Structural assessment of an offshore ship-shaped fish farm

\[(EIv'')' = q - \rho A \ddot{v}\]

\[\begin{align*}
\Delta & = \Theta \sqrt{17} + \Omega \int_{a}^{b} \varepsilon \Theta \\
\chi^{2} & = \sum_{i=1}^{n} \{2.71\}
\end{align*}\]

Peter Angelo Ottersen
June 2017
Summary

Background

Interest in the fish farming industry, together with salmon demand, has had a significant increase in the past few years. At the same time, the problem with lice attaching to the salmon and environmental issues limits the production, forcing the industry to innovate new ideas and concepts. One idea is to move the fish farms from the inner fjords with calm water to the rough offshore sea demanding a much more complicated structure with higher requirements for structure analysis. The Norwegian ship design company "NSK ship design" is at this moment developing a 400m long offshore fish farm for the fish company "Nordlaks". This assignment addresses the hydrodynamic loads on this design using WAMIT to find the response and loads in the frequency domain and analyzed it in a wave spectrum with significant wave heights up to 10 meters.

Assignment

The following tasks for this assignment should be addressed in the project:

1. Literature study on the design of the floating fish farm, methods of relevant hydrodynamic analysis of the fish-farm.

2. Establish the design accordingly to given design drawings from NSK Ship Design. Generate a hydrodynamic model for WAMIT of the Fish-farm in Rhino.

3. Make inputs files to make WAMIT run and prepare Matlab codes to be able to read and post-process the data and results.

4. Obtain the hydrodynamic coefficients (added mass and damping) and excitation forces.

5. Perform a mesh convergence test to find the optimal mesh of the structure to use in the simulations.
6. Compute the RAOs in 6 motions with the headings from 180° to 90° (head-sea to beam-sea) and compute the Vertical and Horizontal Bending Moment (VBM & HBM) for the rigid body.

7. Generate a wave spectra for a sea state representing the position the structure is designed for and compute statistically short term analysis of the structure.

8. Using the VBM and HBM results, do a FEM analyze of a simplified mid-section which is exposed to the highest stress. Identify when yielding and buckling starts.

9. Conclude the work and suggest some recommendation for future work.
Preface

This thesis is submitted to the Nordic Master in Maritime Engineering at the Technical University of Denmark and Chalmers University of Technology.

The project was conducted by Peter Ottersen during the spring of 2017 in collaboration between the Department of Mechanical Engineering, Section of Fluid Mechanics, Coastal and Maritime Engineering at DTU, Mechanics and Maritime Sciences at Chalmers and NSK ship design.

The project was supervised by Associate Professor Ulrik Dam Nielsen and Postdoc Mostafa Amini Afshar from the Department of Mechanical Engineering at DTU, Senior Lecturer Per Hoström from the Department of Mechanics and Maritime Science at Chalmers and Håkon Ådnanes from NSK ship design.

Kongens Lyngby, June 28, 2017

Peter Angelo Ottersen (s162318)
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CHAPTER 1

Introduction

1.1 Introduction to the fish farm industry

With the increasing demand for fish and salmon together with the space and requirements for calm water inside fjords and near land reach the limits, the fish farm industry is facing some challenges to continue growing. While the demand for fish and food increases, the amount of wild fish in the ocean decreases. This makes us more dependent on industrial fish farming in the future. Despite the fact that it is obviously better to produce fish in fish farms compared to overfishing the ocean and exterminate the wild fish, it has some problematic issues to solve. The inshore placement of the fish farms faces concerns that discarded nutrients and feces can settle below the farm on the seafloor and damage the benthic ecosystem. Some critics are especially concerned about the influence of the use of antibiotic, lice medicament and other drugs used in this crowded aquaculture inshore. The consequences of this together with the large scale of escapes may be crucial for the natural aquaculture and are of big concern. Another big and expensive problem the salmon industry is facing is the big amount of lice that get attached to the fish thus may make the fish worthless. Much effort and resources are put into ongoing research to solve these issues. However, the amount of produced salmon has stagnated over the last few years and the industry is desperate to solve these problems to fulfill the demand. A solution is to move the fish cages offshore thus letting the waste sweep over a larger area on the sea bed and dilutes. Moving offshore will also diminish the conflicts that occur with other marine resource users in the inshore waters. Several companies are putting a lot of money and resources into designs of fish cages for the open sea where ocean current and dynamic loads are stronger. Due to this significant increase of dynamic loads from the higher energy, the complexity is higher and the demands for a more accurate analysis and calculation is crucial to succeeding. However, the race has been running for some companies for a while, and it seems that some of them are beginning to succeed. This chapter presents some ideas of the offshore fish farming.
The traditional floating fish farms are placed in protected areas with calm waters and may be a simple construction with floating tubes and with nets. A typical system are showed in fig:(1.1) where it is a stationed service plant where the workers are transported out when needed.

1.2 Offshore fish farms

This section shortly presents the offshore fish farm concept this project is analyzing additional to two other similar projects.

1.2.1 Nordlaks and NSK ship design’s fish farm concept, “Havfarm”

The project ”Havfarm” (offshore fish farm) is a current project by ”Nordlaks” together with ”NSK ship design” to develop a complete facility with all needed systems integrated into one big unit that may be stationed offshore. The project develops the current opportunities of the fish farming industry to new areas with new innovation and future provided solutions. The project may solve many of today’s problem with environmental issues in the fjords and infection of lice and diseases to the existing ecosystem by moving it out of the fjords, using an increased waste area and with 10m closed lice-skirt(walls).
1.2 Offshore fish farms

The fish farm will contain six fishing nets with depth down to 60 meters and may have the capacity to produce 10 000 ton fish. The extra space with access to all facilities as service, maintenance and living facilities on board for the workers makes the concept efficient.

Figure 1.3: Fish Farm illustration seen from side with the 60m deep fishing nets. Picture from presentation video.[17b]

Figure 1.4: Havfarm in rough sea. Picture from presentation video.[17b]

According to Nordlaks, this fish farm hull is designed to sustain 10-meter significant wave height[17b]. Regardless of the structural stress limitation, issues like slamming, green water on deck and escape of fish may occur with significant wave heights above this.
1.2.1.1 Design and dimensions:

The dimensions stated in this report are based on the published dimensions of ”Nordlaks” and NSK’s websites [17b][17a] in January 2017.

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td>431m</td>
</tr>
<tr>
<td>Width</td>
<td>54m</td>
</tr>
<tr>
<td>Height</td>
<td>38m</td>
</tr>
<tr>
<td>Draft</td>
<td>29.5m</td>
</tr>
<tr>
<td>Draft of lice wall</td>
<td>10m</td>
</tr>
<tr>
<td>Draft of note</td>
<td>60m</td>
</tr>
</tbody>
</table>

Table 1.1: Main dimensions for the construction.

1.2.2 Other concepts

1.2.2.1 Ocean Farm 1

Another offshore concept is Salmar’s Ocean Farm 1, which is a circle formed construction with a diameter of 110m. It claims to be the first offshore fish farm in the world which has been constructed in China and at the moment being shipped to Norway with estimated completion in the second half of 2017.
1.2.2 Fish farm egg

The fish farm egg is a completely closed body, developed by "Hauge aqua" for Marine Harvest. With the motivation to solve the problem regarding escape, lice, and waste, this idea hopes to produce cheaper salmon in bigger amounts with this closed solution. As the body is closed, it would be easier to control everything that comes in and out as well as the light. The waste will be collected which makes it possible to use it for e.g. energy generation. [17c]
1.3 Thesis guidance and outline

This thesis is build up with a methodology chapter where all methods and theory are explained, a geometry chapter and then the results presented in each belonging chapter. Following is a short description listed of the outline in this report:

- **Chapter 2 - Methodology:** A chapter explaining the methods and the theory needed to perform the tasks in this project.

- **Chapter 3 - The geometry:** A presentation of how the geometry is made and the "results" of the design and geometry used in the simulation.

- **Chapter 4 - Hydrodynamic calculations:** This chapter presents the post processed results of the WAMIT simulations of the transfer functions.

- **Chapter 5 - Statistic analysis:** A short-term analysis are performed with wave and response spectrum. These results are presented in this chapter.

- **Chapter 6 - Structural analysis of mid-section:** Using the available information of the geometry and the results from the short-term analysis, a stress analysis is presented in this section.

- **Chapter 7 - Discussion and conclusion:** Contains a short discussion and a short summary of the work followed with the final results. A suggestion of future work to complete a structural analysis of this project is listed at the end of this chapter.
CHAPTER 2

Methodology

This chapter contains the theoretical formulations for some of the used methods and explains how it has been conducted. This thesis may be divided into four main parts; 1. the creation of the geometry; 2. the hydrodynamic prediction of the transfer functions related to the hydrodynamic loads and responses; 3. The definition of wave spectra and response spectrum. And 4. the structural stress analysis. This chapter explains the theor of the three last parts.

2.1 Hydrodynamic loads

This section describes the theory in order to obtain the forces due to diffraction and radiation, and the body motions.

2.1.1 Basic knowledge

With the x,y,z coordinate-system, the translatory and angular motions for a ship may be defined as:

- \( \eta_1 \) = Surge
- \( \eta_2 \) = Sway
- \( \eta_3 \) = Heave
- \( \eta_4 \) = Roll
- \( \eta_5 \) = Pitch
- \( \eta_6 \) = Yaw

Table 2.1: Illustration of translatory and angular displacements
The headings used in this thesis are defined as:

![Figure 2.1: Incident wave headings.](image)

Figure 2.1: Incident wave headings.

The hydrodynamic loads can be found by linear wave theory where the total loads contains the loads due to incident waves, diffraction and the loads due to the body motions, radiation as illustrated in fig:(2.2)

In the linear theory, we can obtain results in irregular waves by adding together results from regular waves of different amplitudes, wavelengths and propagation directions.

2.1.1.1 Radiation

The radiation loads also called added mass and damping loads are the steady state hydrodynamic forces and moments due to harmonic rigid body motions without incident waves. The hydrodynamic added mass and damping loads can be written as:

\[ F_k = -A_{kj} \frac{\delta^2 \eta_j}{\delta t^2} - B_{kj} \frac{\delta \eta_j}{\delta t} \]  

(2.1)
2.1 Hydrodynamic loads

where $A_{kj}$ and $B_{kj}$ are the added mass and damping coefficient and $\eta_j$ is the harmonic motion mode.

2.1.1.2 Diffraction

The diffraction loads may be described as the external forces on the body when it is stuck without any motions as visualized in the first rubric in Fig. 2.2. The excitation force is:

$$F_{ex_i} = Re\{Ae^{i\omega t}X_i\}, \quad i = 1, 2, ..., 6$$  \hspace{1cm} (2.2)

where $A$ is the wave amplitude, $\omega$ is the wave frequency and $X_i$ is the complex amplitude of the exciting force or moment and can be found by the eq:

$$X_i = -\rho \int_{S_B} \int (\phi_0 + \phi_7) \frac{\delta \phi_i}{\delta n} dS$$  \hspace{1cm} (2.3)

where $S_B$ is the surface boundary condition, $\phi_0$ is the incident wave potential and $\phi_7$ is the diffraction potential.

2.1.1.3 Equation of motion

The principles of the total force may be described with the Newtons law, $F_{tot} = ma$. This is maintained in the total load of the body in the equation of motion:

$$\sum_{j=1}^{6} \xi_j[-\omega^2(M_{ik} + a_{ij}) + b_{ij} + c_{ij}] = AX_i$$  \hspace{1cm} (2.4)

where $\omega^2$ is the acceleration, $M_{ij}$ are the mass matrix, $a_{ij}$ and $b_{ij}$ is the added mass and damping coefficient and $c_{ij}$ is the hydrostatic force.

As WAMIT computes the displacement RAOs only, the velocity and acceleration RAOs needs to be calculated manually which may be found with the displacement of the oscillator:

$$x_j(t) = \Re\{\xi_j e^{i\omega t}\}$$  \hspace{1cm} (2.5)

where $\xi_j$ is the complex displacement and the velocity oscillator is the derivative of the displacement:

$$\dot{x}_j(t) = \Re\{i\omega \xi_j e^{i\omega t}\}$$  \hspace{1cm} (2.6)

and the acceleration of the oscillator is the double derivative:

$$\ddot{x}_j(t) = \Re\{-\omega^2 \xi_j e^{i\omega t}\}$$  \hspace{1cm} (2.7)
2.2 The internal force and moments

As the internal forces and moments can not be obtained directly in WAMIT, these calculations need to be performed externally in a post-process. This section describes the calculations used as explained in "Ship motions and sea loads" [STF71].

The dynamic loads contribute to shear forces, bending moment and torsional forces on the body visualized in the figure:

![Dynamic loads components on ship.](source)

The shear and compression forces at the section are:

\[ V = V_1 i + V_2 j + V_3 k \]  \hspace{1cm} (2.8)

where \( V_1 \) is the compression, \( V_2 \) is the horizontal shear force and \( V_3 \) is the vertical shear force.

The bending and torsional moment are:

\[ M = V_4 i + V_5 j + V_6 k \]  \hspace{1cm} (2.9)

where \( V_4 \) is the torsional moment, \( V_5 \) is the vertical bending moment and \( V_6 \) is the horizontal bending moment.

The dynamic shear forces are the difference between the inertia force at the cross section and the sum of all external forces and similarly with the bending moment which is the difference between the moment of inertia and the torsional and bending moment.

The external forces are:

\[ V_j = I_j - R_j - E_j - D_j \]  \hspace{1cm} (2.10)

where \( j \) is the axis (1-6), \( I_j \) is the inertia force which basically is the sectional mass times the sectional acceleration, \( R_j \) is the restoring force which is due to the motion of the body. \( E_j \) is the exciting force and \( D_j \) is the hydrodynamic force and moment due to ship motion.
To calculate these components, the $I_j$ and $R_j$ are not given in the WAMIT outputs and need therefore to be calculated manually. It is the shear forces, torsion, vertical and horizontal bending moment which are the most interesting part. To calculate this, following equations are required:

The sectional inertia forces:

\[
I_3 = \int m(\ddot{\eta}_3 - \ddot{\eta}_5)\,d\xi \tag{2.11}
\]

\[
I_4 = \int m(i\dot{\eta}_4 - m\ddot{z}(\ddot{\eta}_2 + \xi\ddot{\eta}_6))\,d\xi \tag{2.12}
\]

\[
I_5 = - \int m(\xi - x)(\ddot{\eta}_3 - \ddot{\eta}_5)\,d\xi \tag{2.13}
\]

\[
I_6 = \int m(\xi - x)(\ddot{\eta}_3 + \xi\ddot{\eta}_6 - \ddot{\eta}_4)\,d\xi \tag{2.14}
\]

Here $\ddot{\eta}_j$ is the body acceleration, $m$ is the sectional mass, $\ddot{z}$ is vertical center of gravity, $i_x$ is the sectional mass moment of inertia and $\xi$ is the section of the ship and would work as a moment arm.

The sectional restoring forces are:

\[
R_3 = -\rho g \int b(\eta_3 - \xi\eta_5)\,d\xi \tag{2.15}
\]

\[
R_4 = g\eta_4 \int (\rho a\ddot{m} - m\ddot{z})\,d\xi \tag{2.16}
\]

\[
R_5 = \rho g \int b(\xi - x)(\eta_3 - \xi\eta_5)\,d\xi \tag{2.17}
\]

where "b" is the sectional beam, "a" is the sectional submerged area, $\ddot{m}$ is the distance between the water plane and the sectional meta-center. $R_6$ is zero.
2.3 Panel method

This section contains a short description of the panel method and the software WAMIT which is used in this project.

2.3.1 Introduction

Numerical calculations to predict wave effects on offshore structures have achieved an important role in offshore engineering, compared with a physical model test. [NL05] John L. Hess and A.M O. Smith published in 1967 a paper [HS67] where they developed the panel method also known as the boundary integral equation method (BIEM) and demonstrated its validity for three-dimensional bodies and it has become a widely used and appropriate method to predict wave effects on large vessels. This method is fundamentally based on Green’s theorem, where the velocity potential at any point in the fluid is represented by surface distributions of singularities over the boundary surfaces. [Fal99] The method of Hess and Smith is referred to as the “low-order panel method” where the following steps are applied: [NL05]

- The potential is represented either by source distribution of unknown strength over the body surface or by Green’s theorem where the source strength is known and the dipole moment is equal to the unknown potential.

- The body surface is approximated by a large number N of small quadrilateral panels.

- The source strength and dipole moment are assumed constant on each panel.

- In the source formulation, the normal derivative of the potential is evaluated at the centroid of each panel and set equal to the normal velocity at that point.

- From this potential the pressure on each panel is evaluated, and integrated to compute the required forces and moments.

2.3.2 About WAMIT

WAMIT is a computer program based on the linear and second-order potential theory using panel method for analyzing a submerged body with an incident wave in the frequency domain. The program computes separate solutions of the diffraction problem and the radiation problem. From this solution, the program computes relevant hydrodynamic parameters like added mass, damping coefficients, exciting forces, RAO’s and hydrodynamic pressure.

The low-order method which is mainly used in this assignment uses the geometry represented with quadrangular panels where the velocity potential is assumed to be constant for each panel.
WAMIT may also consider multiple bodies and compute the hydrodynamic interaction between them. In addition to computing the rigid-body in the six degrees of movement, WAMIT also has the possibility to compute the hydrodynamic computation with hydro-elastic deformation.

2.3.3 Input files

The inputs files needed to run WAMIT is name file (.wam), a geometry file (.GDF), a potential control file (.POT), a force control file (.FRC), and configuration files (wam) and (cfg) which are attached in the appendix.

2.3.3.1 Force Control File

In the force control file, the command of which operations WAMIT shall runs and output, the center of gravity (CG) on the body and the mass matrix is defined. The information of CG and the mass matrix is based on information from RHINO 3D.

The mass matrix contents following components:

\[
M = \begin{pmatrix}
m & 0 & 0 & 0 & mz_g & -my_g \\
0 & m & 0 & -mz_g & 0 & mx_g \\
0 & 0 & m & my_g & -mx_g & 0 \\
mz_g & 0 & -mx_g & I_{11} & I_{12} & I_{13} \\
-my_g & mx_g & 0 & I_{21} & I_{22} & I_{23} \\
\end{pmatrix}
\]  

(2.18)

where m is the mass,

\[
m = \rho \nabla
\]  

(2.19)

and \(x_g, y_g, z_g\) is the coordinates of the center of gravity and the \(I_{ij}\) is the moment of inertia:

\[
I_{ij} = \rho \nabla r_{ij} |r_{ij}|
\]  

(2.20)

where \(\rho\) is the water density and \(r_{ij}\) distance to the hull shell.

