UNIVERSITY OF LISBON

INSTITUTO SUPERIOR TECNICO

Hydrodinamics of floating systems

Project 2

Task 2

Part 1 and Part 2

Analysis of a spread mooring system

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Part 1

Mooring system description

This task's aim is to create a preliminary design of the mooring system. It will employ two different materials in the same cable and water depth to examine how the combination of both influences stress. Furthermore, in this research, it will be determined how vessel movement affects mooring cable stress and the ratio of maximum motion to water depth.

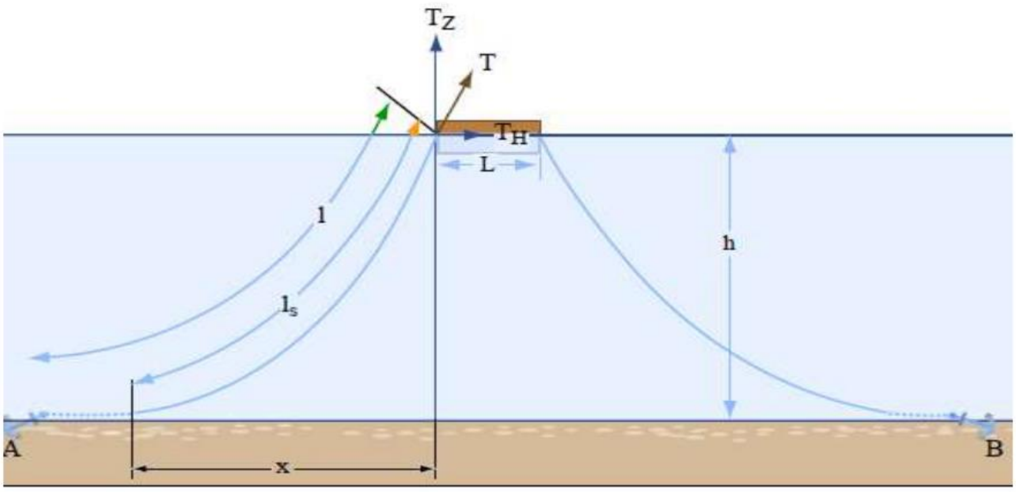


Fig.1 Mooring system configuration

Throughout this project, the static technique will be employed in conjunction with the elastic cable line theory with various materials. Chain and fiber rope, both of which will be composed of polyester, are among the materials to be examined. The table below shows the stiffness per unit length, EA, weight per unit length, phi_w, and breaking strength of the cable for each material. The algorithm for calculating the CBS from chain and poly was borrowed from the previous project.

Additional premise is the water depth, platform length, and external influences. The calculations will be performed for a depth of 2000 m, a platform length of 200 m, and a horizontal steady force caused by wind, wave, and current that is 200KN, 800KN, and 6000KN for the corresponding water depth.

Material 1 - Polyester

	Value	Unit	Description
D_poly	340.75	'm'	'Diameter'
l_poly	2000	'm'	'Line length'
w_poly	777.93	'N/m'	'Submerged weight per unit length'
EA_poly	1.3793e+09	'N/m^2'	'Axial stiffness per unit length'
CBS_poly	2.9027e+07	'N'	'Breaking Strength'

Material 1 - Chain

	Value	Unit	Description
D_chain	106.06	'm'	'Diameter'
l_chain	500	'm'	'Line length'
w_chain	2109.2	'N/m'	'Submerged weight per unit length'
EA_chain	1.6447e+09	'N/m^2'	'Axial stiffness per unit length'
CBS_chain	8.4295e+06	'N'	'Breaking Strength'

Calculation procedure

Step1:

For each arrangement, the first step is to calculate the relationship between horizontal tensions, vertical tensions, total tension force, and the angle phi_w with the horizontal distance X from the anchor point to the fairlead. There are three alternative configurations in this project, and a schematic with the formulation for each is presented below. There is no arrangement without the polyester line since the cable line of chain (500 m) is insufficient for the water depth in issue (500 m).

Segment 1 and a portion of Segment 2 are both on the sea floor, with both anchors holding. If segments 2 and 3 have the same unit weight, this arrangement corresponds to the configuration of a slack single component mooring line used in this investigation if the clump weight is removed.

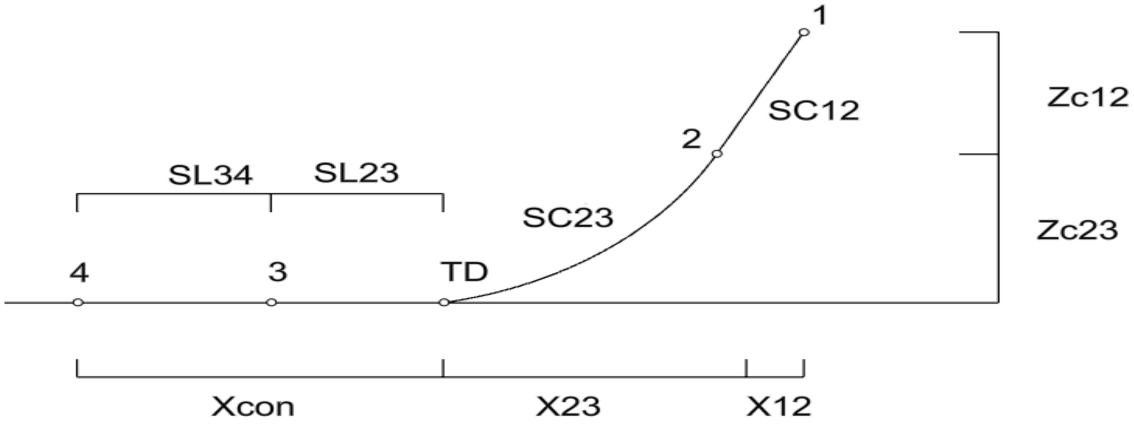


Fig.2 CAD rappresentation of the first configuration

If we suppose a vertical force on point 4

$$V_{1,min} = w_{chain} * l_{chain} + w_{poly} * (h - l_{poly})$$

$$V_{1,max} = w_{chain} * l_{chain} + w_{poly} * l_{poly}$$

So, the following procedure can be applied

$V_2 = V_1 - w_{chain} * S_{L12}$, where S_{L12} is equal to the length of the chain cable (500m).

$$S_{c23} = \frac{V_2}{w_{poly}}$$

$$V_3 = 0$$

$$S_{L12} = l_{chain}$$

$$X_{cons} = S_{L34} + S_{L23} - S_{C23}$$

With the result obtained, the horizontal force, H, in the cable can be find by solving the following equations

$$Z_{12} = \left(\frac{H}{w_{chain}}\right) * \left(\sqrt{1 + \left(\frac{V_1}{H}\right)^2} - \sqrt{1 + \left(\frac{V_2}{H}\right)^2}\right) + \frac{w_{chain} * S_{L12}^2}{2 * EA_{chain}} + \frac{S_{L12} * V_2}{EA_{chain}}$$

$$Z_{23} = \left(\frac{H}{w_{poly}}\right) * \left(\sqrt{1 + \left(\frac{V_2}{H}\right)^2} - \sqrt{1 + \left(\frac{V_3}{H}\right)^2}\right) + \frac{w_{poly} * S_{c23}^2}{2 * EA_{poly}} + \frac{S_{c23} * V_3}{EA_{poly}}$$

$$Z = Z_{12} + Z_{23} = h, \text{ where h is the water depth}$$

After calculating the preceding equation and determining the horizontal force for a given vertical force at point 4, the total horizontal distance, XL, may be calculated using the following formula.

$$X_{c12} = \left(\frac{H}{w_{chain}}\right) * \left(\operatorname{asinh}\left(\frac{V_2 + w_{chain} * S_{L12}}{H}\right) - \operatorname{asinh}\left(\frac{V_2}{H}\right)\right) + \frac{S_{L12} * H}{EA_{chain}}$$

$$X_{c23} = \left(\frac{H}{w_{poly}}\right) * \left(\operatorname{asinh}\left(\frac{V_3 + w_{poly} * S_{c23}}{H}\right) - \operatorname{asinh}\left(\frac{V_3}{H}\right)\right) + \frac{S_{c23} * H}{EA_{poly}}$$

$$X_L = X_{cons} + X_{c23} + X_{c34}$$

Throughout this, now we have to find the total tension T, just calculating $T = \sqrt{V_1^2 + H^2}$ and the angle in the fairlead, phi, is equal to $\emptyset = \tan\left(\frac{V_1}{H}\right)$.

Proceeding with the second configuration, even just a portion of segment 1 is on the sea floor, with anchor 1 in place. The anchor at node 2 has been raised and might imply a clump weight. This setup is a taut mooring because the slope of the line at node 2 is not equal to zero. The formulation is nearly identical to that of configuration 1, and it is detailed below.

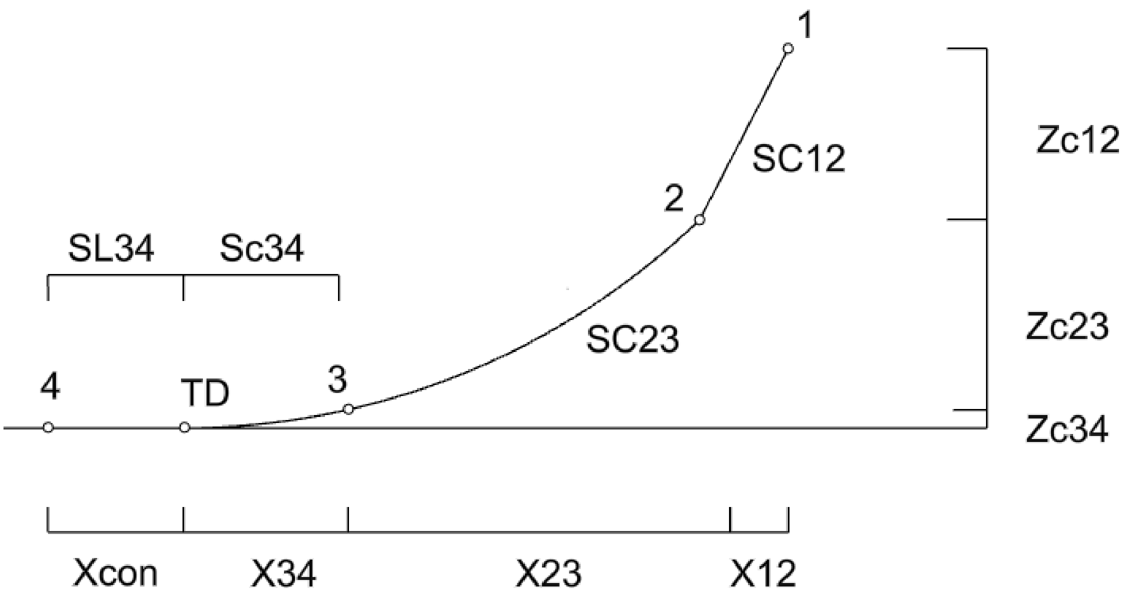


Fig.3 CAD rappresentation of the second configuration

Suppose a vertical force on point 4

$$V_{1,min} = w_{chain} * l_{chain} + w_{poly} * l_{poly}$$

$$V_{1,max} = 2 * w_{chain} * l_{chain} + w_{poly} * l_{poly}$$

So, the following procedure can be applied

$$V_2 = V_1 - w_{chain} * S_{L12},$$

where S_{L12} is equal to the length of the chain cable (500m).

