10. Foundation deck

The independent tank type B which is special for LNG ships, need special foundation and connection to disturb the cargo weight to the hull structure, this foundation follow the skirt in a circle over the slop and longitudinal girder of the main bulkheads as shown in the Figure 5.14, and Figure 5.15.

Figure 5.14 Foundation of spherical tank.

Figure 5.15 Skirt of spherical tank over foundation deck.
5.11. Midship section concept sketch

Figure 5.16 give short description of amidships section, where all main member appears, tank, skirt, slop, cover and double bottom structure where it is clear that the skirt play the main role of distribution of loads and stress come from cargo tanks, in the same time cover of the tank play in addition to its main role which is protect the tank, from any risk, cover play role of distribution the over loaded forces come from heeling or sloshing during ship trip, so it goes to rigid part of the ship which is upper deck, and keep the skirt structure safe.

![Figure 5.16 Amidships section.](image)

More drawing of structure members during modelling stages using Poseidon software are presented in figure 5.17, and Figure 5.18.
1-Defining of the main members.  2-Bulkheads locations.

3-Defining of foundation deck, ballast tanks and weather deck.

**Figure 5.17** Stages of modelling in Poseidon software.
5.12. Conclusion

Ship design is not only put some drawing on papers till reach a nice beautiful shape, none. All ship requirements must be taken in consideration during design stages, this requirement has big influence on the ship design as we have seen in this section, where the spherical tank, give a unique shape for LNG ships. Poseidon software is very powerful program, but it does not make a design where everything must be defined to reach the 3D model, to make all required calculations. All thickness and dimensions are assumed and it will be changed according to GL rules after calculations in the next part 6.
6. Hull structure scantling according to GL rules

6.1. Generality

Scantling is the dimensions of all elements according to global bending moment and local stress. It is also defined as dimension of building material and is basically the measurements of different parts of the ship especially for framing and structural ones. Scantling explains the structural strength through girders and beams in a particular section and scantling length is considered as structural length of the ship.

For the developed design, the structural scantling is performed according to GL rules, with the assistance of Poseidon computer program.

This chapter represents the procedure considered for dimensioning the hull structure, starting from the structural model in the previous section till the sizing of its structural elements.

6.2. Design criteria loads

GL Poseidon was created and is developed mainly to meet the requirements of yards and offices design, and determination of structural dimensions in classification under the provisions of GL and this go through several steps starting by making the model for study as mentioned before, then defining the tank loads, still water bending moment and shear forces.

6.2.1. Tank load

Tank in Poseidon software defined by compartment method, which located in double side shell and double bottom, this compartment define the ballast and fuel tanks, these compartments are separated by the watertight floors and web frames at the level of watertight transverse bulkheads, the arrangement of these tank are defined in Table 6.1, and represented in Figure 6.1.
<table>
<thead>
<tr>
<th>Tank type</th>
<th>Side shell</th>
<th>Start FR</th>
<th>End FR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ballast water</td>
<td>TWB1P</td>
<td>65</td>
<td>77</td>
</tr>
<tr>
<td>Ballast water</td>
<td>TWB1P2</td>
<td>81</td>
<td>86</td>
</tr>
<tr>
<td>Ballast water</td>
<td>TWB1P3</td>
<td>90</td>
<td>95</td>
</tr>
<tr>
<td>Ballast water</td>
<td>TWB1P4</td>
<td>99</td>
<td>108</td>
</tr>
<tr>
<td>Ballast water</td>
<td>TWB1S</td>
<td>65</td>
<td>77</td>
</tr>
<tr>
<td>Ballast water</td>
<td>TWB1S2</td>
<td>81</td>
<td>86</td>
</tr>
<tr>
<td>Ballast water</td>
<td>TWB1S3</td>
<td>90</td>
<td>95</td>
</tr>
<tr>
<td>Ballast water</td>
<td>TWB1S4</td>
<td>99</td>
<td>108</td>
</tr>
<tr>
<td>Ballast water</td>
<td>TWB2P</td>
<td>77+100</td>
<td>81</td>
</tr>
<tr>
<td>Ballast water</td>
<td>TWB2P2</td>
<td>86+100</td>
<td>90</td>
</tr>
<tr>
<td>Ballast water</td>
<td>TWB2P3</td>
<td>95+100</td>
<td>99</td>
</tr>
<tr>
<td>Ballast water</td>
<td>TWB2S</td>
<td>77+100</td>
<td>81</td>
</tr>
<tr>
<td>Ballast water</td>
<td>TWB2S2</td>
<td>86+100</td>
<td>90</td>
</tr>
<tr>
<td>Ballast water</td>
<td>TWB2S3</td>
<td>95+100</td>
<td>99</td>
</tr>
</tbody>
</table>

**Table 6.1** Arrangement of ballast tanks with compartments method.

![Diagram of ballast tanks](image)

**Figure 6.1** Location of compartment and ballast tank in different region.
Cargo tanks location and sizing are defined in Table 6.2 and represented in Figure 6.2 and Figure 6.3 respectively.

<table>
<thead>
<tr>
<th>Tank type</th>
<th>Location</th>
<th>Frame start</th>
<th>Frame end</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cargo tank 1</td>
<td>Symmetrical line (PS)</td>
<td>70+a/2</td>
<td>78+a/2</td>
</tr>
<tr>
<td>Cargo tank 2</td>
<td>Symmetrical line (PS)</td>
<td>79+a/2</td>
<td>87+a/2</td>
</tr>
<tr>
<td>Cargo tank 3</td>
<td>Symmetrical line (PS)</td>
<td>88+a/2</td>
<td>96+a/2</td>
</tr>
<tr>
<td>Cargo tank 4</td>
<td>Symmetrical line (PS)</td>
<td>97+a/2</td>
<td>105+a/2</td>
</tr>
</tbody>
</table>

Table 6.2 Arrangement of cargo tanks with compartments method.

Figure 6.2 Cargo tank location.

Figure 6.3 Ballast and cargo tank distribution.

“EMSHIP” Erasmus Mundus Master Course, period of study September 2011– February 2013
The previous work define the location of the tanks, the second step is define the density and volume of cargo tanks, which will be in option (content of compartment) shown in Figure 6.4.

![Figure 6.4 Content of compartment in Poseidon software.](image)

### 6.2.2. Stillwater bending moments, shear forces and torsion moment

A ship floating in still water has an unevenly distributed weight owing to both cargo distribution and structural distribution, the buoyancy distribution is also non uniform since the underwater sectional area is not constant along the length of the ship. Total weight and total buoyancy are of course balanced, but at each section there will be a resultant force, either an excess of buoyancy or excess of load. Since the vessel remains intact there are vertical upward and downward forces tending to distort the vessel, which are referred to as vertical shearing forces, since they tend to shear the vertical material in the hull.