For a cubic geometry like a barge, the moment of inertia is:

\[
I_{11} = m \frac{(H^2 + B^2)}{12}
\]  

(2.21)

\[
I_{22} = m \frac{(B^2 + L^2)}{12}
\]  

(2.22)

\[
I_{11} = m \frac{(H^2 + L^2)}{12}
\]  

(2.23)

where \(H\) is the height, \(B\) is the width and \(L\) are the lengths of the body.
2.3.4 Output from WAMIT

From the output files .1, .2, .4 and .5p the following results are presented:

| outputfile.1: | PER | I | J | \( \hat{A}_{ij} \) | \( \hat{B}_{ij} \) |
| outputfile.2: | PER | BETA | I | Mod\((\vec{X}_i)\) | Pha\((\vec{X}_i)\) | Re\((\vec{X}_i)\) | Im\((\vec{X}_i)\) |
| outputfile.3: | PER | BETA | I | Mod\((\vec{X}_i)\) | Pha\((\vec{X}_i)\) | Re\((\vec{X}_i)\) | Im\((\vec{X}_i)\) |
| outputfile.4: | PER | BETA | I | Mod\((\vec{\xi}_i)\) | Pha\((\vec{\xi}_i)\) | Re\((\vec{\xi}_i)\) | Im\((\vec{\xi}_i)\) |
| outputfile.5p: | PER | BETA | M | K | Mod\((\vec{p}_i)\) | Pha\((\vec{p}_i)\) | Re\((\vec{p}_i)\) | Im\((\vec{p}_i)\) |

Table 2.2: The content in output files .1 - .5p.

If the option; INUMOPT5=1 is used, the diffraction and radiation, components are separated into following output:

| outputfile.5p: | PER | M | K | Re\((\vec{p}_1)\) | Im\((\vec{p}_1)\) | ... | ... | Re\((\vec{p}_n)\) | Im\((\vec{p}_n)\) |
| PER | BETA | M | K | Re\((\vec{p}_D)\) | Im\((\vec{p}_D)\) |

Table 2.3: The content in the separated pressure output file .5p.

Where "n" is the definition for degree of motion and is 6 for the six rigid-body.
2.3.4.1 Non-dimensional

**ADDED MASS  DAMPING COEFFICIENT**

The non-dimensional definition of the added mass and damping coefficients are:

\[
\bar{A}_{ij} = \frac{A_{ij}}{\rho L^k} \quad \bar{B}_{ij} = \frac{B_{ij}}{\rho L^k \omega} \quad (2.24)
\]

Where:
- \( k = 3 \) for \((i, j) = (1, 2, 3)\)
- \( k = 4 \) for \((i = 1, 2, 3, j = 4, 5, 6)\)
- \( k = 5 \) for \((i, j) = (4, 5, 6)\)

So the dimensional added mass and damping coefficients from WAMIT can be obtained as:

\[
A_{ij} = \bar{A}_{ij} \rho L^k \quad B_{ij} = \bar{B}_{ij} \rho L^k \omega \quad (2.25)
\]

**EXCITING FORCES**

The non-dimensional definition of the exciting forces are:

\[
\bar{X}_i = \frac{X_i}{\rho g A L^m} \quad (2.26)
\]

Where:
- \( m = 2 \) for \((i = 1, 2, 3)\)
- \( m = 3 \) for \((i = 4, 5, 6)\)

So the dimensional exciting forces from WAMIT can be obtained as:

\[
X_i = \bar{X}_i \rho g A L^m \quad (2.27)
\]

**BODY MOTIONS**

The non-dimensional definition of the body motions are:

\[
\bar{\xi}_i = \frac{\xi_i}{A/L^n} \quad (2.28)
\]

Where:
- \( n = 0 \) for \((i = 1, 2, 3)\)
- \( n = 1 \) for \((i = 4, 5, 6)\)

The dimensional body motions (RAOs) are:

\[
\xi_i = \bar{\xi}_i A/L^n \quad (2.29)
\]
HYDRODYNAMIC PRESSURE

The non-dimensional hydrodynamic pressure on each panel is defined as:

\[ \bar{p} = \frac{p}{\rho g A} \]  

(2.30)

So the dimensional pressure from WAMIT can be obtained as:

\[ p = \bar{p} \rho g A \]  

(2.31)

FIND \( \frac{\lambda}{L} \) FROM \( \omega \):

In order to get the ship-length/wave-length \( \frac{\lambda}{L} \) from the frequency \( \omega \), the dispersion equation for deep water are used:

\[ \omega^2 = g k \rightarrow k = \frac{\omega^2}{g} \]  

(2.32)

the wave length may be defined by \( k \), with the eq.:

\[ \lambda = \frac{2\pi}{k} \]  

(2.33)

adding these equations together, the wavelength over ship length is found by:

\[ \frac{\lambda}{L} = \frac{2\pi}{\pi L} \]  

(2.34)
2.4 Strip theory

This section describes the strip theory method used for validation with a simplified body.

2.4.1 Introduction

The fish farm geometry in this project can not be represented with the simple two-dimensional sections as in the strip theory. This is why WAMIT has been used to calculate the hydrodynamic forces. The use of strip theory in this section is only for the verification of the procedure used to get internal force and moments. This is performed by comparing the results for a simple box geometry like a barge.

For this analyze, the program "I-ship" is used which is based on the linear potential flow theory of "Salvesen, Tuck and Faltinsen, 1970". The strip theory divides a 3-dimensional body into a number of 2-dimensional strips to calculate the 2D potential flow solutions of the added mass, damping coefficients and restoring force. The coefficient for the whole hull will then be a summation of all the results of the 2D strips. The 3D effects are assumed to be small and are therefore neglected.[Jan15]

This assumption implies that:

- The ship is slender
- The hull is rigid
- Moderate speed, no planning
- The motions are small
- The ship hull sections are wall-sided
- Deepwater

2.4.2 Line Geometry in I-ship

While WAMIT uses panels, I-ship is using a line defined geometry using nurbes-lines which are build up with vertical station lines, horizontal water lines and vertical buttock lines in the longitudinal direction. These lines are defined in each 2D coordinate system with point definition.
Figure 2.4: The working bench for building the line geometry in I-ship.

It is important that the lines are connected to each other and that they are closing at the symmetry plane (XY-plane at Y=0). Since the lines are defined by points and the line are a continuous nurbes-line, it needs more points to represent the sharp edges, seen in fig:(2.5).

Figure 2.5: One vertical section defined by points.

The results of transfers functions and forces and moments measured at the mid-section are presented in section:(4.1.3)
2.5 Post-processing

This section shortly describes the principles used in order to calculate the hydrodynamic global loads, strains, and stresses in Matlab.

2.5.1 Hydrodynamic global forces

As described in section (2.2) the different components of the external hydrodynamic forces are the exciting forces and the hydrodynamic forces due to the diffraction and the radiation problems. None of these components are given directly from the WAMIT outputs, therefore this needs to be calculated manually which in this assignment is performed in Matlab.

To calculate the total external forces, the complex WAMIT-outputs of hydrodynamic panel-pressure from "outputfile.5p" and the response from "outputfile.4" together with the geometry file, the calculation has been done in the following step.

- **Read the WAMIT files (Appendix:7.3):**
  As the pressure output files from WAMIT are described in section (2.3.4) the columns and data need to be read and output as separate pressure matrices for each heading angle and degree of motions. The Matrix will have the size [number of panels, number of motions, number of headings] which needs to be sorted after the panel id.

- **Define the coordinate information for each panel(Appendix:7.3)**
  When the pressure matrices are made, the position information of each panel needs to be defined which exists in the geometry file from Rhino. To simplify the calculation, and to work with smaller matrices, the panels at same X-direction are merged together to a section and sorted in rising X-position resulting fewer sections with a defined arm-length/X-position. This is done in both X-, Y- and Z-direction with all applicable matrices.

- **Define the sectional geometry information**
  The sectional area and moment need to be stated. This is performed by using the sectional area of the panels combined with total volume displacements and sorted with respect to the defined sections.

- **Generate the complex variable of each component and same dimensional**
  WAMIT outputs the real and imaginary part of each complex parameter. In order to add these variables to the same equation, they need to be all complex and in the same dimension.

- **Calculate the acceleration RAO**
  As the displacement RAO is known from WAMIT, the motion RAO and acceleration RAO is to be calculated according to Eq:(2.7).
• Calculate the sectional exciting and hydrodynamic force and moments
  The force components $E_j$ and $D_j$ together are found by integrating the sectional panel-pressures over the ship length in the horizontal and vertical plane, while the moments are the product of the forces times the sectional lever arm integrated along the length of the structure (X-direction). For the sectional torsional components, the arm-length in both Z- and y-direction needs to be implemented.

• Calculating the moment of inertia and inertia forces
  The equation for this section is described in section:(2.2). This the equation is integrated with the "cumtrapz" function which integrates the equation with respect to the sections and outputs a matrix with [number of sections, number of frequencies]. This makes it possible to plot the moment and force both over the ship length or over the frequencies for a specific section like mid-section

• Calculating the restoring forces and moment
  These components are calculated in the same manner as the above using the equation given in section(2.2). To include the sectional beam and integrate it over the ship length, the sectional XY-area is used.

• The total force and moments
  These complex components are just added together accordingly to Eq:(2.8)(2.9).

After finding the total sectional forces and moments for each frequency, the results are plotted with the Matlab code, Appendix(7.3) and can be seen in section:(4.3)

2.5.2 Internal stress
The theory behind the structural calculations is mainly based on the "Marine Structural Engineering"[Nie10].

The cross section in this project is a simplified design as it is none detailed information or scantling diagrams of the design available. Based on this simplified design, it has been performed a stress analysis with use of the global forces calculated in section.(4.3). The aim of this section is to give an estimation of needed second order moment of area moment of the cross section and estimate the stress distribution. A midsection based on the outer dimensions similar to the structure made in the FEM analyze program are made and analyzed in Matlab, Appendix:(7.3) in following steps:

• Making the geometry:
  As the design of the structure is defined in section:(3.1), this same data are used to establish the corner coordinates for each beam to generate vectors of each plate on the midsection. When the vectors are established, a thickness is added and then the information of the position, length, and area of each plate are found to calculate the moment of area and the neutral axis based on the equations in section:(2.7).
• **Calculating the stresses:**
The stresses are calculated accordingly to the equations in section (2.7) with the use of $I_{yy}$, VBM and the distance to the neutral axis. The neutral axis is defined at vertical zero, $Z=0$.

• **Buckling mode:**
Each buckling mode is calculated in both Z- and Y-direction using the beam length and the second order moment of area of each beam to find the Euler buckling mode. This is modified later with the Johnson-Ostenfeld correction. The beam length used for the lower beam in Z- direction is the beam length divided by three since it is reinforced by the diagonal supporting rods.

The results of this calculation may be seen in section (6.1)
2.6 Short time wave condition

This section presents the theory behind the short time analysis to obtain the wave spectra, response spectra and extreme values for a storm.

Figure 2.6: Illustration of short time analysis. DNVGL-RP-C103

The purpose of this section is to calculate the most probably largest bending moment the structure may be exposed to at a certain sea state. This section is based on the DNVGL standard RP-C205 [11] and Ship operations compendium[TR12]

The short time irregular sea state at a state may be described by a wave spectrum which describes the power spectral density function of the vertical surface displacement. The wave spectrum is often defined by using the significant wave height ($H_s$) and the spectral peak period($T_p$). $H_s$ represents the height between trough and crest of the highest 1/3-waves in a specified time period and $T_p$ represent the period the wave spectrum has its maximum value at. The time period in a short term is usually between 20min and 3-6 hours.

2.6.1 Pierson-Moskowitz and JONSWAP spectra

The Pierson-Moskowitz spectrum was originally proposed for fully-developed sea. The JONSWAP spectrum extends PM to include fetch-limited seas. Both spectra describe wind sea conditions that often occur for the most severe sea- states.

The equation for PM-spectra is:

$$S_{PM}(\omega) = \frac{5}{16} H_s^2 \omega_p^4 \omega^{-5} \exp \left( - \frac{5}{4} \left( \frac{\omega}{\omega_p} \right)^{-4} \right)$$  \hspace{1cm} (2.35)

Where $\omega$ is wave frequency and $\omega_p=\frac{2\pi}{T_p}$ is the angular spectral frequency where $T_p$ is a arbitrary input. The fetch limited sea, JONSWAP spectrum $S_J(\omega)$ is:

$$S_J(\omega) = A_\gamma S_{PM}(\omega) \gamma \exp \left( -0.5 \left( \frac{\omega-\omega_p}{\sigma \omega_p} \right)^2 \right)$$  \hspace{1cm} (2.36)

where $\sigma$ is the spectral width parameter equal to 0.07 when $\omega>\omega_p$ and 0.09 when $\omega<\omega_p$, and $\gamma$ is a non-dimensional peak shape parameter found by:

$$\gamma = \exp \left( \frac{5.75 - 1.5T_p}{\sqrt{H_s}} \right)$$  \hspace{1cm} (2.37)
2.6.2 Maximum value in a stationary sea state

From a stationary measurement, with N independent local maximum wave heights (usually N=1000 for 30 min measurement), the max value predictions in the sea state can be taken as:

Most probably largest wave:

\[ \tilde{H}_{max} = H_s \sqrt{\frac{1}{2} \ln N} \tag{2.38} \]

to find the probably largest value from a spectrum:

\[ \tilde{H}_{max} = 2\sqrt{2m_0 \ln N} \tag{2.39} \]

Where \( m_0 \) may be found by the eq.:

\[ m_n = \int_0^\infty \omega^n S_\zeta(\omega) d\omega \quad (n = 0, 1, 2...) \tag{2.40} \]

where \( S_\zeta(\omega) \) is the wave spectrum.

2.6.3 Response Spectra

The response spectrum \( S_R \) is obtained by the equation:

\[ S_R(\omega) = S_\zeta(\omega)\phi_R(\omega)\overline{\phi_R(\omega)} = S_\zeta(\omega)|\phi_R(\omega)|^2 \tag{2.41} \]

where \( S_\zeta(\omega) \) is the wave spectrum, e.g JONSWAP spectrum and \( \phi_R(\omega) \) is the transfer function. The spectral moment of the response is

\[ m_{n,R} = \int_0^\infty S_R(\omega)\omega^n d\omega \tag{2.42} \]

The standard deviation of the response is found from the 0th order moment:

\[ s_R = \sqrt{m_{0,R}} \tag{2.43} \]
2.7 Internal stresses

This section goes through the method in order to calculate the stress and the strength in a stiffened plate system. The derivation is based on general beam theory from linear theory elasticity of a three-dimensional body in an XYZ-coordinate system and the equations in this section are based on the compendium for the Chalmers course: MMA167. [Nie10]

Consider a volume-element in the fish farm body as shown in fig.(2.7) where the sides are parallel to the coordinates system.

![Illustration of the shear and normal forces in a peace of the body.](image)

Figure 2.7: Illustration of the shear and normal forces in a peace of the body. [17d]

This element consists of nine stress components which may be represented in the following 3×3 matrix:

\[
\sigma = \begin{bmatrix}
\sigma_x & \tau_{xy} & \tau_{xz} \\
\tau_{yx} & \sigma_y & \tau_{yz} \\
\tau_{zx} & \tau_{zy} & \sigma_z
\end{bmatrix}
\]  

(2.44)

where the normal stresses \( \sigma_x, \sigma_y \) and \( \sigma_z \) are directed normal to the element-surfaces and the shear stresses \( \tau_{xy}, \tau_{yx}, \tau_{yz}, \tau_{zy}, \tau_{xz} \) and \( \tau_{zx} \) are parallel to the element-surfaces.

In order to calculate the stress over the midsection, following steps are to be performed:

The natural axis for the structure:

\[
\bar{z} = \frac{\sum A_i \bar{z}_i}{\sum A_i}
\]  

(2.45)
where $A_i$ is for each plate or beam and the $z_i$ is a distance from a reference line, which is in our case the y-axis.

The equation to calculate the second moment of area is:

$$I_x = \int \int_R y^2 \delta y \delta x$$  \hspace{1cm} (2.46)

from this the equation for a rectangular area is:

$$I_x = \frac{\int_{b/2}^{h/2} \int_{h/2}^{b/2} y^2 \delta y \delta x}{12}$$ \hspace{1cm} (2.47)

Including the parallel axis theorem, the equation is:

$$I_x = \frac{bh^3}{12} + Ad^2$$ \hspace{1cm} (2.48)

Where $d$ is the distance to the neutral axis or a reference point.

The general equation for normal stress is:

$$\sigma_x = \frac{N}{A} + \frac{(M_y I_{yz} + M_z I_y - Z) y - (M_z I_{yz} + M_y I_y) z}{I_{yz}^2 - I_y I_z}$$ \hspace{1cm} (2.49)

The normal stress due to bending moment is then:

$$\sigma_x = -\frac{M_z}{I_z} \bar{y} + \frac{M_y}{I_y} \bar{z}$$ \hspace{1cm} (2.50)

Where $M_z$ is the horizontal bending moment, $M_y$ is the vertical bending moment, $I_z$ is the moment area around the z-axis, $I_y$ is the moment area around the y-axis and where $y$ and $z$ are the distance to the neutral axis.

2.7.1 Beam strength

To find the maximum stress the structure may be exposed to without any plastic deformation, the Ultimate tensile strength, UTS of the material are the strength in the stretch mode, while the Euler buckling cases together with Johnson-Ostenfeld correction may be used to find the strength of the beams in pressure mode. The Euler buckling is based on the yield strength of the material and a correlation between the second-moment area and the length of the beam consists of four different cases, where the boundary condition of the beam alter the buckling characteristics. [Euler]

The material used for this calculation has the properties: yield strength, $\sigma_y = 350\text{Mpa}$ and Young’s modulus, E=210Gpa.
The four cases are presented in the following picture:

![Diagram of four Euler cases](image)

Figure 2.8: The four Euler cases.[17e]

Where the Euler equations for each case are:

**Euler I:**
\[
\sigma_E = \frac{\pi^2}{4} \cdot \frac{EI}{Al^2}
\]  \hspace{1cm} (2.51)

**Euler II:**
\[
\sigma_E = \pi^2 \cdot \frac{EI}{Al^2}
\]  \hspace{1cm} (2.52)

**Euler III:**
\[
\sigma_E = 2.05\pi^2 \cdot \frac{EI}{Al^2}
\]  \hspace{1cm} (2.53)

**Euler IV:**
\[
\sigma_E = 4\pi^2 \cdot \frac{EI}{Al^2}
\]  \hspace{1cm} (2.54)

Where \(E\) is Young’s modulus of elasticity, \(A\) is the cross-section area of the beam and \(l\) is the length.

