Master Thesis

Structural Optimisation of Midship Region for Ro-Pax Vessel in Early Design Stage using FEA

Supervisors: Prof. Zbigniew Sekulski, West Pomeranian University of Technology, Szczecin
Mr. Abbas Bayatfar, Research Engineer, ANAST, University of Liege, Belgium
Reviewer: Prof. Philippe Rigo, University of Liege, Belgium

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1. Introduction

- **Optimisation**
  - the process of decision making when a number of alternative choices are available
  - an optimal solution has to be determined with regard to specific criteria
  - taking into account the restrictions and constraints set by the environment

- **Ship design** – a typical optimisation problem *involving multiple* and frequently contradictory *objective functions* and constraints
1. Introduction (contd.)

- Ships need to be optimised for
  - cost effectiveness
  - highest operational efficiency or lowest required freight rate
  - passenger and crew comfort and safety
  - minimum environmental impact, etc.

- Optimisation often requires **minimization** or **maximization** of property(ies) of the structure under given load cases and constraints.
2. Objectives

- Development of an **integrated platform** for the **optimisation of midship region of Ro-Pax vessel** using **ANSYS® APDL**, as finite element tool and **modeFRONTIER®**, as optimisation tool

- **No manual intervention** in the GUI of the integrated platform

- Determination of **optimum scantlings** and thereby the **minimum weight** *(objective)* of the midship region of Ro-Pax vessel

- Developing **polynomial response surfaces** *(RSM)* to replace the FEM package to reduce calculation time
3. Methodology

- **Response Surface (R Tool)**
- **Optimum Design**
- **Platform for Optimisation (modeFRONTIER)**
  - Objective Functions and Constraints
  - Design Variables
  - FEM Model (ANSYS APDL)
  - CAD Model (AVEVA Marine)
  - Idealised CAD Model (AVEVA Marine)
  - Loads and Boundary Conditions (BV Rules)
3. Methodology (contd.)

![Diagram of methodology](Image)

- Design Variables
- Optimiser
- Design Evaluation

**FEM Software**

- 3D CAD Model
- Modified CAD Model
- Mesh Generation
- Boundary Conditions & Loads
- Solution
4. Stiffened Panel Optimisation

• **Stiffened Panels**
  - basic building blocks in ships and marine structures
  - also find applications in box girder bridges, nuclear power plants, etc.
  - *reduction in stiffened panel weight* without losing their structural integrity yields *reduction in ship’s weight*
  - optimisation process to test the codes developed in ANSYS® APDL and understand the working of ANSYS® and modeFRONTIER® coupled loop
  - **Seven design variables**
    - plate thickness
    - number of longitudinal stiffeners
    - number of transverse stiffeners
    - longitudinal stiffener web height and web thickness
    - transverse stiffener web height and web thickness
  - **Weight – Objective function**
4. Stiffened Panel Optimisation (contd.)

- Optimisation loop using ANSYS® APDL
4. Stiffened Panel Optimisation (contd.)

- Convergence history for **Objective** function (**Weight** of the stiffened panel)
4. Stiffened Panel Optimisation (contd.)

- **Response Surface Method (RSM)**
  - Response surface using second order polynomial regression model

\[
W = 836.09904 + 233.42986Y_1 + 168.72417Y_2 + 116.81434Y_3 + 155.13404Y_4 + 114.26292Y_5 + 190.34547Y_6 + 136.51625Y_7 - 19.93504Y_1Y_2 + 12.16043Y_1Y_3 - 32.46640Y_1Y_4 + 16.12237Y_1Y_5 + 5.33439Y_1Y_6 - 13.15543Y_2Y_3 + 114.30040Y_2Y_4 + 90.76182Y_2Y_6 - 10.15464Y_2Y_7 + 76.85179Y_3Y_5 - 16.71419Y_3Y_6 + 41.21212Y_3Y_7 - 54.10183Y_4Y_5 + 70.96034Y_4Y_6 + 19.71127Y_4Y_7 + 58.45976Y_5Y_7 - 11.18839Y_2^2 + 21.54268Y_4^2 + 3.36939Y_7^2
\]

- **Relative difference in the weight** between FEM and RSM is less than **4%**
- Time taken for one calculation in a machine with Intel® Core i3, 2.0 GHz CPU and 4GB RAM
  - **FEM** – 30 seconds
  - **RSM** – milliseconds
5. Midship Region Optimisation of Ro-Pax Vessel

- **Ro-Pax Vessels**
  - designed to transport vehicles and passengers efficiently
  - midship structural design can be considered as a basic structural problem
  - the major part of hull follows the pattern of midship section
  - provides an approximate estimation of hull weight

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Length overall</td>
<td>220.00 m</td>
</tr>
<tr>
<td>Length between perpendiculars</td>
<td>210.00 m</td>
</tr>
<tr>
<td>Breadth</td>
<td>30.00 m</td>
</tr>
<tr>
<td>Depth</td>
<td>9.0 m</td>
</tr>
<tr>
<td>Draft</td>
<td>6.50 m</td>
</tr>
<tr>
<td>Block coefficient</td>
<td>0.629</td>
</tr>
<tr>
<td>Displacement</td>
<td>28000.00 t</td>
</tr>
</tbody>
</table>
5. Midship Region Optimisation of Ro-Pax Vessel

All dimensions are in mm
Drawings are not to scale
### Load Cases Based on BV Rules