According the fact that ship hull bend as a beam, Poseidon uses the maximum value of still water bending moment and shear forces, to calculate the scantling of longitudinal elements this values are provided by Poseidon based on GL rules. Figure 6.5 represent the default values of still water bending moment and shear forces given by Poseidon.
6.3. Scantling of longitudinal and transversal plates and its stiffeners

For determining the scantlings of the longitudinal hull structure, the maximum values given by Poseidon of the still water bending moments and shear forces are to be used [10], where Poseidon will consider the whole ship as a beam. The first step was to propose the scantling, and this scantling is checked by rules, according to the principal dimensions of the ship, and the section modulus results, every time the small or incorrect dimensions appear in the results window Figure 6.7, it will be changed according to the required thickness till we reach the correct values, for all members (longitudinal plating, stiffeners, girders, etc), the following algorithm in Figure 6.6, for Poseidon software shows all factors taken in consideration during the scantling progress.
**Figure 6.6** Scantling algorithms using in Poseidon, Germanischer Lloyd, 2012.

**Figure 6.7** Results of check command in Fr 83.
In the same time the type of steel also will be checked, in order to optimize the results come from rules check command, because program gives results according to our decisions for material used and other important factors, and this is the role of engineer, in my model at first using normal mild steel, it was not good for some places where there is high stress and big loading, like in weather deck, bilge and bottom, so it’s necessary to highlight some points which was taken in consideration and remarked during scantling progress where big dimensions are used in the results:

1. **For deck sizing**

Deck subjected to many various forces coming from cargo loads, wave loads, and axial forces due to sagging and hogging moments and because it is far from the neutral axis of the amidships section this stress goes to the maximum. Stress concentration also occurs at the corners of hatch openings, and the thickness of deck plates in such an area must be increased and be thick as shown in Figure 6.8. The scantlings of the strength deck must be determined so that the section modulus required for the amidships section is obtained.

![Figure 6.8 Deck region sizing.](image)
2. For bilge sizing

For bilge area, there is a huge pressure come from big ballast tanks with height goes to 23 m, also external pressure come from draft up to 12 m, so it really need big elements dimensions as shown in Figure 6.9, to resist such huge pressure and stress.

![Figure 6.9 Bilge region sizing.](image)

3. Bottom sizing

In a ship the natural axis is generally nearer to the bottom, since the bottom shell will be heavier than the deck, having to resist water pressure as well as the bending stresses, in calculation of the second moment of area of the cross section all longitudinal material is of greatest importance [1]. Figure 6.10 represent the stiffened plat scantling of bottom.

![Figure 6.10 Bottom region sizing.](image)

Another point of view for the material properties, the geometry of places, also can play big role in the decision, for example, it is not acceptable or even good to use normal steel in some
places with big dimension just because this dimensions good for such stress in this area, so the steel with $R_{eh} = 355\text{N/mm}^2$, is chosen to reduce this thickness and avoid congestion.

The primary scantling results is in the Table 6.3, this values in the table is approached to the maximum values, and also take some other consideration into account like docking for keel so one or one and half mm have been added:

<table>
<thead>
<tr>
<th>Name of element</th>
<th>t [mm]</th>
<th>Material type</th>
<th>Profile type</th>
<th>Dimension</th>
<th>Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shell keel</td>
<td>20</td>
<td>1</td>
<td>T</td>
<td>500<em>15.0</em>100*20.0</td>
<td>1</td>
</tr>
<tr>
<td>B1</td>
<td>17</td>
<td>1</td>
<td>T</td>
<td>500<em>15.0</em>100*20.0</td>
<td>2</td>
</tr>
<tr>
<td>B2</td>
<td>16</td>
<td>2</td>
<td>T</td>
<td>550<em>15.0</em>200*20.0</td>
<td>2</td>
</tr>
<tr>
<td>B3</td>
<td>18</td>
<td>2</td>
<td>T</td>
<td>800<em>15.0</em>200*20.0</td>
<td>2</td>
</tr>
<tr>
<td>Bilge</td>
<td>20</td>
<td>2</td>
<td>T</td>
<td>800<em>15.0</em>200*20.0</td>
<td>2</td>
</tr>
<tr>
<td>SH1</td>
<td>17</td>
<td>2</td>
<td>T</td>
<td>500<em>15.0</em>200*20.0</td>
<td>2</td>
</tr>
<tr>
<td>SH2</td>
<td>25</td>
<td>2</td>
<td>T</td>
<td>500<em>15.0</em>200*20.0</td>
<td>2</td>
</tr>
<tr>
<td>SH3</td>
<td>17</td>
<td>2</td>
<td>T</td>
<td>450<em>12.0</em>180*25.0</td>
<td>2</td>
</tr>
<tr>
<td>SH4</td>
<td>30</td>
<td>1</td>
<td>T</td>
<td>450<em>12.0</em>180*25.0</td>
<td>2</td>
</tr>
<tr>
<td>SH5</td>
<td>50</td>
<td>1</td>
<td>FB</td>
<td>500*50.0</td>
<td>1</td>
</tr>
<tr>
<td>Weather deck</td>
<td>50</td>
<td>1</td>
<td>FB</td>
<td>500*50.0</td>
<td>1</td>
</tr>
<tr>
<td>Second deck</td>
<td>40</td>
<td>2</td>
<td>T</td>
<td>300<em>10.0</em>200*10.0</td>
<td>1</td>
</tr>
<tr>
<td>Stringer at Z6</td>
<td>20</td>
<td>2</td>
<td>T</td>
<td>300<em>10.0</em>200*10.0</td>
<td>2</td>
</tr>
<tr>
<td>IH1</td>
<td>50</td>
<td>1</td>
<td>FB</td>
<td>500*50.0</td>
<td>2</td>
</tr>
<tr>
<td>IH2</td>
<td>30</td>
<td>1</td>
<td>T</td>
<td>500<em>15.0</em>100*20.0</td>
<td>2</td>
</tr>
<tr>
<td>IH3</td>
<td>14</td>
<td>2</td>
<td>T</td>
<td>500<em>15.0</em>100*20.0</td>
<td>2</td>
</tr>
<tr>
<td>IH4</td>
<td>13</td>
<td>2</td>
<td>T</td>
<td>500<em>15.0</em>100*20.0</td>
<td>2</td>
</tr>
<tr>
<td>IH5</td>
<td>14</td>
<td>2</td>
<td>T</td>
<td>500<em>15.0</em>100*20.0</td>
<td>2</td>
</tr>
<tr>
<td>Foundation deck</td>
<td>17</td>
<td>2</td>
<td>T</td>
<td>400<em>12.0</em>180*22.0</td>
<td>2</td>
</tr>
<tr>
<td>Slop</td>
<td>15</td>
<td>2</td>
<td>T</td>
<td>400<em>12.0</em>180*22.0</td>
<td>2</td>
</tr>
<tr>
<td>Double bottom</td>
<td>16</td>
<td>2</td>
<td>L</td>
<td>300<em>12.0</em>180*25.0</td>
<td>2</td>
</tr>
<tr>
<td>LG0</td>
<td>20</td>
<td>2</td>
<td>T</td>
<td>500<em>15.0</em>100*20.0</td>
<td>2</td>
</tr>
<tr>
<td>LG1</td>
<td>16</td>
<td>2</td>
<td>FB</td>
<td>200*12</td>
<td>2</td>
</tr>
<tr>
<td>LG2</td>
<td>16</td>
<td>2</td>
<td>FB</td>
<td>200*12</td>
<td>2</td>
</tr>
<tr>
<td>LG3</td>
<td>22</td>
<td>2</td>
<td>L</td>
<td>300<em>11.0</em>100*16.0</td>
<td>2</td>
</tr>
</tbody>
</table>

Table 6.3 Scantling for all longitudinal members and its stiffeners.