$$V_3 = V_2 - w_{poly} * S_{c23}$$

$$S_{c34} = \frac{V_3}{w_{chain}}$$

$$V_4 = 0$$

$$X_{cons} = S_{L34} - S_{C34}$$

After the past result, the horizontal force, H, in the cable can be find by solving the following equations

$$Z_{12} = \left(\frac{H}{w_{chain}}\right) * \left(\sqrt{1 + \left(\frac{V_1}{H}\right)^2} - \sqrt{1 + \left(\frac{V_2}{H}\right)^2}\right) + \frac{w_{chain} * S_{L12}^2}{2 * EA_{chain}} + \frac{S_{L34} * V_2}{EA_{chain}}$$

$$Z_{23} = \left(\frac{H}{w_{poly}}\right) * \left(\sqrt{1 + \left(\frac{V_2}{H}\right)^2} - \sqrt{1 + \left(\frac{V_3}{H}\right)^2}\right) + \frac{w_{poly} * S_{c23}^2}{2 * EA_{poly}} + \frac{S_{c23} * V_3}{EA_{poly}}$$

$$Z_{34} = \left(\frac{H}{w_{chain}}\right) * \left(\sqrt{1 + \left(\frac{V_3}{H}\right)^2} - \sqrt{1 + \left(\frac{V_4}{H}\right)^2}\right) + \frac{w_{chain} * S_{c34}^2}{2 * EA_{chain}} + \frac{S_{c12} * V_4}{EA_{chain}}$$

$Z = Z_{34} + Z_{23} + Z_{12} = h$, where h is the water depth

Following computating the preceding equation and determining the horizontal force for a given vertical force at point 4, the total horizontal distance, XL, may be calculated using the following formula.

$$X_{c34} = \left(\frac{H}{w_{chain}}\right) * \left(\operatorname{asinh}\left(\frac{V_4 + w_{chain} * S_{c34}}{H}\right) - \operatorname{asinh}\left(\frac{V_4}{H}\right)\right) + \frac{S_{c34} * H}{EA_{chain}}$$

$$X_{c23} = \left(\frac{H}{w_{poly}}\right) * \left(\operatorname{asinh}\left(\frac{V_3 + w_{poly} * S_{c23}}{H}\right) - \operatorname{asinh}\left(\frac{V_3}{H}\right)\right) + \frac{S_{c23} * H}{EA_{poly}}$$

$$X_{c12} = \left(\frac{H}{w_{chain}}\right) * \left(\operatorname{asinh}\left(\frac{V_2 + w_{chain} * S_{c12}}{H}\right) - \operatorname{asinh}\left(\frac{V_2}{H}\right)\right) + \frac{S_{c12} * H}{EA_{chain}}$$

$$X_L = X_{cons} + X_{c23} + X_{c34} + X_{c12}$$

Throughout, now to find the total tension T, just need to do $T = \sqrt{V_1^2 + H^2}$ and the angle in the fairlead, phi, is equal to $\emptyset = \tan\left(\frac{V_1}{H}\right)$.

At least, the third configuration is explained and calculated considering a multi-component line mooring with a taut mooring. There is no cable on the seafloor, but anchor 1 is holding. The slope of the line at node 1 is not equal to zero. The formulation from configuration 2 is the same, with a few small adjustments mentioned below.

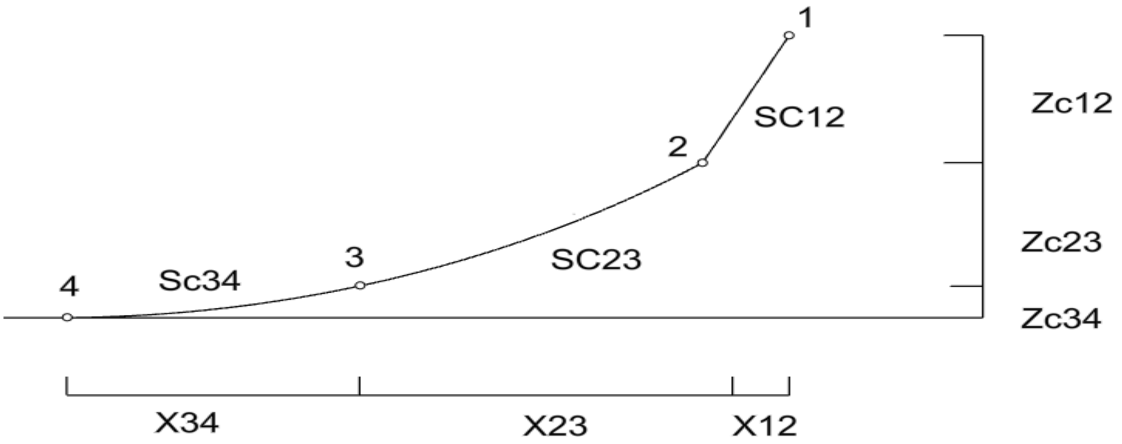


Fig.4 CAD rappresentation of the third configuration

Suppose a vertical force on point 4

$$V_{1,min} = 2 * w_{chain} * l_{chain} + w_{poly} * l_{poly}$$

$$V_{1,max} = \min\left(\frac{CBS_{chain}}{1.8}, \frac{CBS_{poly}}{1.8}\right),$$

where the 1.8 is the safety factor from IACS

So, the following procedure can be applied

$$V_2 = V_1 - w_{chain} * S_{L12},$$

where S_{L12} is equal to the length of the chain cable (500m).

$$V_3 = V_2 - w_{poly} * S_{L23}$$

$$V_4 = V_3 - w_{chain} * S_{L34}$$

$$X_{cons} = 0$$

After the value obtained, the horizontal force, H, in the cable can be find by solving the following equations

$$Z_{12} = \left(\frac{H}{w_{chain}}\right) * \left(\sqrt{1+\left(\frac{V_1}{H}\right)^2} - \sqrt{1+\left(\frac{V_2}{H}\right)^2}\right) + \frac{w_{chain} * S_{L12}^2}{2 * EA_{chain}} + \frac{S_{L34} * V_2}{EA_{chain}}$$

$$Z_{23} = \left(\frac{H}{w_{poly}}\right) * \left(\sqrt{1+\left(\frac{V_2}{H}\right)^2} - \sqrt{1+\left(\frac{V_3}{H}\right)^2}\right) + \frac{w_{poly} * S_{c23}^2}{2 * EA_{poly}} + \frac{S_{c23} * V_3}{EA_{poly}}$$

$$Z_{34} = \left(\frac{H}{w_{chain}}\right) * \left(\sqrt{1+\left(\frac{V_3}{H}\right)^2} - \sqrt{1+\left(\frac{V_4}{H}\right)^2}\right) + \frac{w_{chain} * S_{c34}^2}{2 * EA_{chain}} + \frac{S_{c12} * V_4}{EA_{chain}}$$

$Z = Z_{34} + Z_{23} + Z_{12} = h$, where h is the water depth

Upon calculating the preceding equation and determining the horizontal force for a given vertical force at point 4, the total horizontal distance, XL, may be calculated using the following formula.

$$X_{c34} = \left(\frac{H}{w_{chain}}\right) * \left(\operatorname{asinh}\left(\frac{V_4 + w_{chain} * S_{c34}}{H}\right) - \operatorname{asinh}\left(\frac{V_4}{H}\right)\right) + \frac{S_{c34} * H}{EA_{chain}}$$

$$X_{c23} = \left(\frac{H}{w_{poly}}\right) * \left(\operatorname{asinh}\left(\frac{V_3 + w_{poly} * S_{c23}}{H}\right) - \operatorname{asinh}\left(\frac{V_3}{H}\right)\right) + \frac{S_{c23} * H}{EA_{poly}}$$

$$X_{c12} = \left(\frac{H}{w_{chain}}\right) * \left(\operatorname{asinh}\left(\frac{V_2 + w_{chain} * S_{c12}}{H}\right) - \operatorname{asinh}\left(\frac{V_2}{H}\right)\right) + \frac{S_{c12} * H}{EA_{chain}}$$

$$X_L = X_{cons} + X_{c23} + X_{c34} + X_{c12}$$

Thus, now to find the total tension T, just need to do $T = \sqrt{V_1^2 + H^2}$ and the angle in the fairlead, phi, is equal to $\emptyset = \tan\left(\frac{V_1}{H}\right)$

Step 2:

Step two entails determining:

- The distance between the two anchors for each horizontal pre-tension based on the findings of step one (200 kN, 800 kN and 6000 kN)
- The load excursion relationship for each cable in respect to the vessel's motion
- The restoring force produced by the mooring lines, which maintains the platform in static equilibrium.

The formula for obtaining these findings is shown below.

- Determine the static equilibrium, X0, by inputting the necessary horizontal tension in the X versus H graph. This value X0 may be determined via interpolation.

- To get the maximum displacement of the platform (delta max), do Xmax-X0 for each pre-tension, where X max is the maximum X for the platform.

- For each pretension, perform Xmax-X0 to get the maximum displacement of the platform (delta max), where X max is the maximum X for the given configuration related to the horizontal value of the pretension (configuration 1,2 or 3). If the pre-tension is greater than the maximum value of H on the X versus H graph, indicating that this force is ineffective, a delta max of 200 m will be applied (10 percent of the water depth).

- For each setup, a delta range between the negative and positive values of delta max will be assumed.

The distance between anchors may be calculated by multiplying 2*X0+L platform by each pre-tension. The following approach may be used to get the values of the force in each cable and the restoring force for a given value of delta: Ha is equal to the horizontal value of the graph X against H, where X is given as X0+delta and Hb is given as X0-delta. The restoring force, F, equals Ha-Hb. Va is half the vertical force of the graph x versus V, resulting in X as X0+delta and Vb equal to Va.

Results discussion

Two items are expected for step one. First, it is expected to discover an X value that results in a zero-horizontal force. This is a variant of the first setup, in which the cable is completely vertical and its length is equal to the depth of the water. Second, after the maximum value of configuration 1 is supplied as input as the lowest value of configuration 2, the curves of the different configurations must be continuous with each other. The graphs below show how the horizontal, vertical, total force, and angle phi change with X for each setup. Furthermore, the results appear to be plausible because the graphs exhibit the predicted tendency.

