University of Lisbon
Instituto Superior Técnico

Hydrodynamics of floating systems

Project work-Floating production systems

Part 1: Hydrodynamics of floating bodies

Project realised by:

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Academic year 21/22
MENO
First period
First semester

Task 1: Frequency domain analysis (WADAM)

Task 1A: Responses of floating bodies in regular seas

1. INTRODUCTION

The main purpose of this project consists in analysing in the frequency domain the behaviour of floating bodies subjected to different forces caused by dynamic systems such as waves. In the boundary conditions of these systems, it is important to remember that the variations of the latter, together with the dynamic systems, imply a prediction of the answer of the floating system in response to the variation of the motions with reference to the existing degrees of freedom.
The main degrees of freedom of the floating system, on which the geometrical and physical characteristics of buoyancy and stability are known and fixed, will be studied under the effect of amplitude operators and wave spectra in relation to different wave directions, frequencies and domains.

The 6 degrees of freedom existing in the floating system will be illustrated below:

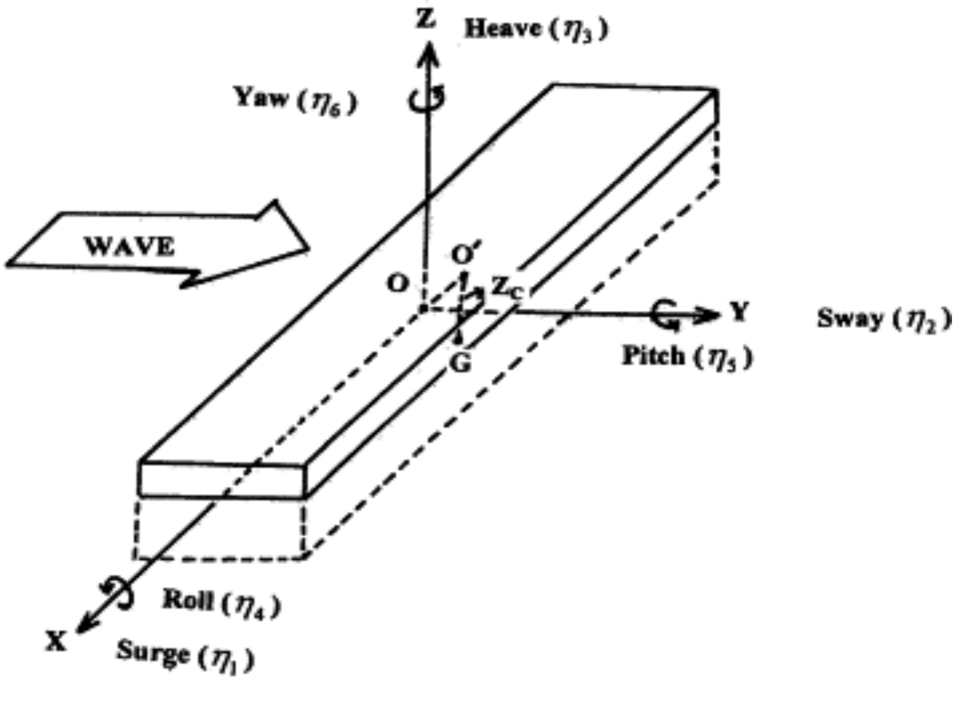


Fig.1 Degrees of freedom

2. FREQUENCY DOMAIN ANALYSIS (WADAM)

The main software used for this task is WADAM.
Wadam is a general hydrodynamic analysis program for calculating wave-structure interaction for fixed and floating structures of arbitrary shape. The analysis features of the Wadam software module represent state-of-the-art technology and the program is unsurpassed for practical applications. Airy wave theory is applied and results are presented as complex transfer functions or as deterministic results for specified phases of the wave. The technical used is the analysis of a frequency domain.

In a frequency domain the wave loads are defined in terms of wave frequency and direction. The wave heights are not specified. The analysis is performed in the frequency domain meaning that the wave loads are given as complex loads with real and imaginary parts that together describe the load value and phase shift compared with the incoming wave. The analysis may be static or dynamic and demands limited computer resources. The frequency domain method requires linearization for the nonlinear terms since it employs the linear principle of superposition. It is very efficient and useful for dynamic response problems with less severe nonlinearity.

Wadam uses widely accepted linear frequency domain methods for marine hydrodynamics

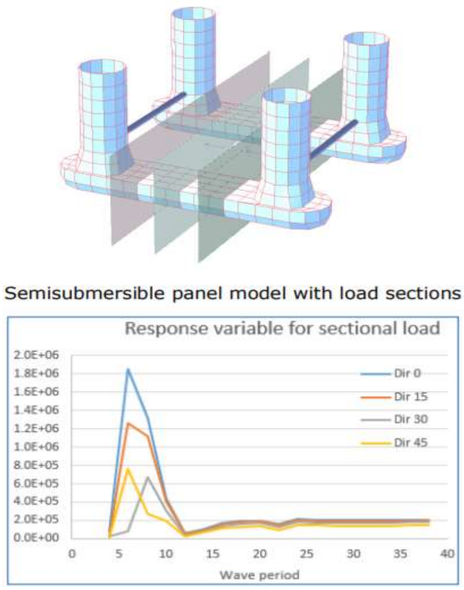


Fig.2 Analysis of a frequency domain

The definition of models in Wadam includes three main model types: (1) the hydro model which is used to calculate hydrodynamic forces, (2) the structural model where hydrodynamic and hydrostatic loads are represented as finite element loads and (3) the mass model.

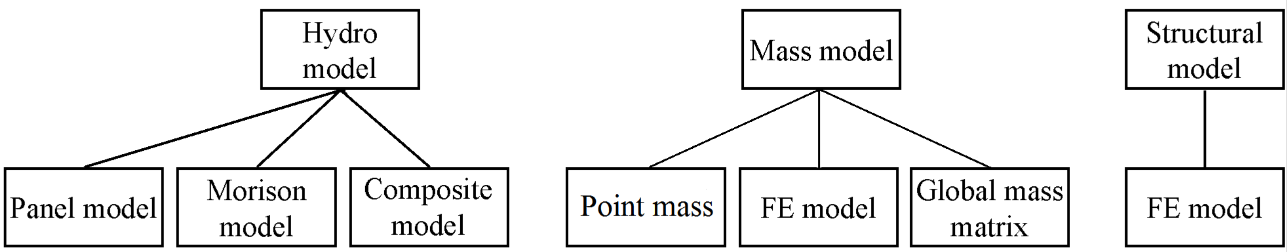


Fig.3 Differents models in Wadam

We will mainly consider models subject to hydrodynamic forces, in particular panels.

3. PLOTS OF RAOs

RAOs are typical results attributes like global response data and detailed results for selected panels/points.

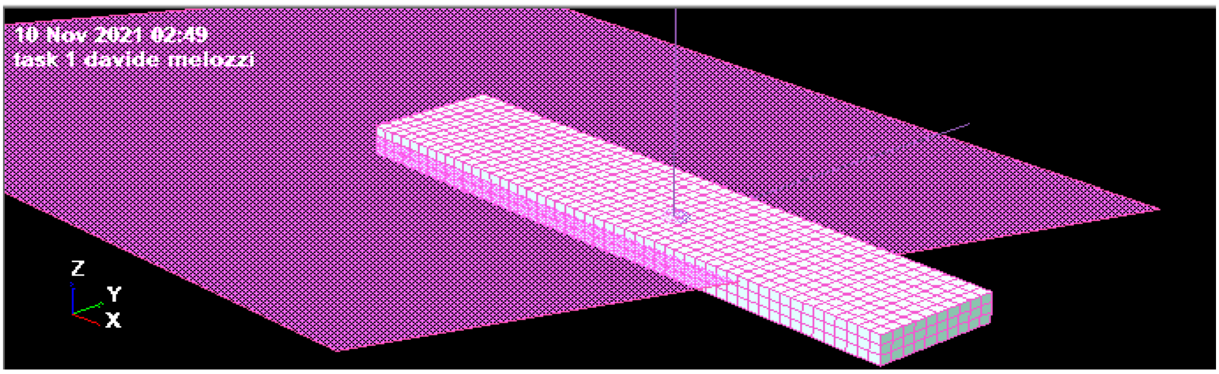
In our case we calculated and composed 6 different plots based on the chosen and recommended domain frequencies (First value 0.04, Last value 1.22, Step 0.02 = 60 frequencies) and the following wave directions: 0°, 15°, 30°, 45°, 60°, 75°, 90°.

In addition, as assigned to me by the personal data, the float system has the following features:

Length [m]	Tfore [m]	Taft [m]	Phi [deg]	CB-CG [m]
180	5	3	10	5

From this we can deduce that the baseline is centred with the intersection of the axes and ship reference XY, the difference in draught between bow and stern presents a TRIM which is subsequently influenced by the presence of a heeling angle phi.

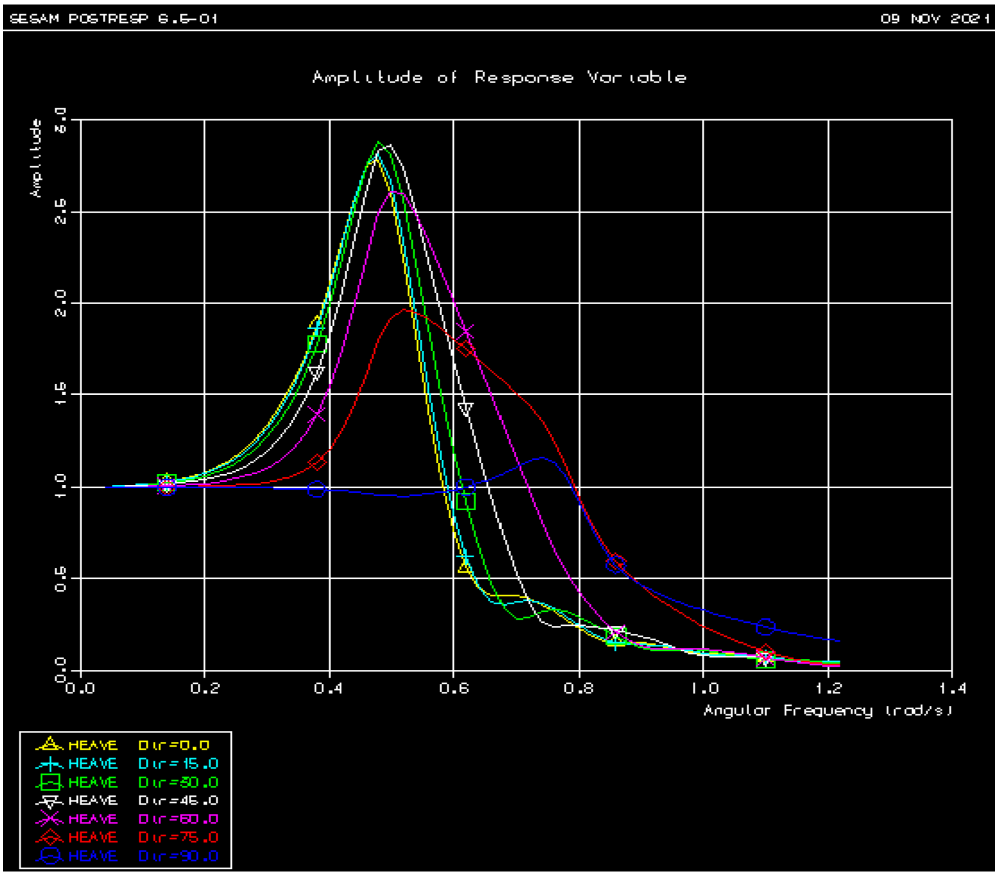
The selection of the panel related to the homogeneity of the density implements considerable simplifications on the considerations related to the variations of the distance between centre of gravity G and centre of buoyancy B.



Having now analysed the physical characteristics of the structure, let's look at its behaviour within the frequency domain listed above, graphically analysing the variations of the six fundamental degrees of freedom, taking into account responses inherent in peaks and amplitude values and above all spectral responses:

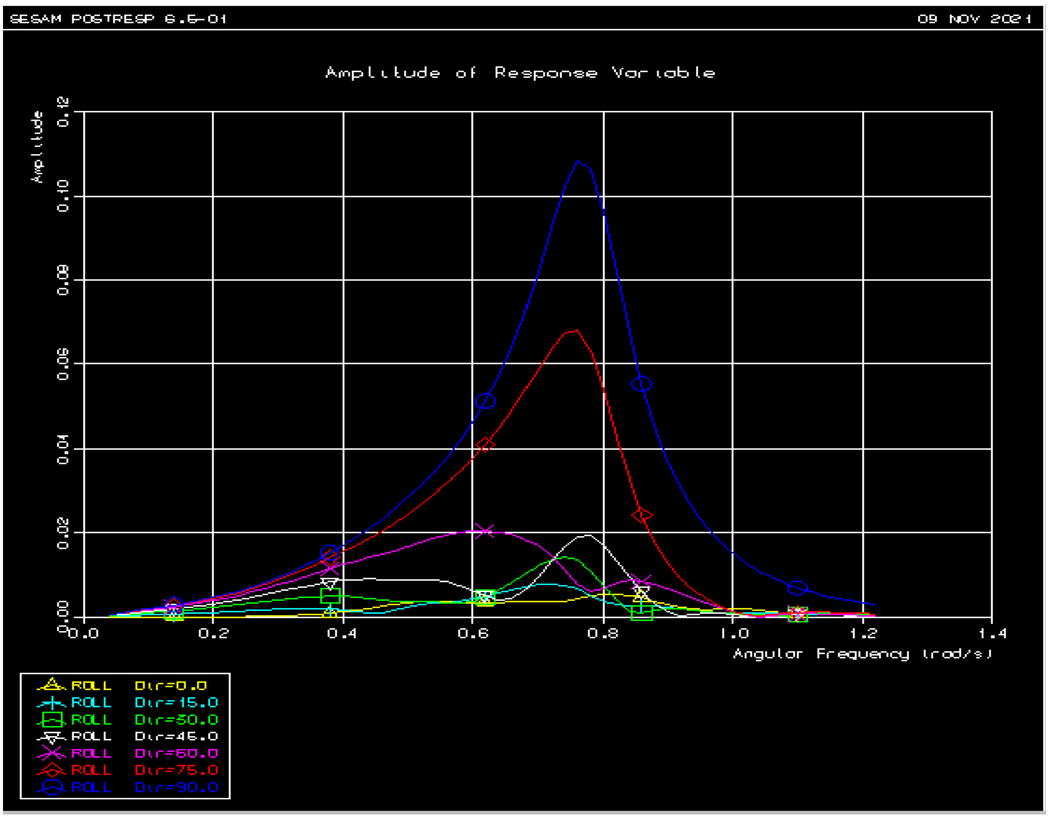
HEAVE, ROLL, PITCH, YAW, SURGE, SWAY.

HEAVE:



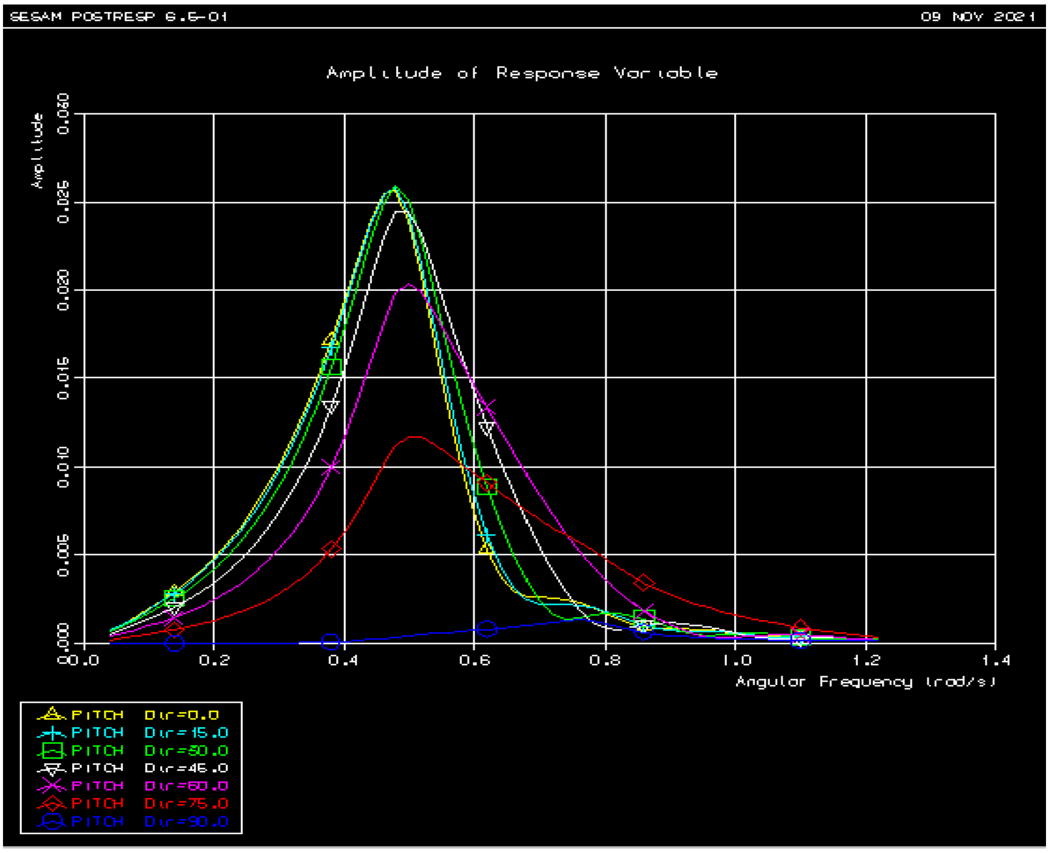
Amplitude of response variable inherent in the different wave directions of the dynamic system and angular frequency.

ROLL:

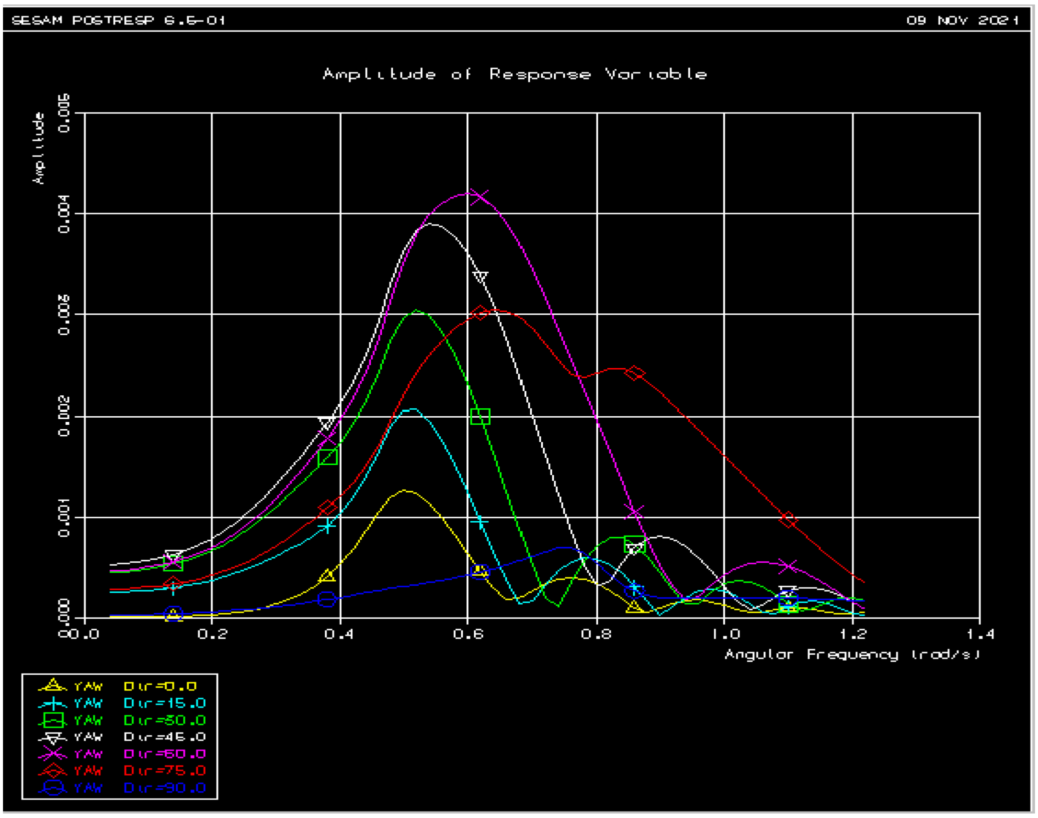


Amplitude of response variable inherent in the different wave directions of the dynamic system and angular frequency.