“EMSHIP” Erasmus Mundus Master Course, period of study September 2011–February 2013
The final section modulus values achieved according to results of scantling is $W = 55.253 \text{ m}^3$.
The value of midship section moment of inertia $I = 454 \text{ m}^4$.

6.3.1. Scantling of transversal plate

Using the same method the results of transversal plating are in table 6.4.

<table>
<thead>
<tr>
<th>Plate name</th>
<th>t [mm]</th>
<th>Material</th>
<th>Profile type</th>
<th>Dimensions</th>
<th>Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>W97H</td>
<td>16</td>
<td>3</td>
<td>FB</td>
<td>200*12.0</td>
<td>1</td>
</tr>
<tr>
<td>W97B</td>
<td>16</td>
<td>3</td>
<td>FB</td>
<td>200*12.0</td>
<td>1</td>
</tr>
<tr>
<td>W97A</td>
<td>18</td>
<td>2</td>
<td>FB</td>
<td>200*12.0</td>
<td>1</td>
</tr>
<tr>
<td>B97A</td>
<td>16</td>
<td>2</td>
<td>FB</td>
<td>200*12.0</td>
<td>1</td>
</tr>
<tr>
<td>B97B</td>
<td>15</td>
<td>2</td>
<td>FB</td>
<td>200*12.0</td>
<td>1</td>
</tr>
<tr>
<td>B97C</td>
<td>30</td>
<td>3</td>
<td>FB</td>
<td>250*16</td>
<td>1</td>
</tr>
<tr>
<td>FL97C</td>
<td>15</td>
<td>2</td>
<td>T</td>
<td>250<em>15.0</em>90*10.0</td>
<td>1</td>
</tr>
<tr>
<td>F97A</td>
<td>16</td>
<td>1</td>
<td>T</td>
<td>250<em>15.0</em>90*10.0</td>
<td>1</td>
</tr>
<tr>
<td>F97B</td>
<td>16</td>
<td>2</td>
<td>T</td>
<td>250<em>15.0</em>90*10.0</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 6.4 Transversal plat sizing.
6.3.2. Scantling of bulkheads structural elements

Ship is divided into subdivisions by transverse watertight bulkheads in accordance with the requirements of the rules. These watertight bulkheads are provided at the fore peak and aft peak, afore and abaft machinery spaces, and in cargo holds in a number corresponding to a ship's size. Watertight bulkheads are provided to prevent flooding due to collision or some other cause from spreading to other subdivisions and to serve as transverse structural hull members. In addition to the functions above, bulkheads act as fire partitions in case of fire and also as partitions for separating cargoes when loading. Watertight bulkheads are designed to prevent a ship sinking when flooded.

Using the Posidon section part for bulkheads, it is necessary to define the design criteria of bulkheads, which is watertight (WT), for every transversal plat. In the calculation it is clear the big thicknesses required for plating because of big frame spacing in the midship area, this thicknesses will be varied from the double bottom till the second deck and this thicknesses can be reduced using transversal stiffeners the results are shown in the Table 6.5 below, where stiffener support bulkheads goes from double bottom to foundation deck, then from foundation deck to second deck:

<table>
<thead>
<tr>
<th>Plat name</th>
<th>High of load center [m]</th>
<th>Thickness [mm]</th>
<th>Stiffeners, profile type</th>
<th>Dimensions</th>
</tr>
</thead>
<tbody>
<tr>
<td>F88A1</td>
<td>4</td>
<td>75</td>
<td>T</td>
<td>450<em>12.0</em>125*25.0</td>
</tr>
<tr>
<td>F88A2</td>
<td>7</td>
<td>68</td>
<td>T</td>
<td>450<em>12.0</em>125*25.0</td>
</tr>
<tr>
<td>F88A3</td>
<td>9</td>
<td>65</td>
<td>T</td>
<td>450<em>12.0</em>125*25.0</td>
</tr>
<tr>
<td>F88B1</td>
<td>12</td>
<td>55</td>
<td>T</td>
<td>550<em>12.0</em>200*20.0</td>
</tr>
<tr>
<td>F88B2</td>
<td>17</td>
<td>38</td>
<td>T</td>
<td>550<em>12.0</em>200*20.0</td>
</tr>
<tr>
<td>F88B3</td>
<td>21</td>
<td>28</td>
<td>T</td>
<td>550<em>12.0</em>200*20.0</td>
</tr>
</tbody>
</table>

Table 6.5 Calculation of bulkheads plating.
6.3.3. Transversal and longitudinal hull strength

6.3.3.1. Transverse members

According to GL rules under the given load assumptions the following stress values are not to be exceeded in the transverses and in the bulkhead girders: bending and axial stresses:

Normal stress  \( \sigma_x = \frac{150}{K} \) [N/mm\(^2\)]

Shear stress  \( \tau = \frac{100}{K} \) [N/mm\(^2\)]

Equivalent stress:  \( \sigma_v = \sqrt{\sigma_x^2 + 3\tau^2} \) [N/mm\(^2\)]

6.3.3.2. Longitudinal members

In the longitudinal girders at deck and bottom, the combined stress resulting from local bending of the girder and longitudinal hull girder bending of the ship's hull under sea load is not to exceed 230 N/mm\(^2\).

Poseidon give the default values of permissible still water bending moment, shear forces in both seagoing condition and harbour condition, the results are shown in the Figure 6.12 below:

![Figure 6.12 Calculation of permissible still water stresses.](image)
From Figure 6.12, we can see that that the permissible stress in Fr.86, in the deck region is 221 N/mm² and in the bottom 156 N/mm², from the same section in Poseidon in another table we can see the maximum bending moment and share forces in sagging condition and harbour condition, as shown in Figure 6.13.