To decide which Euler case to use on the beam calculation, the buckling length, \(l\), is the deciding parameter. When considering beams welded in the ends like the fish farm cases, Euler case II may be used as a conservative solution.

To check the buckling mode for a plate system with longitudinal and stiffeners and also to find which part that buckles first, the calculations are needed for each part of
2.7 Internal stresses

the plate system. The calculations may be done according to following equations:

- **Plate Buckling between the transverse**

\[
\sigma_E = \frac{\pi^2 E}{12(1-\mu^2)} \left(\frac{t}{b}\right)^2 k_1 \tag{2.55}
\]

where \(E\) is the young modulus, \(t\) is the plate thickness, \(b\) is the width and \(k_1\) a factor of the relation between the sides:

\[
k_1 = \left(\frac{mb}{a} + \frac{a n^2}{m b}\right)^2 \tag{2.56}
\]

- **Calculations of stability of the longitudenals:**
  a) Lateral buckling: Euler II

\[
\sigma_E = \frac{\pi^2 EI_a}{AI^2} \tag{2.57}
\]

b) Torsional buckling:

\[
\sigma_E \phi = \frac{G K_v}{I_p} + \frac{\pi^2 EI_w}{I^2} \tag{2.58}
\]

Where \(G\) is the shear modulus, \(K_v\) is the effective length factor, \(I_p\) are for the moment of area of the longitudenals and \(I_w\) for the web.

c) Buckling of the web plate of the stiffeners:

\[
\sigma_E = \frac{\pi^2 E}{12(1-\mu^2)} \left(\frac{t^2}{b}\right)^4 \tag{2.59}
\]

where \(\mu\) is the poisson ratio

d) Buckling of the flange of the stiffeners:

\[
\sigma_E = \frac{\pi^2 E}{12(1-\mu)} \left(\frac{t^2}{b}\right)0.43 \tag{2.60}
\]

- **Control of transverse beam strength:**

\[
I_{b,req} > \frac{b^4}{4sl^3} I_a \tag{2.61}
\]

The Euler equations and buckling modes define the elastic strength in buckling mode for thin-walled beams. When increasing the thickness, the buckling strength reaches above the yield, thus makes the material yield strength more dominant. This overlap and the relationship between buckling mode and yield strength have been defined by Johnson and Ostenfeld who developed an equation which explains this behavior:

\[
\sigma_{corr} = \sigma_y \cdot \left(1 - \frac{\sigma_y}{4 \cdot \sigma_E}\right) \tag{2.62}
\]
where $\sigma_y$ is the yield strength of the material and the $\sigma_E$ is the calculated elastic buckling mode, e.g. Euler buckling. This may be illustrated in this figure 2.9:

![Figure 2.9: Illustration of the Johnson-Ostenfeld corrected graph.][17f]

The results of the stress and strength calculation are presented in chapter 6
2.8 FEM analysis

This section contains an introduction to Finite Element Method (FEM) and a description of how the midsection which is used in the FEM analysis are made and how the loads and constrains are defined. As described in the section(2.5), this design is a simplified design without any longitudinals and stiffeners, the plate thickness represent the area of all details merged together. The FEM model is one section of the main construction cut at the transverse beams, see fig:(2.10).

2.8.1 Finite Element Method- analysis

FEM or FEA (Finite Element Analysis) is a numerical method to compute the state of either stress, strength or heat transfer inside a structure by dividing the structure in smaller meshes to perform the calculation. In this assignment there is made a FEM-model in "Creo Parameters" and performed a stress analyze in "Creo Simulate". The model of he midsection are created by following steps in Creo Parameter:

- The method used to build up the model is by shell function where all plates are defined as surfaces.

- All dimensions of the midsection are created accordingly to the dimensions given in section:(3.1).

- To be sure the stresses will be transferred properly through all parts in the analysis, all surfaces are merged together in one peace.

When the model is ready, the following definitions are required to do a stress analysis in "Creo Simulation":

- **Plate thickness of all surfaces.**

- **Define the material.**

- **Create a mesh.**

- **Define the loads**, which in this test would be the Vertical bending moment which is applied on each side of the section working against each other.

- **Define the constrains.** As this needs to be defined in order to run the simulation, but shall not have any impact on the stresses, it is important that the applied constrain is not working against the moment forces. It is therefore placed on a surface which has none or minimal stress due to the vertical bending moment

The midsection model with load-condition is shown at figure:
Figure 2.10: A simplified construction of the mid section with load condition visualized.

As seen in the above figure, the loads are applied on the surface on each side. As it is reasonable to assume that the outer plate system would have more longitudes, these plates are thicker than the rest of the structure, illustrated in fig: (2.11)

Figure 2.11: Illustration of the two different plate thickness and where they are placed.

The walls(lace skirt) and the diagonal stiffeners are not included in the stress analysis.
CHAPTER 3

The geometry

This chapter contains three parts. A description of how the geometry is defined, an introduction to the software Rhino with a description of some challenges, and a presentation of the whole geometry with surfaces, and the meshed submerged body used in the simulations.

3.1 Making the geometry

3.1.1 Introduction

The main purpose of making a self made geometry is primarily to generate a coordinate geometry-file for use in the hydrodynamic analysis. Moreover, it can also be used to calculate the hydrostatic data which can be compared with existing data. The coordinate information is an important part of the post process in Matlab. Making the geometry in a proper way, and to be able to convert it to a useful WAMIT geometry file, is one of the major challenges in this project, and has been carried out with the software, Rhino. To verify the functionality of Rhino as a tool for making the geometry file, several different simple test cases have been made to compare against the existing test cases in the WAMIT package.

3.1.2 Defining the dimension of geometry

The dimensions for the construction used in this assignment is based on the published outer dimensions and the provided drawing, fig:(3.1). The drawings given from the company are without any dimensions or description, which make the dimensions in this report approximated.
The structure may be divided in section which has the following dimensions on the side:

<table>
<thead>
<tr>
<th>#</th>
<th>Dimension [m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>60.0</td>
</tr>
<tr>
<td>2</td>
<td>11.0</td>
</tr>
<tr>
<td>3</td>
<td>15.0</td>
</tr>
<tr>
<td>4</td>
<td>7.5</td>
</tr>
<tr>
<td>5</td>
<td>8.5</td>
</tr>
<tr>
<td>6</td>
<td>3.0</td>
</tr>
<tr>
<td>7</td>
<td>2.0</td>
</tr>
<tr>
<td>8</td>
<td>5.5</td>
</tr>
<tr>
<td>9</td>
<td>2.0</td>
</tr>
<tr>
<td>10</td>
<td>17.0</td>
</tr>
<tr>
<td>11</td>
<td>38.0</td>
</tr>
<tr>
<td>12</td>
<td>3.5</td>
</tr>
<tr>
<td>13</td>
<td>2.5</td>
</tr>
</tbody>
</table>

Table 3.1: Dimension for section seen from side.
3.1 Making the geometry

The section has following dimensions seen from above:

<table>
<thead>
<tr>
<th>#</th>
<th>Dimension [m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>54,0</td>
</tr>
<tr>
<td>2</td>
<td>46,0</td>
</tr>
<tr>
<td>3</td>
<td>4,0</td>
</tr>
<tr>
<td>4</td>
<td>4,0</td>
</tr>
</tbody>
</table>

Table 3.2: Dimension for section seen from above.

And the tip has following dimensions seen from above:

<table>
<thead>
<tr>
<th>#</th>
<th>Dimension [m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>60,0</td>
</tr>
<tr>
<td>2</td>
<td>54,0</td>
</tr>
<tr>
<td>3</td>
<td>10,0</td>
</tr>
<tr>
<td>4</td>
<td>35,0</td>
</tr>
<tr>
<td>5</td>
<td>25,0</td>
</tr>
<tr>
<td>7</td>
<td>26,3</td>
</tr>
</tbody>
</table>

Table 3.3: Dimension for tip seen from above.
3.2 Rhino

Rhino is a 3D computer graphics and computer-aided design (CAD) software tool for industrial design and modeling. The program is a powerful tool for making mechanical drawings and 3D models of objects from architecture, to detailed part design and assemblies. The program is very user-friendly with four windows visible where the drawing may be made in 2D while the 3D model is visual.

The model may be output to many different file types and are for instant used for 3D-printing. The program is also capable of generating the geometry files directly for use in WAMIT which basically is the coordinate information of each surface either in high-order mode with vertex coordinates and spline information or low-order mode with the coordinates of the corners. It is this low-order file type that is used for the hydrodynamic simulation in WAMIT and to post-processing in Matlab.
3.2.1 Challenges with the Rhino-geometries to WAMIT

To test which geometries from Rhino that works properly in the simulations, the strategy was to start with a simple geometry like a box and a cylinder. It exists several of test cases together with the application package including results which does it possible to compare with the results. When testing the cylinder with a surface geometry, it was discovered that Rhino can not export trimmed areas of the design to the GDF-file as visualized in fig:(3.3).

Figure 3.3: The cylinder from Rhino to the left transformed to a low-order geometry to the left and visualized by the surface plotter, tec360.

This is due to WAMIT only read quadrangular surfaces or meshes which do it difficult to convert curved edges to square mesh in a low-order method. Another issue which appeared when testing the box-case, using regular surfaces to make each side is that it did not ”close” the edges together in a proper way. This caused the geometry to be an open model with no volume or center of volume. Putting these geometries through a WAMIT run resulting a center of buoyancy thousands of meter outside the 10 meter sided box and results that did not converge. The solution it ended up with due to this problem was to make the geometry in the ”box mesh” tool where the number of meshes in each direction may be stated when making it. Unfortunately, the number of meshes can not be increased or decreased with quadrangular meshes after the mesh is made. This affects the convergence study where the different meshed size geometries are made from scratch each time.
3.3 The geometry

This section contains the “results” of the main structure made in Rhino as well as the meshed submerged bode used for hydrodynamic simulation.

3.3.1 The design

The design is a floating beam construction which is build up with six similar sections additional to a front section for the anchor attachment and the aft section, presented in the following figures:

Figure 3.4: The Rhino model in perspective view.

In the scantling diagrams, fig:(3.5), (3.6) and (3.7) the main dimensions and the water lines are visualized.
3.4 Submerged part

As the whole purpose to make this geometry is to simulate it in the program WAMIT, the submerged part is the only part needed which are presented in this section. The geometry is output in a file which gives the coordinate information for each mesh corner. To make a reference geometry, the geometry is cut at the waterline.
Several geometries are tested to check what works in WAMIT. The final geometry is a meshed design output in low-order panels with only quadrangular meshes. The walls (lice skirt) is not included in this design as it made the simulation not to converge.

Figure 3.8: The submerged part of the fish farm.

Figure 3.9: Meshed submerged geometry made in Rhino used for WAMIT-simulation.
As the length of the fish farm changed during the thesis period, the initial design is scaled down to 402m with each sections 56m instead of 60m. This is done simply with the scale commando in 1D which also change the length of the vertical beam. The original dimensions of draft, height, and width are retained as described initially.

Figure 3.10: Submerged geometry in mesh seen from side with main dimensions.

Figure 3.11: Submerged meshed-geometry seen from the front with main dimensions.
3.5 Hydrostatic

This section is primarily provided data from NSK, which is compared to the Rhino geometry and WAMIT outputs. Due to flooded sections and ballast water, the geometry contributing for buoyancy is the part shown in fig:(3.13) while the whole geometry is considered in the hydrodynamic part.

Figure 3.12: Hydrostatic table calculated by NSK.
The coordinate system as defined in the table in fig:(3.12) has its point of zero in aft section in front of the at the keel and shown in the figure below:3.13.

![Figure 3.13: Structure contributing to buoyancy. Picture made by NSK.](image)

**3.5.1 mass matrix of fish-farm:**

From the hydrostatic information given above, the displacement at draft 30m is 26023.097mt with LCB=169.652m. However, since this filled area will be considered as weight in the hydrodynamic simulation, the displacement used in the mass matrix in WAMIT is based on the volume displacement from rhino which is 34035 cubic meters(34886mt).

Since there is no information of the vertical center of gravity this is based on the neutral axis of the cross section, calculated in section2.7 which is -14m from the top of the whole structure. The geometry is centered to the body coordinate system, so LCG is at x=0. The center of gravity is then for the submerged body: (0, 0, -6) thus make \(m_x=0\), \(m_y=0\), \(m_z=-2.1E08\) and the mass matrix is:

\[
M_{fishfarm} = \begin{pmatrix}
3.49E7 & 0 & 0 & 0 & -2.1E08 & 0 \\
0 & 3.49E7 & 0 & 2.1E08 & 0 & 0 \\
0 & 0 & 3.49E7 & 0 & 0 & 0 \\
0 & 2.1E08 & 0 & 1.3E10 & 0 & 0 \\
-2.1E08 & 0 & 0 & 0 & 4.7E11 & 0 \\
-0 & 0 & 0 & 0 & 4.74E11 & 0
\end{pmatrix}
\]
This chapter contains the results of the simulations in WAMIT, and are divided into three sections. The first section is a validation section with a mesh convergence study and a comparison between WAMIT and I-ship of a simple barge. The second section presents motion transfer function and the last section presents the force transfer functions.

4.1 Validation

To be able to have a reliable result to work further with, the result needs to be validated. It would have been desirable to have some model tests results to compare with and calibrate this simulation after. Unfortunately, any model test is not available. When running WAMIT with high-order geometry from Rhino the message "number of subdivisions exceeds MAXSQR=2048" appear during the run. Since the high-order panels from Rhino are expected not to work properly, the low-order panels were tried out. To get a reliable result the panels need to be divided into smaller quadrangular meshes, which do the simulation more time-consuming. To find a good mesh-size that have reliable results with the use of reasonable simulation time, a mesh convergence study is performed. To perform this study, a simplified geometry of the fishfarm without the tip or any detailed part are run in WAMIT with mesh from panel size to 1m.
4.1.1 The meshes

((a)) One panel per plate.  

((b)) Panel size of max 16 meter.

((c)) Panel size of max 8 meter.  

((d)) Panel size of max 4 meter.

The geometries that where tested had following mesh size and number of meshes:

<table>
<thead>
<tr>
<th>Max mesh size:</th>
<th>Mesh quantity:</th>
<th>Compu time:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Panel size</td>
<td>222</td>
<td>15sek</td>
</tr>
<tr>
<td>16m</td>
<td>750</td>
<td>1.5min</td>
</tr>
<tr>
<td>8m</td>
<td>1122</td>
<td>6min</td>
</tr>
<tr>
<td>4m</td>
<td>2374</td>
<td>31min</td>
</tr>
<tr>
<td>2m</td>
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<td>7hrs</td>
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</tbody>
</table>

Table 4.1: Table of mesh size and computational time
4.1 Validation

4.1.1 The results:

The results for each low-order mesh are plotted together with the results from the high-order for comparison in figs: (4.2) (4.3) (4.4) (4.5)

Figure 4.2: Comparison of added mass between different meshes sizes.

It is clear that using low-order with only one plate mesh is too far off. In surge, the other meshes are pretty coordinated, while in heave direction only the 4m and 2 m meshes are alike. The added mass from the high order results have the same shape but have a lower magnitude in both cases.

Figure 4.3: Comparison of damping coefficient between different meshes sizes.
The convergence of the damping coefficient have the same trend as in added mass, 2m and 4m meshes have a good fit and seems to converge. The results for the high order in surge direction agree pretty well while it is quite different from those in heave direction.

Figure 4.4: Comparison of response in surge direction between different meshes sizes.

The results for 2 and 4m in the response amplitude operator in surge direction have a good agreement up to 1.5 times the ship length where they have some spikes and then converge to the value of 1 when the wave period goes to a high number.

Figure 4.5: Comparison of response in heave direction between different meshes sizes.
The results for the RAOs in heave direction has a higher difference in the results between the meshes. Although the agreement between 2m and 4m are quite good until $\frac{A}{L}=2$. The maximum value of RAOs in heave direction is usually when the wavelength is the same length as the ship. The high-order results have a significant peak near $\frac{A}{L}=1$ but it is unlikely that the response is 8 times the amplitude for this beam construction.

![RAO Comparison](image)

Figure 4.6: The same comparison as in figure 4.4 and 4.5 but plotted over frequency.

When plotting the results over the frequency it is easier to check that the position RAO is the same as the amplitude for high wave periods / low frequencies. It can be seen in the figure 4.6 that this happens to the meshes with a smaller size than 8m.
4.1.2 Comparison with WADAM

A simplified structure similar to the geometry in the mesh analysis is also performed in the DNV-developed program WADAM. When comparing these results to the RAOs in the mesh analysis, the figure:4.7 is similar to the 4m mesh in figure 4.6. The blue line in fig:(4.7)is the head sea and the yellow line is beam sea for the heave motion.

![Figure 4.7: Heave motion simulated in WADAM](image)

4.1.2 Mesh study conclusion

From this validation study, the higher-order panels and the mesh size above 16m from Rhino seem not to be reliable. The 4meter meshes and the 2meter meshes seem to have a good fit and agreement although it still has some uncontrolled peaks for low frequencies. Since the 4m and 2m has a good agreement but the 2m meshes have a significant longer simulation time, the 4m meshes could be used for further use in this assignment.
4.1 Validation

4.1.3 Comparison between WAMIT and I-Ship

To be able to verify that the input and results from WAMIT and to verify the post-processing and calculations in the Matlab are correct, the strip theory based I-ship program was used to simulate the position responses, the forces and moments at mid-ship to compare it to the results. Since I-ship is a strip theory based program thus require closed walls and closed body, the program is unfit to analyze the fish farm geometry. Therefore, to compare these two methods against each other, a barge with simple box shape is made and simulated in both methods. The dimensions of the barge are:

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>LOA</td>
<td>400m</td>
</tr>
<tr>
<td>B</td>
<td>40m</td>
</tr>
<tr>
<td>Draft</td>
<td>30m</td>
</tr>
</tbody>
</table>

((a)) Line geometry of barge, made in I-ship.  
((b)) Meshed barge created in Rhino.