PITCH:

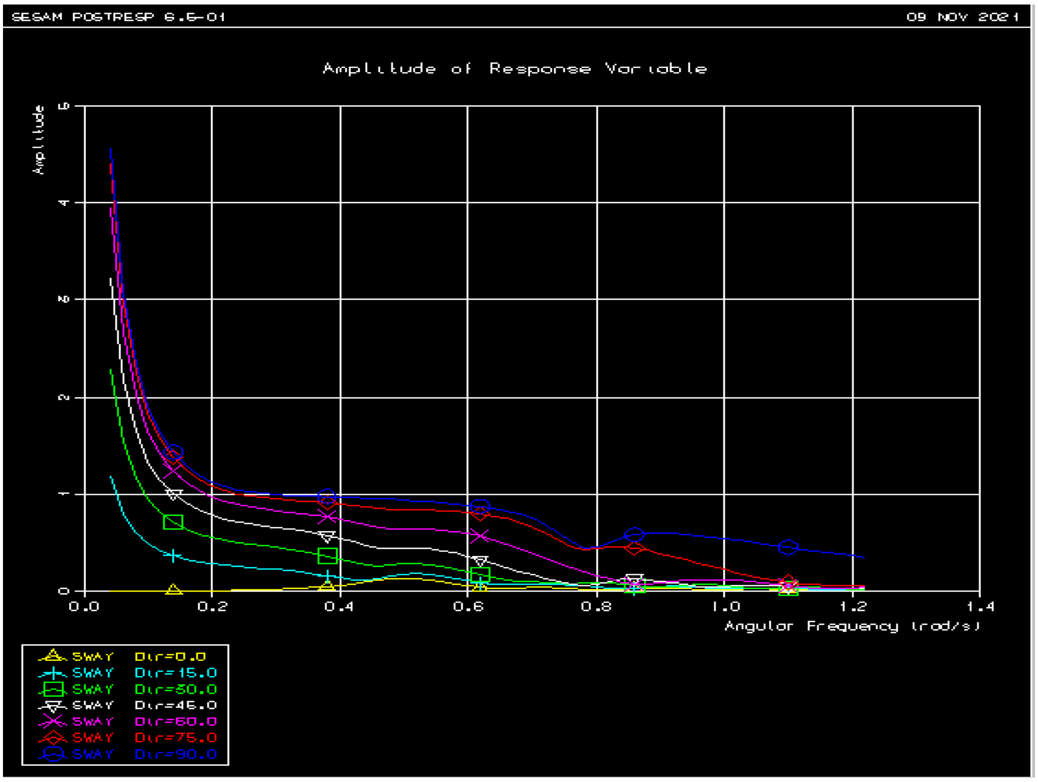


YAW:

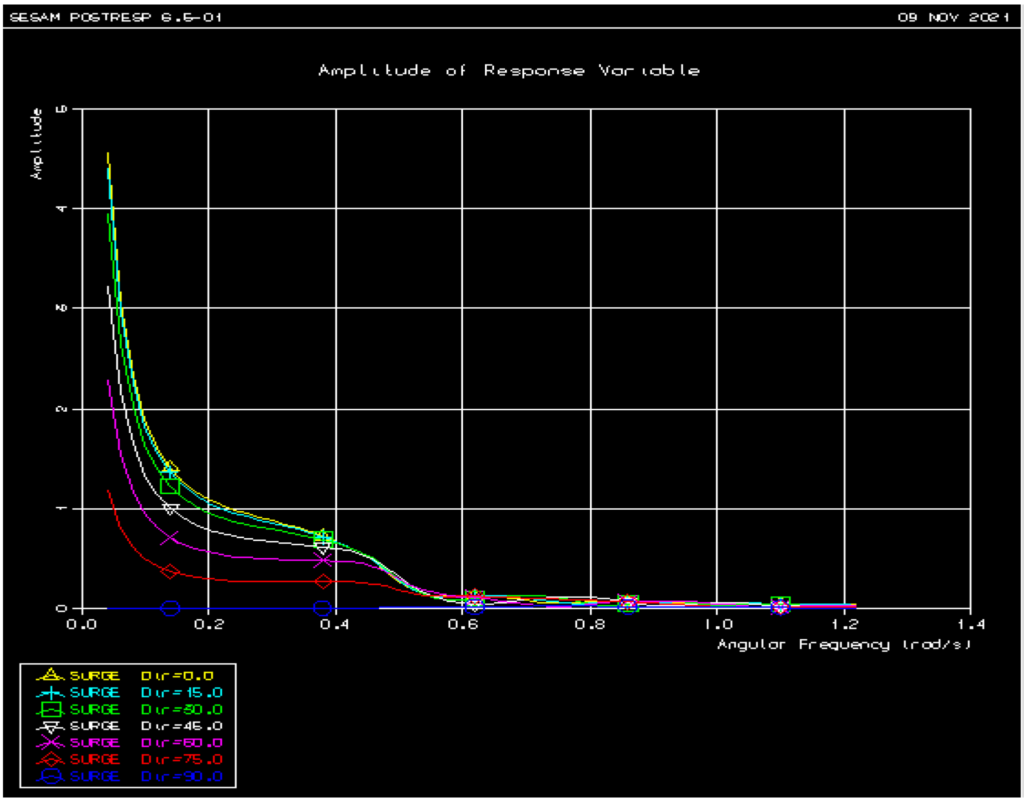


Amplitude of response variable inherent in the different wave directions of the dynamic system and angular frequency.

SWAY:



SURGE:



Amplitude of response variable inherent in the different wave directions of the dynamic system and angular frequency.

4. CONCLUSIONS

Graphically, analysing the situation by means of the calculated plots, we notice how the behaviour of the values of the amplitude and proportionally of the wave energy is strictly correlated to the direction of origin of the wave in the relative degree of freedom constrained and taken into consideration.
For example, we can note that in the Roll, the wave with the highest amplitude has a direction 90°that is completely orthogonal to the rolling axis of the ship, it creates a peak due to the presence of a maximum heeling moment created by the breaking of the wave in the maximum direction.
Differently in Pitch, the wave with the same direction will be concordant with the direction and direction of the Z-axis on which the movement occurs, leading to a significantly lower peak value than at lower angles, i.e. transmitting less energy and impact.

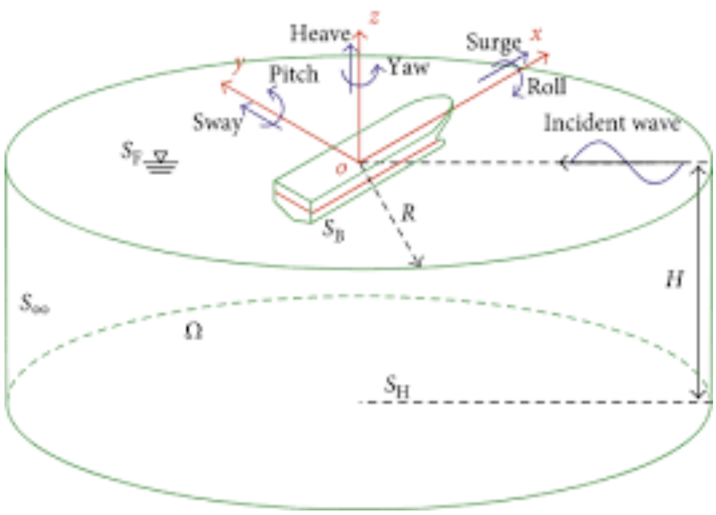


Fig.4 Behaviour of a “ship” in waves condition

For these reasons, we can say that the behaviour of our structure is not optimal, depending mainly on the geometry and considerable energy in response released as a result of the application of dynamic forces.

I think viscous dumping is a problem that should not be underestimated, especially from an energy and vibrational point of view for the structure. There are systems for preventing and exploiting this phenomenon, which allow the energy emitted by the phenomenon to be reused. The viscous dampers convert the kinetic energy of the structural movement into heat and then dissipate that energy into the air, thereby obeying the laws of physics through the conservation of energy, that produces a damping force proportional to the mass's velocity is commonly referred to as "viscous damping".

Task 1B: Responses of floating bodies in irregular seas

1. INTRODUCTION

Linear theory makes it possible to describe wave motion and loads on submerged structures and ships.
The next consideration concerns the application of non-linear principles and their consequent effects in different sea conditions.
For the structure with a regular wave amplitude incident, the considerations of breaking, movement and loading are directly proportional to the function given by the amplitude. This is due to the linear theory, which also makes it possible to obtain irregular wave results by adding together different regular wave results with different amplitudes, wavelengths and directions of propagation.

To accurately predict the linear and non-linear response of structures in marine environments, wave spectra representing a variety of desired sea states are needed.

The wave spectrum method we use is the Pierson-Moskowitz method.
Pierson and Moskowitz analyzed measured wave data taken by accelerometers on British weather ships in the North Atlantic in 1964. Only data taken in fully developed seas were used in the analysis. A fully developed sea is reached at the point of energy saturation in which there is a balance between the rate at which energy is gained from wind and lost by breaking or non-linear wave interaction.

The Pierson–Moskowitz spectrum is:

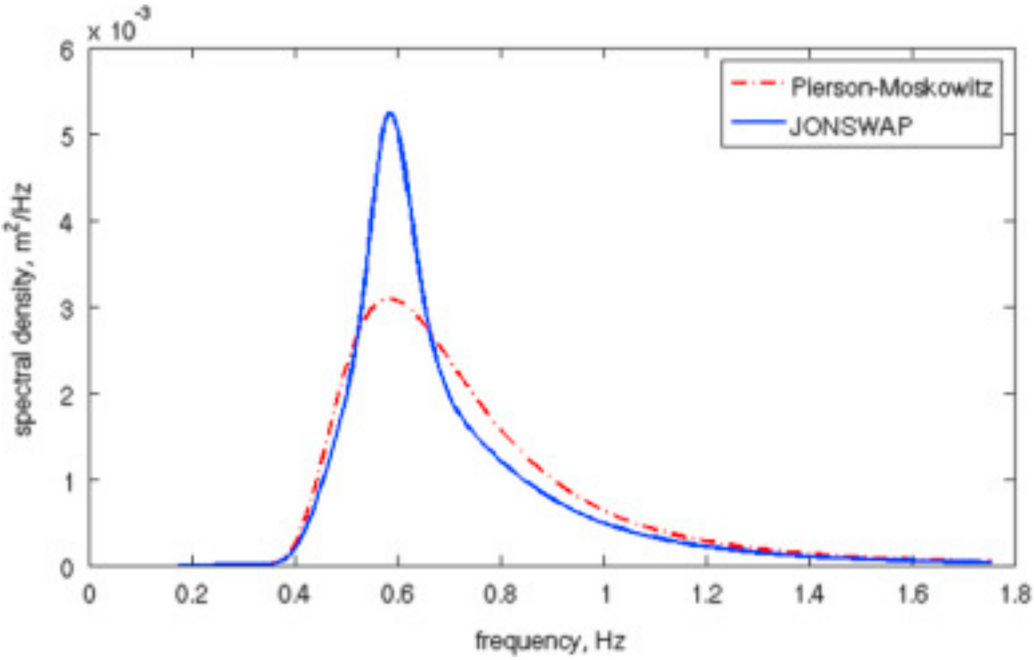
$$S(\omega) = \frac{Ag^2}{\omega^4}\exp\left[-B\left(\frac{g/U}{\omega}\right)^4\right]$$

where, A= $8.10\text{x}10^{-3}$ B=0.74, and U is the wind speed measured at 19.5 m above the sea surface. The Pierson–Moskowitz spectrum depends only on wind speed.

The other most commonly used method is JONSWAP, which is famous for being an extension of the previous method by further considering the fetch parameter.

$$S(\omega) = \alpha\frac{g^2}{\omega^5}\exp\left[-1.25\left(\frac{\omega_m}{\omega}\right)^4\right]\gamma^a$$

where $a = -\frac{(\omega-\omega_m)^2}{2(\sigma\omega_m)^2}$ γ is called the peak enhancement factor between 1 to 6.



From this graphical comparison between the two methods, we can analyse the peak difference given by the spectral density, which is influenced by the main parameters of the method, such as wind and fetch.

2. PLOTS OF WAVE SPECTRA

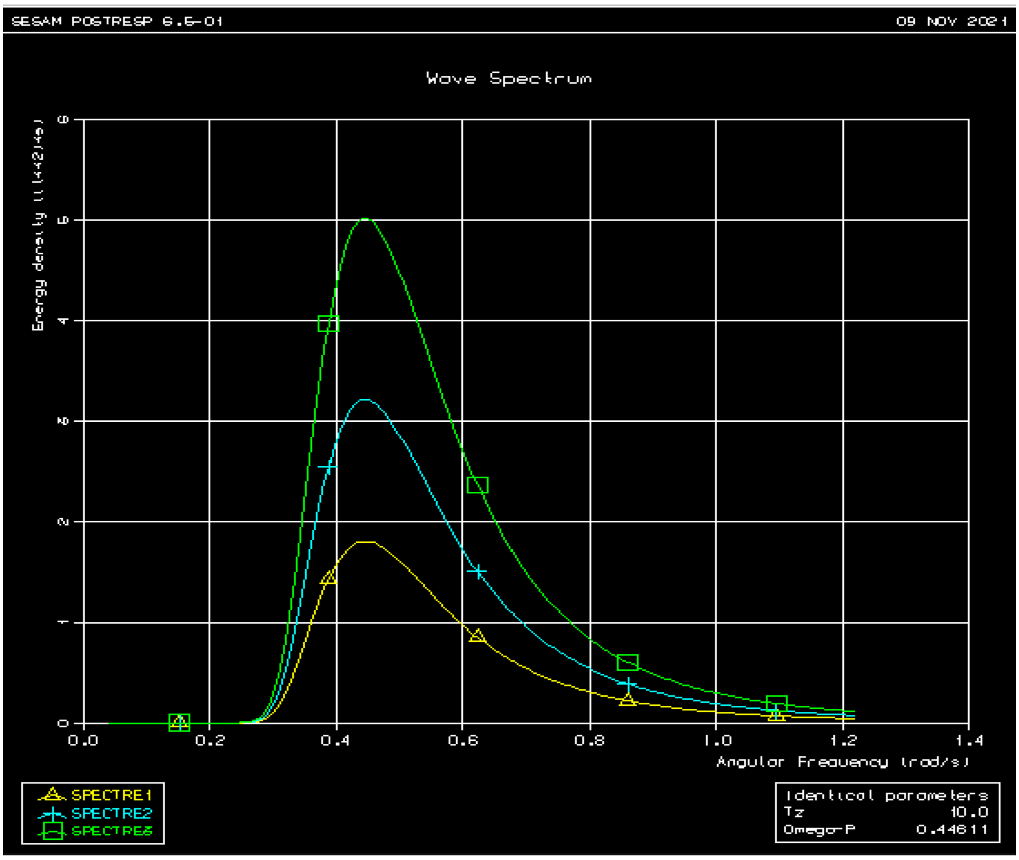
Wave spectrum for a given sea state could be described in terms of two parameters: the significant wave height (H_s) and the modal wave frequency (ω_m). The modal wave frequency is the peak frequency at which the wave spectrum's maximum height occurs.
We have already introduced that peculiar characteristic such as wind and fetch affect the propagation of wave spectra.

In our case, 6 wave spectra were analysed using the Pierson-Moskowitz method, which were grouped into two different sets characterised by the presence of constant period T in the first, and in the second by the constant significant wave height Hs

N° Spectra	T [s]	Hs [m]
1	10	3
2	10	4
3	10	5
4	11	5
5	12	5
6	13	5

Tab.2 Groups of wave spectra

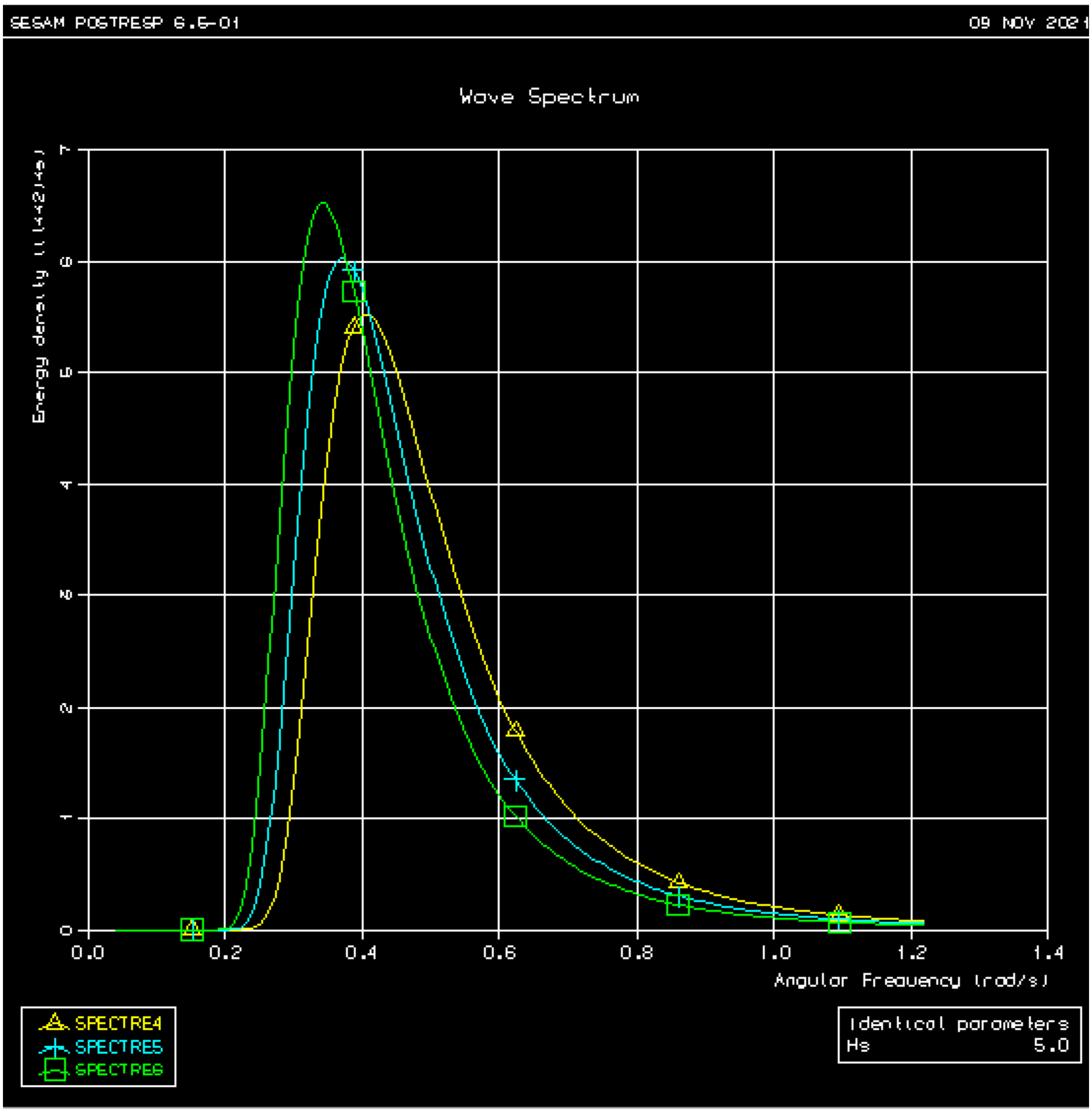
Analysing the plot of the first group with constant frequency, we notice that the significant variations of energy density in the respective peaks occur at the same x-coordinate; this is due to the imposition on the period T in order to be able to compare and analyse the variations of energy density as the significant wave height increases.



POSTRESP 6.5-01 Print

Name	Hs	Tz	OmgP
SPECTRE1	3.000E+00	10.000	0.446
SPECTRE2	4.000E+00	10.000	0.446
SPECTRE3	5.000E+00	10.000	0.446

On the other hand, as regards the analysis of the second plot relating to the variation of period T in time and constant significant wave height Hs, differently we can deduce how waves of different heights result to be translated by a certain quantity (Hs) on which, in relation to the frequency, we obtain different peaks relating to the energy density. This leads to a decrease of the latter directly proportional to the height value.



POSTRESP 6.5-01 Print

Name	Hs	Tz	OmgP
SPECTRE4	5.000E+00	11.000	0.406
SPECTRE5	5.000E+00	12.000	0.372
SPECTRE6	5.000E+00	13.000	0.343

3. PLOTS OF RESPONSE SPECTRA

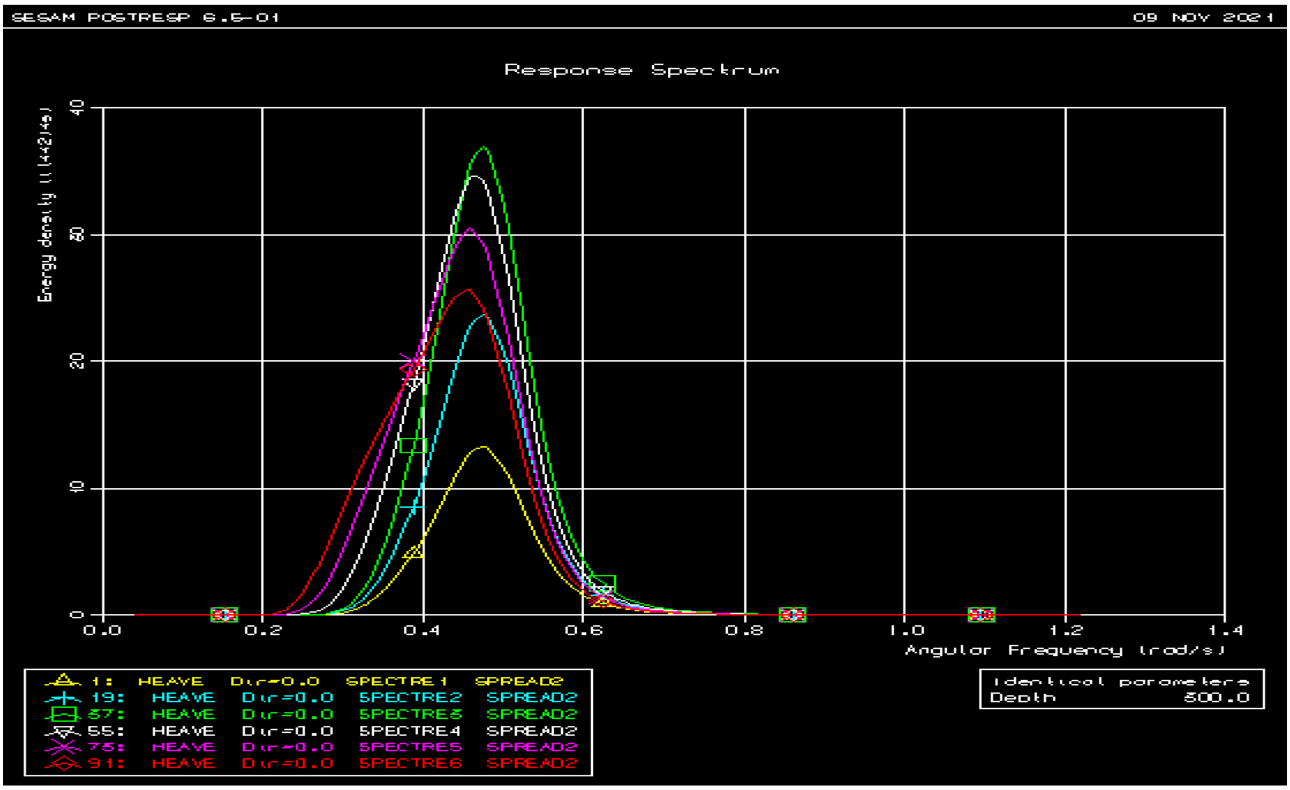
A response spectrum is a plot of the peak or steady-state response (displacement, velocity or acceleration) of a series of oscillators of varying natural frequency, that are forced into motion by the same base vibration or shock. The resulting plot can then be used to pick off the response of any linear system, given its natural frequency of oscillation.