According to GL rules [10], the verification of the stress combinations represented by the normal stresses $\sigma_L$ and shear stress $\tau_L$ due to the hull girder loads, the following load cases have to be considered:

- Load case 1: load caused by vertical bending and static torsional moment;
- Load case 2: load caused by vertical and horizontal bending moment as well as static torsional moment;
- Load case 3: load caused by vertical and horizontal bending moment as well as static and wave induced torsional moment.

Using Poseidon software the results of verification are in the Table 6.6.
Table 6.6 Load cases according to GL rules for Normal stress verification.

Load Case 1

Normal stress distribution

Load Case 2

Normal stress distribution

Load Case 3

Normal stress distribution
From the table above, the highest values of the normal stress it’s always in the weather deck region, because of the big distance from the natural axes, comparing with the other elements. The maximum magnitude is in the load case 1, with value reach to 191 MPa, and then load case 3 by values 182 MPa, then load case 2 by value 182 MPa, which always under the limits. In same manner the verification of shear stress is done, for the three load case as shown in the Table 6.7.

<table>
<thead>
<tr>
<th>Load Case 1</th>
<th>Load Case 2</th>
<th>Load Case 3</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="Shear stress distribution" /></td>
<td><img src="image2" alt="Shear stress distribution" /></td>
<td><img src="image3" alt="Shear stress distribution" /></td>
</tr>
</tbody>
</table>

**Table 6.7** Load cases according to GL rules for shear stress verification.
From the table of results above it's clear that, the shear stress is higher in the shell plates, near to natural axes, the values change from 59 MPa for LC2, 63 MPa for LC1, and 70 MPa for LC3.

The equivalent Von Mises stress for all the load cases is under the limit. The maximum value is observed in the load case1, where it reached 191 MPa in the upper deck, as it shown in Figure 6.14.

![Figure 6.14 Von Mises stress distribution.](image)

From this results we can see that Poseidon is a good insight on the normal stress, shear stress and Von Mises stresses in the amidships section due to the combined vertical bending moment, horizontal bending moment, tensional moment as well as the shear forces, which allows to know the behaviour of the structure and to verify the sufficiency of the scantling.

### 6.4. Hull steel mass estimation

Estimation of mass is very important work during the design phases of a vessel, taking by account the weight optimization and cost of the ship, the good results of this work will have big influence on the success of the project, but in same time the lack of systematic empirical data can also make the job difficult and create considerable uncertainty around the results.

In present the software of societies of classification, as Poseidon can calculate the mass of longitudinal, transversal and bulkheads members, for each section (frame), with details of every member, the total mass of the mid part of the ship (studied part), will be the weight of section, multiplied by the number of frames, but because of the method of calculation of
members in Poseidon, where the bulkheads members are in one different frame, the weight of hull steel will be:
Hull steel mass = mass of one cargo hold * number of cargo hold.
Mass of one cargo hold = mass of sections inside of this hold + mass of bulkheads.

The studied section is from Fr.79 to Fr.88 because of the special structure of the bulkheads where it goes from Fr.86 to Fr.88; the calculation of mass of bulkheads will be in the following frames, as it shows in the Table 6.8.

<table>
<thead>
<tr>
<th>Estimation of mass using Poseidon software (Fr.79 to Fr.88)</th>
<th>mass of Fr.83 t/m</th>
<th>Bulkheads Fr.86 t/m</th>
<th>Bulkheads Fr.88 t/m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Longitudinal plate</td>
<td>101.8</td>
<td>96</td>
<td>72</td>
</tr>
<tr>
<td>Longitudinal stiffener</td>
<td>18.6</td>
<td>22.7</td>
<td>29</td>
</tr>
<tr>
<td>Transversal plates</td>
<td>9.4</td>
<td>4.5</td>
<td>9.7</td>
</tr>
<tr>
<td>Transversal stiffener and girders</td>
<td>1.8</td>
<td>1</td>
<td>2.8</td>
</tr>
<tr>
<td>Mass of one frame</td>
<td>131*5.04 = 655 t</td>
<td>124 t</td>
<td>114 t</td>
</tr>
<tr>
<td>Mass of one cargo hold</td>
<td>655*9 = 5895 t</td>
<td>124*2 =248 t</td>
<td>114*2= 228 t</td>
</tr>
<tr>
<td>Total mass of one cargo hold section</td>
<td>5895+248+228 = 6371 t</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Table 6.8** Calculation of cargo hold mass.
6.5. Conclusion

This section showed how much Poseidon software is powerful and useful, were it was used to calculate the scantling of the ship, starting from proposal dimensions, modification of the these dimensions until the values of the sectional modulus in the midship section become within the limits of the permissible values provided by Poseidon software.

The results of scantling were also checked for normal, shear, and Von Mises stresses, in the studied section under combination of vertical, horizontal, and torsional bending moments in 3 load cases defined by GL rules, to verify the sufficiency of the scantling, which showed that the scantling resulted from Poseidon are sufficient against these loads defined by rules.

From the results of hull mass estimation above, it is obvious that the most quantity of mass is coming from the longitudinal members with percentage about 62% for plates, comparing with the transversal elements. This means that save in the total mass can be reached by saving in the mass of the longitudinal plates, also taking by consideration the cost of steel depending on its type, from the scantling section, a lot of longitudinal members are done by high tensile steel, this mean also the optimization of the longitudinal member weight is optimization of cost.
7. Strength analysis using finite element method

7.1. Objectives and structural modelling

The objective of the global strength analysis is to obtain a reliable description of the overall hull girder stiffness, to calculate and assess the global stresses and deformations of all primary hull members for specified load cases resulting from realistic loading conditions and the wave induced forces and moments, the procedure of stress evaluation are presented in Figure 7.1. The design stresses are to be based on direct calculations normally using general purpose linear FEM program systems or equivalent software as Poseidon in this work. The FEM models may include the complete ship or parts of the ship only, the length of FE model is over the full cargo hold region, taken by account that independent tanks are self supporting they do not form part of the ship's hull and are not essential to the hull strength [8].

The FE model is to include cargo tanks and the tank skirts, this is to ensure that the interaction between the tank and hull structure is correctly represented. The model is also to include the cargo tank covers and their connection to the upper deck.

The objectives of the structural analysis is to verify that the stress level, as well as a reasonable part of the hull, and buckling capability of primary structures under the applied loads cases are within the acceptable limits for the scantling results in the previous section.

Figure 7.1 Algorithm of stress evaluation by GL rules [20].
7.2. Description of the model

The finite element model is generated using Poseidon 3D-model where the mid part of the ship is done, from the objective it is obvious that the results of GL rules [10], scantling of structural elements will be used in this verification, where all the structural elements included in the model, the plates and the stiffeners are idealized using mode (3), in Poseidon, where the plates are modelled as shell elements, and the stiffeners are modelled as beam element.