Figure 4.8: Test barges for comparison of hydrodynamic analysis using in strip theory and panel method.
4.1.3.1 mass matrix for test-barge:

The moment of inertia and mass can be read in RHINO and calculated by using the Volume moments commando thus give the volume and volume-moments of inertia of the geometry or calculated by the equations described in section 2.3.2.

\[ m = 4.8 \times 10^5 m^3 \times \rho = 4.92 \times 10^8 \]

This give the mass matrix as follows:

\[
M_{\text{barge}} = \begin{pmatrix}
4.92E08 & 0 & 0 & 0 & -7.38E09 & -0 \\
0 & 4.92E08 & 0 & 7.38E09 & 0 & 0 \\
0 & 0 & 4.92E08 & 0 & -0 & 0 \\
0 & 7.38E09 & 0 & 1.968E11 & 0 & 0 \\
-7.38E09 & 0 & -0 & 0 & 1.968E13 & 0 \\
-0 & 0 & 0 & 0 & 0 & 1.96E13
\end{pmatrix}
\]

To perform the strip theory simulation, the barge is divided into 30 strips and analyzed in 40 wave periods. The mass is the volume displacement times the water density of salt water.
4.1.4 Results

The two methods have in both heave and pitch a quite good agreement. The WAMIT results have a little bit higher peaks than the strip theory method.

The results for vertical bending moments for the two methods have a good agreement, although the WAMIT results have in this case a bit lower peak than the strip theory method.
For the horizontal bending moment with an incident wave at 120°, the results have a familiar shape for both methods with a peak at the same wavelength. As the WAMIT results do not start or end at zero, the post-processing in Matlab may not be 100% reliable for this results but are about the same magnitude of order.

The vertical shear force at midships has a similar shape and magnitude with a small mismatch after the peak.
4.1.5 Conclusion of comparison

The two methods tested to each other in this section have a pretty good agreement. Although it is a little mismatch in the horizontal bending moment, the post processing of the WAMIT results may be considered as reliable.
4.2 Transfer functions

In this section, the WAMIT simulation results for the response amplitude operator are plotted over the wave period. The simulations are run for four different headings from head sea to beam sea, (180°, 150°, 120° and 90°). A complete overview of the motions in all six degrees may be sin plotted over the frequency in end of this section, page:(59).

Figure 4.13: Response amplitude operator in Surge direction for the fish farm construction

The result of surge response in fig:(4.13) does as expected, vary up to approximated one wave length equal to the ship length where it is approximately 0.3 mplitude and then converge to one amplitude, meaning that the body will have the same position as the wave displacement for very big waves.
As the body is symmetric around x-axis the sway response is zero for head sea.

The heave response has its peak at a wavelength equal to approximately one-half and two ship lengths for head sea and then goes to the amplitude. For beam sea, the response starts at shorter waves and are in general higher than the others.
As expected, the roll angular motions are zero for head sea and the highest response for beam sea. The response at beam sea starts for waves equal to a quarter the ship length, which is approximately the same as the beam width.

The angular pitch responses have the peaks at the wavelength equal to one half ship length. As expected, the highest response is for head sea and decreases as the incident wave angle goes to beam sea. As in surge, the response does not totally disappear at beam sea as the construction is not completely symmetric around y-axis.
Figure 4.18: Response amplitude operator in yaw direction for the fish farm construction

The angular yaw response around z-axis is zero for head sea and small for beam sea. The highest response is for incident waves at 120° and have its maximum for wavelength approximately 0.8 times the ship length.
4.3 Global forces

The global forces and moment in this section are calculated at mid-ship and plotted over frequency.

![Graphs showing vertical bending moment, horizontal bending moment, and vertical shear force at mid-ship plotted in frequency domain.]

Figure 4.19: The vertical Shear force at mid-ship plotted in frequency domain.

The vertical bending moment is by far the largest magnitude of global force working on the body. As expected the head sea contributes to the largest VBM for waves up to approximately 2 times the ship length. At lower frequency near 0.3 rad/s, the beam sea is highest.

The horizontal bending moment is as expected zero for head sea while it is largest for beam sea. The peak is at a smaller wave period and the rest of the responses which make sense since it is the beam width which works as the "ship length" in this case. The magnitude is about 10 times smaller than the vertical bending moment. The Vertical shear force is approximately 100 times smaller than the VBM but follows the same trend.
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CHAPTER 5

Short time analysis

This chapter contains the wave spectra which the structure is tested in and the results of the response spectra.

Usually, a short time analysis is based on a sea state measurement from a specific position. This is not included in this thesis, but as it is published that the construction shall be designed for a significant height, $H_s = 10\text{m}$ and the first one shall be positioned outside "Brottøya" in the northern part of Norway. This project bases the wave spectra on this significant wave height and the Marsden-area 1.

5.1 Wave spectrum

5.1.1 Define $T_p$

The fish farm shall be designed for a significant wave height, $H_s=10\text{m}$. To find a reasonable $T_p$, a scatter diagram is generated based on table C-1 in DNVGL-RP-C205.

![Figure 5.1: Scatter diagram from Marsden area 1.](image)

As seen in the scatter diagram, the appearance of waves at $H_s$ to $9\text{m}-9.9\text{m}$ are used to establish $T_z$-value to find a reasonable $T_p$ with the equation:

$$
\frac{T_z}{T_p} = 0.6673 + 0.05037\gamma - 0.006230\gamma^2 + 0.0003341\gamma^3
$$

(5.1)
From eq.(5.1), the value of $T_p$ are:

$$T_p(T_z=6.5) = 8s \quad T_p(T_z=9.5) = 11.5s \quad T_p(T_z=14.5) = 21s$$

5.1.1.1 The JONSWAP wave spectra

As the position to the fish farm probably will be near shore, the JONSWAP spectrum with the fetch-limited sea is the correct choice for use in this case.

![JONSWAP wave spectrum](image)

Figure 5.2: JONSWAP wave spectrum. For $T_p=21s$, the JONSWAP spectrum is equal to P-M spectra as $\gamma=1$.

5.2 Response spectrum

This section is based on the transfer functions presented in section:2.3.4 which are added together with the wave spectrum in the above section as described in the methodology-section:2.6. The response spectrum of motions, VBM, HBM and VSF are presented over the frequency, $\omega$. The response spectrum shows the energy the construction is exposed for in the sea state and are important to estimate the extreme values. In the following figures:(5.3), (5.5) and (5.7) are the displacements response spectra presented and in figures:(5.4), (5.6) and (5.8) the force response spectra are presented.
5.2.1 Motion response spectrum, $H_s=10m$ and $T_p=8s$

Figure 5.3: Position response of the Fish farm in sea state $H_s=10m$ and $T_p=8s$

Figure 5.4: Force response of the Fish farm in sea state $H_s=10m$ and $T_p=8s$
5.2.2 Motion response spectrum, $H_s=10\text{m}$ and $T_p=11.5\text{s}$

Figure 5.5: Position response of the Fish farm in sea state $H_s=10\text{m}$ and $T_p=11.5\text{s}$

Figure 5.6: Force response of the Fish farm in sea state $H_s=10\text{m}$ and $T_p=11.5\text{s}$
5.2.3 Motion response spectrum, $H_s=10m$ and $T_p=21s$

Figure 5.7: Position response of the Fish farm in sea state $H_s=10m$ and $T_p=21s$

Figure 5.8: Force response of the Fish farm in sea state $H_s=10m$ and $T_p=21s$
Reading the response spectra, it is clear that when the wave spectrum and transfer function have the peaks at same frequency, the response spectrum contains most energy. In table: 5.1, the results of standard deviation and max value of heave motion, force and moment are listed of the response spectrum with $T_p=11.5$.

<table>
<thead>
<tr>
<th>Response:</th>
<th>Heading</th>
<th>Standard deviation:</th>
<th>Most Probable Max:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heave motion</td>
<td>$\beta=90^\circ$</td>
<td>1m</td>
<td>7.7m</td>
</tr>
<tr>
<td>Heave motion</td>
<td>$\beta=120^\circ$</td>
<td>2.4m</td>
<td>18.1m</td>
</tr>
<tr>
<td>Heave motion</td>
<td>$\beta=150^\circ$</td>
<td>2.3m</td>
<td>16.9m</td>
</tr>
<tr>
<td>Heave motion</td>
<td>$\beta=180^\circ$</td>
<td>2.1m</td>
<td>15.7m</td>
</tr>
<tr>
<td>VBM</td>
<td>$\beta=90^\circ$</td>
<td>1.7GNm</td>
<td>12GNm</td>
</tr>
<tr>
<td>VBM</td>
<td>$\beta=120^\circ$</td>
<td>1.5GNm</td>
<td>11GNm</td>
</tr>
<tr>
<td>VBM</td>
<td>$\beta=150^\circ$</td>
<td>1.7GNm</td>
<td>13GNm</td>
</tr>
<tr>
<td>VBM</td>
<td>$\beta=180^\circ$</td>
<td>1.5GNm</td>
<td>11GNm</td>
</tr>
<tr>
<td>HBM</td>
<td>$\beta=90^\circ$</td>
<td>0.3GNm</td>
<td>1.9GNm</td>
</tr>
<tr>
<td>HBM</td>
<td>$\beta=120^\circ$</td>
<td>0.2GNm</td>
<td>1.3GNm</td>
</tr>
<tr>
<td>HBM</td>
<td>$\beta=150^\circ$</td>
<td>67MNm</td>
<td>0.5GNm</td>
</tr>
<tr>
<td>HBM</td>
<td>$\beta=180^\circ$</td>
<td>0GNm</td>
<td>0GNm</td>
</tr>
<tr>
<td>Vertical shear force</td>
<td>$\beta=90^\circ$</td>
<td>17MN</td>
<td>128MN</td>
</tr>
<tr>
<td>Vertical shear force</td>
<td>$\beta=120^\circ$</td>
<td>11MN</td>
<td>84MN</td>
</tr>
<tr>
<td>Vertical shear force</td>
<td>$\beta=150^\circ$</td>
<td>6MN</td>
<td>50MN</td>
</tr>
<tr>
<td>Vertical shear force</td>
<td>$\beta=180^\circ$</td>
<td>7MN</td>
<td>52MN</td>
</tr>
</tbody>
</table>

Table 5.1: Results from the response spectrum of $H_s=10m$ and $T_p=11.5s$.

The most extreme values are the vertical bending moment for incident waves with a heading, $\beta=150^\circ$ with a value of 13GNm. For head sea, the VBM is 11GNm.
This chapter contains the results of the stress analysis of the hand calculations and the FEM analysis.

6.1 Internal stresses

In this section, a calculation of the weakest beam in buckling mode as well as a stress analyze is performed. The design of the cross-section is a simplified design without longitudes and stiffeners. Instead, a merged plate thickness is representing the same moment of area. This applies for both of the geometries in Matlab and Creo Parametric where the hand-calculation and FEM analyze are performed. The equations for the hand-calculation are presented in sect:(2.7). When considering head sea, the structure will have normal stresses in x-direction due to the vertical bending moment and a shear stress parallel to the yz-plane due to the shear force. As illustrated in fig:(6.1) the normal stresses will in hogging mode give a tension (positive $\sigma_x$) to the upper structure and a pressure (negative $\sigma_x$) at the lower beams, and hence the opposite behavior for the sagging mode.

![Hogging and Sagging Illustration](image)

Figure 6.1: Illustration of the loads in Hogging and sagging.
6.1.1 Buckling modes

The buckling mode is calculated for each beam in Y and Z direction according to the equations in section 2.7.1. The support from the upper wall on upper beam is not considered. The beam length for lower beam during calculating of the buckling mode in z direction is divided by 3 due to the lower obliquely stiffeners.

<table>
<thead>
<tr>
<th>Buckling mode</th>
<th>Euler strength:</th>
<th>J-O corrected:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper beam, Y-direction</td>
<td>2820 [MPa]</td>
<td>339 [MPa]</td>
</tr>
<tr>
<td>Upper beam, Z-direction</td>
<td>8280 [MPa]</td>
<td>345 [MPa]</td>
</tr>
<tr>
<td>Lower beam, Y-direction</td>
<td>2890 [MPa]</td>
<td>339 [MPa]</td>
</tr>
<tr>
<td>Lower beam, Z-direction</td>
<td>1590 [MPa]</td>
<td>331 [MPa]</td>
</tr>
</tbody>
</table>

Table 6.1: Euler II results with Johnson-Ostenfeld correction

After Johnson-Ostefeld correction, all the results of buckling mode are close to the yield strength. The lowest value in hogging mode is at the lower beam which have a strength of 331MPa in z-direction and 339 MPa in y-direction. For Sagging the lowest value is at the upper beam with 339MPa in y direction and 345MPa in z-direction. The weakest strength on the construction according to the buckling mode results, is the lower beam. The lowest beam strength will therefore effect the allowed stress in hogging most.

6.1.2 Stresses

The midsection applied in the hand calculation has following data:

<table>
<thead>
<tr>
<th>Outer plate thickness:</th>
<th>4cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main plate thickness:</td>
<td>3cm</td>
</tr>
<tr>
<td>Neutral axis:(from keel)</td>
<td>23.3m</td>
</tr>
<tr>
<td>Second order area moment:</td>
<td>825.3m$^4$</td>
</tr>
</tbody>
</table>

Table 6.2: Basic information of mid-section.

With the max VBM applied to this cross section the stress distribution is visualized in the following fig:6.2
6.2 FEM analysis in Creo

Figure 6.2: The midsection plotted in Matlab with the max VBM results from the short time analyze. Z-distance on "y-axis" is the distance from neutral axis.

For a second order area of moment equal to $825.3m^4$ and a neutral axis 23.3m from keel, the maximum stress at the lower beam are 324Mpa and the max stress for the upper beam are 205Mpa. This results indicate again that the lower beam is the most critical beam on this construction.

6.2 FEM analysis in Creo

This section present a simple FEM analysis with the hydrodynamic global loads applied as described in section:2.8. A complete FEM analysis will include all global loads as hydrodynamic, hydrostatic, weights, external and internal moment of inertia on the whole body, which does cancel each other out. The FEM analysis in this project is a simplified version where one part of the body cut at the transverse beams are evaluated with only the bending moment applied. The bending moment is applied on each side of the truncated part, working against each other on the plates. The point of this analysis, additional to measure and visualize the stresses is also to confirm the results of the hand calculation.
6.2.1 Result

When reading the stresses on the middle of the longitudinals, the stress should be approximately the same as the result from the hand calculation. On this FEM model the max stress at the upper beam is 3240Mpa and 380Mpa at the lower beam. This results are higher than hand calculation. It is clear that the stresses are distributed a little bit different as in the hand calculation, but are in about the same order of magnitude. As the allowed max stress on the lower beam is 331 the plate thickness need according to the FEM analysis to be higher.
6.2.2 Increased thickness

In figure (6.4), a outer plate thickness of 5cm instead of 4cm is applied.

![Stress analysis of half midsection simulated in PTC Creo measured in MPa.](image)

With the main plate thickness of 3cm and a increased thickness of 5cm on the outer longitudinal beams, representing a area moment of 980m$^4$, the max stresses decreased markedly and are 310Mpa at upper beam and 320Mpa lower beam which is in between limit.

6.2.3 Worst case scenario

This FEM model is also analyzed with both horizontal and vertical bending moment at the heading with max moment which appeared at the heading equal to 150°, where VBM is 13GNm and HBM is 0.5GNm. It is reasonable to assume that the torsional moment would be present in this wave heading, but is not calculated and thereof not applied. The result are visualized in fig:(6.5)
Figure 6.5: Stress analysis of half midsection in PTC Creo with HBM and VBM included. The stress is in the left picture and the displacement is in the right. Both figures visualize the displacement of 5 times the real.

The result of this analysis shows that the stresses increase significantly on some of the beams with max value near 500MPa, which is far above the yield strength.
CHAPTER 7

Discussion/ Conclusion

7.1 Discussion

7.1.1 Geometry

The geometry is not in the exact dimension as the original model nor has all the elements, and the non-linear effect from the beams above sea level are not included in this analysis. This may influence the accuracy of the results to some extent.

7.1.2 Method

The structure in this analysis is build up with several slender beams which have a length/diameter ratio above 5. Use of panel method only, without including any calculations for the viscous drag force, the effect of this may affect the accuracy of the results, especially in roll motions where the viscous effect have a large impact.

7.1.3 Post-processing

As the post-processing for the forces and moments are proved to be good for a barge in section:4.1.3, the results for the fishfarm is not verified directly. The geometry of the barge and the fishfarm are incomparable which means that the fishfarm geometry could not be imported to the Matlab code directly without some changes related to the surface definitions. This makes the results for the fishfarm post-processing less reliable as they are not compared to something or verified directly. However, the results seem to be reasonable and good.

7.1.4 Results of WAMIT calculations

The structure has some beams and sections filled with water. The simulations are performed with use of the displacement of the whole submerged part which means that the filled water is contributed to the body mass and mass matrix. Big changes in the mass matrix may affect the transfer functions significantly. How open these filled sections are, and how big part of this extra mass that should be included is unknown.
The response amplitude operators in this project are compared with results performed by the subcontractor company, Multiconsult, which also used WAMIT for the analysis. The geometry they used is defined by high-order panels. The dimensions of this geometry are assumed to be similar to the final geometry simulated in this report. To compare these results, digit reader is used to plotting the results obtained from a picture. These results are plotted together in the figure:(7.1).

Figure 7.1: Response amplitude operator of fish farm construction compared with WAMIT simulation of a high order surface geometry performed by the company Multiconsult. These complete results can be seen in App: 7.3

Both these simulations have the assumptions that the structure floats freely without any anchor and fishnets. Both of the simulations have peaks several times the amplitude near the wave period equal to 13s. The company has a repeating peak near 20s which does not appear in this project.
7.2 Conclusion

In this project, a geometry similar to the "Fish farm" has been made in Rhino and simulated in WAMIT. The mesh size used on the geometry is tested in a mesh convergence study where the mesh size of 4m was concluded to be reliable. The results from WAMIT has been post processed in Matlab and presented in this report. This hydrodynamic simulation and post processing has been validated with a comparison with the strip theory potential based program "I-ship", where the RAOs, VBM, and VSF turned out to have a good agreement. These results are then analyzed in a short-term sea state with \( H_s = 10m \) in the north sea where the outcome is the response spectra and extreme values for this sea state. These extreme values are then used to perform a stress analysis for a simplified cross section and FEM-model created in Creo. The outcome of this project is the transfer functions, response spectra and a required second order of area moment representing a plate thickness of the structure on the midsection of the body.