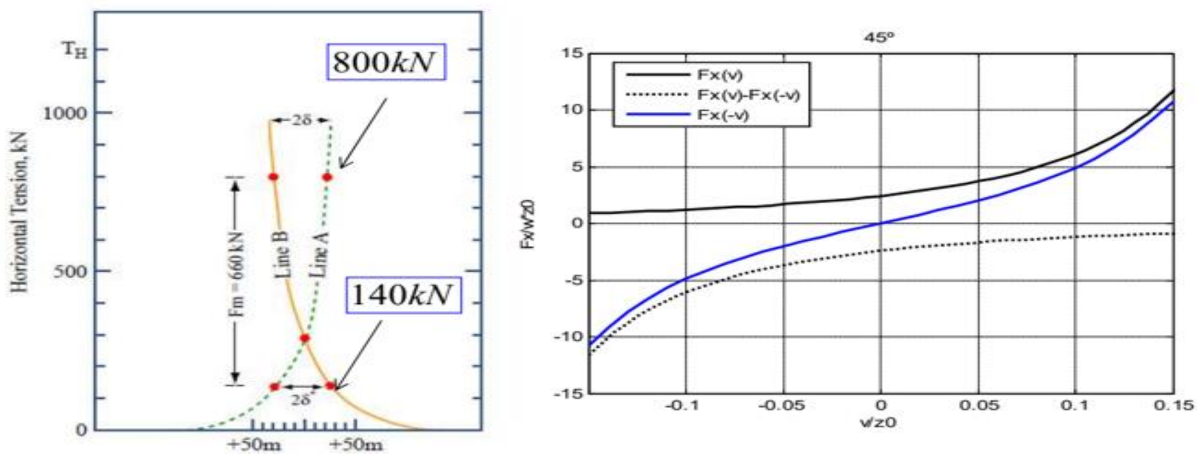


Fig.5 Horizontal forces and restoring forces in a mooring system with mooring lines are expected values.

The greatest value, as shown by the graph of H as a function of X, is somewhere between 2500 and 3500 kN. Thus, a horizontal pre-tension of 6000 kN would break the cable if it exceeded the maximum horizontal force allowed. However, in order to investigate the hypothetical scenario, the delta max will be considered to be 200 m, and the results of X0 and force will be obtained by linearly extrapolating the results. Furthermore, the graphs of the loads-excursion should be identical to the ones presented below based on the lecture appointments. As a result, this will be utilized to validate the Ha, Hb, and F findings.

The results were computed in the order specified and are shown below. Figure X depicts the horizontal static equilibrium position (X0), delta range, and distance between anchors for each pre-tension. Also shown in figure x are the load-excursion charts for each pre-tension, which appear to exhibit the behavior predicted by the theory. Furthermore, the results appear to be fair, because the values of the different variables (horizontal forces, point X0, and restoring force) rise in modulus when pre-tension is applied.

Equilibrium Displacement

	Value	Unit
PreT=200kN	1485.8	'm'
PreT=800kN	1906.9	'm'
PreT=6000kN	2310.1	'm'

Values of delta

	Minimum	Maximum	Unit
PreT=200kN	-242.53	242.53	'm'
PreT=800kN	-201.8	201.8	'm'
PreT=6000kN	-200	200	'm'

Distance from anchor

	Value	Unit
PreT=200kN	3171.7	'm'
PreT=800kN	4013.9	'm'
PreT=6000kN	4820.1	'm'

Fig.6 Results obtained from calculations

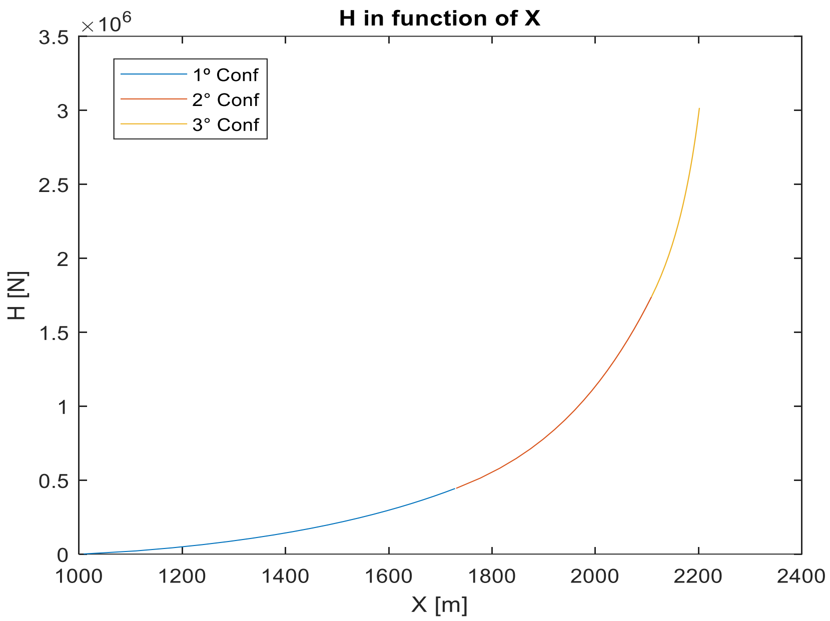


Fig.7 Horizontal force in the cable as a function of horizontal length for various configurations

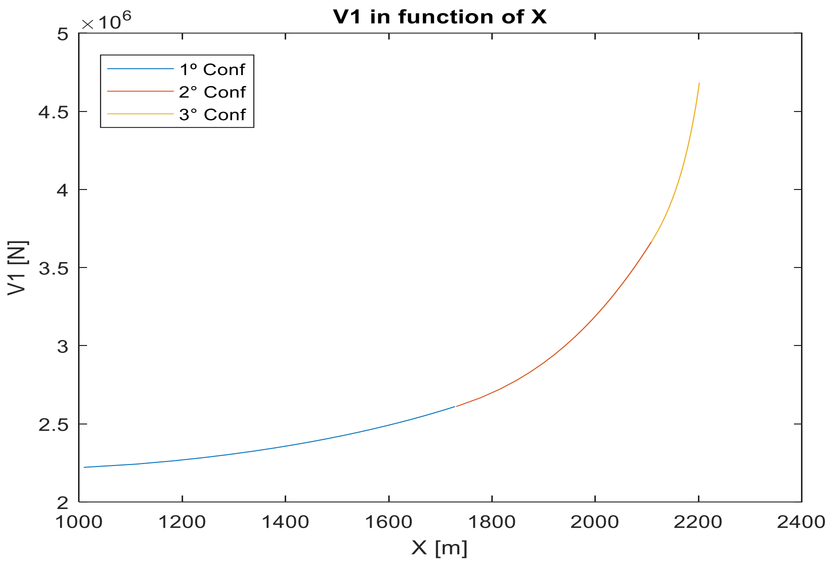


Fig.8 Vertical force in the cable as a function of horizontal length for various configurations

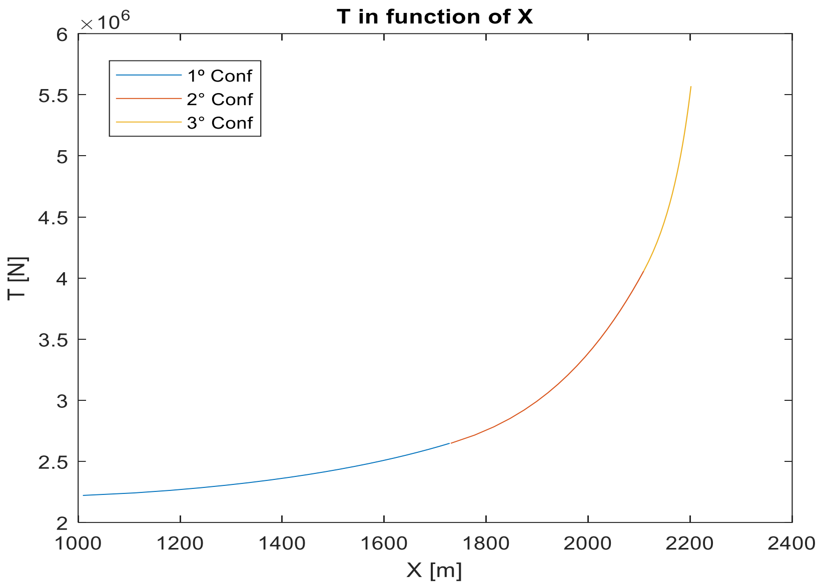


Fig.9 Total force in the cable as a function of horizontal length for various configurations

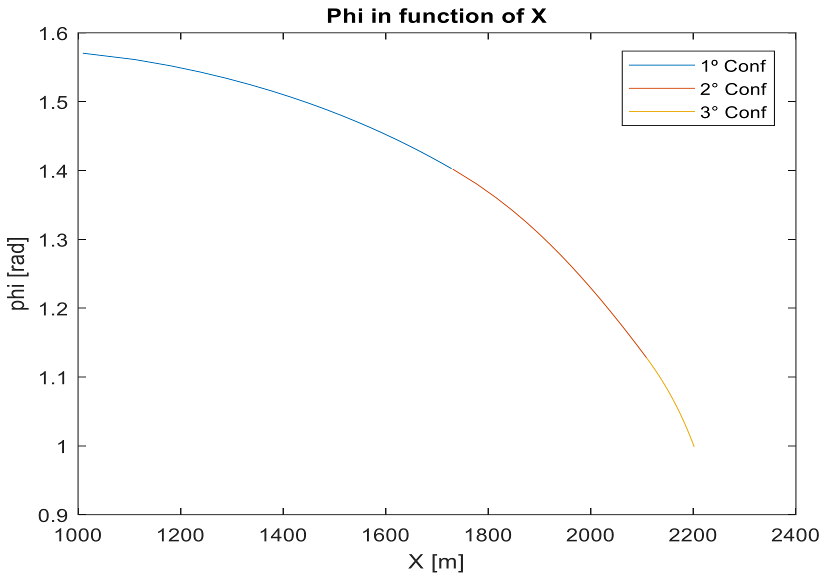


Fig.10 Angle in the fairlead point as a function of horizontal cable length for various configurations

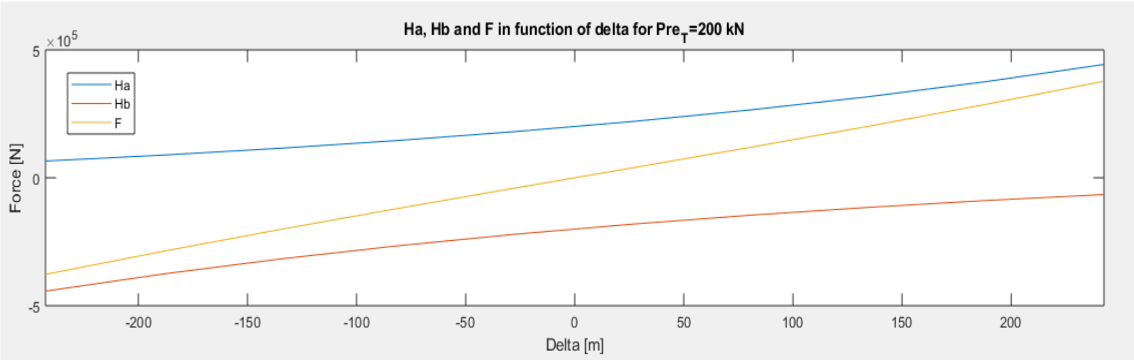


Fig.11 Horizontal force in each cable and restoring forces with a 200 kN pretension