According to the requirement given in the section cargo hold analysis of the GL rules, the model considered shall extend over one complete cargo hold and two half cargo holds.

Full details of the discontinuous mesh areas including example holes and man excess will be representing as it is where the model could show the correct behaviour of connecting elements. The Figure 7.2 represent mesh model for all designed part of the ship from Fr.70 to Fr.108.

![Figure 7.2 Full FE model.](image)
Because of the symmetry in all parts of the studied model, computer memory, available licenses, and limited time, generation of the FEM will be in half part of the ship, as shown in Figure 7.3.

![Figure 7.3 Mesh tolerances for studied part of LNG carrier.](image)

### 7.3. Boundary condition

The boundary conditions to be applied to the FE model are dependent on the extent of ship modelled and the load case to be analyzed. Different boundary conditions need to be applied for symmetric and asymmetric load cases. Symmetric boundary conditions for global loads suitable for the analysis of global loads. These boundary conditions allow the FE model to deflect globally under the action of hull girder vertical shear forces and bending moments. In the other hand symmetrical boundary conditions for local loads suitable for calculating stresses resulting from local loads. Because it removes the effects of hull girder bending from the FE model.

Unless there is asymmetry of the ship and cargo tank primary structure about the ship's centreline, then only one side of the ship needs to be modelled with appropriate boundary conditions imposed at the centreline.

The applied boundary conditions described in this subsection include the different requirements for half breadth FE ship models, taken in consideration that my study will be only for verification of stress coming from global bending moment resulting from applied load cases which will be defined in the next subsection 7.4, the definition of boundary condition in Poseidon will be as shown in Figure 7.4.
Figure 7.4 Boundary condition tables in Poseidon software.

<table>
<thead>
<tr>
<th>Model No</th>
<th>Item</th>
<th>cargc hold analysye fr 75-93</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location of Section</td>
<td>Support Condition</td>
<td>Boundary Value</td>
</tr>
<tr>
<td>X-Start</td>
<td>X-End</td>
<td>Y-Z Start</td>
</tr>
<tr>
<td>75</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>93</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>*</td>
<td></td>
<td>0.0 mm</td>
</tr>
<tr>
<td>*</td>
<td></td>
<td>0.0 mm</td>
</tr>
</tbody>
</table>

Table 7.1 Description of boundary condition.

In the same time another boundary element must be applied so the model can bend under loads as in real situation, these boundaries will be defined on 4 selected nodes in shell and inner hull in both model sides (Fr.75 & Fr.93), as shown in Figure 7.5, where the red colour related to applied boundaries.

Figure 7.5 Applied boundary condition on FEM model.
7.4. Loads specifications

7.4.1 Generality

It is necessary to investigate the longitudinal resistance of the vessel for different loading conditions, where the selected load cases for finite element model are defined according to the GL rules for liquefied natural gas; these load cases are based on the specified ship’s operating loading conditions and include all static load components. The actual draughts and all deadweight and lightweight items are to be applied. The rule design wave vertical bending moment distribution and the permissible vertical still water bending moment envelope, \( M_{sw} \) are also included. Buoyancy loads are to be applied as pressures, \( \rho gh \), to wetted shell elements, where \( h \) is the vertical distance from the waterline to the centre of the element.

According to GL rules [19], tanks together with their supports and other fixtures are to be designed taking into account proper combinations of the various loads listed hereafter:

- Internal pressure
- External pressure
- Dynamic loads due to the motion of the ship
- Thermal loads
- Sloshing loads

In this work the selected loads are:

1. External hydrostatic pressures,
2. Cargo pressure loads acting on the cargo tank structure, distributed to hull structure,
3. Permissible vertical still water bending moment envelope, \( M_{sw} \),
4. Vertical bending moment coming from wave \( M_{wv} \).

7.4.2. External loads

Using Poseidon software, it is easy to define the external loads, static and dynamic water pressure, for hogging and sagging conditions as shown in Figure 7.6.
In same manner, the maximum amplitude of waves related to hogging and sagging conditions must be defined.

**Figure 7.6** Definition of draught margin and wave number.

**Figure 7.7** Hogging wave height definitions.
7.4.3. Tank loads

In the same section in Poseidon the tank loads must be defined to be considered in the FEM calculation results, which is very important, the window of load defining is represented in Figure 7.9, where the only static pressure will be take in consideration without heeling and sloshing.

Figure 7.8 Sagging wave height definition.

Figure 7.9 Specification of loads in Poseidon software.
7.5. Selected load cases

The selection of load case is done taken by account the worst cases could ship face during its life, according to the rules; they are descript in the Table 7.2.

<table>
<thead>
<tr>
<th>Load case N</th>
<th>Load case description</th>
<th>Still water bending moment</th>
<th>Vertical wave bending moment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Tow full tanks and one empty in the middle + hogging wave, All still water load items</td>
<td>$M_{sw}$</td>
<td>$M_{wv}$</td>
</tr>
<tr>
<td></td>
<td>are to be applied. External hydrostatic pressure due the static waterline is to be</td>
<td>Hogging</td>
<td>Hogging</td>
</tr>
<tr>
<td></td>
<td>applied.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>One full tanks in the middle of the model</td>
<td>$M_{sw}$</td>
<td>$M_{wv}$</td>
</tr>
<tr>
<td></td>
<td>and tow empty in the two sides, + Sagging wave, All still water load items are to be</td>
<td>Sagging</td>
<td>Sagging</td>
</tr>
<tr>
<td></td>
<td>applied. External hydrostatic pressure due the static waterline is to be applied.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 7.2 Selected load cases [9].
More details about load case 1 and load case 2, are described in Table 7.3, and Table 7.4, and represented in Figure 7.11, 7.12, and Figure 7.13, respectively.

### 1- Load case 1 description

<table>
<thead>
<tr>
<th>Loading condition</th>
<th>2 full tanks with empty tank in middle</th>
</tr>
</thead>
<tbody>
<tr>
<td>External pressure</td>
<td>Hydrostatic due to static water line</td>
</tr>
<tr>
<td>Cargo pressure</td>
<td>Cargo pressure due to gravity</td>
</tr>
<tr>
<td>Additional applied</td>
<td>Rule hogging vertical design wave bending moment distribution and permissible hogging still water bending moment envelope, $M_{sw}$, are to be applied.</td>
</tr>
<tr>
<td>External pressure</td>
<td>Local wave crest (to be applied to full length of FE model)</td>
</tr>
</tbody>
</table>

**Table 7.3** Load case 1 description.

![Studied part, load case 1](image)