It has in this assignment been successfully performed hydrodynamic simulations in WAMIT with the use of Rhino geometries which is processed in Matlab and analyzed in Creo. According to the analysis, the structure evaluated in a sea state with \( H_s = 10m \) in Marsden area 1 would have a max vertical bending moment at head sea of \( 1.15GNm \), and the cross-section of this structure with a sufficient strength needs a second order of moment area above \( 980m^4 \) which represents a thickness of 3cm on the main plates and 5cm on the outer plates. According to the hand calculation only, an area moment of \( 825m^4 \) is needed to resist the Vertical bending moment at head sea.

7.2.1 Rhino as a tool for generating geometry file to WAMIT.

Rhino has is this assignment been successfully used to generate WAMIT geometries, although it has been some difficulties. As a tool for generating high-order panels, Rhino may be a very good tool for simple models with few surfaces. Although the spline file thus defines the curve of the surface whether it is flat or round needs to be manually made. This information exists in the GDF-file but needs to be sorted out to a separate spline input file. For a more complicated geometry, this could be very time-consuming. It has not been discovered in this assignments how to export functional quadrangular trapeze shaped meshes from Rhino which is necessary for some of the details in the fish-farm geometry. To make a approximated geometry with flat sides only, the low-order panel method is an easy way to generate the model with building the geometry using the mesh-box tool commando.
7.3 Suggestions for future work

This thesis has used simplified models and geometries affecting almost all steps. Due to this simplification, it may not be considered as a complete structural analysis for the fish farm construction. It is clear that without the time limit, much more could be done and in a more accurate way. To get a more complete analyze it is suggested some items for future work:

- **Physical model tests.** It would be very beneficial and interesting to compare these results with some physical tests results.

- **Non-linear effects.** As the construction is only tested for a linear water area, the effects of slamming, and forces on waves in time-domain is not considered in his thesis and would be interesting to see how much it changes the results.

- **Effects of the fish net.** Test the damping coefficient and forces of the fishnets to the body.

- **Effects of the Anchor.** Test the forces and effects from the anchor to the body.

- **Check for effects of viscous damping.** The fish farm construction is build up with beams slender than 1/5 wavelength. As the method used is based on potential theory without viscous effects, it would be interesting to see how much the viscous damping affects the total results.

- **Perform the analysis with flex body.** This project uses the rigid body for the analyze. When ship length is above 350m, the effects of flexibility in the body are known to be noticeable. As this structure are a 400m long beam construction it would be useful to perform this analysis with flex body. This may be performed with adding a flex mode matrix in WAMIT.

- **Load combinations.** Extend the structural analysis to include all load cases and combinations, according to applicable design standards.

- **Long-therm analysis.** A statistical long-term analysis with following fatigue analysis.

- **Local structural analysis** When all forces are applied, a detailed structural analysis of all local areas should be done.


Appendices: Matlab codes

Mesh convergence study

Contents

- Panelsize:
  - Panelsize 16 meter:
  - Panelsize 8 meter:
  - Panelsize 4 meter:
  - Panelsize 2 meter:
  - Nurbes High order:
  - plot:

clc; clear all; close all;

Read and plot the geometry in the .gdf file. This also sets the ulen and grav values for non-dimensionalization.

[ulen,grav]=textread('panel_mesh.GDF','%f %f %*s',1,'headerlines',1);
[is(1,1),is(2,1)]=textread('panel_mesh.GDF','%d %d %*s',1,'headerlines',2);
[np]=textread('panel_mesh.GDF','%d %*s',1,'headerlines',3);
xp,yp,zp=textread('panel_mesh.GDF','%f %f %f ',...
  'headerlines',4);

figure(); clf; hold on;
for k=1:4:4*np
    plot3(xp([k:k+3 k],1),yp([k:k+3 k]),zp([k:k+3 k],1),'k')
end
AZ=50;
EL=30;
view(AZ,EL)
xlabel('x')
ylabel('y')
zlabel('z')
axis('equal'); hold off;

Read and plot the geometry in the .gdf file. This also sets the ulen and grav values for non-dimensionalization.

[ulen,grav]=textread('16m_mesh.GDF','%f %f %*s',1,'headerlines',1);
[is(1,1),is(2,1)]=textread('16m_mesh.GDF','%d %d %*s',1,'headerlines',2);
[np]=textread('16m_mesh.GDF','%d %*s',1,'headerlines',3);
[xp,yp,zp]=textread('16m_mesh.GDF','%f %f %f ',...
    'headerlines',4);

figure(); clf; hold on;
for k=1:4:4*np
    plot3(xp([k:k+3 k],1),yp([k:k+3 k]),zp([k:k+3 k],1),'k')
end
AZ=50;
EL=30;
view(AZ,EL)
xlabel('x')
ylabel('y')
zlabel('z')
axis('equal'); hold off;

Read and plot the geometry in the .gdf file. This also sets the ulen and grav values for non-dimensionalization.

[ulen,grav]=textread('8m_mesh.GDF','%f %f %*s',1,'headerlines',1);
[is(1,1),is(2,1)]=textread('8m_mesh.GDF','%d %d %*s',1,'headerlines',2);
[np]=textread('8m_mesh.GDF','%d %*s',1,'headerlines',3);
[xp,yp,zp]=textread('8m_mesh.GDF','%f %f %f ',...
    'headerlines',4);

figure(); clf; hold on;
for k=1:4:4*np
    plot3(xp([k:k+3 k],1),yp([k:k+3 k]),zp([k:k+3 k],1),'k')
end
AZ=50;
EL=30;
view(AZ,EL)
xlabel('x')
ylabel('y')
zlabel('z')
axis('equal'); hold off;

Read and plot the geometry in the .gdf file. This also sets the ulen and grav values for non-dimensionalization.

[ulen,grav]=textread('4m_mesh.GDF','%f %f %*s',1,'headerlines',1);
[is(1,1),is(2,1)]=textread('4m_mesh.GDF','%d %d %*s',1,'headerlines',2);
[np]=textread('4m_mesh.GDF','%d %*s',1,'headerlines',3);
[xp,yp,zp]=textread('4m_mesh.GDF','%f %f %f ',

    'headerlines',4);

figure(); clf; hold on;
for k=1:4:4*np
    plot3(xp([k:k+3 k],1),yp([k:k+3 k]),zp([k:k+3 k],1),'k')
end
AZ=50;
EL=30;
view(AZ,EL)
xlabel('x')
ylabel('y')
zlabel('z')
axis('equal'); hold off;

Read and plot the geometry in the .gdf file. This also sets the ulen and grav values for non-dimensionalization.

[ulen,grav]=textread('2_4m_mesh.GDF','%f %f %*s',1,'headerlines',1);
[is(1,1),is(2,1)]=textread('2_4m_mesh.GDF','%d %d %*s',1,'headerlines',2);
[np]=textread('2_4m_mesh.GDF','%d %*s',1,'headerlines',3);
[xp,yp,zp]=textread('2_4m_mesh.GDF','%f %f %f ',

    'headerlines',4);

figure(); clf; hold on;
for k=1:4:4*np
    plot3(xp([k:k+3 k],1),yp([k:k+3 k]),zp([k:k+3 k],1),'k')
end
AZ=50;
EL=30;
view(AZ,EL)
xlabel('x')
ylabel('y')
zlabel('z')
axis('equal'); hold off;

Panelsize:
Set the water depth and the primary numeric output

h=-1;
fname='panel_mesh'; % Primary output file name.
% % Read the added mass and damping coefficients
% fnamerad=strcat(fname,'.1'); % The added mass and damping output file
nHead=1; % The number of header lines in the file
Order='TM'; % Order the results first by period then mode
[T,A_panel,B_panel]=ReadWAMIT1file(fnamerad,nHead,Order);
nper=length(T); % The total number of frequencies run
ip=1:nper-2;
% nmodes=length(A_panel(1,:,1)); % The number of modes (at least 6)
modes=[1:nmodes]; % The mode numbers (1:6 => rigid-body modes)
newmodes=max(nmodes-6,0); % The number of additional generalized modes
% omegaA=2*pi./T;omegaA=omegaA(ip); if omegaA(1,1)<0, omegaA(1,1)=0; end;
% disp(['Found ',num2str(nper),' periods in the .1 file.']);
%
% Read the RAO's
clear T;
fnamerao=strcat(fname,'.4'); % The RAO output file
[beta,T,RAOmag_panel,RAOphase,XR,XI]=ReadWAMIT234file(fnamerao,nHead,Order);
% Form the non-dimensional diffraction/RAO radian frequency vector
omega=2*pi./T; %omega=omega(ip);
Mesh convergence study

%% Read the Haskind Diffraction exciting forces

fnamediff=strcat(fname,'.2'); \% The Haskind diffraction file
[beta,T,XDmag_panel,XDphase,XR,XI]=ReadWAMIT234file(fnamediff,nHead,Order);

%% dimensionalizing the Motion response:

RAO_123_panel= RAOmag_panel(:,1:3,:)./ulen^0;
RAO_456_panel= RAOmag_panel(:,4:6,:)./ulen^1;

%% from frequency to waveLeangt/ulen:
\%\lambda= 2\pi/k, k=\omega^2/g
lambda_L=(2*pi./(omega(ip).^2./grav))./ulen;
lambda_LA=(2*pi./(omegaA(ip).^2./grav))./ulen;

%% added mass
A11(:,1)= A_panel(ip,1,1);\%\rho*(ulen^3);
A33(:,1)= A_panel(ip,3,3);\%\rho*(ulen^3);
\%
B11(:,1)= B_panel(ip,1,1);\%\rho*(ulen^3).*omega(ip);
B33(:,1)= B_panel(ip,3,3);\%\rho*(ulen^3).*omega(ip);
\%
X1(:,1)= XDmag_panel(ip,1,3);\%\rho*grav*(ulen^2);
X3(:,1)= XDmag_panel(ip,3,3);\%\rho*grav*(ulen^2);
\%
Response Amplitude:
RAO1(:,1)=RAO_123_panel(ip,1,:);
RAO3(:,1)=RAO_123_panel(ip,3,:);

Panelsize 16 meter:

Set the water depth and the primary numeric output

h=-1;
fname='16m_mesh'; \% Primary output file name.
\%
%% Read the added mass and damping coefficients

fnamerad=strcat(fname,'.1'); \% The added mass and damping output file
nHead=1; \% The number of header lines in the file
Order='TM';  % Order the results first by period then mode
[T,A_16m,B_16m]=ReadWAMIT1file(fnamerad,nHead,Order);
nper=length(T);  % The total number of frequencies run
ip=1:nper-2;

nmodes=length(A_16m(1,:,1));  % The number of modes (at least 6)
modes=[1:nmodes];  % The mode numbers (1:6 => rigid-body modes)
newmodes=max(nmodes-6,0);  % The number of additional generalized modes

omegaA=2*pi./T;omegaA=omegaA(ip); if omegaA(1,1)<0, omegaA(1,1)=0; end;

% disp(['Found ',num2str(nper),' periods in the .1 file.']);
%
% Read the RAO's

clear T;
fnamerao=strcat(fname,'.4');  % The RAO output file
[beta,T,RAOmag_16m,RAOphase,XR,XI]=ReadWAMIT234file(fnamerao,nHead,Order);
% Form the non-dimensional diffraction/RAO radian frequency vector
% omega=2*pi./T; omega=omega(ip);

% % Read the Haskind Diffraction exciting forces

fnamediff=strcat(fname,'.2');  % The Haskind diffraction file
[beta,T,XDmag_16m,XDphase,XR,XI]=ReadWAMIT234file(fnamediff,nHead,Order);

% dimensionalizing the Motion response:
RAO_123_16m= RAOmag_16m(:,1:3,:)./ulen^0;
RAO_456_16m= RAOmag_16m(:,4:6,:)./ulen^1;

% added mass
A11(:,2)= A_16m(ip,1,1);%*rho*(ulen^3);
A33(:,2)= A_16m(ip,3,3);%*rho*(ulen^3);
% damping
B11(:,2)= B_16m(ip,1,1);%*rho*(ulen^3).*omega(ip);
B33(:,2)= B_16m(ip,3,3);%*rho*(ulen^3).*omega(ip);
% exiting force
Mesh convergence study

X1(:,2)= XDmag_16m(ip,1,3);%*rho*grav*(ulen^2);
X3(:,2)= XDmag_16m(ip,3,3);%*rho*grav*(ulen^2);
% Response amplitude:
RAO1(:,2)=RAO_123_16m(ip,1,:);
RAO3(:,2)=RAO_123_16m(ip,3,:);

Panelsize 8 meter:
Set the water depth and the primary numeric output

h=-1;
fname='8m_mesh'; % Primary output file name.
%
% Read the added mass and damping coefficients
%
fnamerad=strcat(fname,'.1'); % The added mass and damping output file
nHead=1; % The number of header lines in the file
Order='TM'; % Order the results first by period then mode
[T,A_8m,B_8m]=ReadWAMIT1file(fnamerad,nHead,Order);

%i per=length(T); % The total number of frequencies run
ip=1:i per-2; %

nmodes=length(A_8m(1,:,1)); % The number of modes (at least 6)
modes=[1:nmodes]; % The mode numbers (1:6 => rigid-body modes)
newmodes=max(nmodes-6,0); % The number of additional generalized modes
%
omegaA=2*pi./T;omegaA=omegaA(ip); if omegaA(1,1)<0, omegaA(1,1)=0; end;
% disp([-found ',num2str(nper),' periods in the .1 file.']);
%
% Read the RAO's
clear T; clear omega;
fnamerao=strcat(fname,'.4'); % The RAO output file
[b eta,T,RAOmag_8m,RAOphase,XR,XI]=ReadWAMIT234file(fnamero,Order);
% Form the non-dimensional diffraction/RAO radian frequency vector
omega=2*pi./T; omega=omega(ip);
%
% % Read the Haskind Diffraction exciting forces
%
fnamediff=strcat(fname,'.2'); % The Haskind diffraction file
[beta,T,XDmag_8m,XDphase,XR,XI]=ReadWAMIT234file(fnamediff,nHead,Order);

% dimensionalizing the Motion response:
RAO_123_8m= RAOmag_8m(:,1:3,:)./ulen^0;
RAO_456_8m= RAOmag_8m(:,4:6,:)./ulen^1;

% added mass
A11(:,3)= A_8m(ip,1,1);%*rho*(ulen^3);
A33(:,3)= A_8m(ip,3,3);%*rho*(ulen^3);
% damping
B11(:,3)= B_8m(ip,1,1);%*rho*(ulen^3).*omega(ip);
B33(:,3)= B_8m(ip,3,3);%*rho*(ulen^3).*omega(ip);
% exiting force
X1(:,3)= XDmag_8m(ip,1,3);%*rho*grav*(ulen^2);
X3(:,3)= XDmag_8m(ip,3,3);%*rho*grav*(ulen^2);
% Response amplitesde:
RAO1(:,3)=RAO_123_8m(ip,1,:);
RAO3(:,3)=RAO_123_8m(ip,3,:);

Panelsize 4 meter:
Set the water depth and the primary numeric output

h=-1;
fname='4m_mesh'; % Primary output file name.

% Read the added mass and damping coefficients
nHead=1; % The number of header lines in the file
Order='TM'; % Order the results first by period then mode
[T,A_4m,B_4m]=ReadWAMIT1file(fnamerad,nHead,Order);

newmodes=max(nmodes-6,0); % The number of additional generalized modes
omegaA=2*pi./T;omegaA=omegaA(ip); if omegaA(1,1)<0, omegaA(1,1)=0; end;
disp(['Found ',num2str(nper),', periods in the .1 file.']);

% Read the RAO's
T; clear omega;
fnamerao=strcat(fname,'.4'); % The RAO output file
[beta,T,RAOmag_4m,RAOphase,XR,XI]=ReadWAMIT234file(fnamerao,nHead,Order);

% Form the non-dimensional diffraction/RAO radian frequency vector
omega=2*pi./T; %omega=omega(ip);

% % Read the Haskind Diffraction exciting forces
%
fnamediff=strcat(fname,'.2'); % The Haskind diffraction file
[beta,T,XDmag_4m,XDphase,XR,XI]=ReadWAMIT234file(fnamediff,nHead,Order);

% dimensionalizing the Motion response:
RAO_123_4m= RAOmag_4m(:,1:3,:)./ulen^0;
RAO_456_4m= RAOmag_4m(:,4:6,:)./ulen^1;

% added mass
A11(:,4)= A_4m(ip,1,1); %*rho*(ulen^3);
A33(:,4)= A_4m(ip,3,3); %*rho*(ulen^3);
%
damping
B11(:,4)= B_4m(ip,1,1); %*rho*(ulen^3).*omega(ip);
B33(:,4)= B_4m(ip,3,3); %*rho*(ulen^3).*omega(ip);
%
exiting force
X1(:,4)= XDmag_4m(ip,1,3); %*rho*grav*(ulen^2);
X3(:,4)= XDmag_4m(ip,3,3); %*rho*grav*(ulen^2);

% Response amplitude:
RAO1(:,4)=RAO_123_4m(ip,1,:);
RAO3(:,4)=RAO_123_4m(ip,3,:);

Panelsize 2 meter:
Set the water depth and the primary numeric output

h=-1;
fname='2m_mesh'; % Primary output file name.
% Read the added mass and damping coefficients
fnamerad=strcat(fname,'.1'); % The added mass and damping output file
nHead=1; % The number of header lines in the file
Order='TM'; % Order the results first by period then mode
[T,A_2m,B_2m]=ReadWAMIT1file(fnamerad,nHead,Order);
nper=length(T); % The total number of frequencies run
ip=1:nper-2;
% nmodes=length(A_2m(1,:,1)); % The number of modes (at least 6)
modes=[1:nmodes]; % The mode numbers (1:6 => rigid-body modes)
newmodes=max(nmodes-6,0); % The number of additional generalized modes
% omegaA=2*pi./T;omegaA=omegaA(ip); if omegaA(1,1)<0, omegaA(1,1)=0; end;
% disp(['Found ',num2str(nper),' periods in the .1 file.']);
%
% Read the RAO's
clear T; clear omega;
fnamerao=strcat(fname,'.4'); % The RAO output file
[beta,T,RAOmag_2m,RAOphase,XR,XI]=ReadWAMIT234file(fnamerao,nHead,Order);
% Form the non-dimensional diffraction/RAO radian frequency vector
omega=2*pi./T;% omega=omega(ip);
%
% % Read the Haskind Diffraction exciting forces
% fnamediff=strcat(fname,'.2'); % The Haskind diffraction file
% [beta,T,XDmag_2m,XDphase,XR,XI]=ReadWAMIT234file(fnamediff,nHead,Order);
%
% dimensionalizing the Motion response:
RAO_123_2m= RAOmag_2m(:,1:3,:)./ulen^0;
RAO_456_2m= RAOmag_2m(:,4:6,:)./ulen^1;
%
% added mass
A11(:,5)= A_2m(ip,1,1);%*rho*(ulen^3);
A33(:,5)= A_2m(ip,3,3);%*rho*(ulen^3);
Mesh convergence study