In our case we analysed the 6 different waves with frequency domains equal to the initial conditions of analysis, but with different directions of wave propagation. The data taken was valid for the angles 0° 45° 90° direction.
Once the main characteristics of the waves have been set, it is important to remember the 6 degrees of freedom of the structure in order to create a valid spectrum response for the analysis.

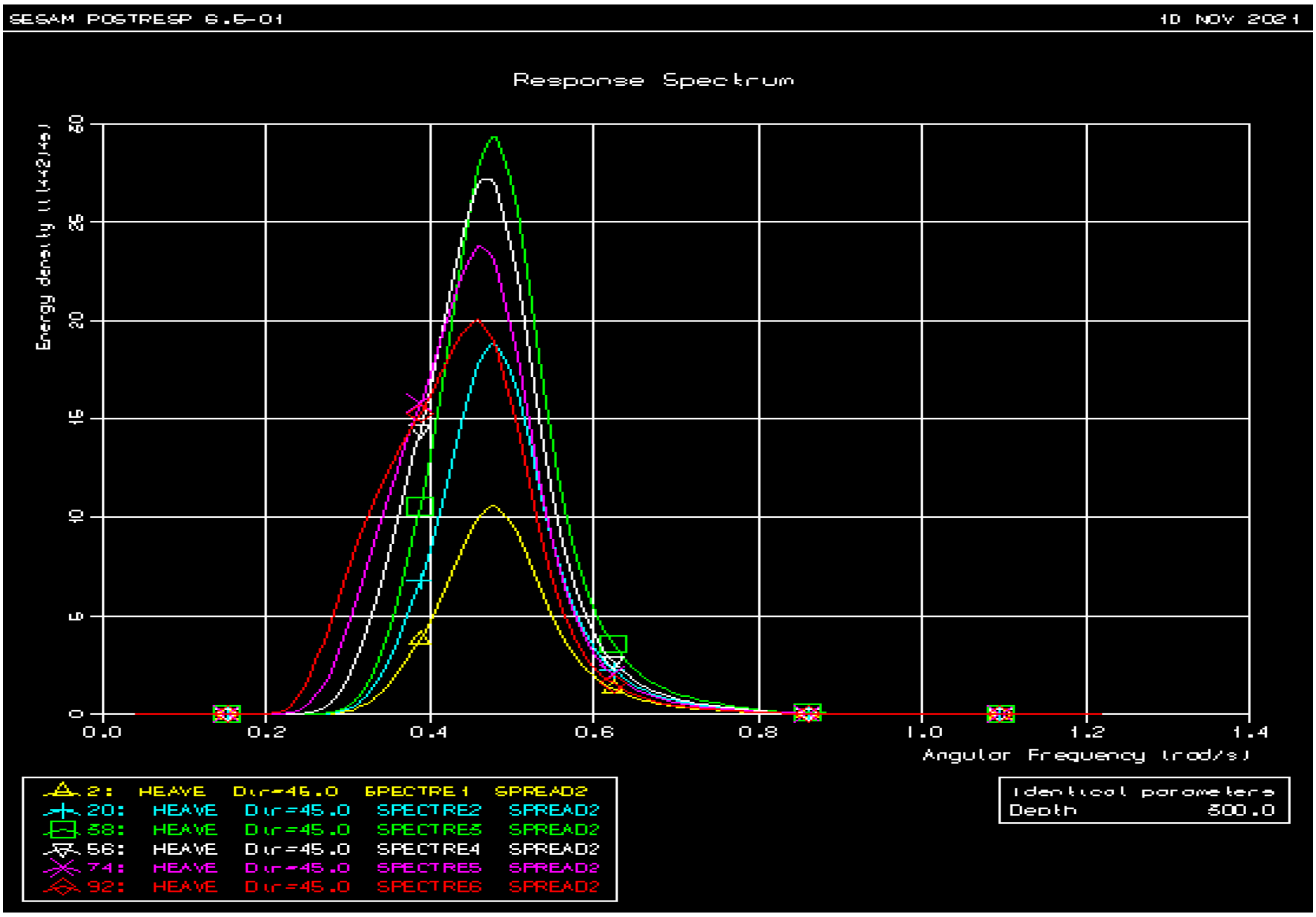
The subsequent division of the plots was designed to compare 6 responses of 6 different wave spectra while maintaining the same degree of freedom under analysis and the same wave propagation direction.
This is mainly to allow a greater and globalised comparison under the aspects of the different wave spectra which depend on two groups, one with constant period and the other with constant height.

This allows us to expose the graphical comparison of responses under frequency domain analysis.

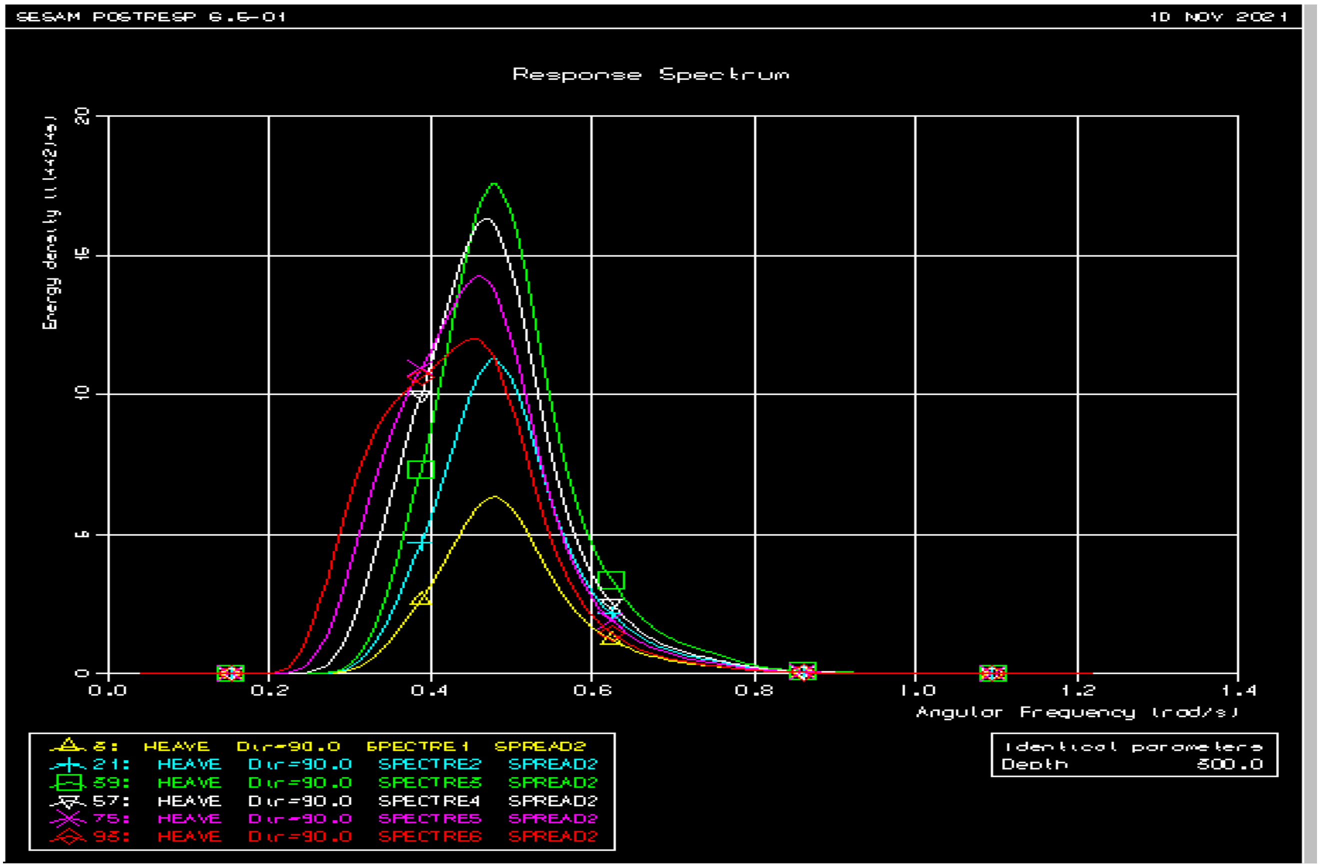
HEAVE: 0°



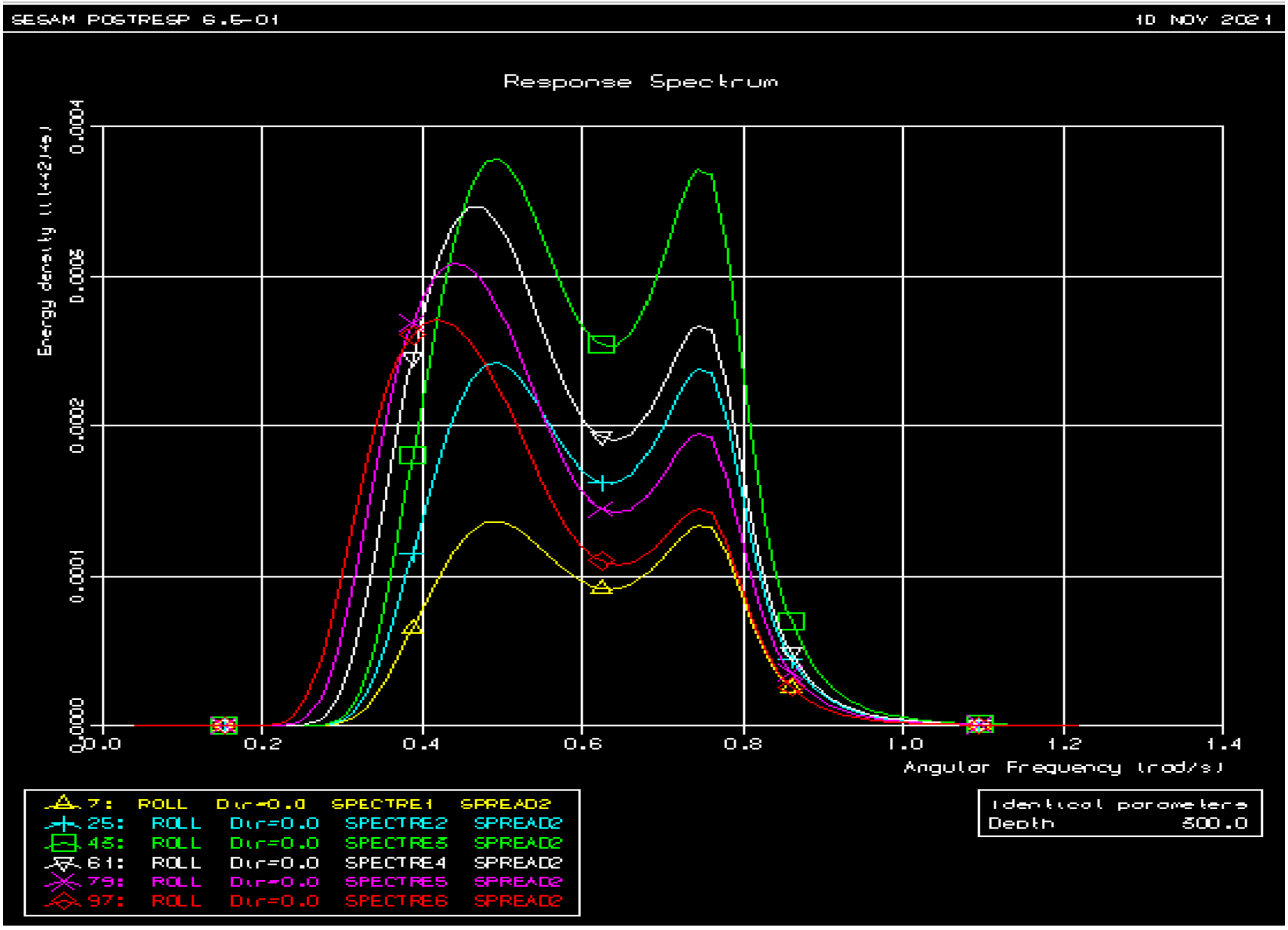
45°


SESAM POSTRESP 6.6-01
10 NOV 2021
Response Spectrum
Energy density (1(x42)4s)
Angular Frequency (rad/s)
2: HEAVE Dir=45.0 SPECTRE1 SPREAD2
20: HEAVE Dir=45.0 SPECTRE2 SPREAD2
38: HEAVE Dir=45.0 SPECTRE3 SPREAD2
56: HEAVE Dir=45.0 SPECTRE4 SPREAD2
74: HEAVE Dir=45.0 SPECTRE5 SPREAD2
92: HEAVE Dir=45.0 SPECTRE6 SPREAD2
Identical parameters
Depth 300.0

90°

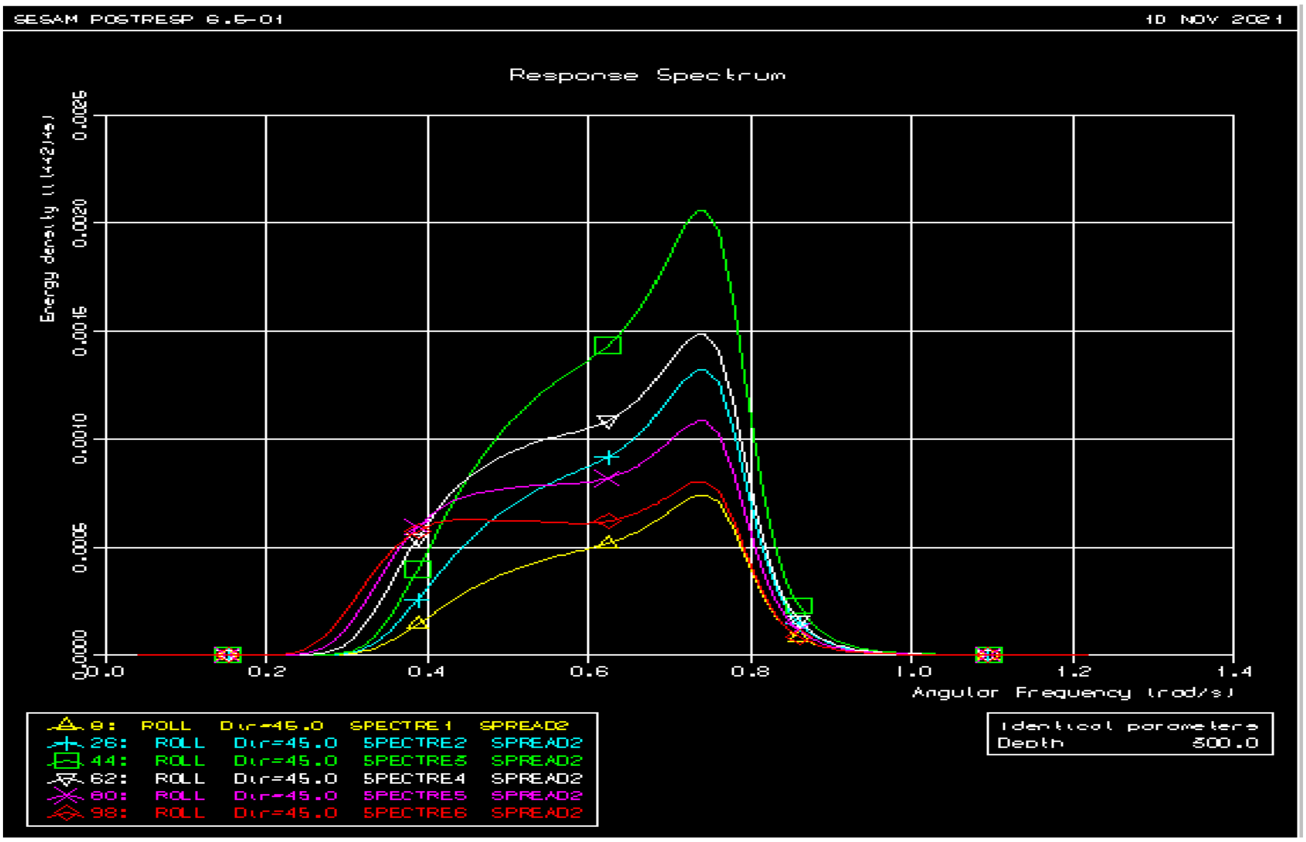

SESAM POSTRESP 6.6-01
10 NOV 2021
Response Spectrum
Energy density (1(x42)4s)
Angular Frequency (rad/s)
3: HEAVE Dir=90.0 SPECTRE1 SPREAD2
21: HEAVE Dir=90.0 SPECTRE2 SPREAD2
39: HEAVE Dir=90.0 SPECTRE3 SPREAD2
57: HEAVE Dir=90.0 SPECTRE4 SPREAD2
75: HEAVE Dir=90.0 SPECTRE5 SPREAD2
93: HEAVE Dir=90.0 SPECTRE6 SPREAD2
Identical parameters
Depth 300.0

ROLL: 0°



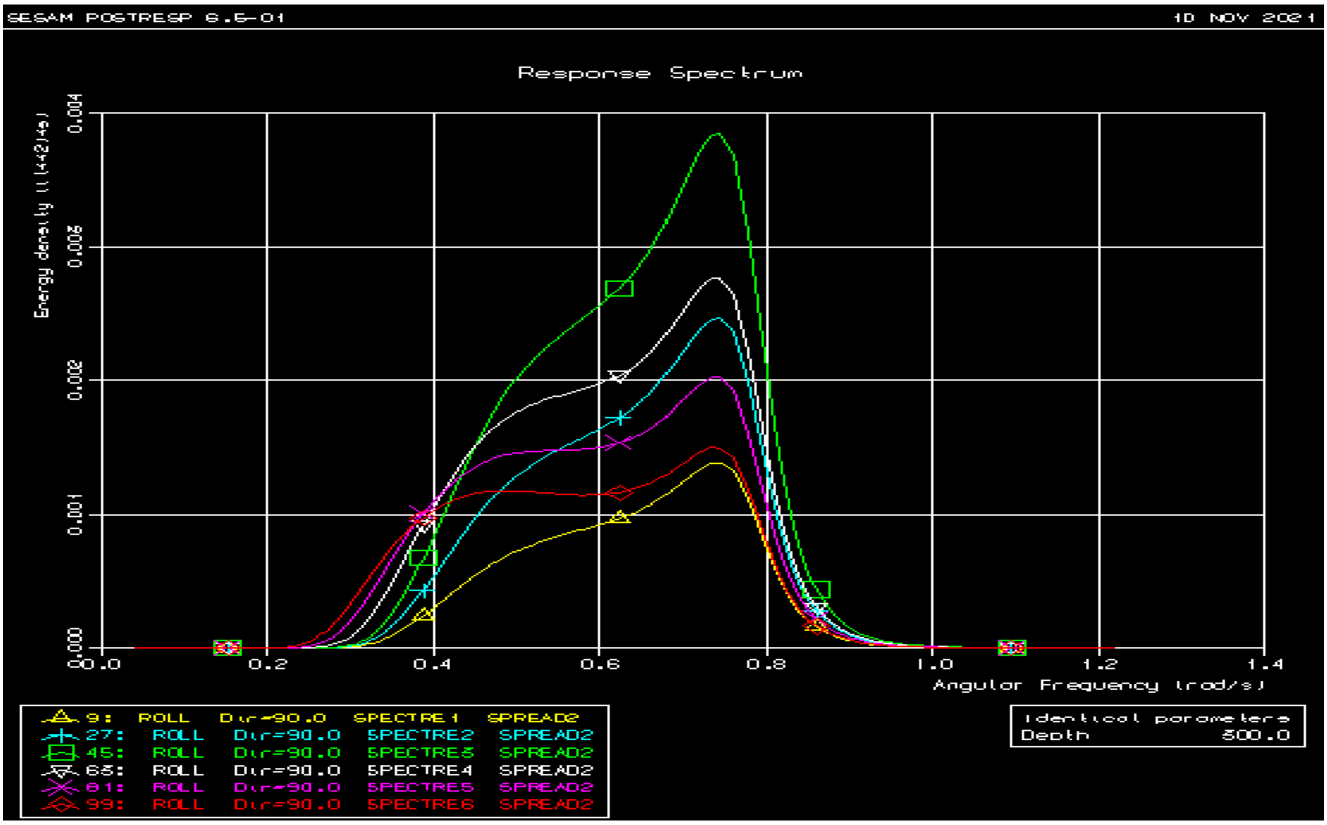
SESAM POSTRESP 6.5-01
10 NOV 2021
Response Spectrum
Energy density ((1/s)^2)/(rad/s))
0.0000
0.0001
0.0002
0.0003
0.0004
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
Angular Frequency (rad/s)
7: ROLL Dir=0.0 SPECTRE1 SPREAD2
25: ROLL Dir=0.0 SPECTRE2 SPREAD2
43: ROLL Dir=0.0 SPECTRE3 SPREAD2
61: ROLL Dir=0.0 SPECTRE4 SPREAD2
79: ROLL Dir=0.0 SPECTRE5 SPREAD2
97: ROLL Dir=0.0 SPECTRE6 SPREAD2
Identical parameters
Depth 300.0