![Figure 7.11 Load case 1.](image)
2- Load case 2 description

<table>
<thead>
<tr>
<th>Loading condition</th>
<th>one full tank with two empty tanks in both sides</th>
</tr>
</thead>
<tbody>
<tr>
<td>External pressure</td>
<td>Hydrostatic due to static water line</td>
</tr>
<tr>
<td>Cargo pressure</td>
<td>Cargo pressure due to gravity</td>
</tr>
<tr>
<td>Additional applied</td>
<td>Rule sagging vertical design wave bending moment distribution and permissible sagging still water bending moment envelope, $M_{sw}$, are to be applied.</td>
</tr>
<tr>
<td>External pressure</td>
<td>Local wave crest (to be applied to full length of FE model)</td>
</tr>
</tbody>
</table>

Table 7.4 Load case 2 description.
Figure 7.13 FE model of load case 2.
7.6. Global load adjustment

It is necessary before run the calculation to calculate the applied global bending moment coming from still water, sagging and hogging conditions, to reach to the target value which will be adjusted on the model length after run the finite element model, the calculation of the target bending moment is presented in Table 7.5. After the generation of the finite element model and the unit loads, the global load case is adjusted in order to produce the target hogging or sagging scenarios and obtain the equilibrium of the full balanced model. This is achieved by applying the sectional forces and moments at the forward and aft ends of the model.

<table>
<thead>
<tr>
<th></th>
<th>Bending moment hogging KN·m</th>
<th>Bending moment sagging KN·m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Still water BM</td>
<td>4346759</td>
<td>-3591816</td>
</tr>
<tr>
<td>Vertical waves BM</td>
<td>5323515</td>
<td>-6078458</td>
</tr>
<tr>
<td>Total (target)</td>
<td>9670274</td>
<td>-9670274</td>
</tr>
</tbody>
</table>

Table 7.5 Total subjected bending moment.

From GL rules the allowable stress for the primary structural members are given in Table 7.6. Where: \( \sigma_N = \frac{Mt}{W} \), and the section model reached from pervious section after scantling results \( W = 55.259 \text{ m}^3 \).

<table>
<thead>
<tr>
<th></th>
<th>k</th>
<th>Normal stress ( \sigma_N ), N/mm²</th>
<th>Shear stress ( \tau ), N/mm²</th>
<th>Equivalent stress ( \sigma_v ), N/mm²</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>calculated</td>
<td>Allowable</td>
<td>calculated</td>
</tr>
<tr>
<td>Longitudinal members</td>
<td>0.72</td>
<td>247</td>
<td>190/k</td>
<td>138</td>
</tr>
<tr>
<td>Transverse members</td>
<td>1</td>
<td>150</td>
<td>150/k</td>
<td>100</td>
</tr>
</tbody>
</table>

Table 7.6 Allowable stresses.
7.7. Results evaluation

The stresses resulting from the application of the selected load cases are not to exceed the maximum permissible values given in Table 7.6 and since the permissible stresses is not the same for all the primary structural members, stresses have been checked separately. In the following figures the distribution of the Von Mises stress, and shear stress in the structural elements subjected to the load case 1, and load case 2 are given.

- **Von Mises stress results**

The distribution of Von Mises stress in the structure in both load cases is given in the Figure 7.15, 7.16, 7.17, and 7.18.
Figure 7.15 Von Mises stress results for load case 1.

Figure 7.16 Von Mises stress results in shell and bottom for load case 1.
Figure 7.17 Result of Von Mises stress of load case 2.

Figure 7.18 Von Mises stress results in shell and bottom for load case 2.
From the distribution of the Von Mises stress given in Figures above, in the both load cases considered the stresses tend to zero at the neutral axis, and start to increase until reach their maximum values at the structural elements which are located far from the neutral axis such as the upper deck and the outer bottom. The magnitude of the stresses is higher in the deck than in the bottom, this is because the deck is far from the neutral axis comparing with the outer bottom, as shown in Figure 7.19. This distribution conforms to the hull girder theory. In both load cases it is clear that in the main member the Von Mises stress are under the maximum value given in Table 7.6, except in some region where there is concentration of stress come from the geometry of this region, or width of the plats as its clear in case or sagging Figure 7.17 in the plat connecting the upper deck with cover of the tank, this plat has very small width (between DK1 and tank cover), and thickness 30 mm so it recommended to increase the thickness of this plate in all similar region to 35 mm.

Also in both load cases we can see that only part exceed the permissible stress, in the longitudinal girder supporting the bulkhead, as shown in Figure 7.15, and Figure 7.17 respectively, in the same level but in deferent side (if consider the bulkhead like reference), and this refer actually to high concentration of stress, in plat under the foundation deck, when it bend under sag or hog condition, this high stress can be understood more clear after seen the deformations in both load cases, because of the high shear forces in bulkhead region too.
Figure 7.20 Distribution of the Von Mises stresses in the transverse members for load case 1 & load case 2.

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The high stress appear in near to boundary region in Figure 7.20, is because of the high moment and shear forces, and this values are not real and it can be neglected. Also in the connection of tank cover and upper deck, but still under limits. Another high stress area noticed in the plat W97A, in load case1 (hogging), this can be explained because of the high shear stress near to the natural axes and compressing pressure coming from outside high draft (static pressure) and the distribution of the tank load through skirt and foundation deck to the hull structure near to this region.

- **Normal stresses**

The distribution of the normal stress in the model is represented in the Figure 7.21, where a smaller scale used to show the distribution of stress, up to 180 MPa.

![Figure 7.21](image_url)

**Figure 7.21** Distribution of the normal stresses in the model, used scale up to 180 MPa.
In the load case 1 (hogging), the stresses are higher in the middle of the model and decrease at the ends; this can be explained by the bending moment curve where the magnitude of the bending moment is significant in the middle of the model than at the ends. The distribution of the normal stress due to the longitudinal bending moment given in Figure 7.21 is conforming to the hull girder theory, since the stresses tend to zero at the level of the neutral axis and reach their maximum values at the upper deck and bottom areas.

All main members has normal stress under the limits, as shown in Figure 7.22 for normal scale, where the maximum values goes up to 225 MPa.

Figure 7.22 Normal stress distribution for load case 2, scale up to 300 MPa.
Shear stresses

The distribution of the shear stress for load case 1 and load case 2, in the model is represented in Figure 7.23 and Figure 7.24 respectively.

Figure 7.23 Shear stress distributions for load case 1.
The distribution of the shear stress in Figure 7.23 and Figure 24, for both load cases can be explained by the shear forces curves, for the first load case the shear stress is almost zero in the middle of the model and starts to increase at the regions which are close to the boundaries. Also it’s higher in the area near to the neutral axes as it’s clear in slop and region of foundation deck still all values under allowable values for shear stress given in Table 7.6. That conforms to the distribution of the shear force over the model which its magnitude is almost null at the centre and more important at the boundaries. Same distribution for the second load case (sagging), where the value of shear stress start to increase far from middle of model to the boundaries.

In the both load cases also it is clear that the shear stress values go high in the region of bulkhead (longitudinal girder supporting bulk head, foundation deck, and LG0 in double bottom).