% damping
B11(:,5)= B_2m(ip,1,1);%*rho*(ulen^3).*omega(ip);
B33(:,5)= B_2m(ip,3,3);%*rho*(ulen^3).*omega(ip);
% exiting force
X1(:,5)= XDmag_2m(ip,1,3);%*rho*grav*(ulen^2);
X3(:,5)= XDmag_2m(ip,3,3);%*rho*grav*(ulen^2);
% Response amplitude:
RA01(:,5)=RAO_123_2m(ip,1,:);
RA03(:,5)=RAO_123_2m(ip,3,:);

Nurbes High order:
Set the water depth and the primary numeric output

h=-1;
fname='fishfarmnurbes'; % Primary output file name.
%
% Read the added mass and damping coefficients
%
fnamerad=strcat(fname,'.1'); % The added mass and damping output file
nHead=1; % The number of header lines in the file
Order='TM'; % Order the results first by period then mode
[T,A_nurbe,B_nurbe]=ReadWAMIT1file(fnamerad,nHead,Order);
nper=length(T); % The total number of frequencies run
%
% nmodes=length(A_nurbe(1,:,1)); % The number of modes (at least 6)
modes=[1:nmodes]; % The mode numbers (1:6 => rigid-body modes)
newmodes=max(nmodes-6,0); % The number of additional generalized modes
%
omegaA2=2*pi./T
%
disp(['Found ',num2str(nper),' periods in the .1 file.']);
%
%
% Read the RAO's
clear T;
fnamerao=strcat(fname,'.4'); % The RAO output file
[beta,T,RA0mag_nurbe,RA0phase,XR,XI]=ReadWAMIT234file(fnamerao,nHead,Order);
% Form the non-dimensional diffraction/RAO radian frequency vector
omega2=2*pi./T;
% % Read the Haskind Diffraction exciting forces 
%
fnamediff=strcat(fname,.2);  % The Haskind diffraction file 
[beta,T1,XDmag_nurbe,XDphase,XR,XI]=ReadWAMIT234file(fnamediff,nHead,Order); 
omega2=2*pi./T1;

% dimensionalizing the Motion response:

RAO_123_nurbe= RAOmag_nurbe(:,:,1:3,:)./ulen^0;  
RAO_456_nurbe= RAOmag_nurbe(:,:,4:6,:)./ulen^1;

% from frequency to waveLeangt/ulen:
%\lambda = 2\pi/k, k=w^2/g 
lambda_L=(2*pi./(omega(ip).^2./grav))./ulen;
lambda_LA=(2*pi./(omegaA(ip).^2./grav))./ulen;
lambda_L2=(2*pi./(omega2.^2./grav))./ulen;
lambda_LA2=(2*pi./(omegaA2.^2./grav))./ulen;

% added mass 
A11_high= A_nurbe(:,:,1,1);%*rho*(ulen^3);  
A33_high= A_nurbe(:,:,3,3);%*rho*(ulen^3);
% damping 
B11_high= B_nurbe(:,:,1,1);%*rho*(ulen^3).*omega(:);  
B33_high= B_nurbe(:,:,3,3);%*rho*(ulen^3).*omega(:);
% exiting force 
X1_high= XDmag_nurbe(:,:,1,3);%*rho*grav*(ulen^2); 
X3_high= XDmag_nurbe(:,:,3,3);%*rho*grav*(ulen^2);
% Response Amplitude: 
RA01_high=RAO_123_nurbe(:,:,1,3);  
RA03_high=RAO_123_nurbe(:,:,3,3);

plot:

close all

%plot the Added mass in Heave and surge 
figure() 
subplot(2,1,1) 
plot(lambda_LA,A33(:,:,1),lambda_LA,A33(:,:,2)...
Mesh convergence study

xlabel('$\frac{\lambda}{L} \left[ \frac{m}{m} \right]$','interpreter','latex','fontsize',17)
ylabel('A33','fontsize',17)
title(['Added mass',', Heave',' $\beta=180$']);
legend('platesize mesh','16m mesh','8m mesh','4m mesh','2m mesh','Highorder')
axis([0.25 5 4.5*10^-4 8.5*10^-4])

subplot(2,1,2)
plot(lambda_LA,A11(:,1),lambda_LA,A11(:,2),
     lambda_LA,A11(:,3),lambda_LA,A11(:,4),lambda_LA,A11(:,5),
     lambda_LA2,A11_high,'-+','LineWidth',2)
xlabel('$\frac{\lambda}{L} \left[ \frac{m}{m} \right]$','interpreter','latex','fontsize',17)
ylabel('A11','fontsize',17)
title(['Added mass',', surge',' $\beta= 180$']);
legend('platesize mesh','16m mesh','8m mesh','4m mesh','2m mesh','Highorder')
axis([0.25 5 1.8*10^-4 2.7*10^-4])

plot(lambda_LA,B33(:,1),lambda_LA,B33(:,2),
     lambda_LA,B33(:,3),lambda_LA,B33(:,4),lambda_LA,B33(:,5),
     lambda_LA2,B33_high,'-+','LineWidth',2)
xlabel('$\frac{\lambda}{L} \left[ \frac{m}{m} \right]$','interpreter','latex','fontsize',17)
ylabel('B33','fontsize',17)
title(['Damping',', Heave',' $\beta= 180$']);
legend('platesize mesh','16m mesh','8m mesh','4m mesh','2m mesh','Highorder')
axis([0.25 5 0 4*10^-5])

subplot(2,1,2)
plot(lambda_LA,B11(:,1),lambda_LA,B11(:,2),
     lambda_LA,B11(:,3),lambda_LA,B11(:,4),lambda_LA,B11(:,5),
     lambda_LA2,B11_high,'-+','LineWidth',2)
xlabel('$\frac{\lambda}{L} \left[ \frac{m}{m} \right]$','interpreter','latex','fontsize',17)
ylabel('B11','fontsize',17)
title(['Damping',', Surge',' $\beta= 180$']);
legend('platesize mesh','16m mesh','8m mesh','4m mesh','2m mesh','Highorder')
axis([0.25 5 0 0.5*10^-5])

%rao 1
figure
plot(lambda_L,RAO1(:,1),lambda_L,RAO1(:,2),... 
lambda_L,RAO1(:,3),lambda_L,RAO1(:,4),lambda_L,RAO1(:,5),lambda_L2,RAO1_high,'+-','LineWidth',2)
title(['RAO',', Surge'],'fontsize',17);
ylabel('$\frac{\xi_1}{A}\left[\frac{m}{m}\right]$','interpreter','latex','fontsize',17)
set(get(gca,'YLabel'),'Rotation',90)
xlabel('$\frac{\lambda}{L}\left[\frac{m}{m}\right]$','interpreter','latex','fontsize',17)
legend('platesize mesh','16m mesh','8m mesh','4m mesh','2m mesh','Highorder')
xlim([0.25 5])

figure
plot(lambda_L,RAO3(:,1),lambda_L,RAO3(:,2),... 
lambda_L,RAO3(:,3),lambda_L,RAO3(:,4),lambda_L,RAO3(:,5),lambda_L2,RAO3_high,'+-','LineWidth',2)
title(['RAO',', Heave']);
ylabel('$\frac{\xi_3}{A}\left[\frac{m}{m}\right]$','interpreter','latex','fontsize',17)
set(get(gca,'YLabel'),'Rotation',90)
xlabel('$\frac{\lambda}{L}\left[\frac{m}{m}\right]$','interpreter','latex','fontsize',17)
legend('platesize mesh','16m mesh','8m mesh','4m mesh','2m mesh','Highorder')
xlim([0.25 5])

figure
subplot(2,1,1)
plot(omega,RAO1(:,1),omega,RAO1(:,2),... 
omega,RAO1(:,3),omega,RAO1(:,4),omega,RAO1(:,5),omega2,RAO1_high,'+-','LineWidth',2)
title(['RAO',', Surge'],'fontsize',17);
ylabel('$\frac{\xi_1}{A}\left[\frac{m}{m}\right]$','interpreter','latex','fontsize',17)
set(get(gca,'YLabel'),'Rotation',90)
xlabel('$\omega\left[\frac{rad}{s}\right]$','interpreter','latex','fontsize',17)
legend('platesize mesh','16m mesh','8m mesh','4m mesh','2m mesh','Highorder')
xlim([0.1 0.7])
ylim([0 1.5])

subplot(2,1,2)
plot(omega,RAO3(:,1),omega,RAO3(:,2),... 
omega,RAO3(:,3),omega,RAO3(:,4),omega,RAO3(:,5),omega2,RAO3_high,'+-','LineWidth',2)
title(['RAO',', Heave'],'fontsize',17);
ylabel('$\frac{\xi_3}{A}\left[\frac{m}{m}\right]$','interpreter','latex','fontsize',17)
set(get(gca,'YLabel'),'Rotation',90)
xlabel('$\omega\left[\frac{rad}{s}\right]$','interpreter','latex','fontsize',17)
legend('platesize mesh','16m mesh','8m mesh','4m mesh','2m mesh','Highorder')
xlim([0.1 0.7])
ylim([0 10])
function [beta,T,K,pMag,pPhase,pR,pI]=ReadWAMIT5pfile(fnamep,nHead)
    
    fin=fopen(fnamep);
    
    for i=1:nHead, buffer = fgetl(fin); end; % skip the header line(s)
    tmp=fscanf(fin,'%f'); nd=length(tmp);
    fclose(fin);
    beta=unique(tmp(2:8:end),'stable'); nbeta=length(beta);
    M=unique(tmp(3:8:end),'stable'); nM=length(M);
    K=unique(tmp(4:8:end),'stable'); nK=length(K);
    %
    stride=nbeta*nM*8;
    stride1=nbeta*nM*8*nK;
    nf=(nd)/stride;
    
    T=tmp(1:stride1:end);
    
    nmodes=max(max(M));
    
    pMag=zeros(nf,nmodes,nbeta); pPhase=pMag;
    pR=pMag; pI=pMag;
    %
    for ib=1:nbeta
        for im=1:nM
            i0=(ib-1)*nM*8+(im-1)*8+4;
            pMag(:,:,M(im),ib)=tmp(i0+1:stride:end);
            pPhase(:,:,M(im),ib)=tmp(i0+2:stride:end);
            pR(:,:,M(im),ib)=tmp(i0+3:stride:end);
            pI(:,:,M(im),ib)=tmp(i0+4:stride:end);
        end
    end
end

Calculating the Hydrodynamic forces

article graphicx color
Contents

- Read the Geometry files
- Read the pressure from WAMIT:
- Read the RAO geometry
- Hydrodynamic bending moment from .5p pressure-file
- Moment of Inertia / inertia force;
- Hydrostatic restoring Force and Moment:
- Bending Moment

clc
clear all
close all

Read the Geometry files

basic inputs:

rho=1025;
A=1;

% Read and plot the geometry in the .gdf file. This also sets the ulen and
% grav values for non-dimensionalization.
%
% Choose primary WAMIT output file name.
fname='fishfarm_90';
% choose Geometry file name
fnameGDF='fishfarm';

GDFFile=strcat(fnameGDF,'.GDF');
[ulen,grav]=textread(GDFFile,'%f %f %*s',1,'headerlines',1);
[np]=textread(GDFFile,'%d %*s',1,'headerlines',3);
[xp,yp,zp]=textread(GDFFile,'%f %f %f ',...
    'headerlines',4);
% B=max(yp)-min(yp); %m
B=(ulen*8+4*46*7)/ulen; %m
VCG=-16;

% to centering the geometry along the x-axis;
x=ulen/2;
xp=xp+((max(xp)-min(xp))./2 - max(xp));
Read the pressure from WAMIT:

```matlab
fnamep=strcat fname,'.5p'); % The pressure output file
nHead=1; % The number of header lines in the file
[beta,T1,K,pMag,pPhase,pR,pI]=ReadWAMIT5pfile(fnamep,nHead);

% The total number of frequencies run
nper=length(T1);

if omega(1,1)<0, omega(1,1)=0; end;

nf=length(T1);
nd=length(pR(:,1))/nf;
jf=2:nf-1;

for n=1:nf
    pMag1(:,n)=pMag(1+nd*(n-1):nd*n);
    pPhase1(:,n)=pPhase(1+nd*(n-1):nd*n);
    pR1(:,n)=pR(1+nd*(n-1):nd*n);
    pI1(:,n)=pI(1+nd*(n-1):nd*n);
end

%%%%% Pressure on each panel %%%%%

p_bar=(pR1+sqrt(-1).*pI1); % complex number of pressure non dimensin
p=(p_bar).*rho*grav*A; % dimensionalized: N/m^2
```

Read the RAO

```matlab
clear T
fnamerao=strcat fname,'.4'); % The RAO output file
[beta,T,RA0mag,RA0phase,XR,XI]=ReadWAMIT234file(fnamerao,nHead,Order);
omega=2*pi./T;
RA0mag(:,4:6)=RA0mag(:,4:6)./ulen.*A; % dimensionalize RAO

% Make the comlex response variable:
Xi=XR+sqrt(-1).*XI;

% define each motion and acceleration:
RA03_elev=(Xi(:,3)).*A; % frequency domain
RA04_elev=(Xi(:,4)).*A; % frequency domain
RA05_elev=(Xi(:,5))./ulen.*A; % frequency domain
RA06_elev=(Xi(:,6))./ulen.*A; % frequency domain
RA02_acc=(-omega.^2.*Xi(:,2)).*A; % frequency domain
RA03_acc=(-omega.^2.*Xi(:,3)).*A; % frequency domain
RA04_acc=(-omega.^2.*Xi(:,4))./ulen.*A; % frequency domain
RA05_acc=(-omega.^2.*Xi(:,5))./ulen.*A; % frequency domain
```
RA06_acc=(-omega.^2.*Xi(:,6))./ulen.*A;  \% frequency domain

gamey

Find coordinates for each panel:

for i=1:4
    panel_x(:,i)=xp(i:4:end);
    panel_y(:,i)=yp(i:4:end);
    panel_z(:,i)=zp(i:4:end);
end
\% to only include panels evaluated in file .5p
    panel_x=panel_x(K,:);
    panel_y=panel_y(K,:);
    panel_z=panel_z(K,:);

\% x distance of panel:
    x_dist= (panel_x(:,1)+panel_x(:,3))./2;
\% Area of panels in xy-plane:
    xy_area=abs((panel_x(:,1)-panel_x(:,3)).*abs((panel_y(:,1)-panel_y(:,3))));
\% z- distance of panel:
    xz_dist= (panel_z(:,1)+panel_z(:,3))./2;
\% Area of panels in xy-plane:
    xz_area=abs((panel_z(:,1)-panel_z(:,3)).*(panel_x(:,1)-panel_x(:,3)));
\% XY area at each section:
    xy_loop=sortrows([xy_area x_dist],2);
    xy_panel=xy_loop(:,1);
    xy_panel_pos=xy_loop(:,2);
\% Sectionalize the area and define the longitudinal position:
    [a1,~,c1] = unique(xy_panel_pos(:,1));
    xy = [a1, accumarray(c1,xy_panel)];
\%
    xy_area_sect=xy(:,2);
    xy_area_sect_pos=xy(:,1);
\% for i=1:length(xy_area_sect_pos)-1
    dx_sect(i,:)=abs(xy_area_sect_pos(i)-xy_area_sect_pos(i+1));
end
    dx_sect(length(xy_area_sect_pos))=dx_sect(end);
\% ZY area at each section:
    xz_loop=sortrows([xz_area x_dist],2);
    xz_panel=xz_loop(:,1);
    xz_panel_pos=xz_loop(:,2);
Calculating the Hydrodynamic forces

```
[a1,-,c1] = unique(xz_panel_pos(:,1));
xz= [a1, accumarray(c1,xz_panel)];

xz_area_sect=xz(:,2);
xz_area_sect_pos=xz(:,1);

% volume & mass:
m=34417; % volume displacement from Rhino
thickness=m/sum(xz_area_sect);
vol_sect=thickness.*xz_area_sect; % m^3
m_sect=vol_sect.*rho; % kg/m^3
m_tot=sum(m_sect); % To check if it the same as " m "

armlength=xy_area_sect_pos;

% Hydrodynamic bending moment from .5p pressure-file

% vertical force of each panel:
F_vert_panel= p.*xy_area; % Newton
% horizontal force at each panel
F_hor_panel= p.*xz_area; % Newton
%
% sort the vertical forces accordingly to the rising x and y position:
for n=1:nf
looprun_x=sortrows([F_vert_panel(:,n) x_dist],2);
F_vert_xsort(:,n)=looprun_x(:,1);
end
x_pos=looprun_x(:,2);
% sort the horizontal forces accordingly to the rising x position:
for n=1:nf
looprun1=sortrows([F_hor_panel(:,n) x_dist],2);
F_hor_sort(:,n)=looprun1(:,1);
end
yx_pos=looprun1(:,2);
% forces at same x-position summarized:
for n=1:nf
    % x_sorted_
    [a1,-,c1] = unique(x_pos(:,1));
    vert_force_xrun= [a1, accumarray(c1,F_vert_xsort(:,n))];
    vert_force_xrun(all(vert_force_xrun==0,2),:)=[]; % removes all rows with zero
    vert_force_xsect(:,n)=vert_force_xrun(:,2);
end
```

% horizontal:
[a1, - , c1] = unique(yx_pos(:, 1));
hor_force_run = [a1, accumarray(c1, F_hor_sort(:, n))];
hor_force_run(all(hor_force_run == 0, 2), :) = [] ;  % removes all rows with zero
hor_force_sect(:, n) = hor_force_run(:, 2);
end

ED3 = (cumtrapz(vert_force_xsect));
x_pos = vert_force_xrun(:, 1); npos = length(x_pos);
% ED4_sect = vert_force_ysect.*yarmength;
% ED4 = (cumtrapz(ED4_sect));
ED5_sect = vert_force_xsect.*armlength;
ED5 = -(cumtrapz(ED5_sect));

ED6_sect = hor_force_sect.*armlength;
ED6 = (cumtrapz(ED6_sect));

beam_sect = repmat(B, npos, 1); beam_sect(1) = 0; beam_sect(end) = 0;
% sectional moment of inertia around x-axis:

% i_sect = m_tot./12.*(beam_sect.^2 + draft^2);