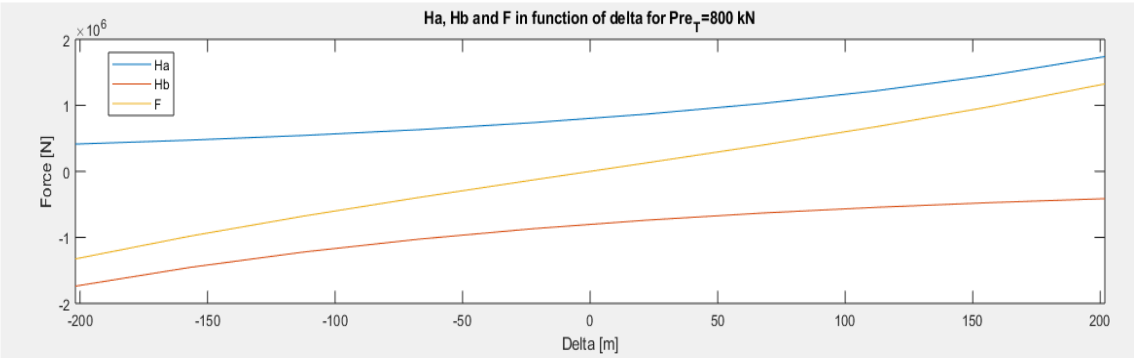


Fig.12 Horizontal force in each cable and restoring forces with a 800 kN pretension

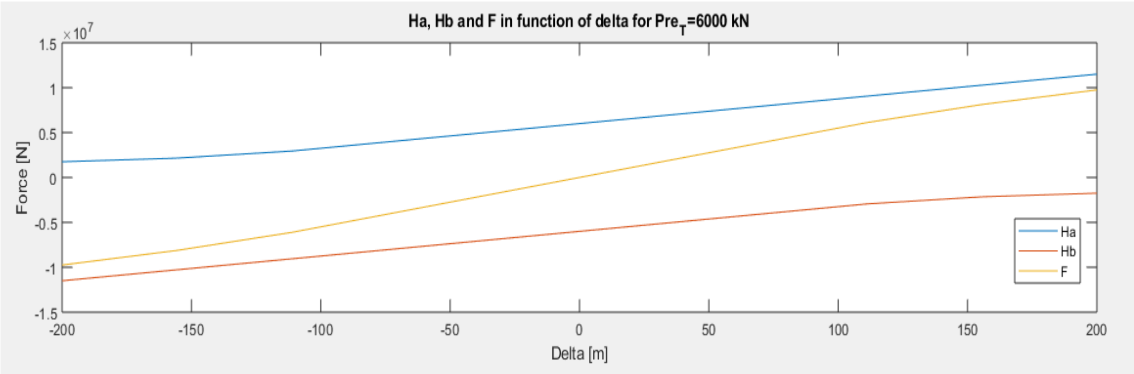


Fig.13 Horizontal force in each cable and restoring forces with a 6000 kN pretension

Furthermore, the equivalent stiffness of the cable was calculated by dividing the values of F by the relevant delta for each pretension. This will display the linear coefficient, which is only valid for small values of delta. The results are displayed below.

	Value	Unit
200kN	1.4669	'kN/m'
800kN	5.8087	'kN/m'
6000kN	54.997	'kN/m'

Fig.14 Stiffness values

Conclusions

The preliminary design of a mooring system with two Multi-Component lines for a specified water depth is the goal of this project. The material parameters, including as specific weight, CBS, and stiffness, were first determined. Following that, it was computed how the various forces vary with the length X of a single mooring cable. Contuining the analysis, the required horizontal pre-tension, which reflects the environment forces in the FPSO, was supplied as input, and the horizontal force in each anchor, as well as the restoring force in FPSO, were derived by interpolating the graphs for a range of vessel motions. When the results are close to the predicted behavior indicated by the theory, they appear to be legitimate.