Figure 7.24 Shear stress distributions for load case 2.
– Deflections

Because these calculations and results treat the whole ships structure as a single beam, where total bending loads, including still water bending moment and wave vertical bending moment, are the forces that the overall hull primary beam has to be capable of withstanding, deflection shows the response of the ship under considered loads, and what is important that the structure bend under limits which make all structural member safe and always far from critical states, which could produce concentration of high stress, fracture and fatigue.

Maximal deflections of the model under the considered loading cases are given in Table 7.7. The deformations of the model under the two first load cases are shown in Figure 7.25.

From Table 7.5, which show the same value of target moment for both load cases, it give the right explanation of the same values of deflection in Z direction in both load cases.

<table>
<thead>
<tr>
<th>Load case</th>
<th>Maximum deflection in [m]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>In X direction</td>
</tr>
<tr>
<td>Load case 1 (LC1)</td>
<td>-0.07702</td>
</tr>
<tr>
<td>Load case 2 (LC2)</td>
<td>-0.13711</td>
</tr>
</tbody>
</table>

Table 7.7 Maximum deflection of the studied ship under considered load cases.
Figure 7.25 Model deformations under selected load cases, scale 60.

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Deflection give good explanation about the results of stress distribution in pervious subsections, it shows the high compression in deck region, and high tension in bottom region in case of sagging, the same phenomena appear but in opposite manner in case of hogging where high compression appear in bottom, and high tension in deck region, far from neutral axes region which in both load cases has small displacement and.

In the same time deflection results give explanation about the high shear forces in region of bulkheads as shown in Figure 7.26.

![Figure 7.26 Von Mises stress & model deflection.](image_url)
7.8. Buckling

Buckling is to be investigated for all areas of primary structure, but particular attention is to be paid to the areas specified in Table 7.8. From Figure 7.26, for load case 1, where the model is subjected to the hogging condition, the bottom plating is subjected to compressing, in the other hand deck is subjected to compressing for load case 2, all members subjected to compression are listed in the table below:

<table>
<thead>
<tr>
<th>Structure item</th>
<th>Factor against buckling</th>
<th>Load case</th>
<th>Actual thickness</th>
<th>Required thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bottom structure</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bottom shell plating</td>
<td>1</td>
<td>LC1</td>
<td>20</td>
<td>18</td>
</tr>
<tr>
<td>Side structure</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Side shell plating</td>
<td>1</td>
<td>LC2</td>
<td>17</td>
<td>16</td>
</tr>
<tr>
<td>Inner side plating</td>
<td>1.1</td>
<td>All cases</td>
<td>13</td>
<td>12.7</td>
</tr>
<tr>
<td>Deck structure and tank covers</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Upper deck,</td>
<td>1</td>
<td>LC2</td>
<td>50</td>
<td>48.4</td>
</tr>
<tr>
<td>Tank covers</td>
<td>1</td>
<td>LC2</td>
<td>30</td>
<td>25</td>
</tr>
<tr>
<td>Structure supporting containment system</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Foundation deck in way of skirts</td>
<td>1,1</td>
<td>All cases</td>
<td>17</td>
<td>16</td>
</tr>
<tr>
<td>Skirt</td>
<td>1,1</td>
<td>All cases</td>
<td>25</td>
<td>25</td>
</tr>
</tbody>
</table>

Table 7.8 Buckling results.

Taken in account that the verification of buckling is done in Poseidon software section (GL rules, design principal), where the maximum values of normal and shear stress is used, so we can see that some of results are very close to the scantling result, but in the same time this results (required thickness), could be a bit smaller taking in account that the distribution of the stress along members are not the same.
7.9. Conclusion

From the result of finite element study, it’s obvious that the model is resist against the selected load cases which present the worst cases that ship could face during its serves, this loads as discussed previously are coming from static loads of cargo, and external loads, the discussion did not cover the extra loads coming from heeling, and sloshing of cargo tanks, because of limited time, also the study did not cover verification of stress in tank structure, because my thesis is focus on hull structure primary design. The results of high stress in critical region resulting from studied load cases are presented in Table 7.9.

<table>
<thead>
<tr>
<th>Load case</th>
<th>Structural member</th>
<th>Maximum Von Mises stress/ MPa</th>
<th>Verification with allowable stresses</th>
</tr>
</thead>
<tbody>
<tr>
<td>LC1</td>
<td>deck</td>
<td>261</td>
<td>✓</td>
</tr>
<tr>
<td>LC2</td>
<td>deck</td>
<td>260</td>
<td>✓</td>
</tr>
<tr>
<td>LC1</td>
<td>bottom</td>
<td>225</td>
<td>✓</td>
</tr>
<tr>
<td>LC2</td>
<td>bottom</td>
<td>238</td>
<td>✓</td>
</tr>
<tr>
<td>LC1</td>
<td>Cover connection with upper deck</td>
<td>189</td>
<td>✓</td>
</tr>
<tr>
<td>LC2</td>
<td>Cover connection with upper deck</td>
<td>185</td>
<td>✓</td>
</tr>
<tr>
<td>LC1</td>
<td>Tank cover</td>
<td>127</td>
<td>✓</td>
</tr>
<tr>
<td>LC2</td>
<td>Tank cover</td>
<td>94</td>
<td>✓</td>
</tr>
<tr>
<td>LC1</td>
<td>skirt</td>
<td>162</td>
<td>✓</td>
</tr>
<tr>
<td>LC2</td>
<td>skirt</td>
<td>146</td>
<td>✓</td>
</tr>
</tbody>
</table>

Table 7.9 Maximum recorded stresses for selected load cases.
7.10. Technical description

Figure 7.27 present technical description of the midship section of studied LNG carrier, as presented during the study, this ship is type B, with spherical tank, double hull, rounded bilge, type of profiles, material and dimensions of longitudinal stiffeners are presented in Table 6.3. Double hull and double bottom play big role in longitudinal strength of the ship and provide space for ballast. Upper deck region needed a very high thickness and material properties because it is farther from neutral axes, then bottom and other structures.

![Figure 7.27 Final technical description of midship section.](image-url)
8. Technology of hull construction

8.1. Manufacturing of the shell

Manufacture of the hull tanker is characterized by a particular technological process cycle. Tracing, marking sheets, profiles processing, prefabrication of the elements of the hull, welding sections, junction blocks and finally afloat, as shown in Figure 8.1.


Plates and sections undergo several preliminary steps such as:

**A- Leveling of plats**

The plates and sections used in the construction of the hull must be uniform and flat surfaces. Surface irregularities cause serious problems during tracing, cutting, dismantling and especially welding. Almost always the sheets and profiles supplied by the metallurgical complexes are deformed during transport, handling and storage.