<table>
<thead>
<tr>
<th>Load Conditions</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Full load on decks + (a+) + Sagging</td>
</tr>
<tr>
<td>2</td>
<td><strong>Full load on decks + (a+) + Hogging</strong></td>
</tr>
<tr>
<td>3</td>
<td>Full load on decks + (a-) + Sagging</td>
</tr>
<tr>
<td>4</td>
<td>Full load on decks + (a-) + Hogging</td>
</tr>
<tr>
<td>5</td>
<td>Full load on decks + (b) + Sagging</td>
</tr>
<tr>
<td>6</td>
<td>Full load on decks + (b) + Hogging</td>
</tr>
<tr>
<td>7</td>
<td>Full load on decks + (c+) + Sagging</td>
</tr>
<tr>
<td>8</td>
<td>Full load on decks + (c+) + Hogging</td>
</tr>
<tr>
<td>9</td>
<td>Full load on decks + (d+) + Sagging</td>
</tr>
<tr>
<td>10</td>
<td>Full load on decks + (d+) + Hogging</td>
</tr>
<tr>
<td>11</td>
<td>Ballast Condition + (a+) + Hogging</td>
</tr>
</tbody>
</table>
5. Midship Region Optimisation of Ro-Pax Vessel (contd.)

- Finite element model of midship region selected between two main frames, 4.8m extension.
- SHELL181 elements for plates
- BEAM188 elements for stiffeners
- Load case 2 considered
- RIGID elements are employed on ends of the model
- 2 Materials are available (Mild Steel and HSS)

<table>
<thead>
<tr>
<th>Material</th>
<th>Young’s modulus (MPa)</th>
<th>Yield Strength (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mild Steel</td>
<td>206000</td>
<td>235</td>
</tr>
<tr>
<td>High Strength Steel</td>
<td>206000</td>
<td>355</td>
</tr>
</tbody>
</table>
5. Midship Region Optimisation of Ro-Pax Vessel (contd.)

- Midship Region Optimisation
  - 58 Design variables in total
    - 30 for representing plate thicknesses
    - 10 for stiffener geometry
    - 18 for stiffener spacing
  - Constraints imposed
    \[
    \begin{align*}
    6 \text{ mm} & \leq t_p \leq 17 \text{ mm} \\
    400 \text{ mm} & \leq S_g \leq 700 \text{ mm}
    \end{align*}
    \]
  - Stiffener geometry database available from shipyard
  - Allowable stress values for the materials are calculated using the below equation (BV Rules NR467, Part B, Chapter 7, Section 3)
    \[
    \sigma_{VM} = \frac{R_y}{\gamma_R \gamma_M}
    \]
  - Resistance partial safety factor, \( \gamma_R = 1.2 \)
  - Material partial safety factor, \( \gamma_M = 1.02 \)
5. Midship Region Optimisation of Ro-Pax Vessel (contd.)

- Midship structural optimisation loop

[Diagram showing the optimisation process with various parameters and files such asThickness_Param, Stiff_Space_Param, Stiff_Prof_Param, ANSYS_APDL_Code, Stiff_Prof_DB, CAD_Model, Sea_Pressure_DB, Bilge_Stiff_Space, Plate_Thick_File, Stiff_Space_File, Stiff_Prof_File, DOSBatch, Exit, Trans_Stiff_Prof_File, Trans_Stiff_Space_File, Trans_Plate_Thick_File, vonMises_Stress_Mat1, Weight, vonMises_Stress_Mat2, Yield_Stress_Mat1, Min_Weight, Yield_Stress_Mat2]
5. Midship Region Optimisation of Ro-Pax Vessel (contd.)

- Convergence history for **Objective function** (Weight of the midship region of Ro-Pax vessel)
Comparison of Results with RSM

\[ W = 365.9242 + 4.3065Y_1 + 8.4978Y_3 + 18.1669Y_5 + 2.3236Y_6 + 21.1239Y_8 + \\
3.3606Y_{10} + 7.6034Y_{11} - 2.3262Y_{12} + 9.8896Y_{13} + 3.5447Y_{14} - 2.2277Y_{15} + \\
3.8099Y_{16} + 8.3646Y_{19} + 4.6476Y_{20} + 4.1471Y_{23} - 4.007Y_{24} + 24.7047Y_{25} + \\
8.0861Y_{26} - 2.3731Y_{28} + 9.2455Y_{31} + 1.9007Y_{32} + 2.4002Y_{33} + 16.3632Y_{34} + \\
5.0619Y_{35} + 7.6309Y_{37} + 17.3196Y_{38} + 10.2807Y_{39} + 31.5779Y_{40} - 29.7439Y_{41} \]
6. Summary

- Optimisation convergence history shows the ability to couple ANSYS® and modeFRONTIER® for structural optimisation.

- Feasibility of an automated structural optimisation loop achieved.

- Significant reduction of structural weight is possible through the optimisation in early design stage.

- Parametric code developed using ANSYS® APDL can be applied to different kind of ships with slight modifications.

- Response surface method is a reliable tool to replace the existing optimisation loops to reduce the calculation time.
7. Recommendations

- Frame spacing can be considered as design variable
- A coupled tool between CAD, FEA and optimisation software
- Loads from CFD analyses instead of rule based loads
- Load case 2 considered. All identified load cases have to be included.
Thank you!

http://www.wildoceanfilm.com/marketing/images/photos/marinelife/Big%20Ship.jpg