45°

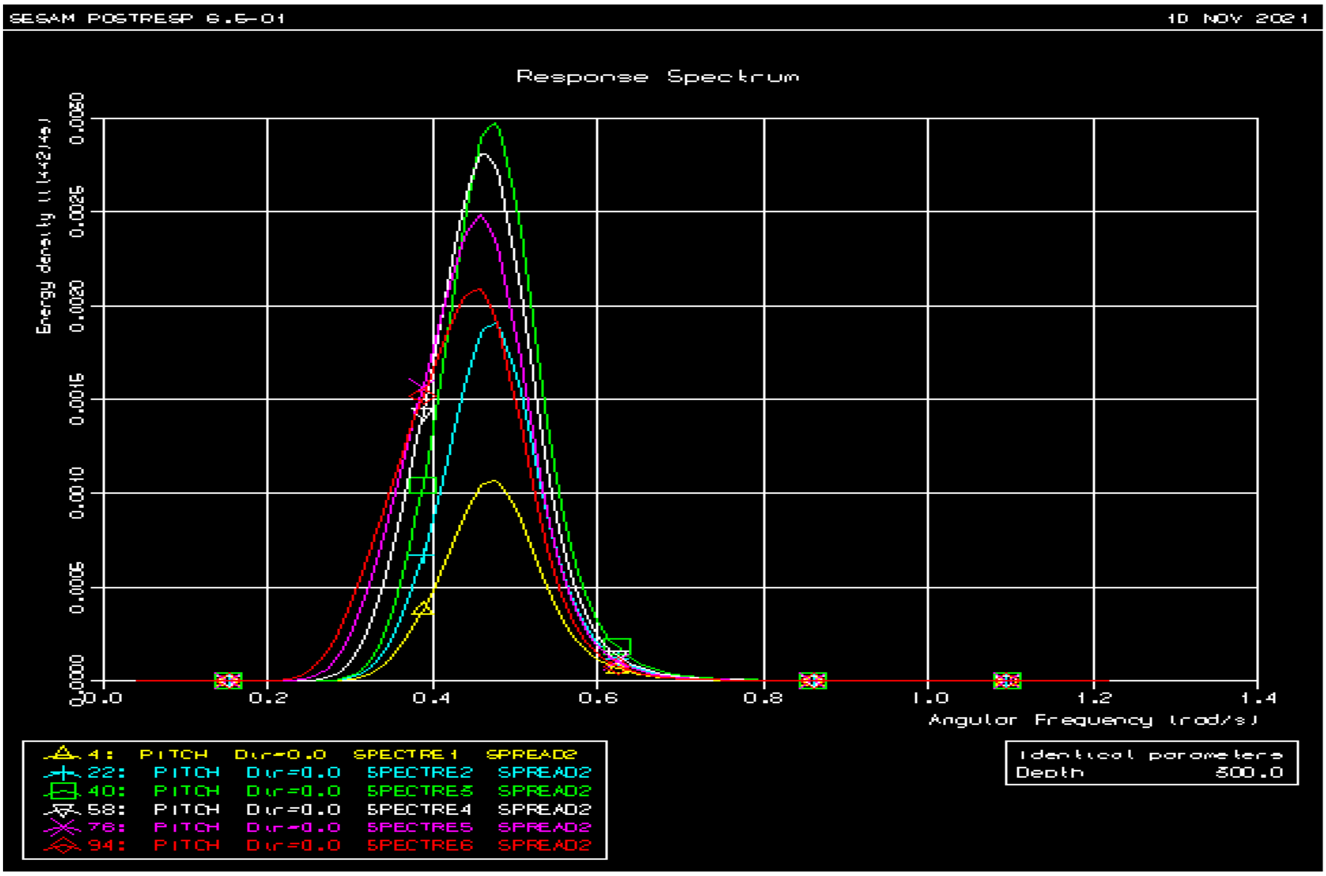


SESAM POSTRESP 6.5-01
10 NOV 2021
Response Spectrum
Energy density ((1/s)^2)/(rad/s))
0.0000
0.0005
0.0010
0.0015
0.0020
0.0025
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
Angular Frequency (rad/s)
8: ROLL Dir=45.0 SPECTRE1 SPREAD2
26: ROLL Dir=45.0 SPECTRE2 SPREAD2
44: ROLL Dir=45.0 SPECTRE3 SPREAD2
62: ROLL Dir=45.0 SPECTRE4 SPREAD2
80: ROLL Dir=45.0 SPECTRE5 SPREAD2
98: ROLL Dir=45.0 SPECTRE6 SPREAD2
Identical parameters
Depth 300.0

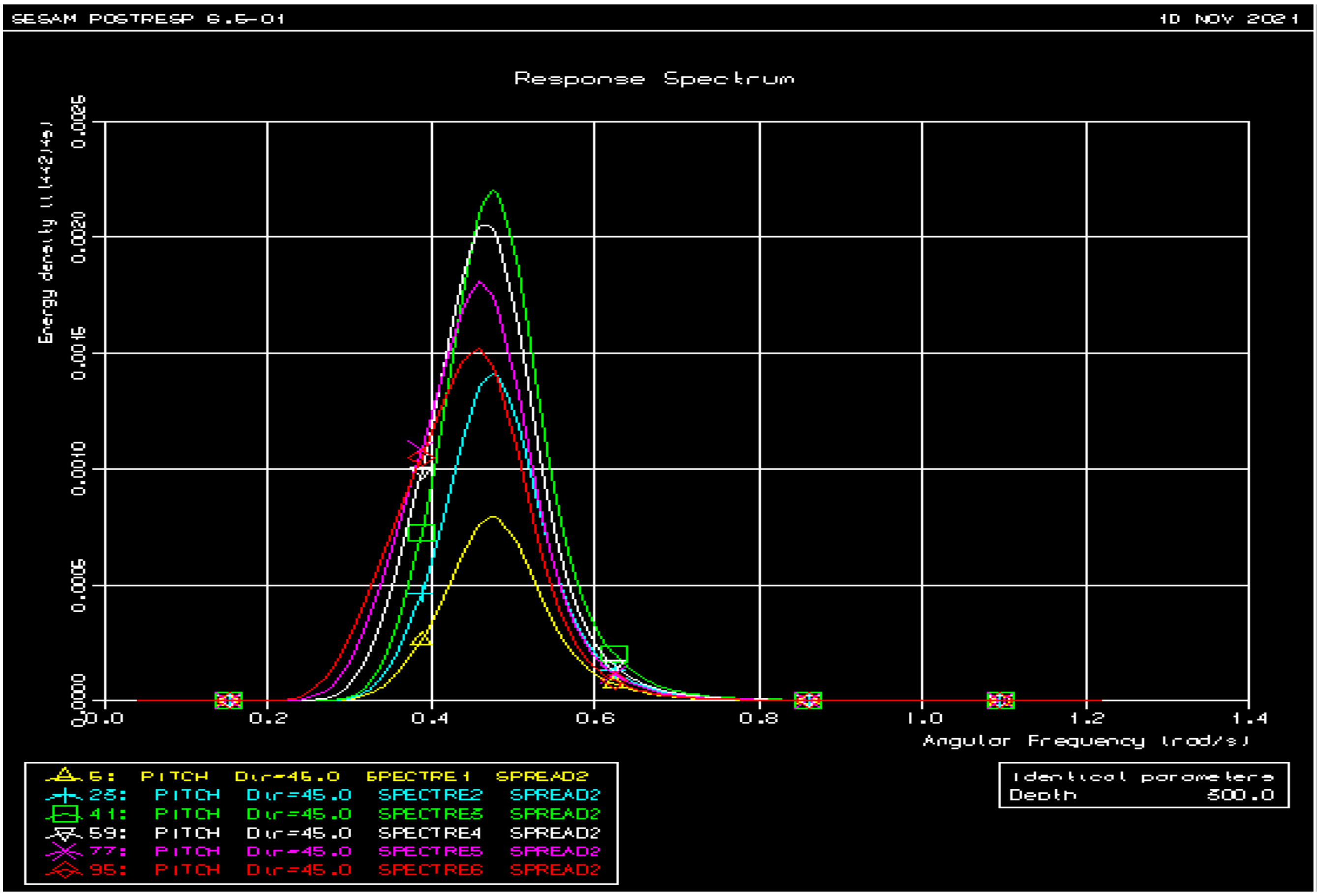
90°


SESAM POSTRESP 6.5-01
10 NOV 2021
Response Spectrum
Energy density ((*2)*s)
Angular Frequency (rad/s)
9: ROLL Dir=90.0 SPECTRE1 SPREAD2
27: ROLL Dir=90.0 SPECTRE2 SPREAD2
45: ROLL Dir=90.0 SPECTRE3 SPREAD2
63: ROLL Dir=90.0 SPECTRE4 SPREAD2
81: ROLL Dir=90.0 SPECTRE5 SPREAD2
99: ROLL Dir=90.0 SPECTRE6 SPREAD2
Identical parameters
Depth 300.0

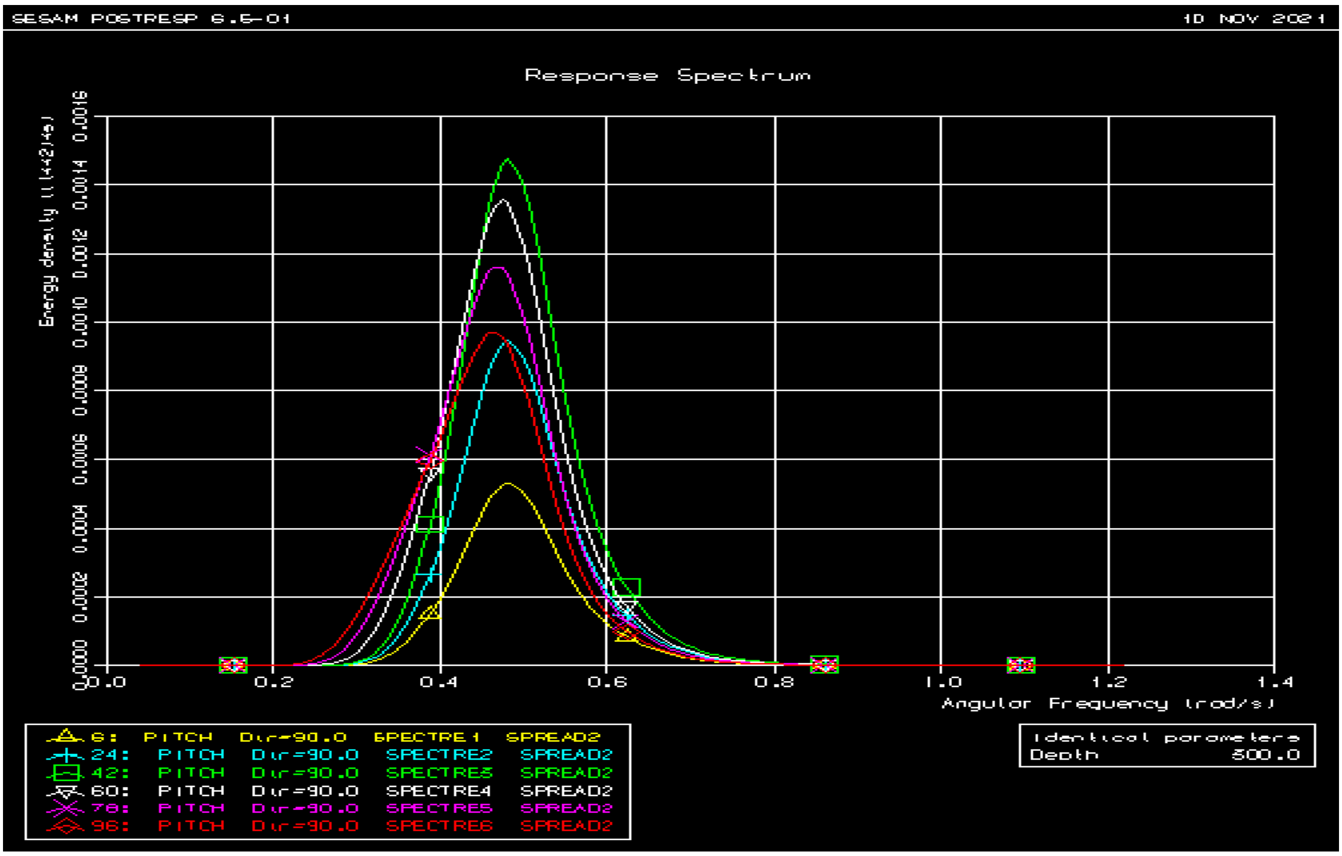
PITCH: 0°


SESAM POSTRESP 6.5-01
10 NOV 2021
Response Spectrum
Energy density ((*2)*s)
Angular Frequency (rad/s)
4: PITCH Dir=0.0 SPECTRE1 SPREAD2
22: PITCH Dir=0.0 SPECTRE2 SPREAD2
40: PITCH Dir=0.0 SPECTRE3 SPREAD2
58: PITCH Dir=0.0 SPECTRE4 SPREAD2
76: PITCH Dir=0.0 SPECTRE5 SPREAD2
94: PITCH Dir=0.0 SPECTRE6 SPREAD2
Identical parameters
Depth 300.0

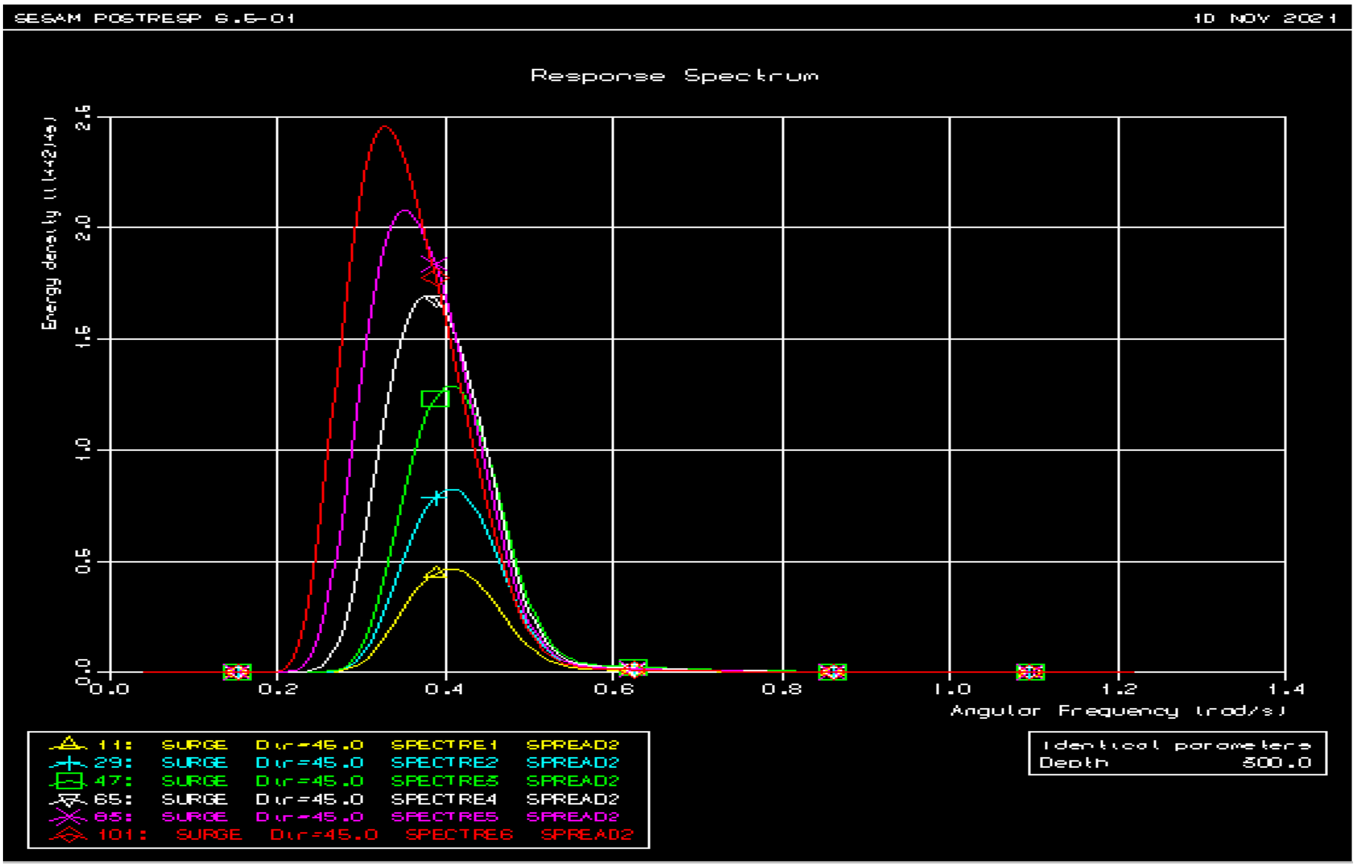
45°


SESAM POSTRESP 6.6-01
10 NOV 2021
Response Spectrum
Energy density ((A**2)*s)
Angular Frequency (rad/s)
6: PITCH Dir=45.0 SPECTRE1 SPREAD2
23: PITCH Dir=45.0 SPECTRE2 SPREAD2
41: PITCH Dir=45.0 SPECTRE3 SPREAD2
59: PITCH Dir=45.0 SPECTRE4 SPREAD2
77: PITCH Dir=45.0 SPECTRE5 SPREAD2
95: PITCH Dir=45.0 SPECTRE6 SPREAD2
Identical parameters
Depth 300.0

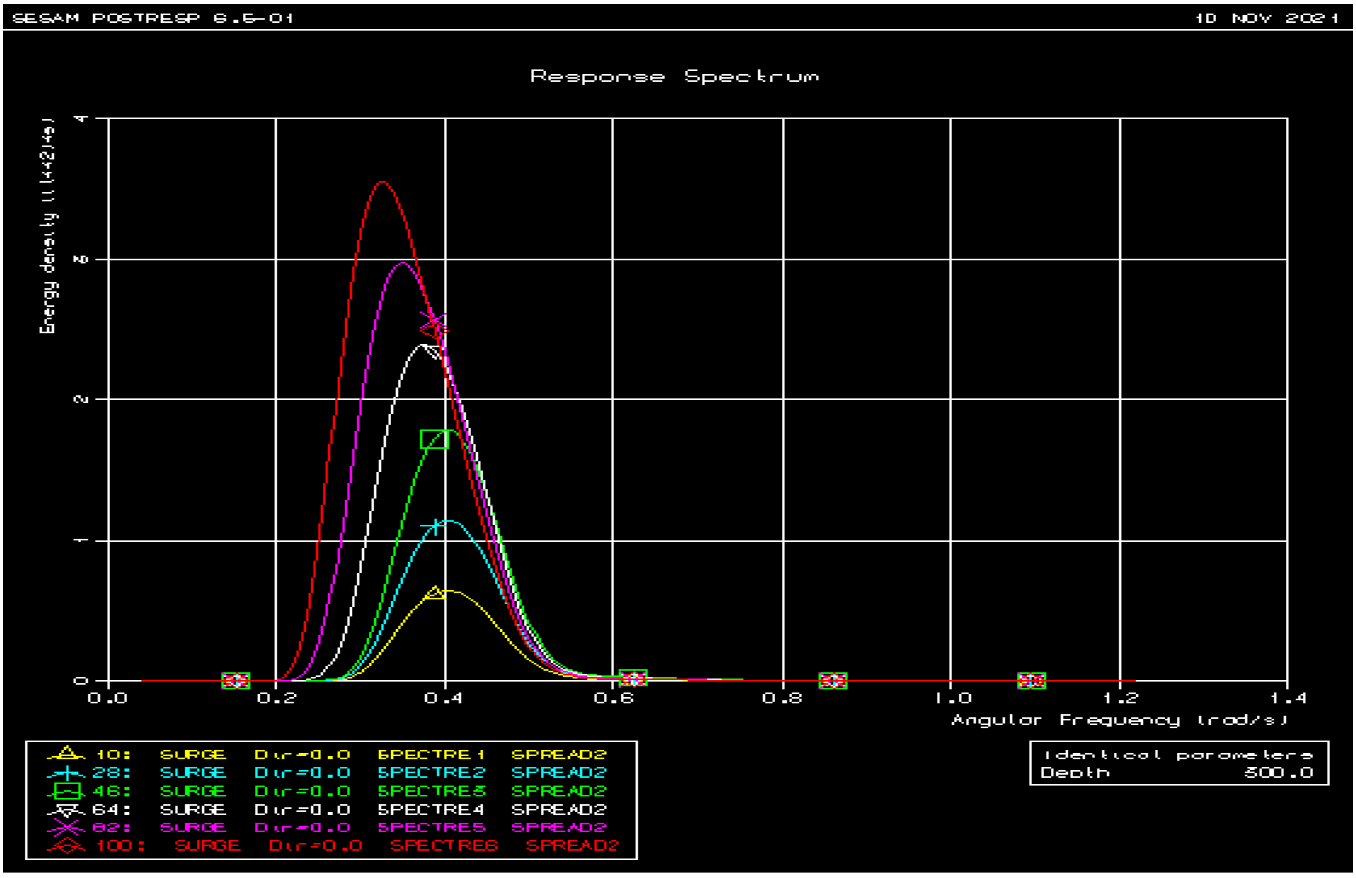
90°


SESAM POSTRESP 6.6-01
10 NOV 2021
Response Spectrum
Energy density ((A**2)*s)
Angular Frequency (rad/s)
6: PITCH Dir=90.0 SPECTRE1 SPREAD2
24: PITCH Dir=90.0 SPECTRE2 SPREAD2
42: PITCH Dir=90.0 SPECTRE3 SPREAD2
60: PITCH Dir=90.0 SPECTRE4 SPREAD2
78: PITCH Dir=90.0 SPECTRE5 SPREAD2
96: PITCH Dir=90.0 SPECTRE6 SPREAD2
Identical parameters
Depth 300.0