**B- Surface Cleaning**

This is the process that allows us to clean the plates and sections of rust, corrosion and protect against moisture from the atmosphere. Before the execution of the plates and profiles that will be painted on both sides of a primer for its conservation and finally drying.
C- Cutting

Cutting plates and profiles suitable for the shell is a process related to equipment and resources available in the shipyards.

8.2. Prefabrication of sections

The appearance of the welding advantages, give the ability to increase the size of the ships, and the development of capability of production have led to a base of prefabricated of important elements. In addition, this leads us to reduce costs, improve quality, reduce assembly operations, and make the construction in the extreme conditions of manufacturing the most useful and easier. Figure 8.2 shows the manufacturing process in the shipyard.

![Figure 8.2 Manufacturing process.](http://www.marine-marchande.net/Reportages/500.000/500000.ht)[Access 7 Jan 2013].

8.3. Procedure of hull assembly

8.3.1. Determination of blokes

The calculation of the masses of the different blocks is made by means of the curve of the weight of the metal shell.

Note: The block of the superstructure is mounted separately.
8.3.2. Succession of assembly

Modern shipbuilders have widely adopted the concept of modular construction and are realizing the benefits associated with these methods. The most critical assembly phase is erecting the hull. It is most important that the huge 3D structural blocks assembled at this stage are accurately built. To achieve the required manufacturing accuracy these structural modules are nowadays commonly built with excess material which is trimmed before assembly. Advanced 3D coordinate measurement technology can be used to position these blocks efficiently at the hull erection site.

• Preparation of sections before their junctions,
• Tracing surplus assembly sections,
• Preparation of pieces of bottom, deck, bulkheads and side lined,
• Preparation of the sections to the carriage,
• Adjustment and control of the exact dimensions (depending on length and width),
• The transport of sections using cranes

![Figure 8.3 Hull assembly using cranes.](http://mpckr.blogspot.com/)[Access 7 Jan 2013].
8.3.2.1. Installation of the bottom

The bottom layers decomposed to make the construction more easy, Second step is to be reinforced by stiffeners very straight, their mating does not require the application of forces to ensure their adhesion. Just keep them vertically in their positions by suitable devices (combs, magnetic positioners). Welding is semi automatic, positioning of the center keel to weld the layers of both sides, positioning of the floors, as shown in Figure 8.4.

![Figure 8.4 Positioning of bottom](http://www.hazegray.org/shipbuilding/quincy/mps/constr.htm)[Access 6 Jan 2013].

8.3.2.2. Installation of bulkheads

It is verified after their positioning and fixing by welding points.

8.3.2.3. Installation of shell

Shell Assembly as shown in Figure 8.5 it involves the following steps:
- Installation and adjustment depending on the size of the upper deck,
- Assembly of parts: brackets, and webs,
- Control of element positions,
- Welding of the wall is done automatically.
8.3.2.4. Installation of the upper deck

The structure of the upper deck is composed of deck longitudinal and beams. The welding will be performed by the semi-automatic. After the welding and assembly operation, the block will be checked with X-ray photographs, a buoyancy control and finally we did the editing mechanisms piping.

8.3.2.5. Installation of LNG tanks

Because the spherical tanks are totally independent from the hull strength, it can be done alone then install it using cranes as shown in Figure 8.6.
9. Conclusion general

Ship design as seen previously, is not just one step or even hundred of steps but Spiral of stages overlapped, and often during design progress, some stages imposes significant changes on the design of the ship and especially in terms of stability calculations, which is with the strength calculation have the biggest influence on ship design after placing basic dimensions according to the ship serves, my previous studies, which included design using Poseidon software, then calculation of scantling according to GL rules integrated in the software, and strength calculation under selected load cases. Fall within primary structural design, which in design offices and shipyards must take into account more calculations and load cases, which make impossible for design to be applied or made in reality without run all necessary calculations in all spiral stages, as in strength calculation it should cover the local stress, coming from heeling, sloshing which by its turn depend on the tank type for LNG carriers.
Acknowledgements

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Many thanks to all the people I have come to know in Liege, Nantes, and Szczecin.

Finally, I want to extend my profound appreciation to my beloved parents for their love, and invaluable support during my life and studies.
List of references


[18] All drawing for studied ship are conventional for Algerian company of transport maritime, HYPROC.

[20] *GL HullManager & GL Poseidon* | 03.10.2012 | No. 42

## APPENDIX

**GERMANISCHER LLOYD**

- **PROGRAM**: POSEIDON ND RELEASE :12.0.2.1 (11. 6.12)
- **PROJECT/YARD NO.**: LNG mega carrier
- **MODELED BY**: hasan
- **PATH**: C:\Users\hp dv5\Desktop\EMSHIPHasanDeeb_DiplomaProjectLNG_final4
- **DATE AND TIME**: 04.01.13 17:53:56

- **NO. OF NODAL POINTS**: 22393
- **NO. OF BEAM ELEMENTS**: 14716
- **NO. OF PLANE STRESS ELEMENTS**: 25903
- **NO. OF BOUNDARY ELEMENTS**: 846
- **NO. OF P.S.E. MATERIAL**: 4
- **NUMBER OF EQUATIONS**: 133818

### GLC | FORCE (kN) | MOMENT (kN*m)
<table>
<thead>
<tr>
<th>No.</th>
<th>X</th>
<th>Y</th>
<th>Z</th>
<th>XX</th>
<th>YY</th>
<th>ZZ</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2083.0</td>
<td>-8121.7</td>
<td>33985.5</td>
<td>-924025.6</td>
<td>-4241758.2</td>
<td>-0.1020E+08</td>
</tr>
<tr>
<td>2</td>
<td>2680.3</td>
<td>21591.9</td>
<td>56175.8</td>
<td>-240734.4</td>
<td>-3633816.0</td>
<td>1095145.2</td>
</tr>
</tbody>
</table>

**STIFFNESS MATRIX DIAGONALS:**
- **MIN DIA=** 0.0000E+00
- **MAX DIA=** 0.1026E+12
- **COND.CHECK=** 0.1374E+03

Constraint Equations not considered for check of matrix.

- **Start of Solution**: 04.01.13 17:54:02
- **(with Pivoting)**
- **Factorization**: 04.01.13 17:54:08
- **Solve the linear system**: 04.01.13 17:54:31
- **End of Solution**: 04.01.13 17:54:33

### Loadcase | MAX DISPLACEMENTS | MAX ROTATIONS
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>X Nod 989</td>
<td>Y Nod20305</td>
</tr>
<tr>
<td>HOG</td>
<td>-0.07702</td>
<td>0.07057</td>
</tr>
<tr>
<td>2</td>
<td>X Nod17778</td>
<td>Y Nod 7400</td>
</tr>
<tr>
<td>SAG</td>
<td>-0.13711</td>
<td>-0.10131</td>
</tr>
</tbody>
</table>