Reference

- Hydrodynamics of floating systems lectures

ANNEX (MATLAB CODE)

```
clc
clear variables
close all

%% input data
h = 2000; %[meter] water depth
L_platform = 200; %[meter] horizontal length of the platform
Pre_T = [200 800 6000]*10^3; %[N] horizontal pre-tension

% Chain
l_chain=500; %[meter] length of the cable
w_chain=215*9.81; %[N/m] weight of the cable
EA_chain=1644740000; %[N/m] stiffness of the cable
D_chain=sqrt(w_chain/0.1875); %[mm]
CBS_chain=21.1*(44-0.08*D_chain)*D_chain^2;

T_print = table([D_chain;l_chain;w_chain; EA_chain; CBS_chain],...
    {'mm';'m';'N/m';'N/m^2';'N'},{'Diameter';'Line length';'Submerged weight per unit
length';...
    'Axial stiffness per unit length'; 'Breaking Strength'});
T_print.Properties.VariableNames = {'Value' 'Unit' 'Description'};
T_print.Properties.RowNames = {'D_chain' 'l_chain' 'w_chain' 'EA_chain' 'CBS_chain'};
disp('Material 1 - Chain')
disp(T_print)
disp(' ')

% Polyester
l_poly=2000; %[meter] length of the cable
w_poly=79.3*9.81; %[N/m] weight of the cable
EA_poly=1379310000; %[N/m] stiffness of the cable
D_poly=sqrt(w_poly/0.0067);
CBS_poly=250*D_poly^2;
T_print = table([D_poly;l_poly;w_poly; EA_poly; CBS_poly],...
    {'mm';'m';'N/m';'N/m^2';'N'},{'Diameter';'Line length';'Submerged weight per unit
length';...
    'Axial stiffness per unit length'; 'Breaking Strength'});
T_print.Properties.VariableNames = {'Value' 'Unit' 'Description'};
T_print.Properties.RowNames = {'D_poly' 'l_poly' 'w_poly' 'EA_poly' 'CBS_poly'};
disp('Material 1 - Polyester')
disp(T_print)
disp(' ')

%% First Part
CONFIGURATION 1
```

```
function [H,X] = conf1(V1,w1,w2,h,Sc12,SL23,EA1,EA2)
V2=V1-w1*Sc12;
Sc23=V2/w2;
SL34=Sc12;
Xcons=SL34+SL23-Sc23;
V3=0;
syms a
%a is the horizontal force
Zc1=symfun((a/w1)*(sqrt(1+(V1/a)^2)-sqrt(1+(V2/a)^2))...
    +0.5*w1*(Sc12^2)/EA1+Sc12*V2/EA1,a);
Zc2=symfun((a/w2)*(sqrt(1+(V2/a)^2)-sqrt(1+(V3/a)^2))...
    +0.5*w2*(Sc23^2)/EA2+Sc23*V3/EA2,a);
Z=Zc1+Zc2;
H=double(vpasolve(Z==h,a,10^4));
if isempty(H)
    H = -1;
end
if H>=0
    Xc12=(H/w1)*(asinh((V2+w1*Sc12)/H)-asinh(V2/H))+H*Sc12/EA1;
    Xc23=(H/w2)*(asinh((V3+w2*Sc23)/H)-asinh(V3/H))+H*Sc23/EA2;
    X=Xcons+Xc12+Xc23;
else
    X=-1;
end

%first configuration
V1_conf1_min=w_chain*l_chain+w_poly*(h-l_chain); %[N] Minimum vertical force
V1_conf1_max=w_chain*l_chain+w_poly*l_poly; %[N] Maximum vertical force
V1_conf1=linspace(V1_conf1_min,V1_conf1_max,20);
H_conf1=[];
X_conf1=[];
T_conf1=[];
phi_conf1=[];
for i=1:length(V1_conf1)
    disp(['iteration ' num2str(i) ' conf1'])
    [H,X]=conf1(V1_conf1(i),w_chain,w_poly,h,l_chain,l_poly,EA_chain,EA_poly);
    if X>=0
        H_conf1=cat(2,H_conf1,H);
        X_conf1=cat(2,X_conf1,X);
        T_conf1=cat(2,T_conf1,sqrt(H^2+V1_conf1(i)^2));
        phi_conf1=cat(2,phi_conf1,atan2(V1_conf1(i),H));
    end
end

% %second configuration
CONFIGURATION 2
function [H,X] = conf2(V1,w1,w2,h,Sc12,Sc23,EA1,EA2)
V2=V1-w1*Sc12;
V3=V2-w2*Sc23;
Sc34=V3/w1;
SL34=Sc12;
Xcons=SL34-Sc34;
V4=0;
syms a %a is the horizontal force
Zc12=symfun((a/w1)*(sqrt(1+(V1/a)^2)-sqrt(1+(V2/a)^2))...
    +0.5*w1*(Sc12^2)/EA1+Sc23*V2/EA1,a);
Zc23=symfun((a/w2)*(sqrt(1+(V2/a)^2)-sqrt(1+(V3/a)^2))...
    +0.5*w2*(Sc23^2)/EA2+Sc23*V3/EA2,a);
Zc34=symfun((a/w1)*(sqrt(1+(V3/a)^2)-sqrt(1+(V4/a)^2))...
    +0.5*w1*(Sc34^2)/EA1+Sc34*V4/EA1,a);
Z=Zc12+Zc23+Zc34;
```

```
H=double(vpasolve(Z==h,a,10^4));
if isempty(H)
    H = 0;
end
if H>0
    Xc12=(H/w1)*(asinh((V2+w1*Sc12)/H)-asinh(V2/H))+H*Sc12/EA1;
    Xc23=(H/w2)*(asinh((V3+w2*Sc23)/H)-asinh(V3/H))+H*Sc23/EA2;
    Xc34=(H/w1)*(asinh((V4+w1*Sc34)/H)-asinh(V4/H))+H*Sc34/EA1;
    X=Xcons+Xc12+Xc23+Xc34;
else
    X=0;
end


V1_conf2_min=V1_conf1_max;
V1_conf2_max=2*w_chain*l_chain+w_poly*l_poly;
V1_conf2=linspace(V1_conf2_min,V1_conf2_max,20);
H_conf2=[];
X_conf2=[];
T_conf2=[];
phi_conf2=[];
for i=1:length(V1_conf2)
    disp(['iteration ' num2str(i) ' conf2'])
    [H,X]=conf2(V1_conf2(i),w_chain,w_poly,h,l_chain,l_poly,EA_chain,EA_poly);
    if X>0
        H_conf2=cat(2,H_conf2,H);
        X_conf2=cat(2,X_conf2,X);
        T_conf2=cat(2,T_conf2,sqrt(H^2+V1_conf2(i)^2));
        phi_conf2=cat(2,phi_conf2,atan2(V1_conf2(i),H));
    end
end

%third configuration
CONFIGURATION 3
function [H,X] = conf3(V1,w1,w2,h,Sc12,Sc23,EA1,EA2)
    V2=V1-w1*Sc12;
    V3=V2-w2*Sc23;
    V4=V3-w1*Sc12;
    Sc34=Sc12;
    syms a %a is the horizontal force
    Zc12=symfun((a/w1)*(sqrt(1+(V1/a)^2)-sqrt(1+(V2/a)^2))...
        +0.5*w1*(Sc12^2)/EA1+Sc23*V2/EA1,a);
    Zc23=symfun((a/w2)*(sqrt(1+(V2/a)^2)-sqrt(1+(V3/a)^2))...
        +0.5*w2*(Sc23^2)/EA2+Sc23*V3/EA2,a);
    Zc34=symfun((a/w1)*(sqrt(1+(V3/a)^2)-sqrt(1+(V4/a)^2))...
        +0.5*w1*(Sc34^2)/EA1+Sc34*V4/EA1,a);
    Z=Zc12+Zc23+Zc34;
    H=double(vpasolve(Z==h,a,10^4));
    if isempty(H)
        H = -1;
    end
    if H>=0
        Xc12=(H/w1)*(asinh((V2+w1*Sc12)/H)-asinh(V2/H))+H*Sc12/EA1;
        Xc23=(H/w2)*(asinh((V3+w2*Sc23)/H)-asinh(V3/H))+H*Sc23/EA2;
        Xc34=(H/w1)*(asinh((V4+w1*Sc34)/H)-asinh(V4/H))+H*Sc34/EA1;
        X=Xc12+Xc23+Xc34;
    else
        X=-1;
    end
    end
```

```
V1_conf3_min=V1_conf2_max;
V1_conf3_max=min([CBS_chain/1.8 CBS_poly/1.8]);
V1_conf3=linspace(V1_conf3_min,V1_conf3_max,20);
H_conf3=[];
X_conf3=[];
T_conf3=[];
phi_conf3=[];
for i=1:length(V1_conf3)
    disp(['iteration ' num2str(i) ' conf3'])
    [H,X]=conf3(V1_conf3(i),w_chain,w_poly,h,l_chain,l_poly,EA_chain,EA_poly);
    if X>=0
        H_conf3=cat(2,H_conf3,H);
        X_conf3=cat(2,X_conf3,X);
        T_conf3=cat(2,T_conf3,sqrt(H^2+V1_conf3(i)^2));
        phi_conf3=cat(2,phi_conf3,atan2(V1_conf3(i),H));
    end
end

%unification of variables for step 2
X=cat(2,X_conf1,X_conf2(1:end-1),X_conf3);
H=cat(2,H_conf1,H_conf2(1:end-1),H_conf3);
V1=cat(2,V1_conf1,V1_conf2(1:end-1),V1_conf3);
T=cat(2,T_conf1,T_conf2(1:end-1),T_conf3);
phi=cat(2,T_conf1,T_conf2(1:end-1),T_conf3);

%plot of graphs
figure
plot(X_conf1,H_conf1,X_conf2,H_conf2,X_conf3,H_conf3)
title('H in function of X')
xlabel('X [m]')
ylabel('H [N]')
legend('1º Conf','2° Conf','3° Conf')

figure
plot(X_conf1,V1_conf1,X_conf2,V1_conf2,X_conf3,V1_conf3)
title('V1 in function of X')
xlabel('X [m]')
ylabel('V1 [N]')
legend('1º Conf','2° Conf','3° Conf')

figure
plot(X_conf1,T_conf1,X_conf2,T_conf2,X_conf3,T_conf3)
title('T in function of X')
xlabel('X [m]')
ylabel('T [N]')
legend('1º Conf','2° Conf','3° Conf')

figure
plot(X_conf1,phi_conf1,X_conf2,phi_conf2,X_conf3,phi_conf3)
title('Phi in function of X')
xlabel('X [m]')
ylabel('phi [rad]')
legend('1º Conf','2° Conf','3° Conf')

%% Second Part
%finding the equilibrium displacement
X0=[0 0 0];
for i=1:length(Pre_T)
    if Pre_T(i)<=max(H_conf1(:))
```

```
        if Pre_T(i)<min(H_conf1(:))
            X0(i)=X_conf1(1);
        else
            X0(i)=interp1(H_conf1,X_conf1,Pre_T(i));
        end
    elseif max(H_conf1(:))<Pre_T(i) && Pre_T(i)<=max(H_conf2(:))
        X0(i)=interp1(H_conf2,X_conf2,Pre_T(i));
    elseif max(H_conf2(:))<Pre_T(i) && Pre_T(i)<=max(H_conf3(:))
        X0(i)=interp1(H_conf3,X_conf3,Pre_T(i));
    else
        X0(i)=interp1(H_conf3,X_conf3,Pre_T(i),'linear','extrap');
    end
end

disp(' ')
T_print = table(X0',{'m';'m';'m'});
T_print.Properties.VariableNames = {'Value' 'Unit'};
T_print.Properties.RowNames = {'PreT=200kN';'PreT=800kN';'PreT=6000kN'};
disp('Equilibrium Displacement')
disp(T_print)
disp(' ')

%finding the delta for each configuration
delta_max=[-X0(1)+X_conf1(end),-X0(2)+X_conf2(end),200]; %COMO ACHAR O DELTA 3
delta=[linspace(-delta_max(1),delta_max(1),10);linspace(-
delta_max(2),delta_max(2),10);linspace(-delta_max(3),delta_max(3),10)];

T_print = table([-delta_max(1); -delta_max(2);-
delta_max(3)],[delta_max(1);delta_max(2);delta_max(3)],{'m';'m';'m'});
T_print.Properties.VariableNames = {'Minimum' 'Maximum' 'Unit'};
T_print.Properties.RowNames = {'PreT=200kN';'PreT=800kN';'PreT=6000kN'};
disp('Values of delta')
disp(T_print)
disp(' ')

%Distance from anchor
Dist_anchor=[2*X0(1)+L_platform;2*X0(2)+L_platform;2*X0(3)+L_platform];

T_print = table(Dist_anchor,{'m';'m';'m'});
T_print.Properties.VariableNames = {'Value' 'Unit'};
T_print.Properties.RowNames = {'PreT=200kN';'PreT=800kN';'PreT=6000kN'};
disp('Distance from anchor')
disp(T_print)
disp(' ')

%finding the restoring and horizontal forces in the cables
Ha=zeros(3,length(delta(1,:)));
Hb=zeros(3,length(delta(1,:)));
Va=zeros(3,length(delta(1,:)));
Vb=zeros(3,length(delta(1,:)));
F=zeros(3,length(delta(1,:)));
K=zeros(3,length(delta(1,:))); %stiffness of the cable
for i=1:3
    for j=1:length(delta(1,:))
        if i==1
            if X0(i)+delta(i,j)<X(1)
                Ha(i,j)=interp1(X,H,X0(i)+delta(i,j),'linear','extrap');
                Hb(i,j)=interp1(X,H,X0(i)-delta(i,j),'linear','extrap');
                F(i,j)=Ha(i,j)-Hb(i,j);
                Va(i,j)=0.5*interp1(X,V1,X0(i)+delta(i,j),'linear','extrap');
                Vb(i,j)=Va(i,j);
```

```
                K(i,j)=F(i,j)/delta(i,j);
            else
                Ha(i,j)=interp1(X,H,X0(i)+delta(i,j));
                Hb(i,j)=interp1(X,H,X0(i)-delta(i,j));
                F(i,j)=Ha(i,j)-Hb(i,j);
                Va(i,j)=0.5*interp1(X,V1,X0(i)+delta(i,j));
                Vb(i,j)=Va(i,j);
                K(i,j)=F(i,j)/delta(i,j);
            end
        elseif i==2
            Ha(i,j)=interp1(X,H,X0(i)+delta(i,j));
            Hb(i,j)=interp1(X,H,X0(i)-delta(i,j));
            F(i,j)=Ha(i,j)-Hb(i,j);
            Va(i,j)=0.5*interp1(X,V1,X0(i)+delta(i,j));
            Vb(i,j)=Va(i,j);
            K(i,j)=F(i,j)/delta(i,j);
        else
            if X0(i)+delta(i,j)<max(X(:))
                Ha(i,j)=interp1(X,H,X0(i)+delta(i,j),'linear','extrap');
                Hb(i,j)=interp1(X,H,X0(i)-delta(i,j),'linear','extrap');
                F(i,j)=Ha(i,j)-Hb(i,j);
                Va(i,j)=0.5*interp1(X,V1,X0(i)+delta(i,j));
                Vb(i,j)=Va(i,j);
                K(i,j)=F(i,j)/delta(i,j);
            else
                Ha(i,j)=interp1(X,H,X0(i)+delta(i,j),'linear','extrap');
                Hb(i,j)=interp1(X,H,X0(i)-delta(i,j),'linear','extrap');
                F(i,j)=Ha(i,j)-Hb(i,j);
                Va(i,j)=0.5*interp1(X,V1,X0(i)+delta(i,j),'linear','extrap');
                Vb(i,j)=Va(i,j);
                K(i,j)=F(i,j)/delta(i,j);
            end
        end
    end
end

figure
subplot(2,1,1)
plot(delta(1,:),Ha(1,:),delta(1,:),-Hb(1,:),delta(1,:),F(1,:))
title('Ha, Hb and F in function of delta for Pre_T=200 kN')
xlabel('Delta [m]')
ylabel('Force [N]')
xlim([-delta_max(1) delta_max(1)])
legend('Ha','Hb','F')
subplot(2,1,2)
plot(delta(1,:),Ha(1,:),delta(1,:),Hb(1,:))
title('Ha, Hb in function of delta for Pre_T=200 kN')
xlabel('Delta [m]')
ylabel('Force [N]')
xlim([-delta_max(1) delta_max(1)])
legend('Ha','Hb')

figure
subplot(2,1,1)
plot(delta(2,:),Ha(2,:),delta(2,:),-Hb(2,:),delta(2,:),F(2,:))
title('Ha, Hb and F in function of delta for Pre_T=800 kN')
xlabel('Delta [m]')
ylabel('Force [N]')
xlim([-delta_max(2) delta_max(2)])
legend('Ha','Hb','F')
subplot(2,1,2)
```

```
plot(delta(2,:),Ha(2,:),delta(2,:),Hb(2,:))
title('Ha, Hb in function of delta for Pre_T=800 kN')
xlabel('Delta [m]')
ylabel('Force [N]')
xlim([-delta_max(2) delta_max(2)])
legend('Ha','Hb')

figure
subplot(2,1,1)
plot(delta(3,:),Ha(3,:),delta(3,:),-Hb(3,:),delta(3,:),F(3,:))
title('Ha, Hb and F in function of delta for Pre_T=6000 kN')
xlabel('Delta [m]')
ylabel('Force [N]')
xlim([-delta_max(3) delta_max(3)])
legend('Ha','Hb','F')
subplot(2,1,2)
plot(delta(3,:),Ha(3,:),delta(3,:),Hb(3,:))
title('Ha, Hb in function of delta for Pre_T=6000 kN')
xlabel('Delta [m]')
ylabel('Force [N]')
xlim([-delta_max(3) delta_max(3)])
legend('Ha','Hb')

T_print = table([K(1,5);K(2,5);K(3,5)]*10^-3,{'kN/m';'kN/m';'kN/m'});
T_print.Properties.VariableNames = {'Value' 'Unit'};
T_print.Properties.RowNames = {'200kN' '800kN' '6000kN'};
disp('Equvalent Stiffness')
disp(T_print)
disp(' ')
```

Part 2
Purposes of work

Part 2's goal is to compute the mooring-induced damping coefficients caused by surge movements of the moored vessel. The mooring system is studied, which consists of the FPSO being moored to the bottom with two mooring lines (chain-Polyester-chain). Mooring induced damping is calculated using the energy wasted by a mooring line owing to floating body motion. The mooring line's nonlinear dynamic analysis is done in time domain using the DNV program DeepC. The dynamic responses of the mooring line will be calculated using the floating body's wave drift oscillation and wave frequency oscillation.