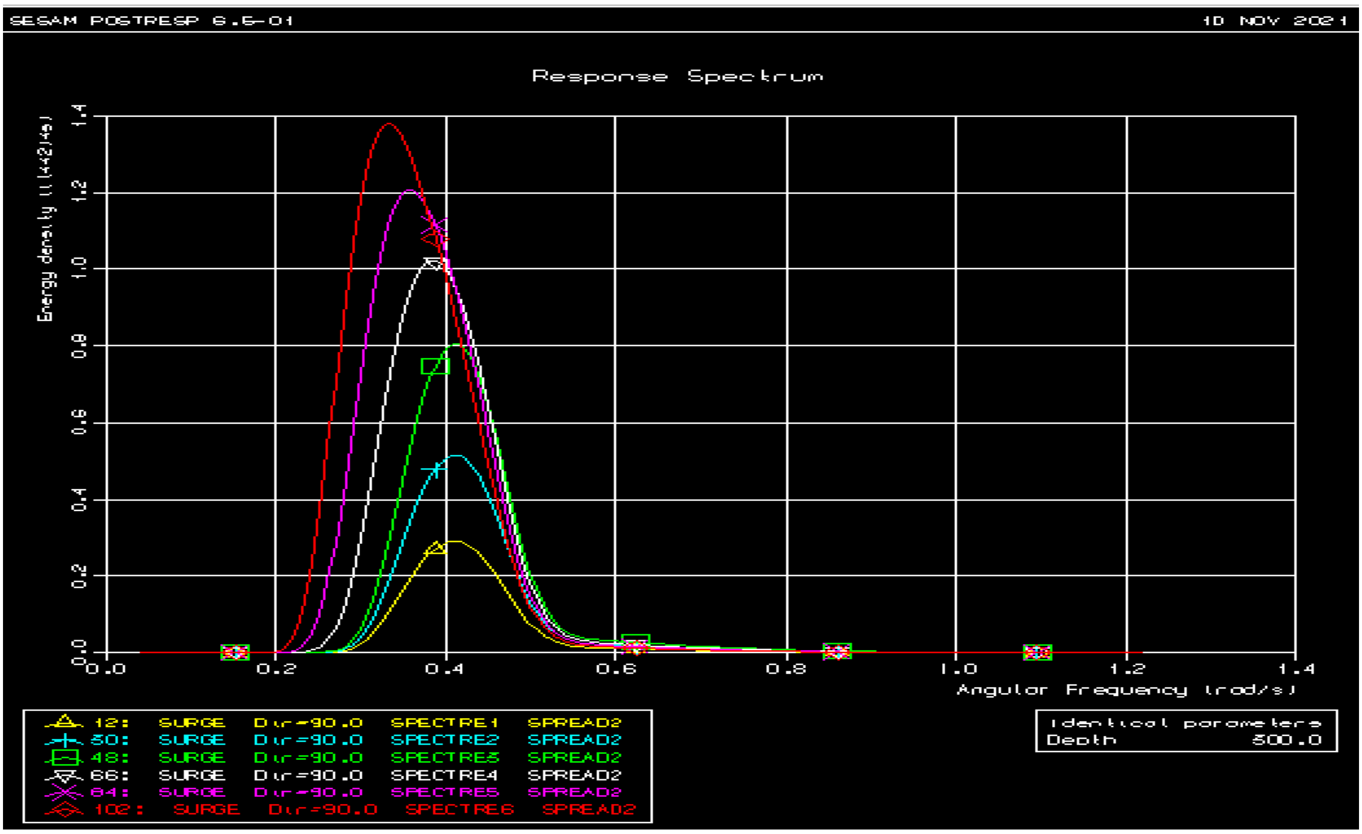
SURGE: 0°


SESAM POSTRESP 6.5-01
10 NOV 2021
Response Spectrum
0.0 0.2 0.4 0.6 0.8 1.0 1.2 1.4
Angular Frequency (rad/s)
11: SURGE Dir=45.0 SPECTRE1 SPREAD2
29: SURGE Dir=45.0 SPECTRE2 SPREAD2
47: SURGE Dir=45.0 SPECTRE3 SPREAD2
65: SURGE Dir=45.0 SPECTRE4 SPREAD2
83: SURGE Dir=45.0 SPECTRE5 SPREAD2
101: SURGE Dir=45.0 SPECTRE6 SPREAD2
Identical parameters
Depth 300.0

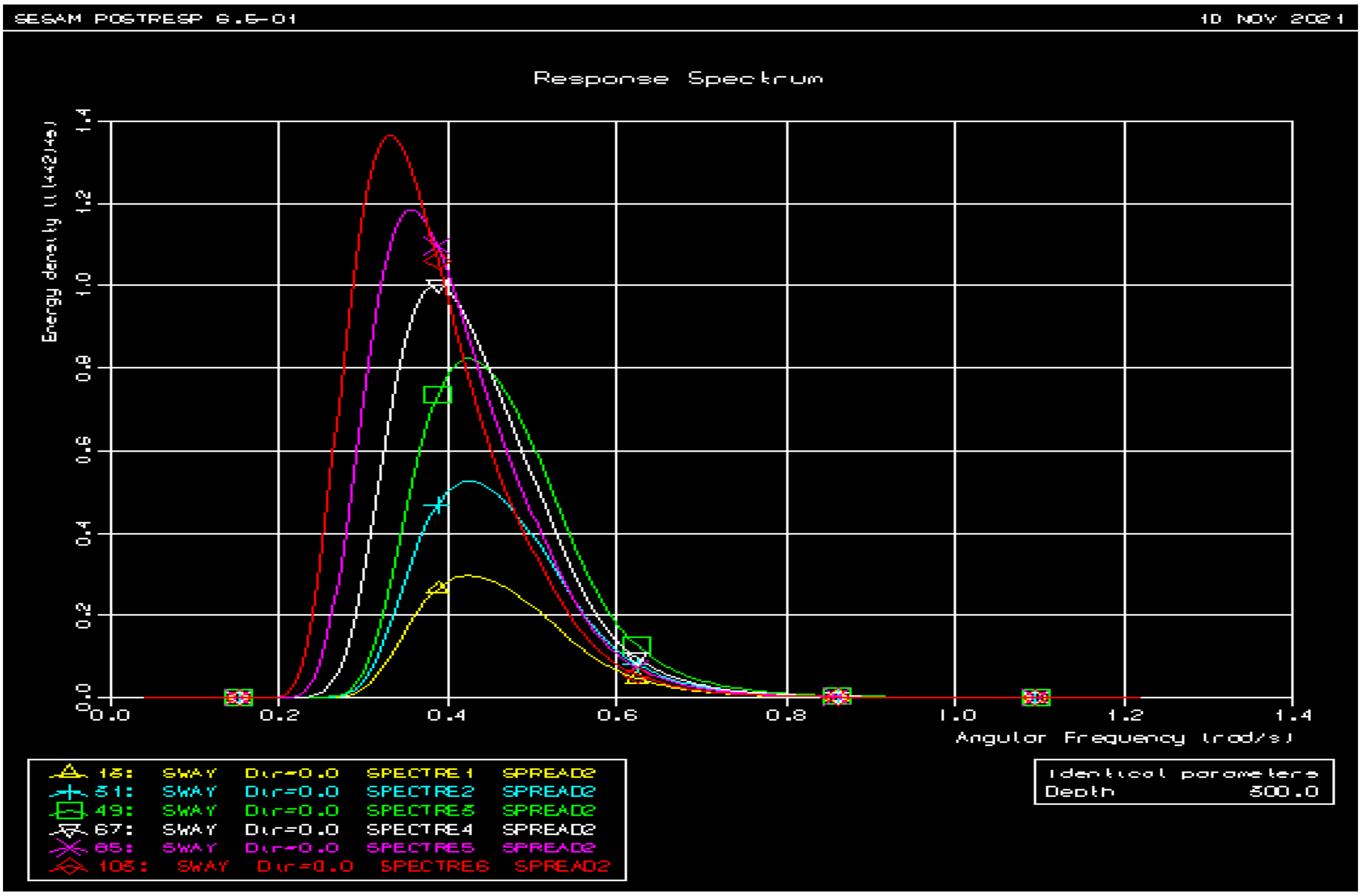
45°


SESAM POSTRESP 6.5-01
10 NOV 2021
Response Spectrum
0.0 0.2 0.4 0.6 0.8 1.0 1.2 1.4
Angular Frequency (rad/s)
10: SURGE Dir=0.0 SPECTRE1 SPREAD2
28: SURGE Dir=0.0 SPECTRE2 SPREAD2
46: SURGE Dir=0.0 SPECTRE3 SPREAD2
64: SURGE Dir=0.0 SPECTRE4 SPREAD2
82: SURGE Dir=0.0 SPECTRE5 SPREAD2
100: SURGE Dir=0.0 SPECTRE6 SPREAD2
Identical parameters
Depth 300.0

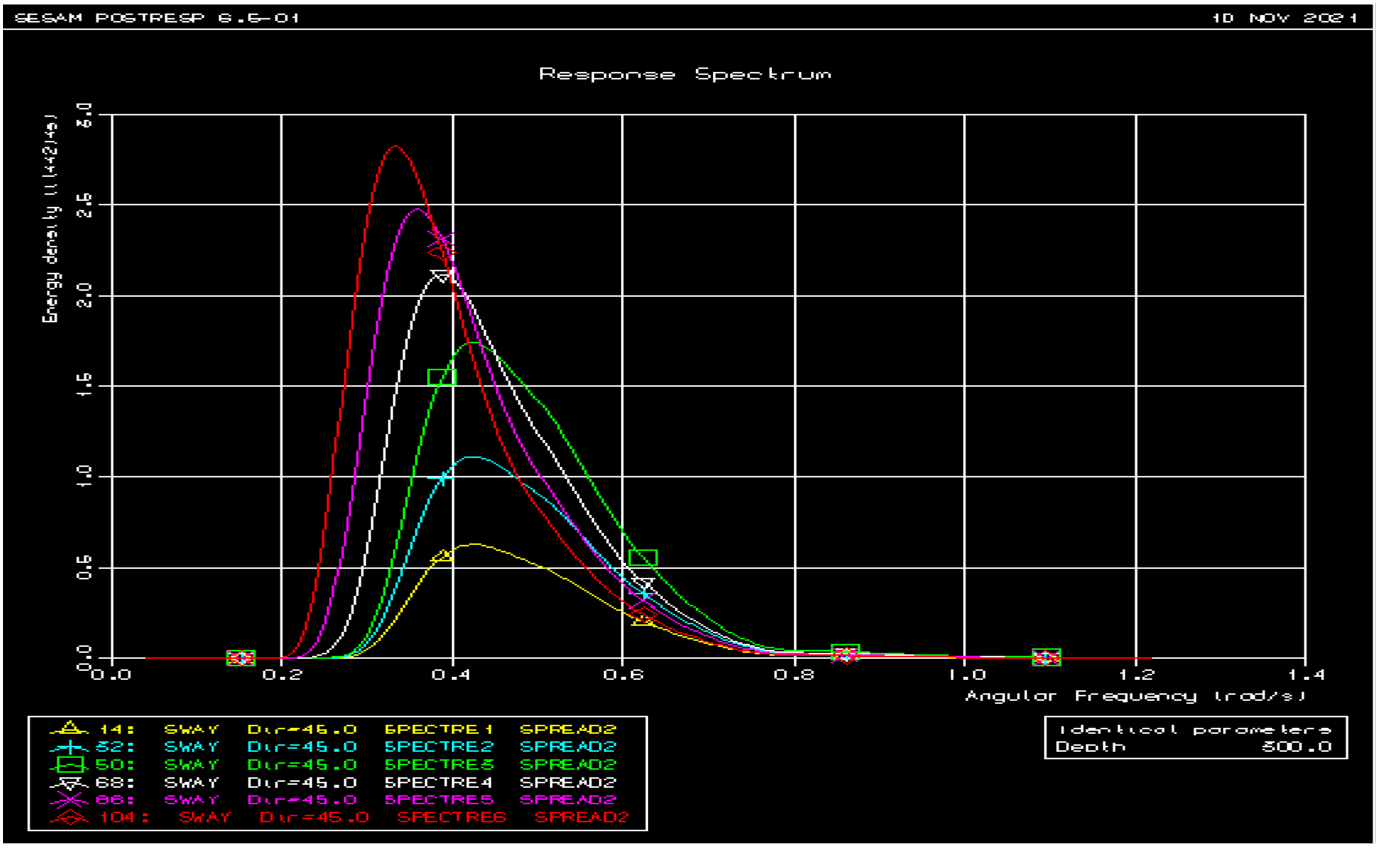
90°


SESAM POSTRESP 6.5-01
10 NOV 2021
Response Spectrum
Energy density
Angular Frequency (rad/s)
12: SURGE Dir=90.0 SPECTRE1 SPREAD2
50: SURGE Dir=90.0 SPECTRE2 SPREAD2
48: SURGE Dir=90.0 SPECTRE3 SPREAD2
66: SURGE Dir=90.0 SPECTRE4 SPREAD2
84: SURGE Dir=90.0 SPECTRE5 SPREAD2
102: SURGE Dir=90.0 SPECTRE6 SPREAD2
Identical parameters
Depth 300.0

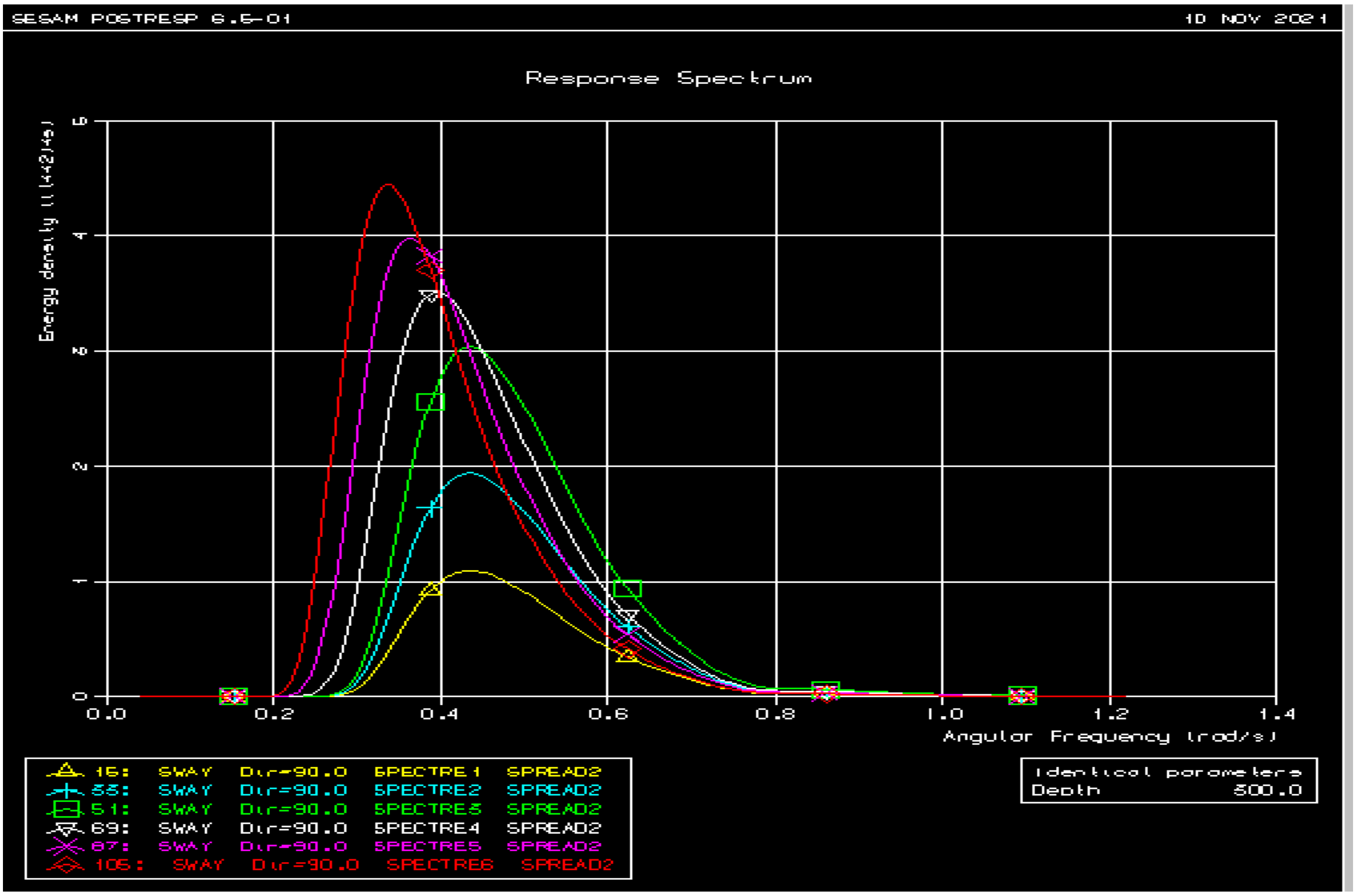
SWAY: 0°


SESAM POSTRESP 6.5-01
10 NOV 2021
Response Spectrum
Energy density
Angular Frequency (rad/s)
15: SWAY Dir=0.0 SPECTRE1 SPREAD2
51: SWAY Dir=0.0 SPECTRE2 SPREAD2
49: SWAY Dir=0.0 SPECTRE3 SPREAD2
67: SWAY Dir=0.0 SPECTRE4 SPREAD2
85: SWAY Dir=0.0 SPECTRE5 SPREAD2
105: SWAY Dir=0.0 SPECTRE6 SPREAD2
Identical parameters
Depth 300.0

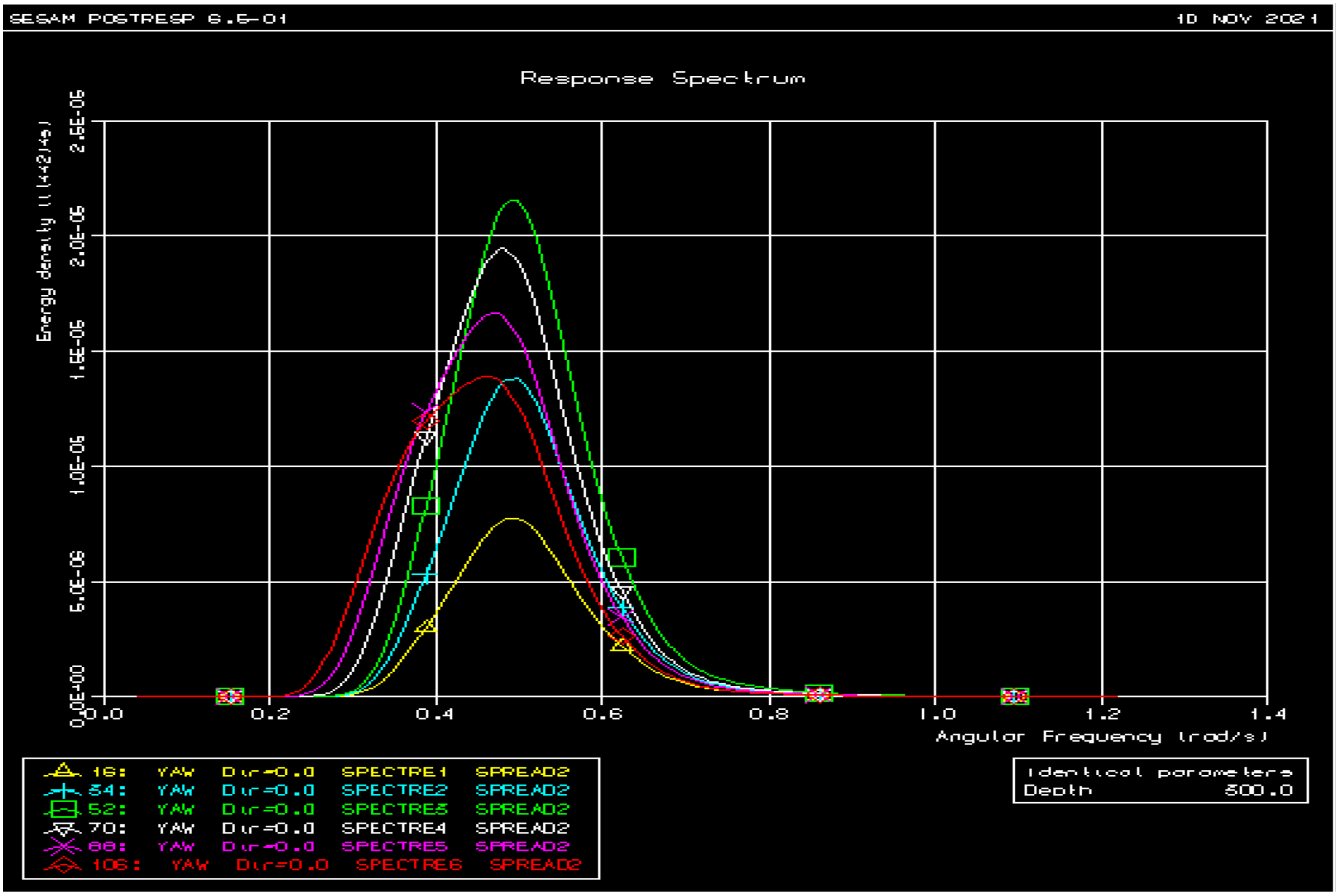
45°


SESAM POSTRESP 6.5-01
10 NOV 2021
Response Spectrum
Energy density
Angular Frequency (rad/s)
14: SWAY Dir=45.0 SPECTRE1 SPREAD2
32: SWAY Dir=45.0 SPECTRE2 SPREAD2
50: SWAY Dir=45.0 SPECTRE3 SPREAD2
68: SWAY Dir=45.0 SPECTRE4 SPREAD2
86: SWAY Dir=45.0 SPECTRE5 SPREAD2
104: SWAY Dir=45.0 SPECTRE6 SPREAD2
Identical parameters
Depth 300.0