Moment of Inertia / inertia force;

x_sect = (ulen/(npos-2));
for n=1:nf
I3(:, n) = cumtrapz(m_sect.*(RAO3_acc(n)-armlength.*RAO5_acc(n)));  
% I4(:, n) = cumtrapz(i_sect.*RAO4_acc(n)-m_sect.*VCG.*(RAO2_acc(n)+armlength.*RAO6_acc(n));
I5(:, n) = -cumtrapz(m_sect.*armlength.*(RAO3_acc(n)-armlength.*RAO5_acc(n)));
I6(:, n) = cumtrapz(m_sect.*armlength.*(RAO2_acc(n)+armlength.*RAO6_acc(n)-VCG.*RAO4_acc(n));
end

Hydrostatic restoring Force and Moment:

Ix = (beam_sect.^3.*ulen)/12;   BM = Ix/m_tot;   KB = draft/2;   KM = KB+BM;
OM = KM - draft;

for n=1:nf
R3(:, n) = rho*grav.*cumtrapz(xy_area_sect.*(RAO3_elev(n)-armlength.*RAO5_elev(n)));  
R4(:, n) = grav.*RAO4_elev(n). *cumtrapz(rho.*xz_area_sect.*OM - m_sect.*VCG);
R5(:, n) = rho*grav.*cumtrapz(xy_area_sect.*armlength.*(RAO3_elev(n)-armlength.*RAO5_elev(n));
R6 = 0;
end
Bending Moment

moment distribution:

\[ V_3 = \text{abs}(I_3 - R_3 - ED_3); \]

\[ V_4 = \text{abs}(I_4 - R_4 - ED_4); \]

\[ V_5 = \text{abs}(I_5 - R_5 - ED_5); \]

\[ V_6 = \text{abs}(I_6 - R_6 - ED_6); \]

for n = 1:nf
  VBM_max(n) = max(abs(V5(:,n)));  
  VSF_midt(n) = V3(round(npos/2),n);  
  VBM_midt(n) = V5(round(npos/2),n);  
  HBM_midt(n) = V6(round(npos/2),n);  
end

dlmwrite('VSF_midt_90',VSF_midt)  
dlmwrite('VBM_midt_90',VBM_midt)  
dlmwrite('HBM_midt_90',HBM_midt)  
dlmwrite('RAOmag_90',RAOmag)  
dlmwrite('omega',omega)  
dlmwrite('T',T)

\[
\lambda_L = \frac{2\pi}{(\omega^2/\text{grav})^{1/2}}/\text{ulen};
\]

Plotting the results
Contents

- Plot the results:

```matlab
clc; clear all; close all;
VSF_midt_180=dlmread('VSF_midt_180');
HBM_midt_180=dlmread('HBM_midt_180');
VBM_midt_180=dlmread('VBM_midt_180');
RAOmag_180=dlmread('RAOmag_180');
VSF_midt_150=dlmread('VSF_midt_150');
HBM_midt_150=dlmread('HBM_midt_150');
VBM_midt_150=dlmread('VBM_midt_150');
RAOmag_150=dlmread('RAOmag_150');
VSF_midt_120=dlmread('VSF_midt_120');
VBM_midt_120=dlmread('VBM_midt_120');
HBM_midt_120=dlmread('HBM_midt_120');
RAOmag_120=dlmread('RAOmag_120');
VSF_midt_90=dlmread('VSF_midt_90');
VBM_midt_90=dlmread('VBM_midt_90');
HBM_midt_90=dlmread('HBM_midt_90');
RAOmag_90=dlmread('RAOmag_90');
omega=dlmread('omega');
T=dlmread('T');
RAO1nsk=dlmread('RAO1nsk');
RAO3nsk=dlmread('RAO3nsk');
RAO5nsk=dlmread('RAO5nsk');

% Read the added mass and damping coefficients
%
jf=1:43;
grav=9.82;
ulen=402;
lambda_L=(2*pi./(omega.^2./grav))./ulen;

Plot the results:

close all

figure
plot(lambda_L,VBM_midt_180,lambda_L,VBM_midt_150,lambda_L,...
VBM_midt_120,lambda_L,VBM_midt_90,'LineWidth',3)
title('Vertical Bending Moment at mid-ship','fontsize',17)
```
legend('180deg','150deg','120deg','90deg')
xlabel('Wave length /Ship length [s]','fontsize',15)
ylabel('$\frac{VBM}{A}\frac{[Nm]}{[m]}$','interpreter','latex','fontsize',17)
xlim([0 5])

figure
plot(T,VBM_midt_180,T,VBM_midt_150,T,...
VBM_midt_120,T,VBM_midt_90,'LineWidth',3)
title('Vertical Bending Moment at mid-ship','fontsize',17)
legend('180deg','150deg','120deg','90deg')
xlabel('Wave length /Ship length [s]','fontsize',15)
ylabel('$\frac{VBM}{A}\frac{[Nm]}{[m]}$','interpreter','latex','fontsize',17)
xlim([0 20])

T_VBM=array2table([VBM_midt_180', T],...
'VariableNames',{VBM_180deg,'Waveperiod'})
figure
plot(lambda_L,HBM_midt_180,lambda_L,HBM_midt_150,lambda_L,...
HBM_midt_120,lambda_L,HBM_midt_90,'LineWidth',3)
title('Horizontal Bending Moment at mid-ship','fontsize',17)
legend('180deg','150deg','120deg','90deg')
xlabel('Wave length /Ship length [s]','fontsize',15)
ylabel('$\frac{HBM}{A}\frac{[Nm]}{[m]}$','interpreter','latex','fontsize',17)
xlim([0 5])

figure
plot(lambda_L,VSF_midt_180,lambda_L,VSF_midt_150,lambda_L,...
VSF_midt_120,lambda_L,VSF_midt_90,'LineWidth',3)
title('Vertical Shear Force at mid-ship','fontsize',17)
legend('180deg','150deg','120deg','90deg')
xlabel('Wave length /Ship length [s]','fontsize',15)
ylabel('$\frac{VSF}{A}\frac{[N]}{[m]}$','interpreter','latex','fontsize',17)
axis([5 30 0 2*10^9])
xlim([0 5])