1. In the DeepC instances, the FPSO will be employed as the floating structure for the Simplified Motion Vessel analysis.
2. The low frequency motion, or wave frequency motion, will be identified as the input for the vessel. Different amplitudes and frequencies are taken into account.
3. Two different mooring line pretensions will be examined. (Task 2's first two cases will be utilized.)
4. After completing dynamic analysis, the dynamic tension on the fairlead will be determined.
The indication diagrams displaying the force-displacement curves will then be obtained.
5. The dissipated energy of the mooring system owing to the vessel's motion will be determined using the indicator diagrams. As a result, the mooring lines' equivalent linear damping coefficient may be computed.

Introduction and definition of main dimensions

This project intends to carry on the examination of a spread mooring system - Task 2 - in which the static analysis was done with a system consisted of a vessel and two mooring lines comprising three materials in extremely deep water. The research object will remain the same, but this time the emphasis will be on dynamic effects and induced damping coefficients.

The prior work involved analyzing one of the cables and calculating a horizontal scope from fairlead to anchor point for a certain environmental force, as indicated in Table 1. Only the first two pre-tensions (TH=200kN; TH=800kN) would be examined in this assignment, as the third was deemed impractical.

Equilibrium Condition

TH [kN]	200	800
X0 [m]	1486	1906

The table shows the mooring line characteristics based on the assignment description. The mooring lines will be made up of three pieces, each of which will be 3000m long.

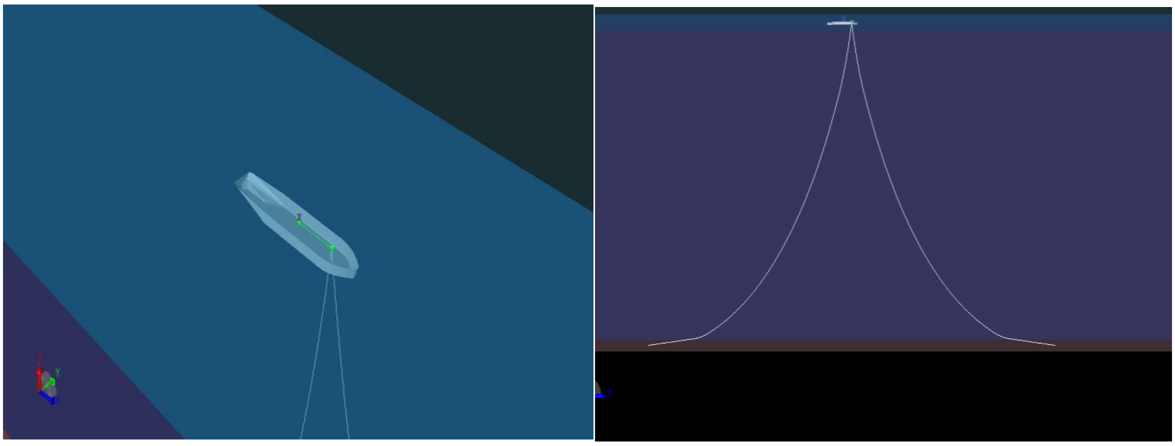
Material	Chain	Polyester	Chain
L [m]	500	2000	500
w [kN/m]	2.11	0.78	2.11
EA [kN]	1644740	1379310	1644740
d [mm]	106.1	340.8	106.1
CBS [kN]	8429.51	29027.4	8429.51
Tbr [kN]	4683.06	16126.31	4683.06

The work description's step-by-step instruction was used to carry out the simplified motion vessel analysis. To build up the simulations model, the parameters and assumptions listed below were used.

Step by step simulation:

When the origin (0, 0, 0) is supposed to be midship, it is assumed that the fairleads of all mooring lines are merged into one turret, which is placed in front of the ship at (61.45m, 0, 0). The turret guarantees that the floating body may freely rotate around the designated mooring termination point. The setup is depicted in figures.

While different configurations are evaluated for the variable pre-tensions, each configuration necessitates a new set of simulations. Figure 2 depicts the DeepC arrangement for the initial stresses investigated for this project.



Several sinusoidal surge movements with a wide range of amplitudes and times were investigated for the analysis. The motion time series was calculated ahead of time with a step of 1s using the Equations 1–6.

Low frequency sinusoidal motion

$$X(t) = 30 \sin\left(\frac{2\pi}{330} t\right)$$

$$X(t) = 30 \sin\left(\frac{2\pi}{290} t\right)$$

$$X(t) = 30 \sin\left(\frac{2\pi}{260} t\right)$$

Wave frequency sinusoidal motion

$$X(t) = 5.4 \sin\left(\frac{2\pi}{15} t\right)$$

$$X(t) = 5.4 \sin\left(\frac{2\pi}{12.5} t\right)$$

$$X(t) = 5.4 \sin\left(\frac{2\pi}{10} t\right)$$

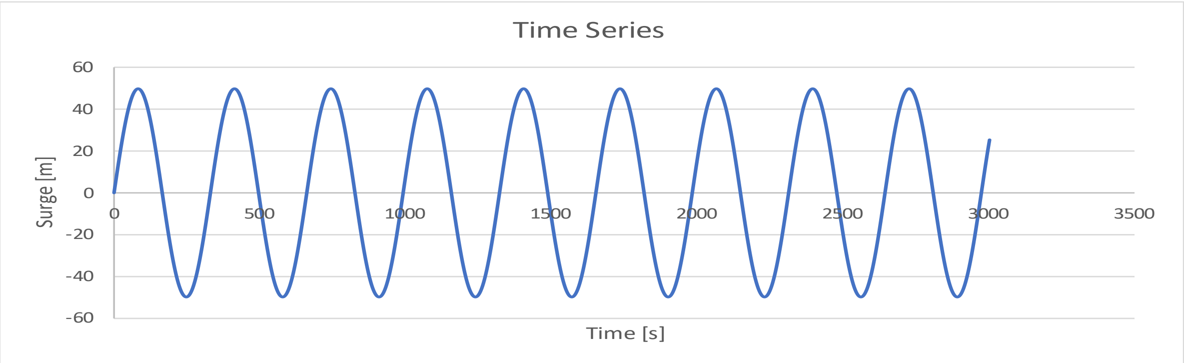
Results of analysis:

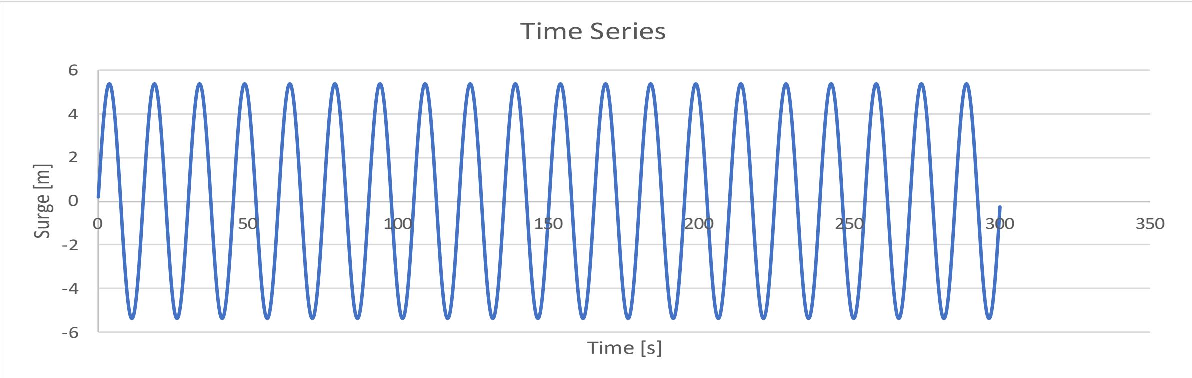
This part will present any of the calculations and findings acquired from the DeepC program, as well as conduct information is made available on modifying dynamic parameters such as amplitude, frequency, and pre-tension. DeepC can deliver a collection of outcomes with their specific behavior that requires attention by modifying these parameters.

The initial stage in obtaining a time series of displacement and horizontal forces. The following steps will be used to accomplish this:
To establish the pre-tension, the configuration discovered in job 2, as mentioned in subsection, is used as the input, and a pre-defined txt file containing the input surge motion with the specified frequency and amplitude is delivered to the program. Because the software already provides them with the signal with respect to the coordinate system, we can say that the software simulation will provide the surge motion and horizontal tensions for lines A and B at the fairlead, FHA and FHB, and the resultant horizontal tension is calculated as

$$TH = FHA + FHB$$

The surge displacement may be generated for the first set of findings. The X location of the fairlead is derived and is depicted in Figures 3–6, where the plots are separated into tensions and frequency kinds (low and wave).