90°

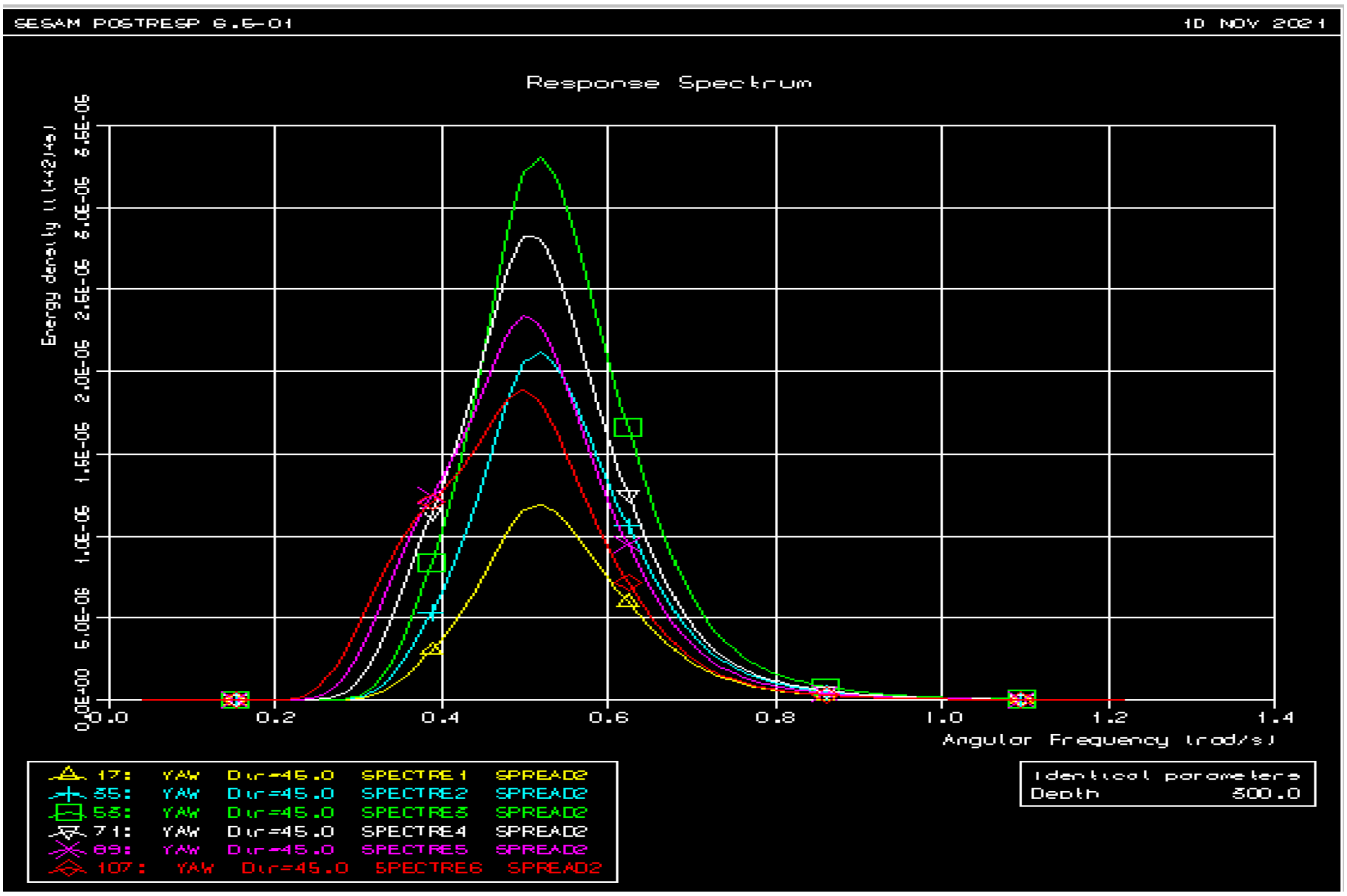

SESAM POSTRESP 6.5-01
10 NOV 2021
Response Spectrum
Energy density
Angular Frequency (rad/s)
15: SWAY Dir=90.0 SPECTRE1 SPREAD2
33: SWAY Dir=90.0 SPECTRE2 SPREAD2
51: SWAY Dir=90.0 SPECTRE3 SPREAD2
69: SWAY Dir=90.0 SPECTRE4 SPREAD2
87: SWAY Dir=90.0 SPECTRE5 SPREAD2
105: SWAY Dir=90.0 SPECTRE6 SPREAD2
Identical parameters
Depth 300.0

YAW: 0°



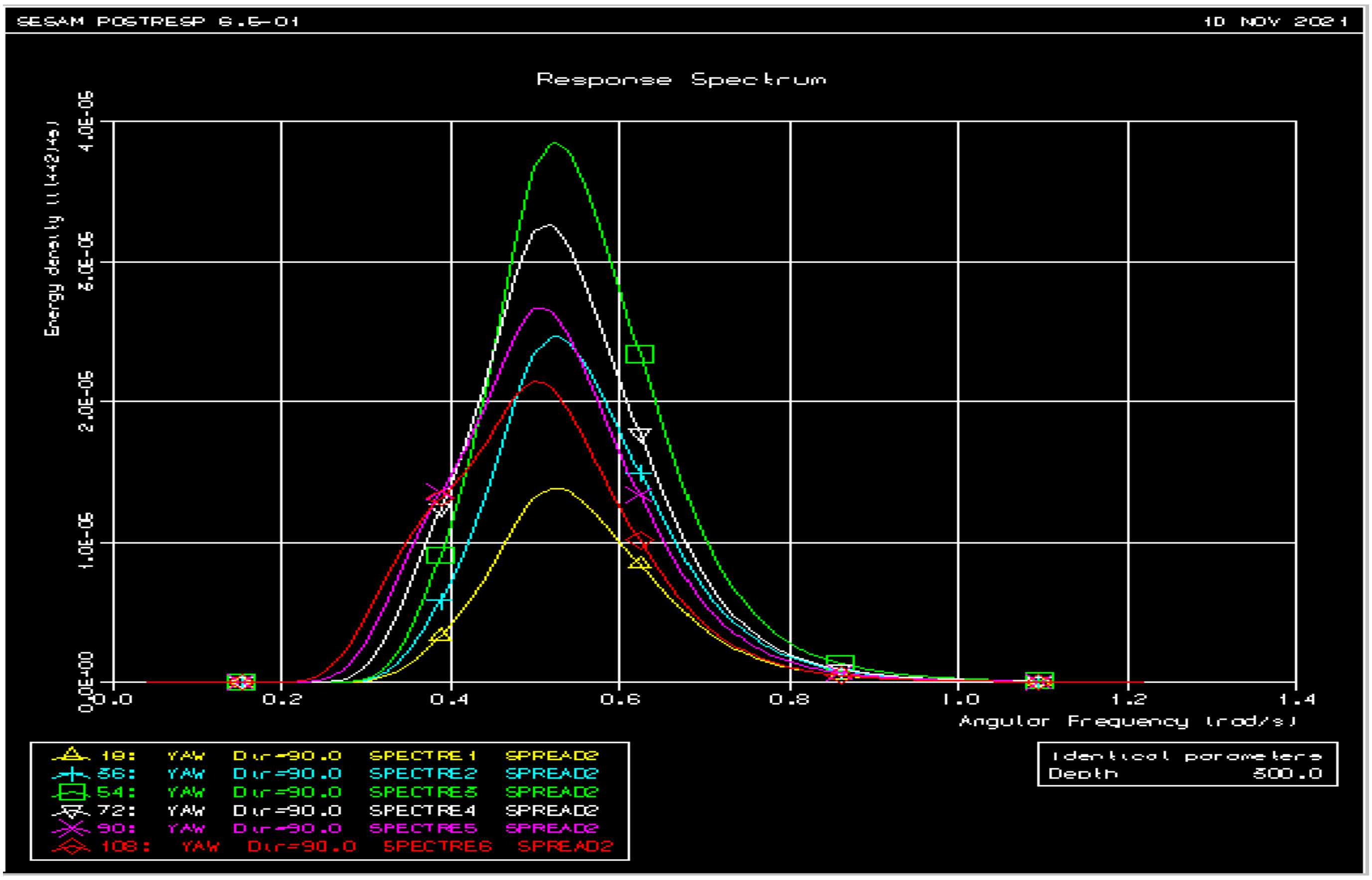
SESAM POSTRESP 6.5-01
10 NOV 2021
Response Spectrum
Energy density ((4*2)*s)
Angular Frequency (rad/s)
16: YAW Dir=0.0 SPECTRE1 SPREAD2
34: YAW Dir=0.0 SPECTRE2 SPREAD2
52: YAW Dir=0.0 SPECTRE3 SPREAD2
70: YAW Dir=0.0 SPECTRE4 SPREAD2
88: YAW Dir=0.0 SPECTRE5 SPREAD2
106: YAW Dir=0.0 SPECTRE6 SPREAD2
Identical parameters
Depth 300.0

45°



SESAM POSTRESP 6.5-01
10 NOV 2021
Response Spectrum
Energy density ((4*2)*s)
Angular Frequency (rad/s)
17: YAW Dir=45.0 SPECTRE1 SPREAD2
35: YAW Dir=45.0 SPECTRE2 SPREAD2
53: YAW Dir=45.0 SPECTRE3 SPREAD2
71: YAW Dir=45.0 SPECTRE4 SPREAD2
89: YAW Dir=45.0 SPECTRE5 SPREAD2
107: YAW Dir=45.0 SPECTRE6 SPREAD2
Identical parameters
Depth 300.0

90°



Finally, it is important to note as a global comparison parameter, the trend on the Y-axis of the energy density for the respective degrees of freedom.

The intensity between Roll and Yaw when compared is of a higher order, as they are two completely different reference systems in terms of how the wave impacts the structure in direction. This allows me to identify major and minor planes of application of energy with respect to the system of principal axes of inertia.

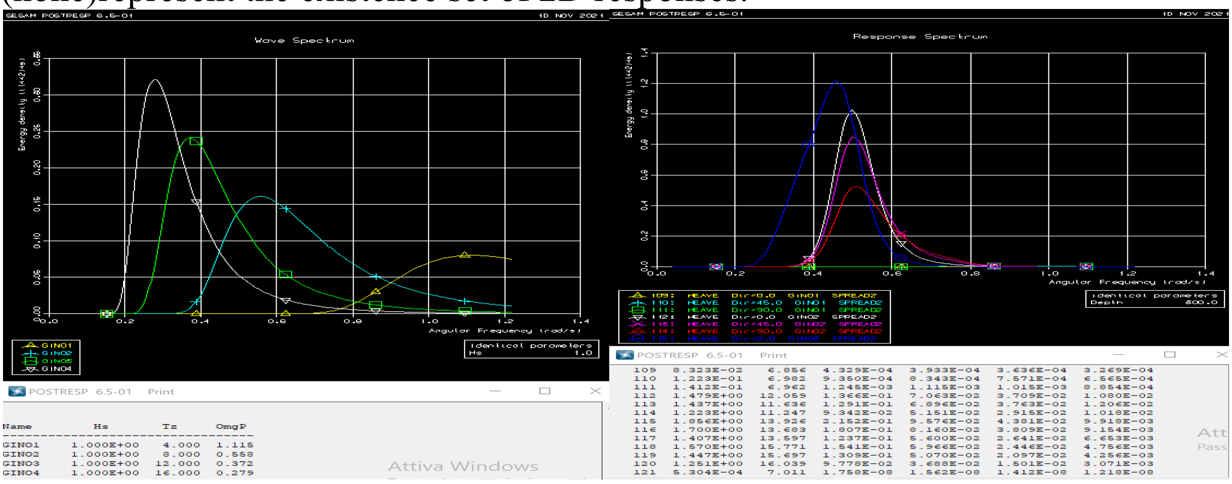
We can conclude by saying that in addition to the comparison proposed by the study of the plots, another important parameter to consider is the comparison in scale between the different degrees of freedom with reference to the energy density.

4. ANALYSIS AND CONCLUSIONS

Analysing the variation and dependence of the shape of the wave spectrum with respect to height and period, we can deduce that in waves ordered in groups with constant period the trend is symmetrical with respect to the vertical axis passing through the peaks and the energy density is lower and drastically decreasing as the significant height varies. However, the area subtended by the curve is greater because the angular frequency of the spectrum is higher.
In the case of the group of waves with constant significant height and variable period, on the other hand, we note that the shape tends to overlap as the period decreases, energy density values are not very distant with reference to the peaks and global areas are considerably greater even if the response tends to exhaust earlier as the angular frequency increases.

We can conclude that the direction of the wave influences the various responses according to the variation of the energy density due to an increased sensitivity effect for certain degrees of freedom of the system.
This means that depending on the direction of origin of the wave, the system will change its energy value because some degrees of freedom will be more sensitive in their plane of reference or plane of application of the dynamic forces of the wave. All this is considered taking into account the different characteristics of the respective spectra in relation to the significant height and period.

The substantial difference related to the spread, i.e. response variation from 2D system to 3D system, can be represented by graphical analysis of a full range wave with minimum period Tz = 4 and maximum Tz = 16, considering an increment of 4 seconds in the frequency domain.
The analysis is done by choosing the application of the Wave Spreading Function, which identifies the presence of a 3D response field to our system.
If the response as a function of the selected function is compared with the respective response values and other response values on which no function is selected, then the required difference can be found, as the response values without function (none)represent the existence set of 2D responses.



Name	Hs	Tz	OmgP
GINO1	1.000E+00	4.000	1.115
GINO2	1.000E+00	8.000	0.558
GINO3	1.000E+00	12.000	0.372
GINO4	1.000E+00	16.000	0.279

109	8.323E-02	6.856	4.329E-04	3.933E-04	3.636E-04	3.269E-04
110	1.223E-01	6.982	9.350E-04	8.343E-04	7.571E-04	6.565E-04
111	1.412E-01	6.962	1.245E-03	1.115E-03	1.015E-03	8.854E-04
112	1.479E+00	12.059	1.366E-01	7.063E-02	3.709E-02	1.080E-02
113	1.437E+00	11.636	1.291E-01	6.896E-02	3.763E-02	1.206E-02
114	1.223E+00	11.247	9.342E-02	5.151E-02	2.915E-02	1.018E-02
115	1.856E+00	13.926	2.152E-01	9.576E-02	4.381E-02	9.918E-03
116	1.700E+00	13.683	1.807E-01	8.160E-02	3.809E-02	9.154E-03
117	1.407E+00	13.597	1.237E-01	5.600E-02	2.641E-02	6.653E-03
118	1.570E+00	15.771	1.541E-01	5.966E-02	2.446E-02	4.756E-03
119	1.447E+00	15.697	1.309E-01	5.070E-02	2.097E-02	4.256E-03
120	1.251E+00	16.039	9.778E-02	3.688E-02	1.501E-02	3.071E-03
121	5.304E-04	7.011	1.758E-08	1.562E-08	1.412E-08	1.218E-08

Task 2A : Responses of a ship in regular waves (WADAM and WASIM)

1. Introduction related differences between WADAM E WASIM

WADAM and WASIM are two software programs used in HdyroD to perform ship evaluations in regular and irregular wave environments.

Wadam is a general hydrodynamic analysis tool that may be used to calculate wave-structure interactions for fixed and floating structures of any type. The airy wave theory is used in this software, and the results are displayed as complex transfer functions or deterministic results for specific wave phases. For marine hydrodynamics, Wadam employs widely established linear frequency domain methods, as well as the 3D radiation-diffraction theory with a panel model and the Morison equation in linearized form with a beam model. The software is run from HydroD, where the model is created.
In HydroD, the environment is modeled, and the structure can be made up of any combination of panel models and beams. Furthermore, hydrodynamic loads computed by Wadam are automatically included in the structural analysis. Wadam can also compute transfer functions of second order mean wave drift forces and pressure distribution on the hull surface, and any wave/current interaction can be handled at current speeds of up to 3-4 knots.

Wasim software is a tried-and-true tool for performing hydrodynamic analyses on fixed and floating vessels with or without forward speed, including the computation of global movements and local pressure loading on the vessel. The simulations are performed in the time domain, but the results may be translated to the frequency domain using Fourier transforms. Both hull and free surface panel models are required; they are generated by HydroD's own mesh generator using hull geometry given by the user. The analysis can involve significant non-linear effects. This is also relevant for offshore buildings. Wasim's hydrodynamic loads are immediately incorporated into the structural analysis.

Loads can be moved as sophisticated loads, time snapshots, or time histories. A predefined motion time history, as well as the accompanying point force and wave time histories, may be input, and the relevant loads calculated.
Wadam and Wasim both employ HydroD for environmental modeling and can apply 3D radiation-diffraction theory in distinct ways.
The key distinction is that Wadam performs simulations entirely in the frequency domain, whereas Wasim performs them in the time domain. Wadam also employs well established linear frequency domain methods for marine hydrodynamics, and Wasim is capable of including significant non-linear factors into the study.

2A(1). Response amplitude operators

We have considered the three wave directions 45° 90° 180° of the following model for the 6 degrees of freedom of our ship in reference.
Applying the frequency domain functions on WADAM