figure()
plot(RAO1nsk(:,1),RAO1nsk(:,2),'-*',T,RAOmag_180(:,1),T,RAOmag_150(:,1),...
T,RAOmag_120(:,1),T,RAOmag_90(:,1),'LineWidth',3)
```matlab
xlim([5 30])
legend('NSK 180deg','180deg','150deg','120deg','90deg')
title('RAO Surge','fontsize',17)
ylabel('$\frac{\xi_1}{A}\left[\frac{m}{m}\right]$',...
'interpreter','latex','fontsize',17)
set(get(gca,'YLabel'),'Rotation',90)
xlabel('Wave period [s]','fontsize',15)
figure()
plot(T,RAOmag_180(:,2),T,RAOmag_150(:,2),...
T,RAOmag_120(:,2),T,RAOmag_90(:,2),'
'LineWidth',3)
xlim([5 30])
legend('180deg','150deg','120deg','90deg')
title('RAO Sway','fontsize',17)
ylabel('$\frac{\xi_2}{A}\left[\frac{m}{m}\right]$',...
'interpreter','latex','fontsize',17)
set(get(gca,'YLabel'),'Rotation',90)
xlabel('Wave period [s]','fontsize',15)
figure()
plot(RAO3nsk(:,1),RAO3nsk(:,2),'-*',T,RAOmag_180(:,3),T,RAOmag_150(:,3),...
T,RAOmag_120(:,3),T,RAOmag_90(:,3),'
'LineWidth',3)
xlim([5 30])
legend('NSK 180deg','180deg','150deg','120deg','90deg')
title('RAO Heave','fontsize',17)
ylabel('$\frac{\xi_3}{A}\left[\frac{m}{m}\right]$',...
'interpreter','latex','fontsize',17)
set(get(gca,'YLabel'),'Rotation',90)
xlabel('Wave period [s]','fontsize',15)
figure()
plot(T,RAOmag_180(:,4).*180/pi,T,RAOmag_150(:,4).*180/pi,...
T,RAOmag_120(:,4).*180/pi,T,RAOmag_90(:,4).*180/pi,'LineWidth',3)
xlim([5 30])
legend('180deg','150deg','120deg','90deg')
title('RAO Roll','fontsize',17)
ylabel('$\frac{\xi_4}{A}\left[\frac{deg}{m}\right]$'...
'interpreter','latex','fontsize',15)
set(get(gca,'YLabel'),'Rotation',90)
xlabel('Wave period [s]','fontsize',15)
figure()
plot(RA05nsk(:,1),RA05nsk(:,2),'-*',T,RAOmag_180(:,5).*180/pi,...
Structural hand-calculation

article graphicx color

Contents

- the mid section in z-y plan:
- Stress on body:
- max VBM:

clc
clear all
close all
z_bar=[-14.517123287671234];  \%result from Nuteral_Z

\%inputs
Sigma_Y=350*10^6;  \% Yield stress Steel:250MPa [N/m^2]
E_module=210*10^9;  \% E module steel 210 GPa [N/m^2]
thick=0.2;  \% [m] plate thickness
thick2=0.3;  \% [m] Plate thickness
Hs= 10;  \% [m] Significant Wave height
H_max=1.86*Hs;
A= H_max/2; % [m] amplitude 
B2=54/2; % [m] Y-distance to beam
n = 2 ;% number of beams

%from WAMIT:
% VBM=A*3.4*10^10;% Nm
VBM= 7e+10;
VSF=1.471*10^8; % N
HSF=0 ;% N

the mid section in z-y plan:

%coordinates;
upr_beamR=[0 0; 4 0; 4 -4; 3 -5.5; 1 -5.5; 0 -4; 0 0]+[23 -z_bar]; % coordinates
um_beam=[0 0; 4 0; 4 -4; -4 -4; -4 -0; 0 0]+[0 -z_bar];
mid_beamR=[0 0; 4 0; 4 -3.5; 0 -3.5; 0 0]+[23 -15-z_bar];% coordinates
mid_beamL=[-1 1].*mid_beamR;% coordinates
lwr_beamR=[0 0; 4 0; 4 -2.5; 0 -2.5; 0 0]+[23 -35.5-z_bar];% coordinates
lwr_beamL=[-1 1].*lwr_beamR;% coordinates

VBM1=VBM;
normalforce_UB=VBM1*upr_beamR(:,2);
normalforce_MB=VBM1*mid_beamR(:,2);
normalforce_LB=VBM1*lwr_beamR(:,2);
clear VBM1

% length vectors of each plate
for i=1:length(upr_beamR)-1
    y_length_UB(i)=upr_beamR(i+1,1)-upr_beamR(i,1);
    z_length_UB(i)=upr_beamR(i+1,2)-upr_beamR(i,2);
    UB_zpos(i)=(upr_beamR(i+1,2)+upr_beamR(i,2))./2;
end
y_length_UB=abs(y_length_UB);
z_length_UB=abs(z_length_UB);

for i=1:length(um_beam)-1
    y_length_UMB(i)=um_beam(i+1,1)-um_beam(i,1);
    z_length_UMB(i)=um_beam(i+1,2)-um_beam(i,2);
    UMB_zpos(i)=(um_beam(i+1,2)+um_beam(i,2))./2;
end
y_length_UMB=abs(y_length_UMB);
z_length_UMB=abs(z_length_UMB);

for i=1:length(mid_beamR)-1
    y_length_MB(i)=mid_beamR(i+1,1)-mid_beamR(i,1);
    z_length_MB(i)=mid_beamR(i+1,2)-mid_beamR(i,2);
    MB_zpos(i)=(mid_beamR(i+1,2)+[-15]+mid_beamR(i,2)+[-15])./2+[-15];
end
y_length_MB=abs(y_length_MB);
z_length_MB=abs(z_length_MB);

for i=1:length(lwr_beamR)-1
    y_length_LB(i)=lwr_beamR(i+1,1)-lwr_beamR(i,1);
    z_length_LB(i)=lwr_beamR(i+1,2)-lwr_beamR(i,2);
    LB_zpos(i)=(lwr_beamR(i+1,2)+[-35.5]+lwr_beamR(i,2)+[-35.5])./2+[-35.5];
end
y_length_LB=abs(y_length_LB);
z_length_LB=abs(z_length_LB);

% area of each plate
y_area_UB=abs(y_length_UB).*thick2;
z_area_UB=abs(z_length_UB).*thick;
area UB=sqrt(y_area_UB.^2+z_area_UB.^2);
y_area_UMB=abs(y_length_UMB).*thick;
z_area_UMB=abs(z_length_UMB).*thick;
area_UMB=sqrt(y_area_UMB.^2+z_area_UMB.^2);
y_area_MB=abs(y_length_MB).*thick;
z_area_MB=abs(z_length_MB).*thick;
area MB=sqrt(y_area_MB.^2+z_area_MB.^2);
y_area_LB=abs(y_length_LB).*thick2;
z_area_LB=abs(z_length_LB).*thick2;
area LB=sqrt(y_area_LB.^2+z_area_LB.^2);

% 2.order area of moment of each plate:
y_MA_UB=thick2^3 .*y_length_UB/12 +y_area_UB.*UB_zpos.^2;
y_MA_UMB=thick^3 .*y_length_UMB/12 +y_area_UMB.*UMB_zpos.^2;
y_MA_MB=thick^3 .*y_length_MB/12 +y_area_MB.*MB_zpos.^2;
y_MA_LB=thick2^3 .*y_length_LB/12 +y_area_LB.*LB_zpos.^2;
z_MA_UB=thick .*z_length_UB.^3/12 +z_area_UB.*UB_zpos.^2;
z_MA_UMB=thick .*z_length_UMB.^3/12 +z_area_UMB.*UMB_zpos.^2;
z_MA_MB=thick .*z_length_MB.^3/12 +z_area_MB.*MB_zpos.^2;
z_MA_LB=thick2 .*z_length_LB.^3/12 +z_area_LB.*LB_zpos.^2;

% total 2.order area of moment of the cross section.
Iyy= sum(y_MA_UB.*n)+sum(z_MA_UB)+sum(y_MA_UMB)+sum(z_MA_UMB)...
+sum(y_MA_MB)+sum(z_MA_MB) +sum(y_MA_LB).*n) +sum(z_MA_LB).*n); % m^4
% 2.order area of moment of each beam:
Izz_LB= sum(thick2^3.*abs(z_length_LB)/12 +thick2.*abs(y_length_LB).^3/12);
Iyy_LB= sum(thick2.*abs(z_length_LB).^3/12 +thick2.^3.*abs(y_length_LB)/12);
Izz_UB= sum(thick^3.*abs(z_length_UB)/12 +thick.*abs(y_length_UB).^3/12);
Iyy_UB= sum(thick2.*abs(z_length_UB).^3/12 +thick2.^3.*abs(y_length_UB)/12);
Iyy_UMB= sum(thick.*abs(z_length_UMB).^3/12+thick.^3.*abs(y_length_UMB)/12);

% calculate the neutral axis:
Natural_Z= (sum(y_area_UB.*UB_zpos).*n + sum(z_area_UB.*UB_zpos).*n...
+ sum(y_area_UMB.*UMB_zpos).*n + sum(z_area_UMB.*UMB_zpos).*n...
+ sum(y_area_MB.*MB_zpos).*n + sum(z_area_MB.*MB_zpos).*n)

% clear y_length_UBR y_length_MBR y_length_LBR z_length_UBR z_length_MBR z_length_LBR
% clear y_area_UBR y_area_MBR y_area_LBR z_area_UBR z_area_MBR z_area_LBR

% plot the mid section:
Na= repmat(Natural_Z, 20);
figure()
plot(normalforce_UB+B2,upr_beamR(:,2)...
,normalforce_MB+B2,mid_beamR(:,2),normalforce_LB+B2,lwr_beamR(:,2),...
-normalforce_UB-B2,upr_beamR(:,2)...
,-normalforce_MB-B2,mid_beamR(:,2),-normalforce_LB-B2,lwr_beamR(:,2))
% clear upr_beamR upr_beamL mid_beamR mid_beamL lwr_beamR lwr_beamL B B2

Stress on body:

% Normal Stress due to bending moment: p.42
Sigma_UB= VBM/Iyy*UB_zpos; % N/m^2
Sigma_MB= VBM/Iyy*MB_zpos; % N/m^2
Sigma_LB= VBM/Iyy*LB_zpos; % N/m^2
% find max and min values of stress.
Sigma_max=max([max(Sigma_UB), max(Sigma_MB), max(Sigma_LB)]) % N/m^2
Sigma_min=min([min(Sigma_UB), min(Sigma_MB), min(Sigma_LB)]) % N/m^2
figure()
plot(Sigma_UB,UB_zpos,'r'... 
,Sigma_MB,MB_zpos,'r',...)
Sigma_LB, LB_zpos, 'r', ...
-Sigma_UB, UB_zpos, 'r' ...
,-Sigma_MB, MB_zpos, 'r' ...
,-Sigma_LB, LB_zpos, 'r')
ylabel('Z-position on structure (height)')
xlabel('Magnitude of Stress [Pa]')
grid on

% Stress due to Shear force
tau_z= VSF/ (sum(area_UB)+sum(area_MB)+sum(area_LB));
tau_y= HSF/ (sum(area_UB)+sum(area_MB)+sum(area_LB));
clear area_UBR area_MBR area_LBR

max VBM:
% Euler II for becalking;
L_LB=(56-2-5.5);
L UB=56-2-11;
S_Euler_LB_y = \pi^2*E_module *Izz_LB./(sum(area_LB)*(L_LB)^2) % Euler buckling lower beam in Y-direction
S_Euler_LB_z = \pi^2*E_module *Iyy_LB./(sum(area_LB)*(L_LB/3)^2) % Euler buckling lower beam in Z-direction
S_Euler_UB_y = \pi^2*E_module *Izz_UB./(sum(area_UB)*L_UB^2) % Euler buckling upper beam in Y-direction
S_Euler_UB_z = \pi^2*E_module *Iyy_UB./(sum(area_UB)*L_UB^2) % Euler buckling upper beam in Z-direction

% Johnson-Ostenfield Correction:
% Tensile:
Sigma_LB_y_corr= Sigma_Y.*(1-(Sigma_Y/(4*S_Euler_LB_y)))
Sigma_LB_z_corr= Sigma_Y.*(1-(Sigma_Y/(4*S_Euler_LB_z)))
Sigma_UB_y_corr= Sigma_Y.*(1-(Sigma_Y/(4*S_Euler_UB_y)))
Sigma_UB_z_corr= Sigma_Y.*(1-(Sigma_Y/(4*S_Euler_UB_z)))

figure() subplot(1,2,1)
plot(upr_beamR(:,1),upr_beamR(:,2),'b',... 
    linspace(-30,30,20),Na,'g-.',... 
    um_beam(:,1),um_beam(:,2),'b',... 
upr_beamL(:,1),upr_beamL(:,2),'b',... 
mid_beamR(:,1),mid_beamR(:,2),'b',... 
mid_beamL(:,1),mid_beamL(:,2),'b',... 
lwr_beamR(:,1),lwr_beamR(:,2),'b',... 
lwr_beamL(:,1),lwr_beamL(:,2),'b',... 
'LineWidth',2)
legend('Midsection','Neutral axis')
xlabel('Y[m]', 'FontSize', 17)
ylabel('Z[m]', 'FontSize', 17)
grid on
set(get(gca,'YLabel'),'Rotation',0)
subplot(1,2,2)
plot(linspace(-4*10^8,3*10^8,20),Na,'g-.',Sigma_UB,UB_zpos,'r'... ,Sigma_MB,MB_zpos,'r',... Sigma_LB,LB_zpos,'r',...
'LineWidth',2)
xlabel('Magnitude of Stress [Pa]', 'FontSize', 17)
grid on

Wave and response spectrum

article graphicx color

Contents

- Pierson-Mosowitz and JONSWAP spectra:
- response spectra:
- standard deviation

clc
clear all
close all
omega=dlmread('omega');
VBM_midt_180=dlmread('VBM_midi_180');
VBM_midt_150=dlmread('VBM_midi_150');
VBM_midt_120=dlmread('VBM_midi_120');
HBM_midt_180=dlmread('HBM_midi_180');
HBM_midt_150=dlmread('HBM_midi_150');
HBM_midt_120=dlmread('HBM_midi_120');
VSF_midt_180=dlmread('VSFi_midi_180');
VSF_midt_150=dlmread('VSFi_midi_150');
VSF_midt_120=dlmread('VSFi_midi_120');
RAOmag_180=dlmread('RAOmag_180');
RAOmag_150=dlmread('RAOmag_150');
RAOmag_120=dlmread('RAOmag_120');

Pierson-Mosowitz and JONSWAP spectra:

Hs=10; %m
\[ T_p = \left[ 11.4, \frac{(11.4+15.8)}{2}, 16 \right] \text{s} \]
\[ \gamma = \exp(5.75-1.15\cdot T_p / \sqrt{H_s}); \]
\[ A_{\gamma} = 1 - 0.287 \cdot \log(\gamma); \]
\[ \omega = \text{linspace}(0.1, 1, 100)'; \text{rad/s} \]
\[ \omega_p = 2\pi / T_p; \]
\[ T = 2\pi / \omega; \]
\[ \sigma = (\omega); \]
\[ \text{for } i = 1: \text{length}(\omega) \]
\[ \text{if } \sigma(i) < \omega_p \]
\[ \sigma(i) = 0.07; \]
\[ \text{end} \]
\[ \text{if } \sigma(i) > \omega_p \]
\[ \sigma(i) = 0.09; \]
\[ \text{end} \]
\[ S_{\text{PM}} = 5/16 \cdot H_s^2 \cdot \omega_p^{-4} \cdot \omega^{-5} \cdot \exp(-5/4 \cdot (\omega / \omega_p)^{-4}); \]
\[ S_{\text{J}} = A_{\gamma} \cdot S_{\text{PM}} \cdot \gamma \cdot \exp(-0.5 \cdot (\omega - \omega_p) / (\sigma \cdot \omega_p))^2; \]
\[ \text{plot:} \]
\[ \text{figure()} \]
\[ \text{plot}(\omega, S_{\text{J}}(:,1), 'r', \omega, S_{\text{J}}(:,2), 'b', \omega, S_{\text{J}}(:,3), 'm'... \]
\[ , \omega, S_{\text{PM}}(:,1), 'r', \omega, S_{\text{PM}}(:,2), 'b', \omega, S_{\text{PM}}(:,3), 'm', 'LineWidth', 2) \]
\[ \text{legend('} T_p=11.4s', 'T_p=13.6s', 'T_p=15.8s') \]
\[ \text{ylabel('} S(\omega) [m^2s/rad] \text{', 'fontsize', 15) \]
\[ \text{xlabel('} \omega \text{', 'fontsize', 15) \]
\[ \text{title('Pierson-Mosowitz and JONSWAP wave spectra H_s=10m')} \]
\[ \text{xlim([0.1 0.95])} \]

**response spectra:**

\[ np = 3; \]
\[ S_{x1,180} = S_{\text{J}}(np) \cdot \text{RAOmag}_{180}(:,1)^2; \]
\[ S_{x2,180} = S_{\text{J}}(np) \cdot \text{RAOmag}_{180}(:,2)^2; \]
\[ S_{x3,180} = S_{\text{J}}(np) \cdot \text{RAOmag}_{180}(:,3)^2; \]
\[ S_{x4,180} = S_{\text{J}}(np) \cdot \text{RAOmag}_{180}(:,4)^2; \]
\[ S_{x5,180} = S_{\text{J}}(np) \cdot \text{RAOmag}_{180}(:,5)^2; \]
\[ S_{x6,180} = S_{\text{J}}(np) \cdot \text{RAOmag}_{180}(:,6)^2; \]
\[ S_{x1,150} = S_{\text{J}}(np) \cdot \text{RAOmag}_{150}(:,1)^2; \]
\[ S_{x2,150} = S_{\text{J}}(np) \cdot \text{RAOmag}_{150}(:,2)^2; \]
\[ S_{x3,150} = S_{\text{J}}(np) \cdot \text{RAOmag}_{150}(:,3)^2; \]
\[ S_{x4,150} = S_{\text{J}}(np) \cdot \text{RAOmag}_{150}(:,4)^2; \]
S_x5_150 = S_J(np) .* RAOmag_150(:,5).^2;
S_x6_150 = S_J(np) .* RAOmag_150(:,6).^2;
S_x1_120 = S_J(np) .* RAOmag_120(:,1).^2;
S_x2_120 = S_J(np) .* RAOmag_120(:,2).^2;
S_x3_120 = S_J(np) .* RAOmag_120(:,3).^2;
S_x4_120 = S_J(np) .* RAOmag_120(:,4).^2;
S_x5_120 = S_J(np) .* RAOmag_120(:,5).^2;
S_x6_120 = S_J(np) .* RAOmag_120(:,6).^2;
S_VBM_180 = S_J(np) .* VBM_midt_180'.^2;
S_VBM_150 = S_J(np) .* VBM_midt_150'.^2;
S_VBM_120 = S_J(np) .* VBM_midt_120'.^2;
S_HBM_180 = S_J(np) .* HBM_midt_180'.^2;
S_HBM_150 = S_J(np) .* HBM_midt_150'.^2;
S_HBM_120 = S_J(np) .* HBM_midt_120'.^2;
S_VSF_180 = S_J(np) .* VSF_midt_180'.^2;
S_VSF_150 = S_J(np) .* VSF_midt_150'.^2;
S_VSF_120 = S_J(np) .* VSF_midt_120'.^2;

% plot
figure()
subplot(3,2,1)
plot(omega,S_x1_180,omega,S_x1_150,omega,S_x1_120,'LineWidth',3)
title('Surge')
ylabel('$S_{x1}[\frac{m^2s}{rad}]$','interpreter','latex','fontsize',17)
xlabel('\omega[rad/s]')
% legend('\beta=180deg','\beta=150deg','\beta=120deg')
xlim([0.1 0.95])
subplot(3,2,3)
plot(omega,S_x2_180,omega,S_x2_150,omega,S_x2_120,'LineWidth',3)
title('Sway')
ylabel('$S_{x2}[\frac{m^2s}{rad}]$','interpreter','latex','fontsize',17)
xlabel('\omega[rad/s]')
% legend('\beta=180deg','\beta=150deg','\beta=120deg')
xlim([0.1 0.95])
subplot(3,2,5)
plot(omega,S_x3_180,omega,S_x3_150,omega,S_x3_120,'LineWidth',3)
title('Heave')
ylabel('$S_{x3}[\frac{m^2s}{rad}]$','interpreter','latex','fontsize',17)
xlabel('\omega[rad/s]')
% legend('\beta=180deg','\beta=150deg','\beta=120deg')
xlim([0.1 0.95]) subplot(3,2,2)
plot(omega,S_x4_180,omega,S_x4_150,omega,S_x4_120,'LineWidth',3)
title('Roll')
ylabel('S_{x4}[rad s]')
xlabel('\omega[rad/s]')
legend('\beta=180deg','\beta=150deg','\beta=120deg')
xlim([0.1 0.95]) subplot(3,2,4)
plot(omega,S_x5_180,omega,S_x5_150,omega,S_x5_120,'LineWidth',3)
title('Pitch')
ylabel('S_{x5}[rad s]')
xlabel('\omega[rad/s]')
legend('\beta=180deg','\beta=150deg','\beta=120deg')
xlim([0.1 0.95]) subplot(3,2,6)
plot(omega,S_x6_180,omega,S_x6_150,omega,S_x6_120,'LineWidth',3)
title('Yaw')
ylabel('S_{x6}[rad s]')
xlabel('\omega[rad/s]')
legend('\beta=180deg','\beta=150deg','\beta=120deg')
xlim([0.1 0.95])

figure() subplot(3,1,1)
plot(omega,S_VBM_180,omega,S_VBM_150,omega,S_VBM_120,'LineWidth',3)
ylabel('$S_{VBM}\left[\frac{Nm^2 s}{rad}\right]$',...
'interpreter','latex','fontsize',17)
title('VBM response spectrum')
xlabel('\omega[rad/s]','fontsize',15)
legend('\beta=180deg','\beta=150deg','\beta=120deg')
xlim([0.1 0.95]) subplot(3,1,2)
plot(omega,S_HBM_180,omega,S_HBM_150,omega,S_HBM_120,'LineWidth',3)
ylabel('$S_{HBM}\left[\frac{Nm^2 s}{rad}\right]$',...
'interpreter','latex','fontsize',17)
title('HBM response spectrum')
xlabel('\omega[rad/s]','fontsize',15)
legend('\beta=180deg','\beta=150deg','\beta=120deg')
xlim([0.1 0.95]) subplot(3,1,3)
plot(omega,S_VSF_180,omega,S_VSF_150,omega,S_VSF_120,'LineWidth',3)
ylabel('$S_{VSF}\left[\frac{N^2 s}{rad}\right]$',...
'interpreter','latex','fontsize',17)
title('VSF response spectrum')
xlabel('\omega [rad/s]', 'fontsize', 15)
legend('\beta=180deg', '\beta=150deg', '\beta=120deg')
xlim([0.1 0.95])

standard deviation

spectral moment

for n=1:length(S_VBM_180(1,:))
    for i=1:length(omega)-1
        M_01(i,n)=S_PM(i,n).*(-omega(i+1)+omega(i));
        M_0RVBM1_180(i,n)=S_VBM_180(i,n).*(-omega(i+1)+omega(i));
        M_0RVBM1_150(i,n)=S_VBM_150(i,n).*(-omega(i+1)+omega(i));
        M_0RVBM1_120(i,n)=S_VBM_120(i,n).*(-omega(i+1)+omega(i));
        M_0RHBM1_180(i,n)=S_HBM_180(i,n).*(-omega(i+1)+omega(i));
        M_0RHBM1_150(i,n)=S_HBM_150(i,n).*(-omega(i+1)+omega(i));
        M_0RHBM1_120(i,n)=S_HBM_120(i,n).*(-omega(i+1)+omega(i));
        M_0RVSF1_180(i,n)=S_VSF_180(i,n).*(-omega(i+1)+omega(i));
        M_0RVSF1_150(i,n)=S_VSF_150(i,n).*(-omega(i+1)+omega(i));
        M_0RVSF1_120(i,n)=S_VSF_120(i,n).*(-omega(i+1)+omega(i));
        M_0RX31_180(i,n)=S_x3_180(i,n).*(-omega(i+1)+omega(i));
        M_0RX31_150(i,n)=S_x3_150(i,n).*(-omega(i+1)+omega(i));
        M_0RX31_120(i,n)=S_x3_120(i,n).*(-omega(i+1)+omega(i));
    end
end
M_0(n)=sum(M_01(:,n))
M_ORVBM_180(n)=sum(M_ORVBM1_180(:,n));
M_ORVBM_150(n)=sum(M_ORVBM1_150(:,n));
M_ORVBM_120(n)=sum(M_ORVBM1_120(:,n));
M_ORHBM_180(n)=sum(M_ORHBM1_180(:,n));
M_ORHBM_150(n)=sum(M_ORHBM1_150(:,n));
M_ORHBM_120(n)=sum(M_ORHBM1_120(:,n));
M_ORVSF_180(n)=sum(M_ORVSF1_180(:,n));
M_ORVSF_150(n)=sum(M_ORVSF1_150(:,n));
M_ORVSF_120(n)=sum(M_ORVSF1_120(:,n));
\[
M_{0RX3\_180}(n) = \sum(M_{0RX3\_180}(:,n));
M_{0RX3\_150}(n) = \sum(M_{0RX3\_150}(:,n));
M_{0RX3\_120}(n) = \sum(M_{0RX3\_120}(:,n));
\]
end

for n=1:length(S_VBM\_180(1,:))
    for i=1:length(omega)-1
        M_{2R1}(i,n) = \omega(i)^2 * S_VBM\_180(i,n) * (-\omega(i+1) + \omega(i));
    end
    M_{2R}(n) = \sum(M_{2R1}(:,n));
end

for n=1:length(S_VBM\_180(1,:))
    for i=1:length(omega)-1
        M_{4R1}(i,n) = \omega(i)^4 * S_VBM\_180(i,n) * (-\omega(i+1) + \omega(i));
    end
    M_{4R}(n) = \sum(M_{4R1}(:,n));
end

std\_VBM\_180 = \sqrt{M_{0RVBM\_180}}; % standard deviation
std\_VBM\_150 = \sqrt{M_{0RVBM\_150}}; % standard deviation
std\_VBM\_120 = \sqrt{M_{0RVBM\_120}}; % standard deviation

std\_HBM\_180 = \sqrt{M_{0RHBM\_180}}; % standard deviation
std\_HBM\_150 = \sqrt{M_{0RHBM\_150}}; % standard deviation
std\_HBM\_120 = \sqrt{M_{0RHBM\_120}}; % standard deviation

std\_VSF\_180 = \sqrt{M_{0RVSF\_180}}; % standard deviation
std\_VSF\_150 = \sqrt{M_{0RVSF\_150}}; % standard deviation
std\_VSF\_120 = \sqrt{M_{0RVSF\_120}}; % standard deviation

std\_X3\_180 = \sqrt{M_{0RX3\_180}}; % standard deviation
std\_X3\_150 = \sqrt{M_{0RX3\_150}}; % standard deviation
std\_X3\_120 = \sqrt{M_{0RX3\_120}}; % standard deviation

RVBM\_180\_max = 2*\sqrt(M_{0RVBM\_180}*2*\log(1000)); % Most probable max value
RVBM\_150\_max = 2*\sqrt(M_{0RVBM\_150}*2*\log(1000)); % Most probable max value
RVBM\_120\_max = 2*\sqrt(M_{0RVBM\_120}*2*\log(1000)); % Most probable max value

RHBM\_180\_max = 2*\sqrt(M_{0RHBM\_180}*2*\log(1000)); % Most probable max value
RHBM\_150\_max = 2*\sqrt(M_{0RHBM\_150}*2*\log(1000)); % Most probable max value
RHBM\_120\_max = 2*\sqrt(M_{0RHBM\_120}*2*\log(1000)); % Most probable max value
RVSF_180_max=2*sqrt(M_0RVSF_180*2*log(1000)); % Most probable max value
RVSF_150_max=2*sqrt(M_0RVSF_150*2*log(1000)); % Most probable max value
RVSF_120_max=2*sqrt(M_0RVSF_120*2*log(1000)); % Most probable max value

RX3_180_max=2*sqrt(M_0RX3_180*2*log(1000)); % Most probable max value
RX3_150_max=2*sqrt(M_0RX3_150*2*log(1000)); % Most probable max value
RX3_120_max=2*sqrt(M_0RX3_120*2*log(1000)); % Most probable max value

%mean upcrosssing rate:
mu_zeta=mu_0.*exp(-RAOmag_180(:,3).^2./(2.*M_0RVBM_180));
Appendices: WAMIT

Potential Control File .POT
Appendices: WAMIT

! 45 frequancies from 1 rad/s to 0.05 rad/s. 4 headings from 90deg to 180deg
-1.
1 1  IRAD, IDIFF
45
0.0  1.6  1.4  1.2  1  0.9750000000000000  0.9500000000000000  0.9250000000000000
0.9000000000000000  0.8750000000000000  0.8500000000000000  0.8250000000000000
0.8000000000000000  0.7750000000000000  0.7500000000000000  0.7250000000000000
0.7000000000000000  0.6750000000000000  0.6500000000000000  0.6250000000000000
0.6000000000000000  0.5750000000000000  0.5500000000000000  0.5250000000000000
0.5000000000000000  0.4750000000000000  0.4500000000000000  0.4250000000000000
0.4000000000000000  0.3750000000000000  0.3500000000000000  0.34  0.33  0.31  0.29  0.28
0.27  0.26  0.25  0.24  0.22  0.19  0.12  0.10  0.05 -1
4
90.00000  120.00000  150.00000  180.00000
1  NBODY
fishfarm1806.GDF
0.  0.  0.  0.  XBODY
1 1 1 1 1 1  IMODE(1-6)

Force Control File .FRC

! Fishfarm rigid 400m
1 0 0 2 1 0 0 0 Contains 0
1025  RHO
0 0  -6.0  CG
1 MASS MATRIX OF THE BODY
3.27E7  0.0  0.0  0.0  -1.96E8  0.0
0.0  3.27E7  0.0  1.96E8  0.0  0.0
0.0  0.0  3.27E7  0.0  -0.0  0.0
0.0  1.96E8  0.0  1.19E10  0.0  0.0
-1.96E8  0.0  0.0  0.0  3.97E11  0.0
0.0  0.0  0.0  0.0  0.0  4.0E11
0  IDAMP
0  ISTIFF
0  NBETAH
0  NFIELD
configuration File .CFG

! lower section of fish farm from rhino-geometry
ipltdat=1
NUMHDR=1
IRR=1
ILOG=1
ISOLVE=1
IPERIN=2
IALTFRC=2
Appendices: RAOs company

RAOs provided by NSK