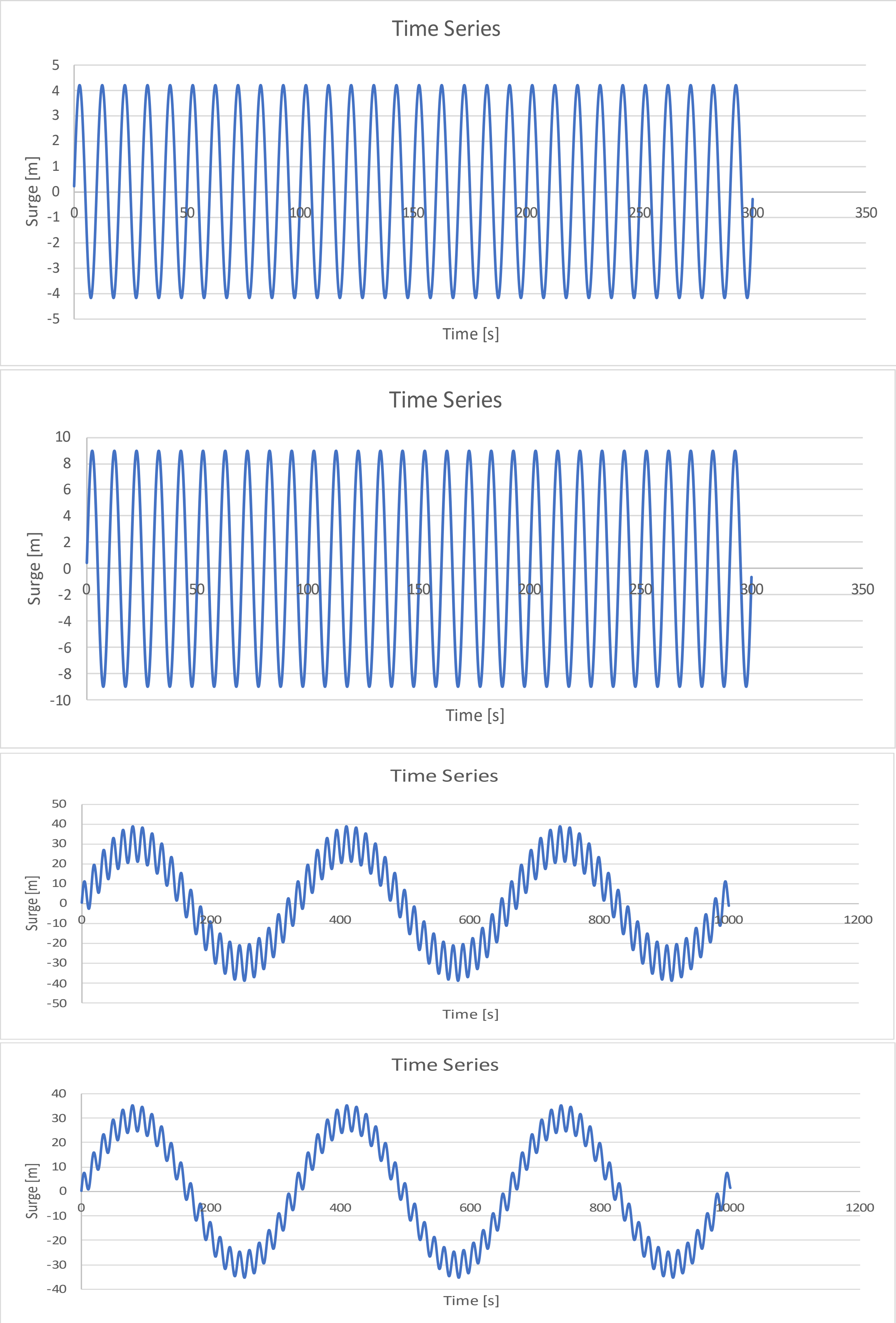
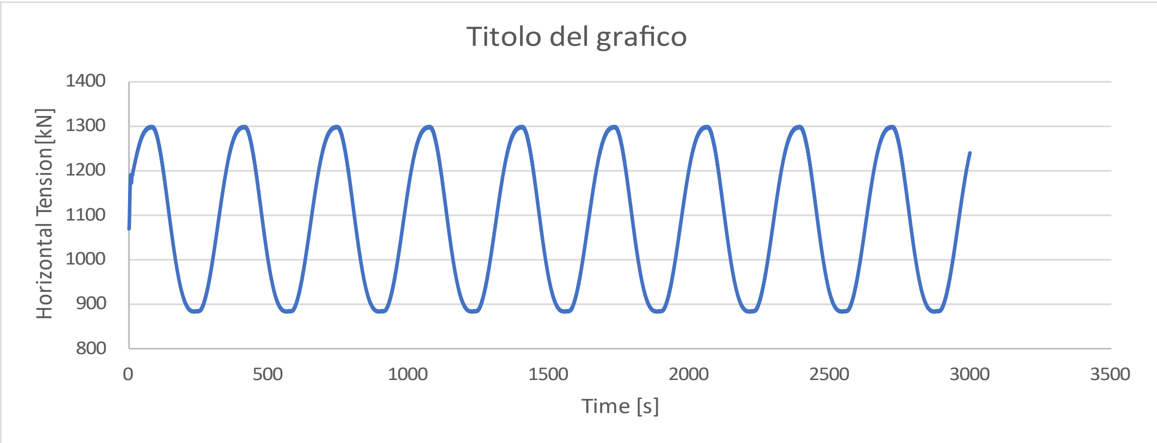
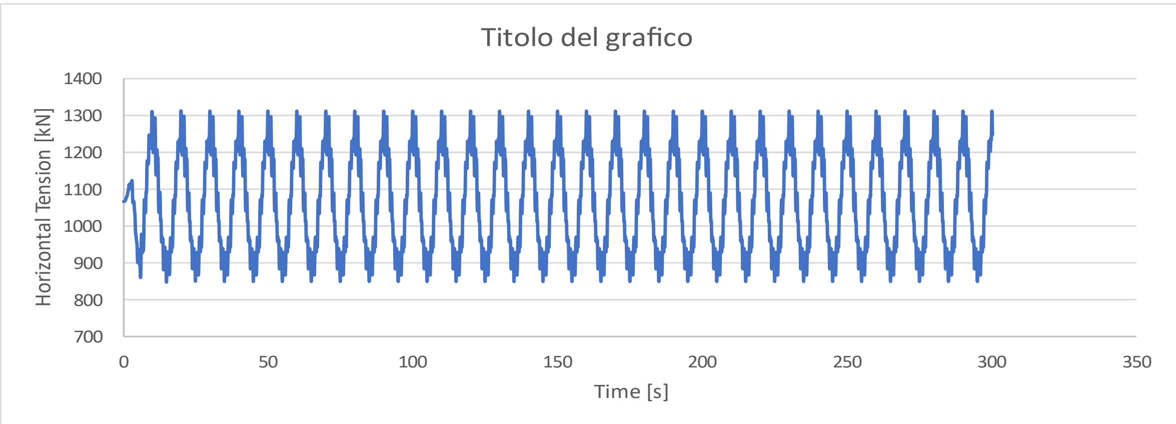


Figure 1-6: Time series of displacement for low frequencies and wave frequencies pre-tension 200kN

The figures show that the results were created to complete 5 oscillations for each period, and the wave frequencies experienced inifial impacts of the transient. This allows for the provision of a time series of the horizontal resultant tension. The first is connected to the low frequency movements for the pre-tensions under consideration, as illustrated in figures.





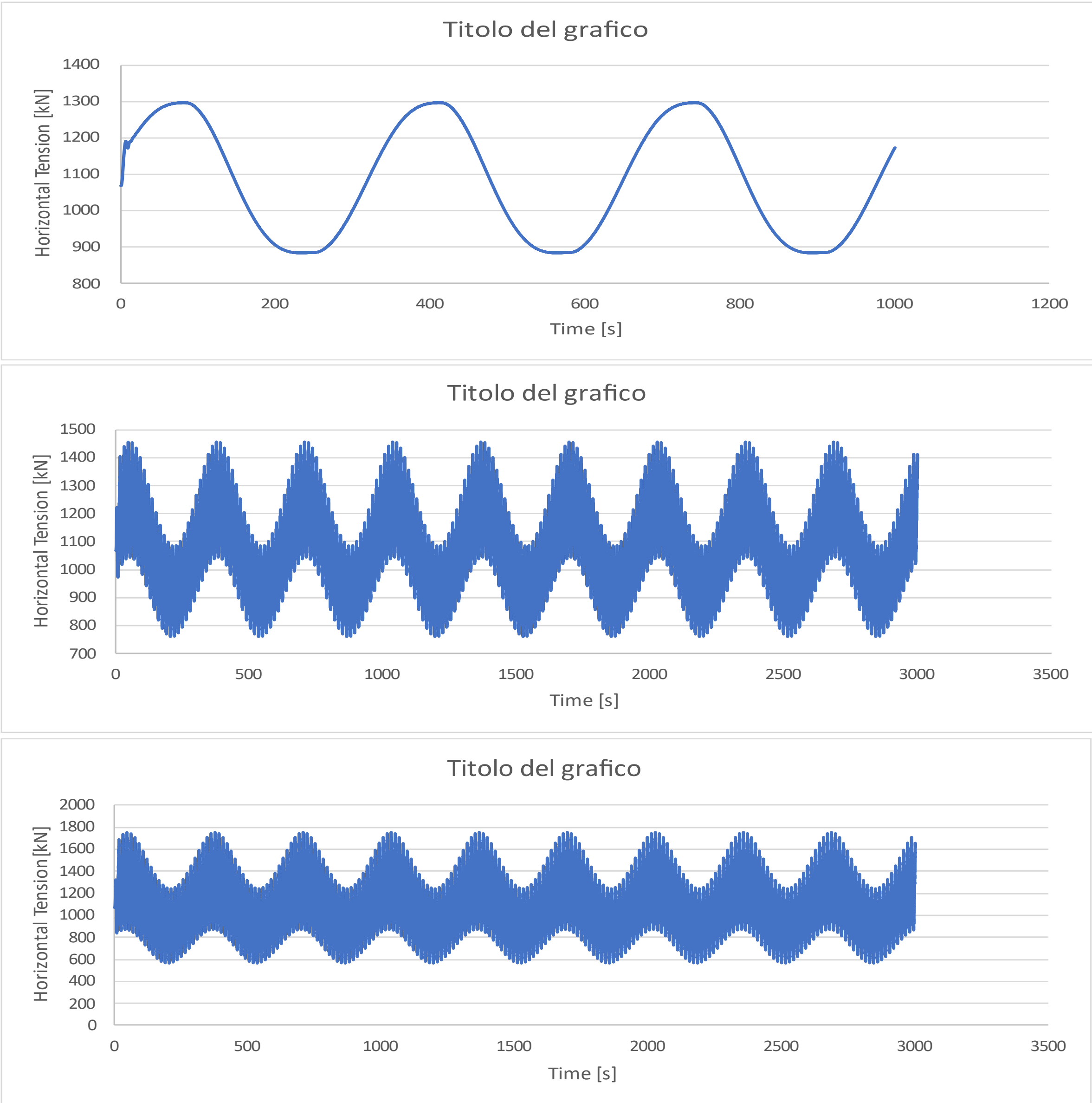
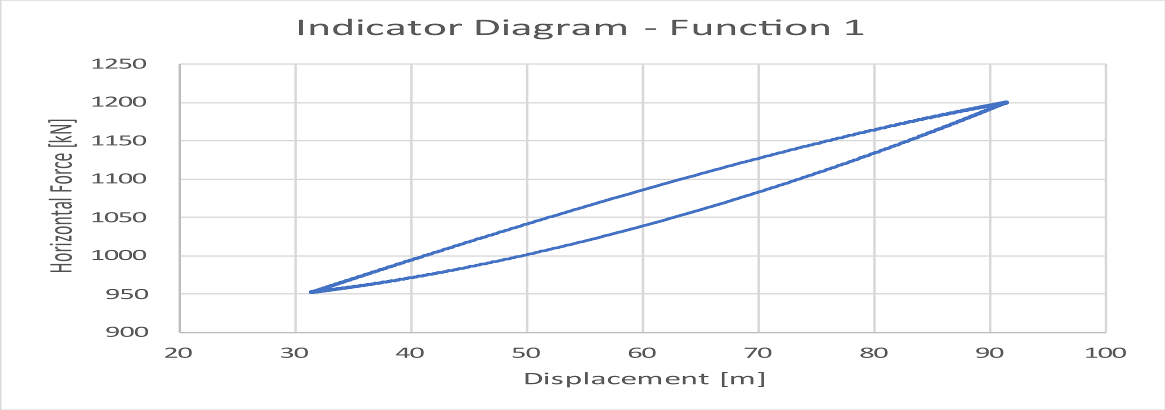