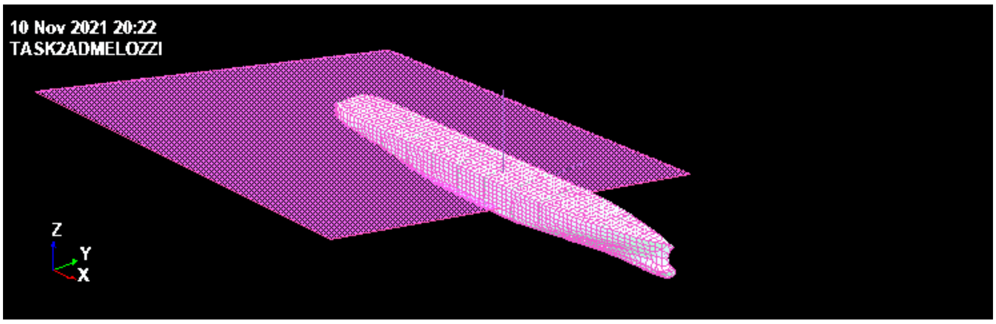
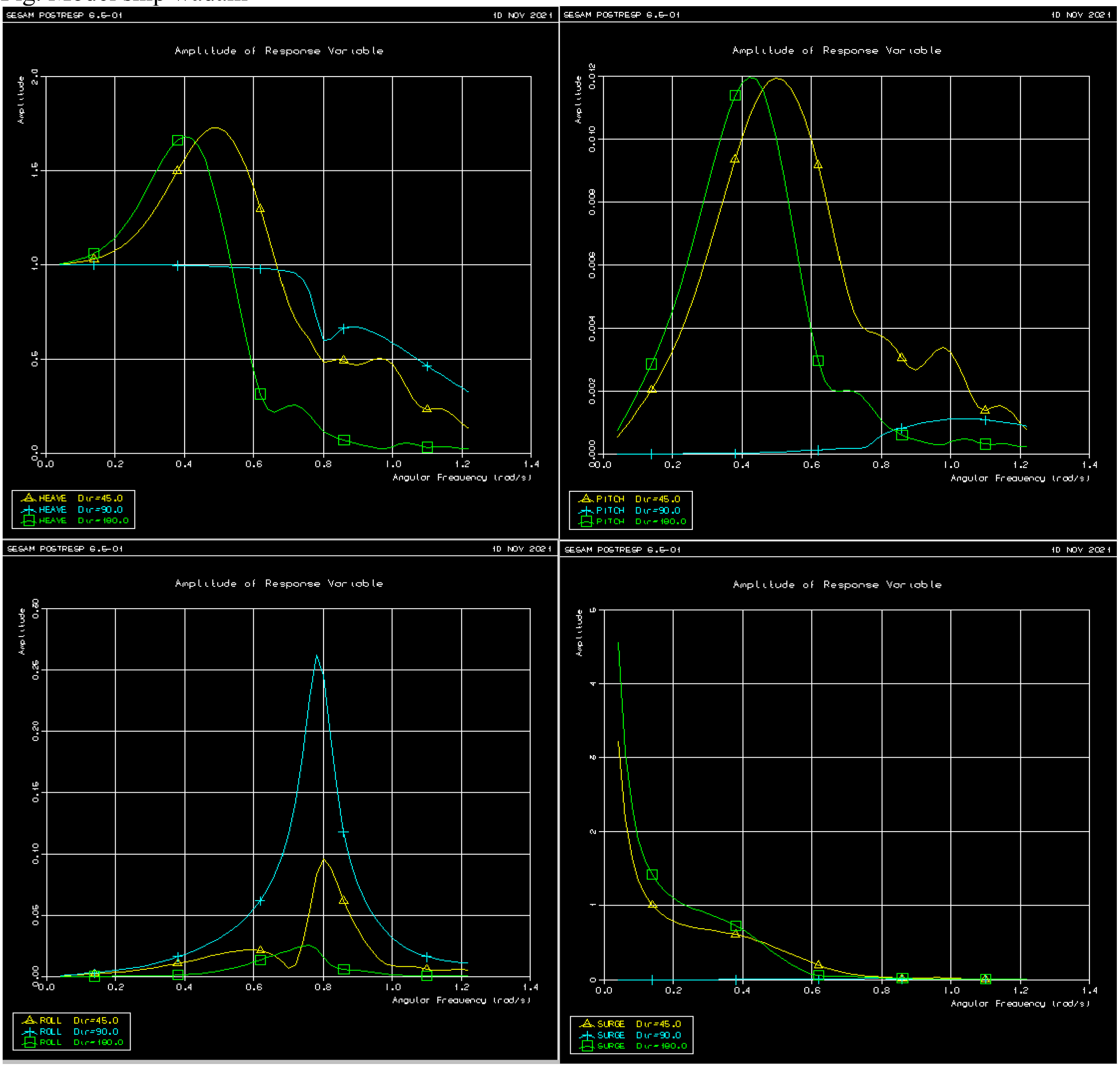
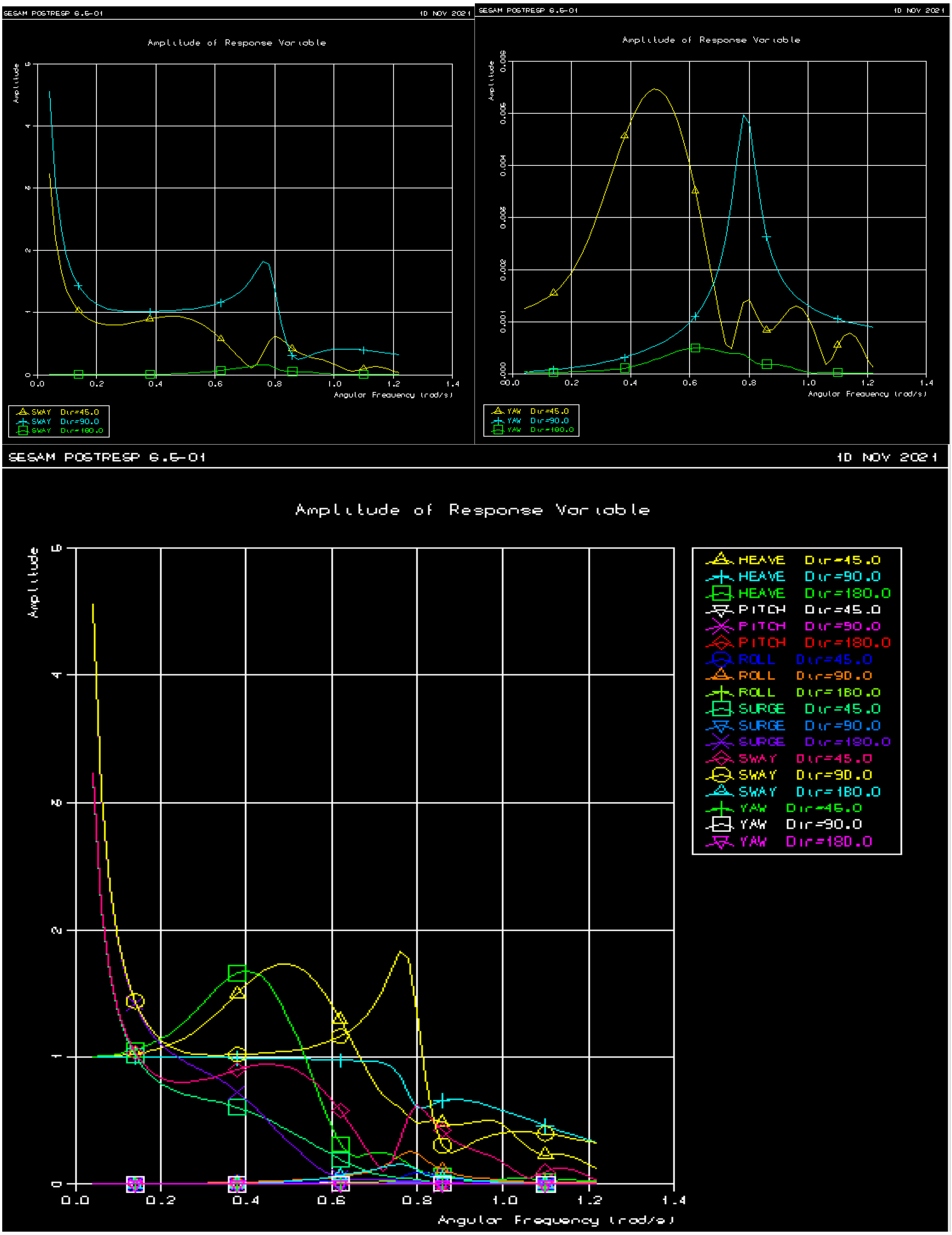


Fig. Model ship wadam





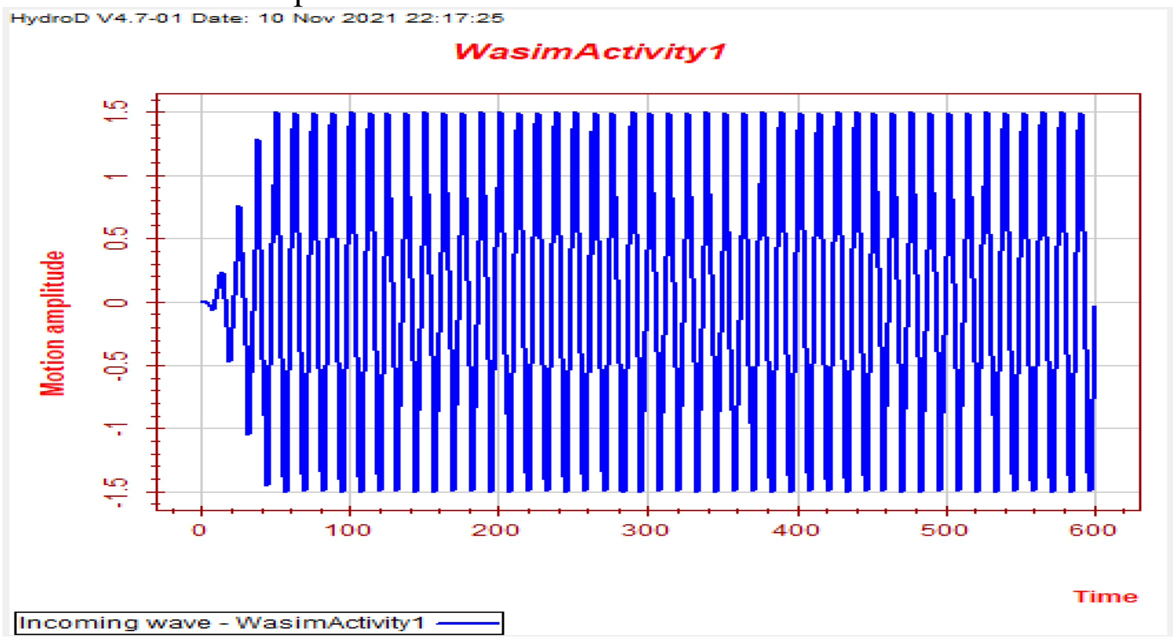
GENERAL RESPONSE OF AMPLITUDE OPERATORS

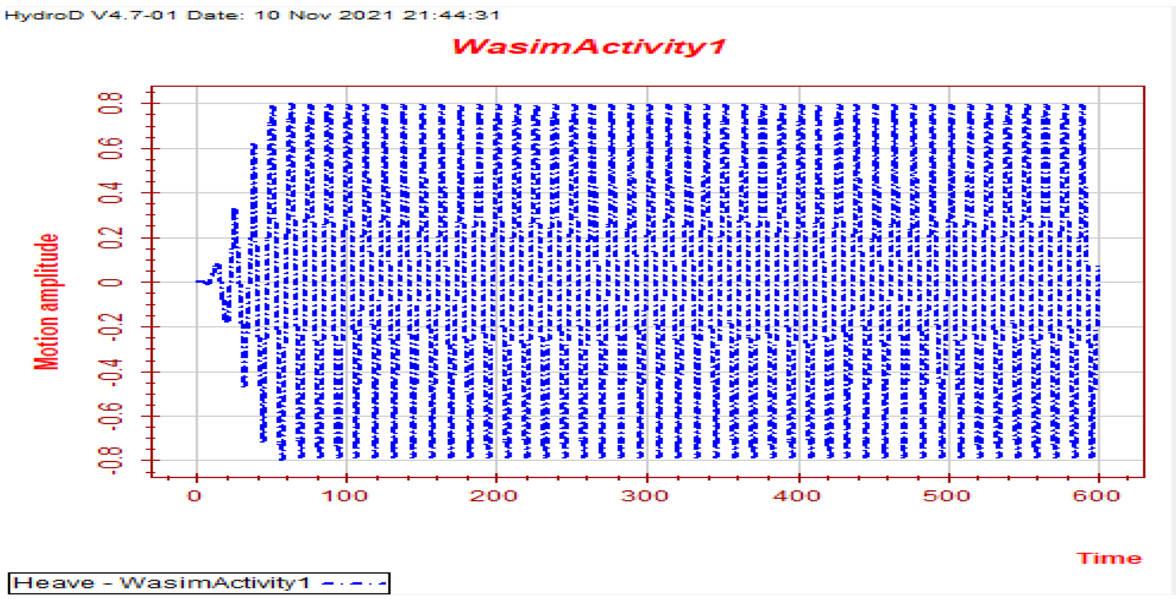
2A(2). Time domain response

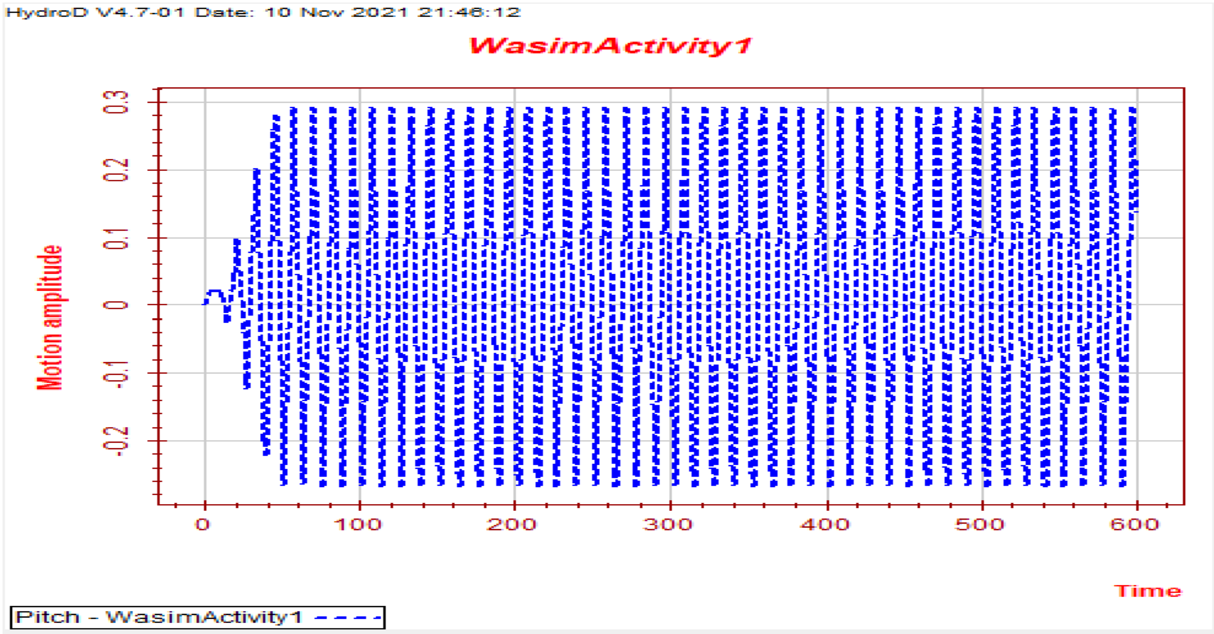
For this task we took the three previous regular wave directions, 45° 90° 180°, and iterated one by one on frequency, wave height and phase angle values in order to obtain a time domain response for a container ship.
The values represented are as follows:

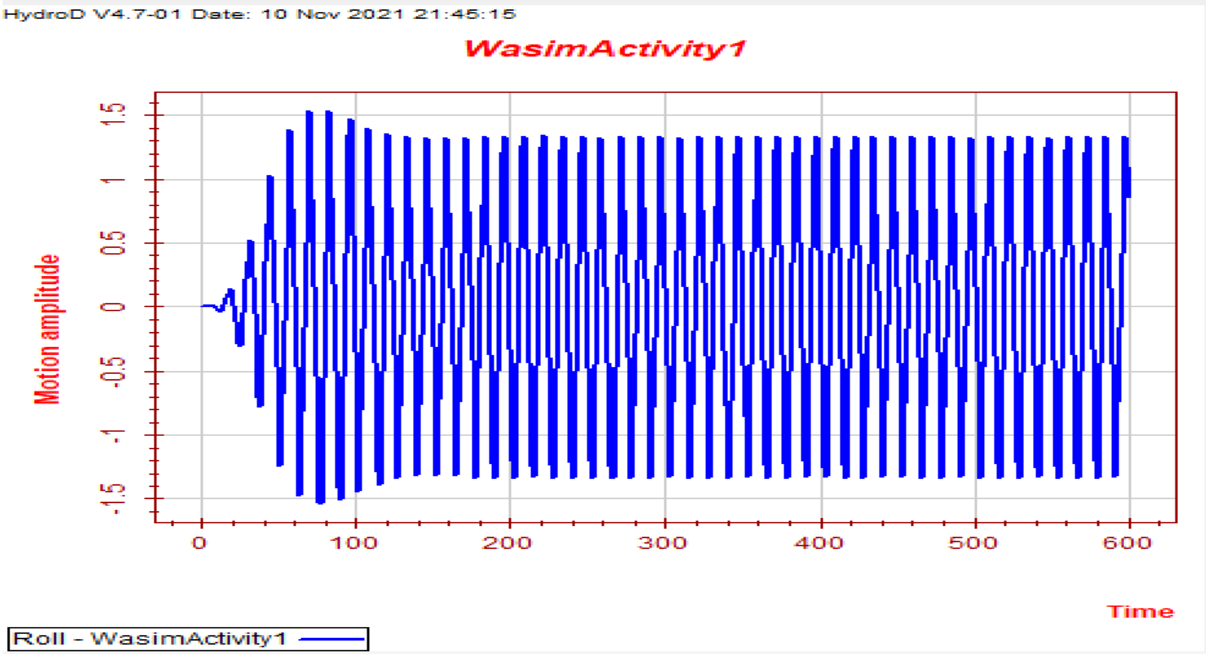
Wave	Direction [deg]	Frequency [rad/s]	Height [m]	Phase angle [deg]
Waveset3	45°	0.5	1	0
Waveset2	90°	0.5	1	0
Waveset1	180°	0.5	1	0

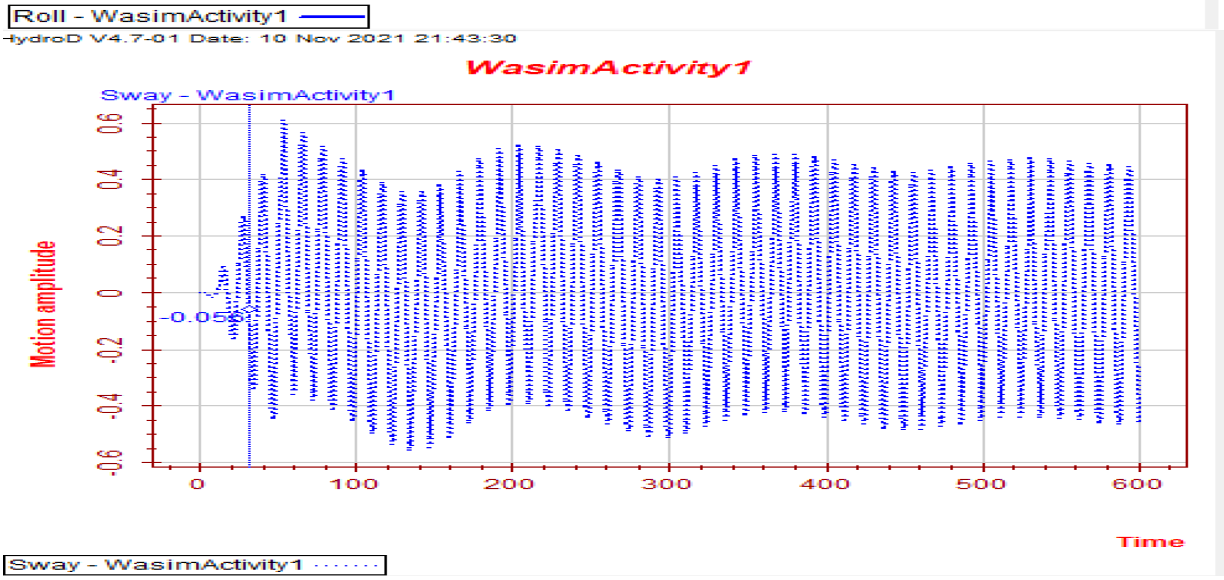
Plots of some example of time series and motion:



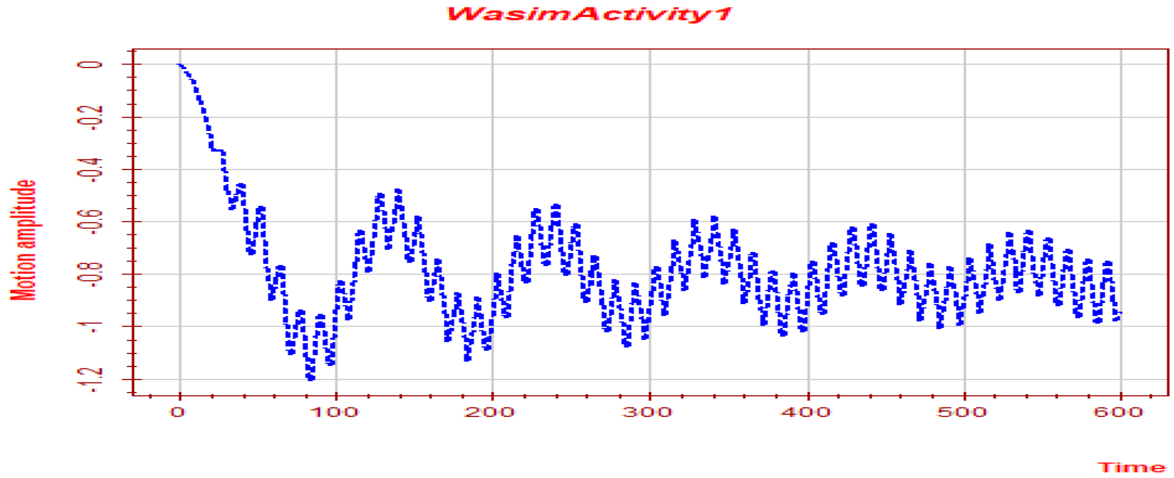



HydroD V4.7-01 Date: 10 Nov 2021 21:46:12
WasimActivity1
Motion amplitude
0.3
0.2
0.1
0
-0.1
-0.2
0
100
200
300
400
500
600
Time
Pitch - WasimActivity1


HydroD V4.7-01 Date: 10 Nov 2021 21:45:15
WasimActivity1
Motion amplitude
1.5
1
0.5
0
-0.5
-1
-1.5
0
100
200
300
400
500
600
Time
Roll - WasimActivity1

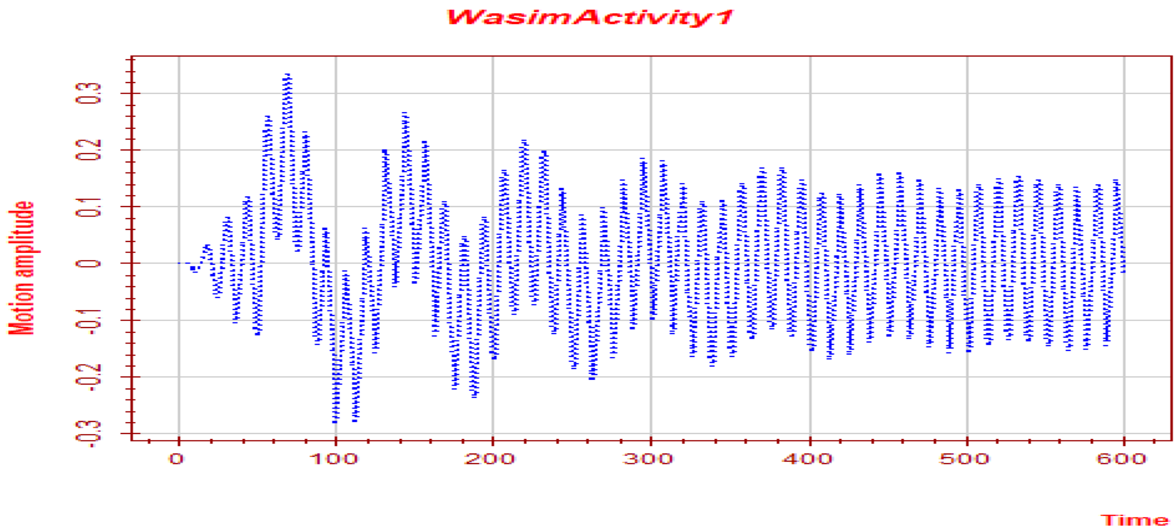

HydroD V4.7-01 Date: 10 Nov 2021 21:43:30
WasimActivity1
Sway - WasimActivity1
Motion amplitude
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.056
0
100
200
300
400
500
600
Time
Sway - WasimActivity1