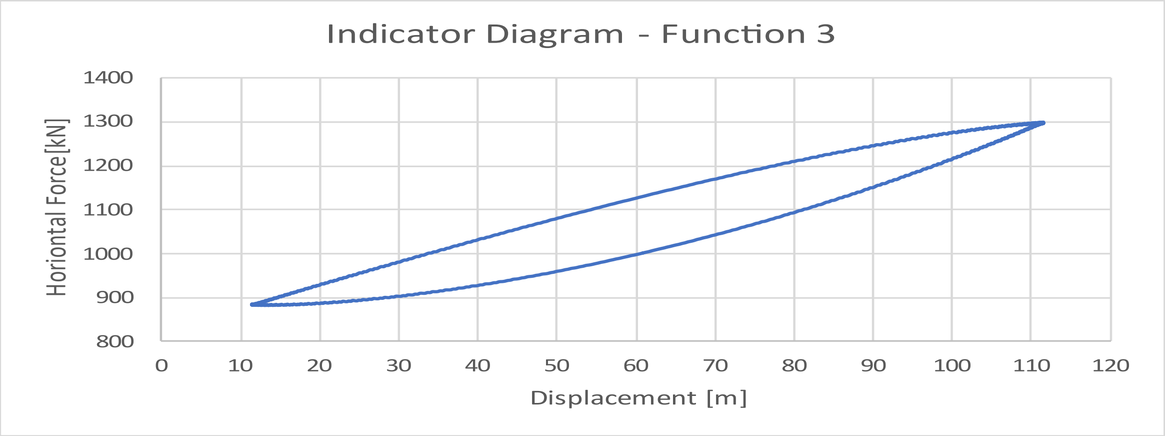
Figure 7-12: Time series of dynamic horizontal tensions for wave frequencies and low frequencies with pre-tension 200kN

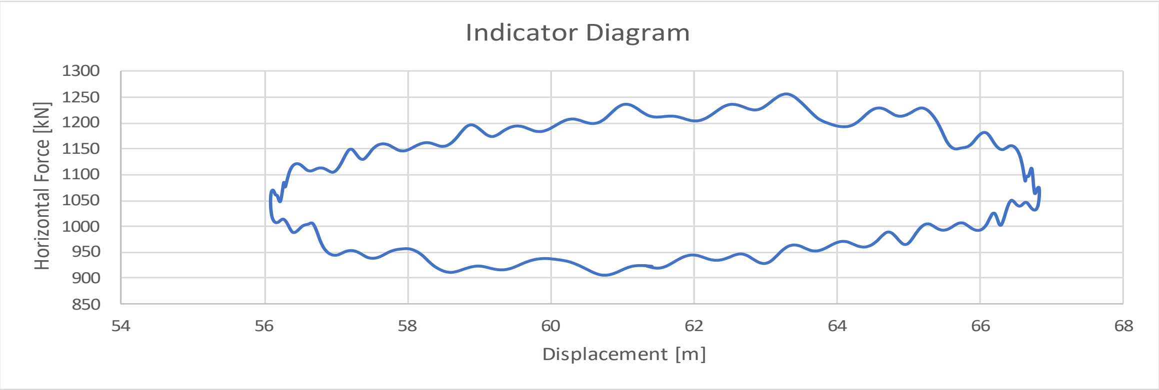
Some aspects of these plots can already be defined, such as their regular and sinusoidal behavior, with the frequency being the same as the displacement and the force amplitude increasing with increasing amplitude. In addition, increasing the frequency resulted in an increase in the force amplitude.

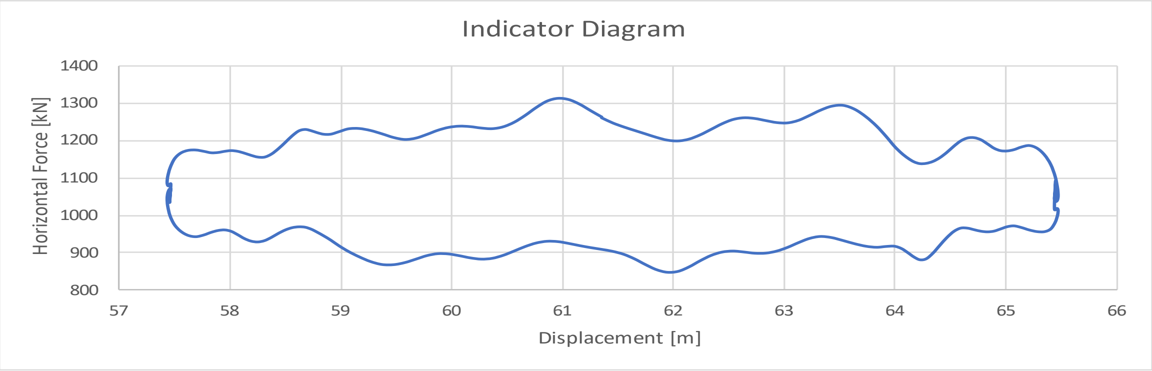
The same plots may be made for wave frequencies, as illustrated in the figures. The periodic pattern might still be visible in the case of wave frequencies, but with "noises" that appear to be oscillation inside oscillation. This is owing to the dynamic impacts of the high frequency oscillation in the cable, whereas the low frequency behavior has these effects as well, but in a more quasi-static manner.

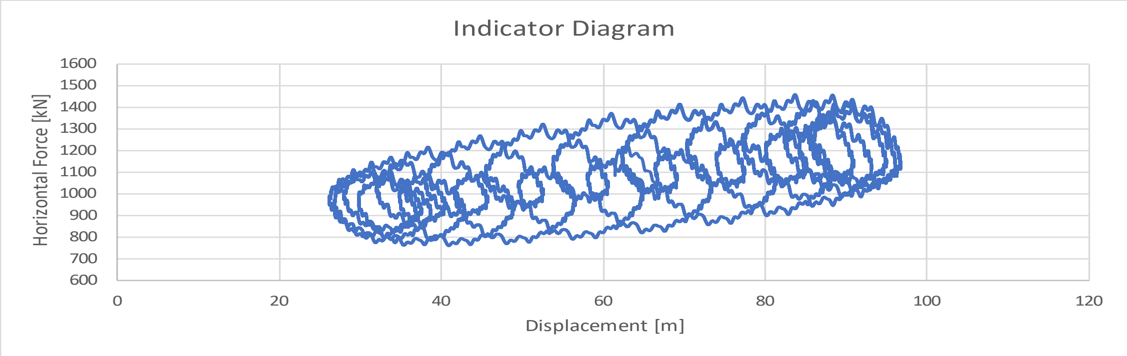
The next analysis will regard the plotting of the Indicator Diagrams, the indication diagram should be created for this section of the project. This is simple to perform using the simulated results by displaying the parametric curve (X(t), TH (t)). The following figures illustrate the findings for low frequency and both pretensions.











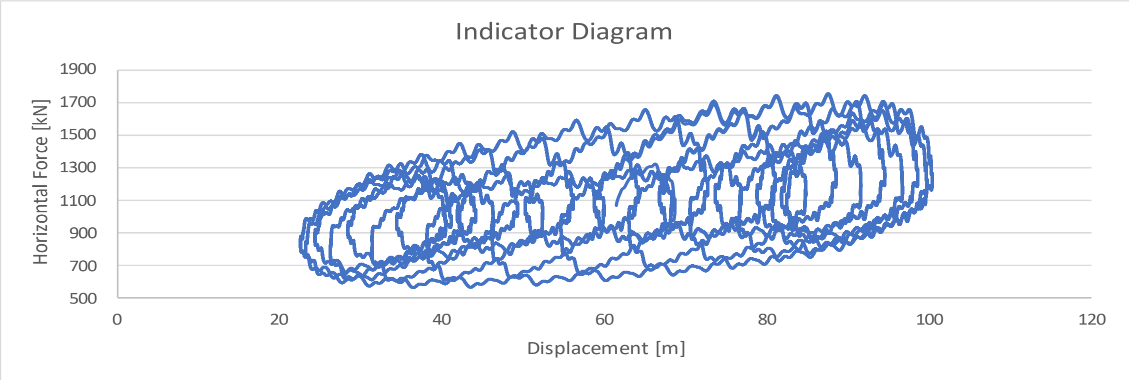


Figure 13-18: Indicator diagrams for wave frequencies and low frequencies with a pre-tension of 200kN

Some crucial elements may be deduced from these curves, such as:
The steady-state curves exhibited smooth and regular behavior, as predicted given the previous regular oscillations.
There was an early temporary impact, as shown in the first lines, which should be ignored in this project.
This is a predictable outcome, because more pre-tension should result in a larger stiffness and slope between force and displacement (restoration).
The curves for greater amplitudes had the same shape for the same frequency but a higher scale (since large amplitudes are associated to high energies) while the curves for various frequencies (and same amplitude) had different forms but a similar scale.
These curves are not as smooth as the previous ones since the "noisy" behavior with oscillation over oscillation was followed, as stated previously in the tension plots. The slope's behavior is less visible in these plots, but the transient, amplitude, and frequencies may still be seen.

Mooring induced damping coefficients

The conservation of energy is used to calculate the induced damping coefficient Bn, and the dissipated energy E should be equal to the work produced by the induced damping. The coefficient is determined using the following equation:

$$B_n = \frac{E\tau}{2\pi^2 q_0^2}$$

Where qo denotes the amplitude and, tau the time.

As a result, the wave spectrum can have a significant influence on the damping coefficient of the mooring system. Because this variable is frequently squared, the amplitude has a substantial impact on the magnitude. The dissipated energy E may be calculated by integrating the work done by the upper tension during one period of oscillation, selected to be far from the initial peak due to the transient's impact. A numerical integration approach was used for this task.

Since the findings are regarded precise enough to identify an acceptable approximation, the trapezoidal integration approach was applied.
The values of dissipated energy and damping coefficients were determined, and the results are presented below for both pretensions and all frequencies addressed.

	Amplitude [m]	Period [s]	Energy dissipated [KJ]	Damping Coefficient [kg/s]
200 kN	30	330	2088,68	138,84
	35	330	1992,14	272,78
	40	330	60911,54	637,10

Values of dissipated energy and induced damping coefficients for low frequency

	Amplitude [m]	Period [s]	Energy dissipated [KJ]	Damping Coefficient [kg/s]
200 kN	5,4	10	1926,86	50,26
	4,2	10	1547,29	44,48
	9	10	11131,45	69,69

Values of dissipated energy and induced damping coefficients for wave frequency

Directly, it was important to notice some essential behavior for the energy dissipated and damping coefficient, which have been we have that either the damping coefficient and energy dissipated are higher for a larger amplitude, which is presumed, since the amplitude is identified as an energetic parameter, for this purpose, low and wave frequency local behavior, increasing the frequency resulted in a significantly larger dissipated energy and damping coefficient and regarding the pre-tension, due to the obvious vast quantity of variable variation and its influence on damping, it is difficult to draw broad predictions on damping based on the impact of parameter interaction. As a result, an analysis for the specific circumstances is strongly advised.

Conclusions

In comparison to the static analysis, which ignored damping forces owing to the vessel's extremely slow motion, the dynamic analysis is complicated and deals with a vast number of factors, each of which influences the ultimate predicted result in its own manner.
When contemplating wave or low frequencies, the distinct behavior begins right away. The low frequency system has a smooth overall behavior because it is a quasi-static system, but the wave frequency system has a more "noisy" behavior because it is impacted by dynamic elements of the environment and components.
In terms of amplitudes, the outcomes were usually better for larger amplitudes.
When comparing different global frequencies, the pre-tension studied has a different relationship between its impedance and stretch, resulting in a different final result of damping coefficient.

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