HydroD V4.7-01 Date: 10 Nov 2021 21:42:21



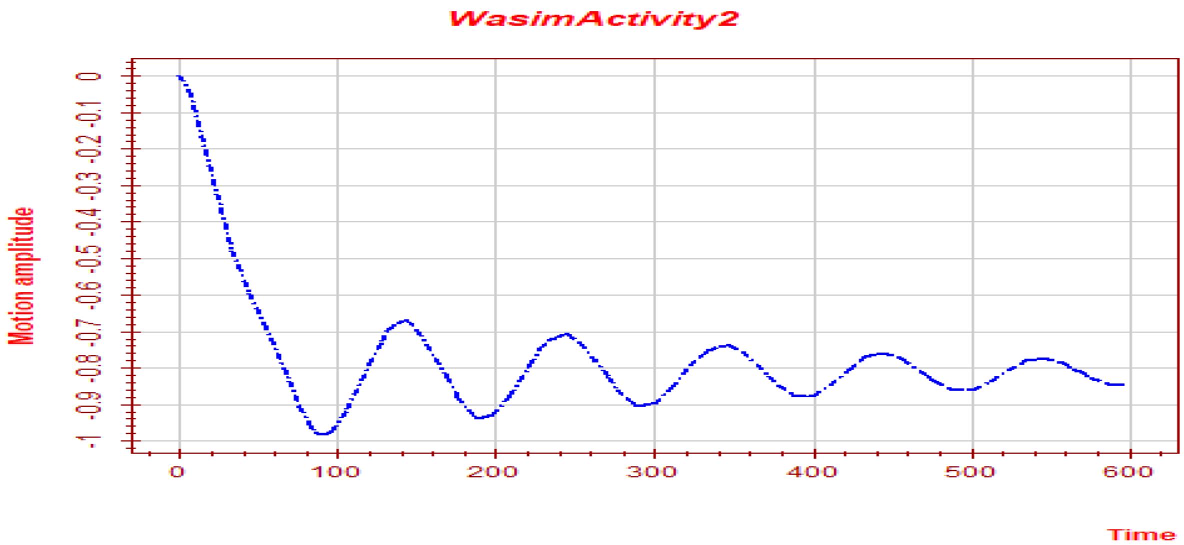
Surge - WasimActivity1

HydroD V4.7-01 Date: 10 Nov 2021 21:47:34

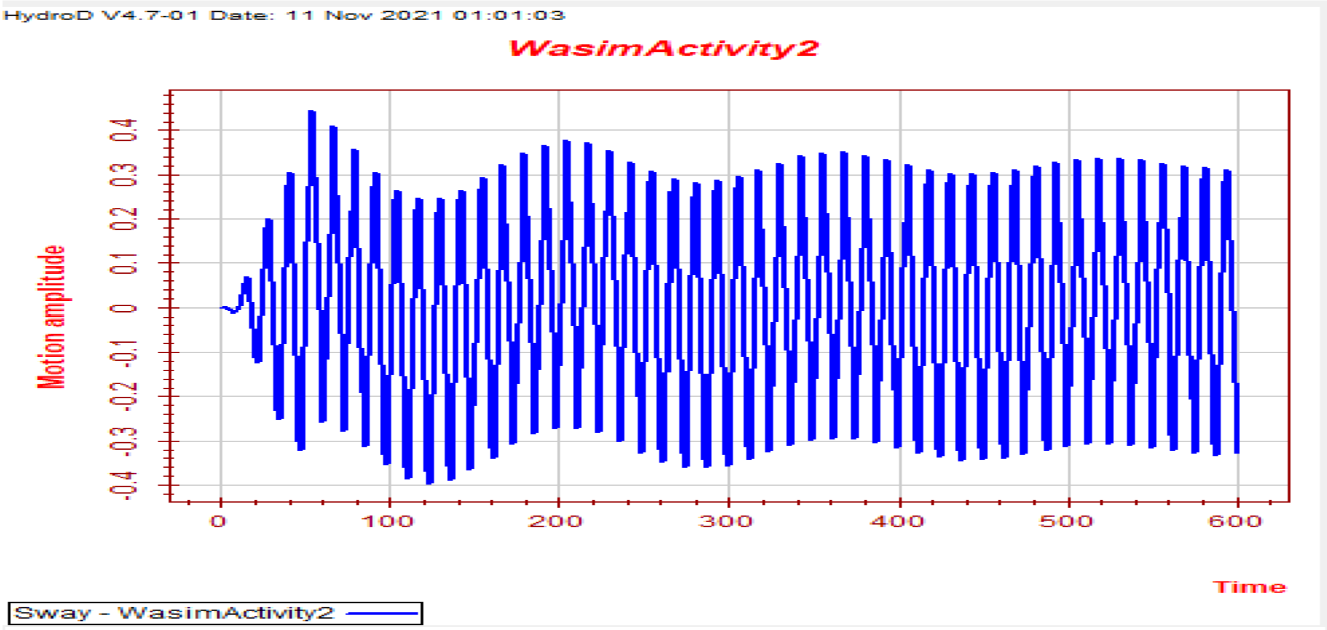


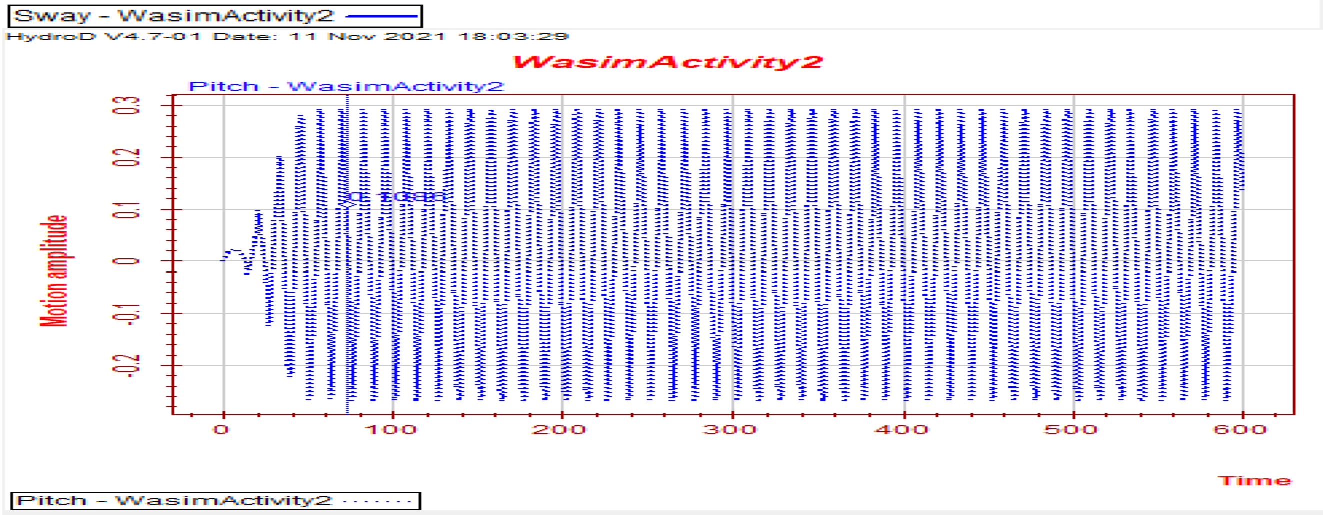
Yaw - WasimActivity1

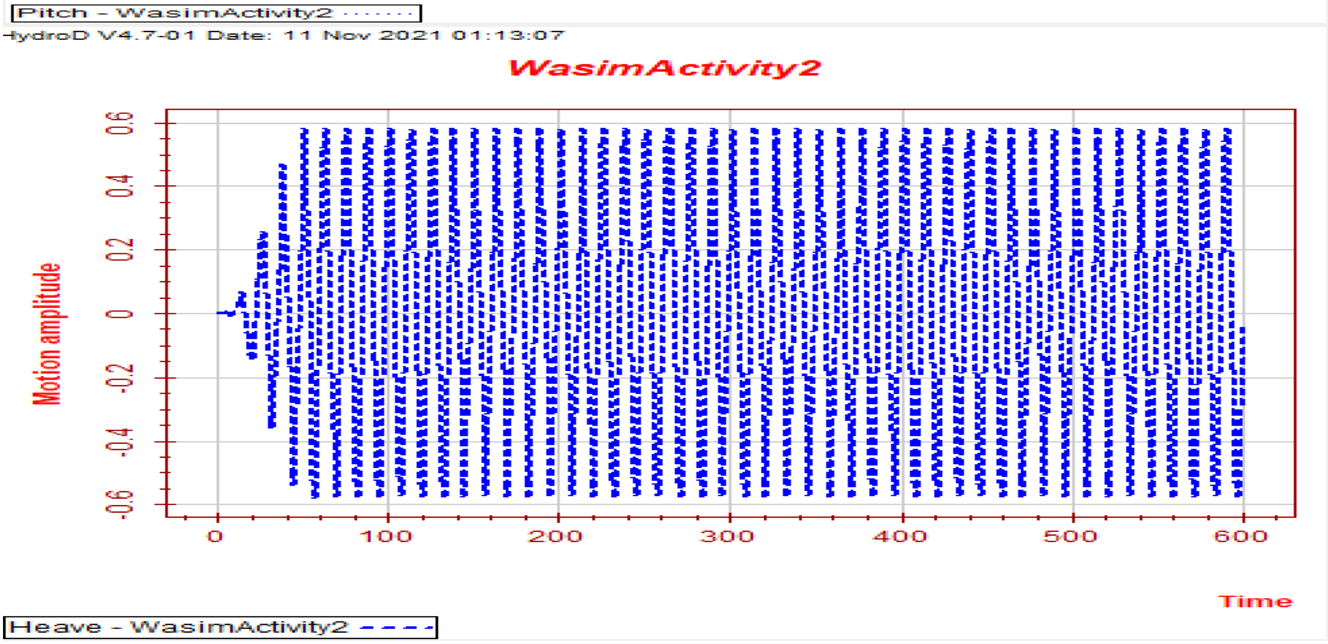
HydroD V4.7-01 Date: 11 Nov 2021 00:58:37

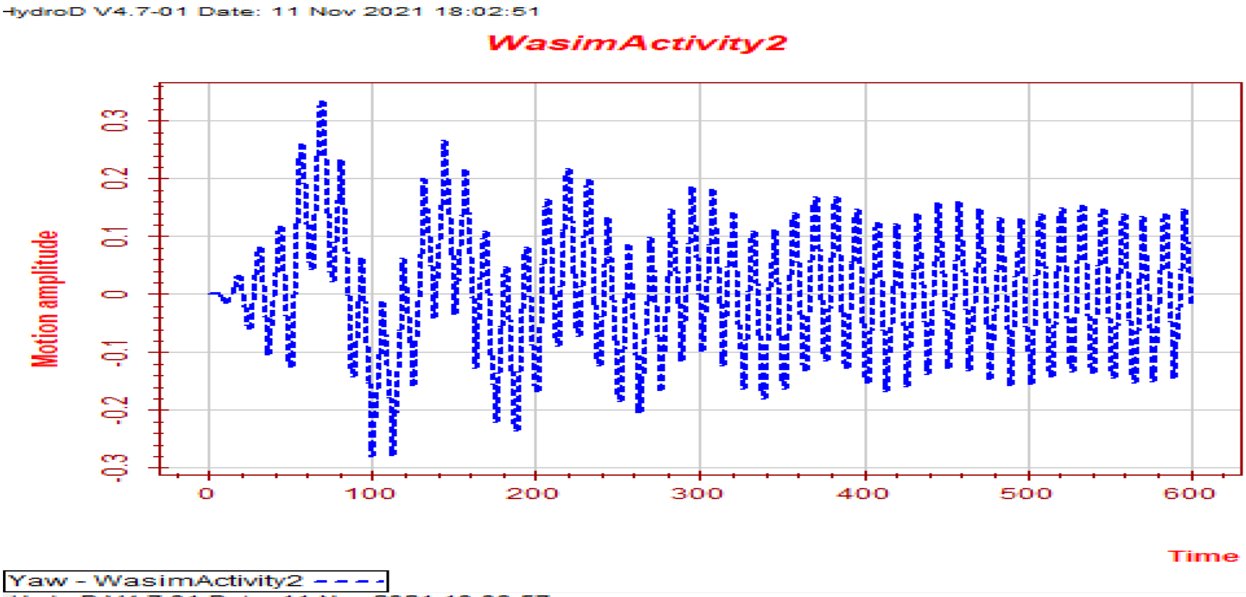


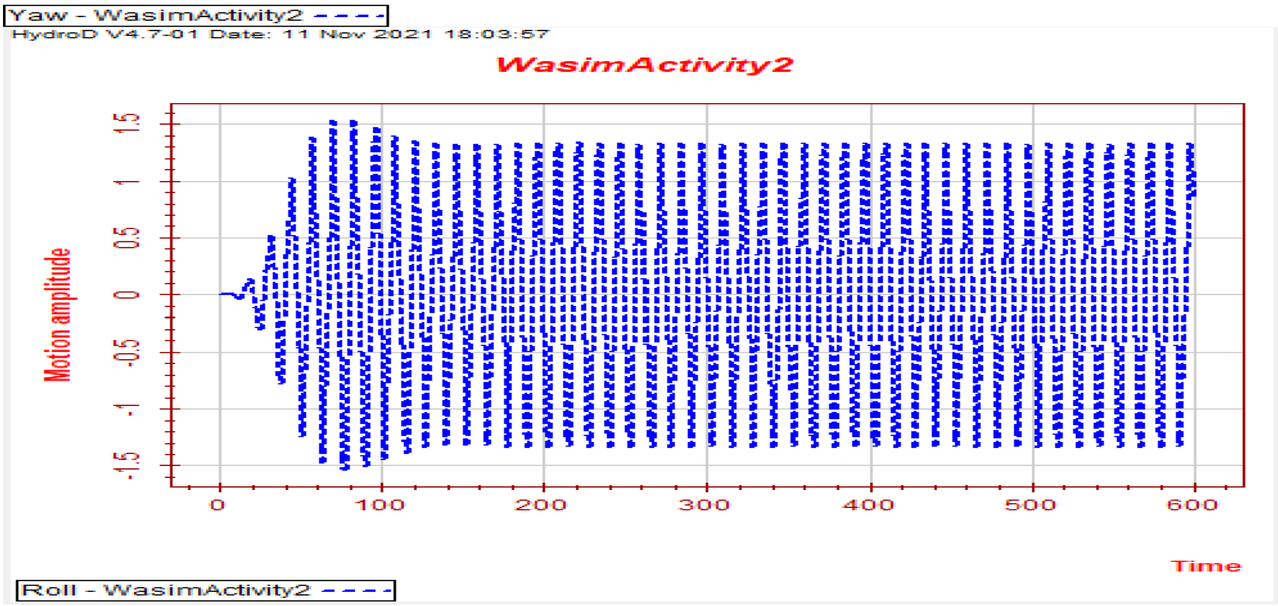
Surge - WasimActivity2


HydroD V4.7-01 Date: 11 Nov 2021 01:01:03
WasimActivity2
Motion amplitude
-0.4 -0.3 -0.2 -0.1 0 0.1 0.2 0.3 0.4
0 100 200 300 400 500 600
Time
Sway - WasimActivity2


HydroD V4.7-01 Date: 11 Nov 2021 18:03:29
WasimActivity2
Pitch - WasimActivity2
Motion amplitude
-0.2 -0.1 0 0.1 0.2 0.3
0 100 200 300 400 500 600
Time
Pitch - WasimActivity2


HydroD V4.7-01 Date: 11 Nov 2021 01:13:07
WasimActivity2
Motion amplitude
-0.6 -0.4 -0.2 0 0.2 0.4 0.6
0 100 200 300 400 500 600
Time
Heave - WasimActivity2


HydroD V4.7-01 Date: 11 Nov 2021 18:02:51
WasimActivity2
Motion amplitude
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
0
100
200
300
400
500
600
Time
Yaw - WasimActivity2

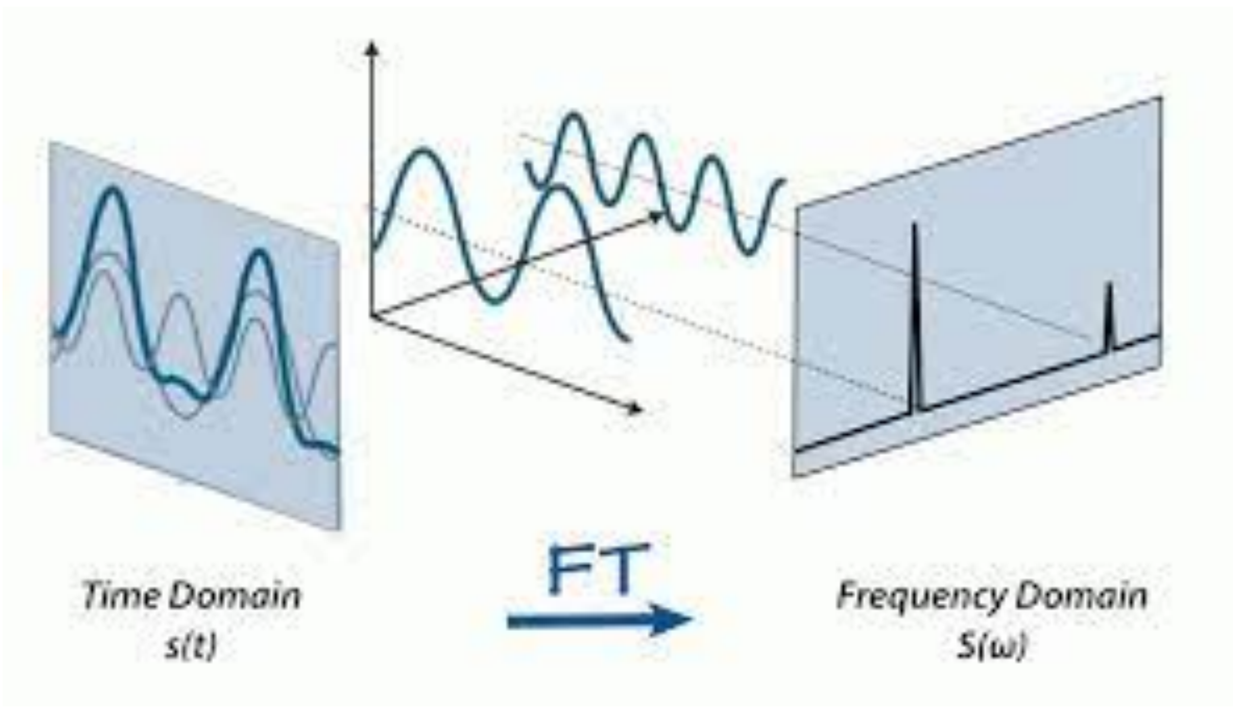

HydroD V4.7-01 Date: 11 Nov 2021 18:03:57
WasimActivity2
Motion amplitude
1.5
1
0.5
0
-0.5
-1
-1.5
0
100
200
300
400
500
600
Time
Roll - WasimActivity2

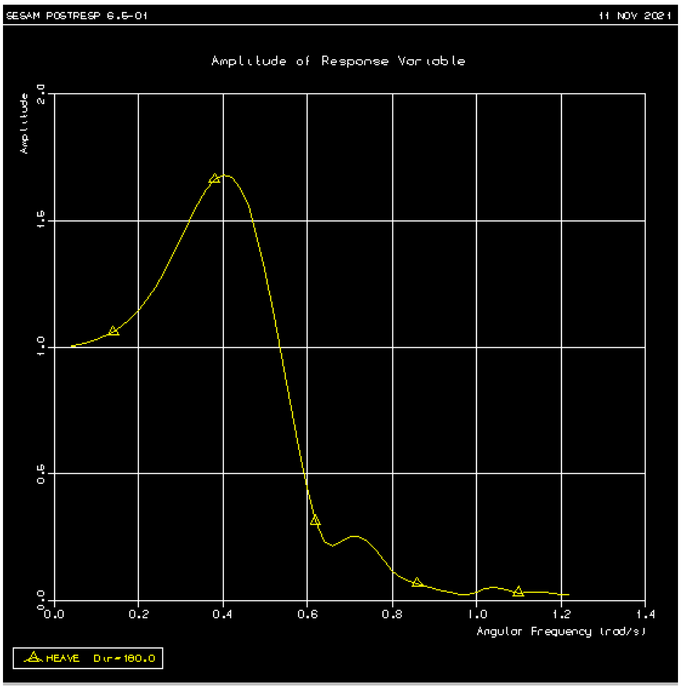
2A(3). Compare Time domain with Frequency domain

To create a comparison between the time domain and the frequency domain, it is necessary to use a transformation of one into the other, taking into account constant parameters such as wave height H= 1m and phase angle at 0°.
The analysis is done on the comparison results for head waves of 180° direction and limiting the degrees of freedom in order to understand only the behaviour of Heave and Pitch.

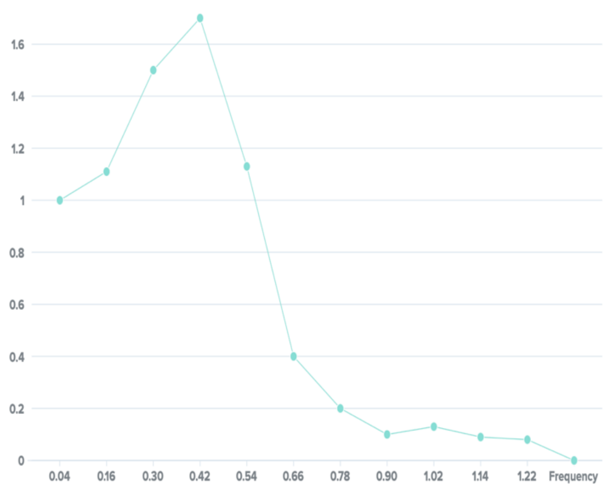
Frequency [rad/sec]	Waveset number
0.04	4
0.16	5
0.30	6
0.42	7
0.54	8
0.66	9
0.78	10
0.90	11
1.02	12
1.14	13
1.22	14

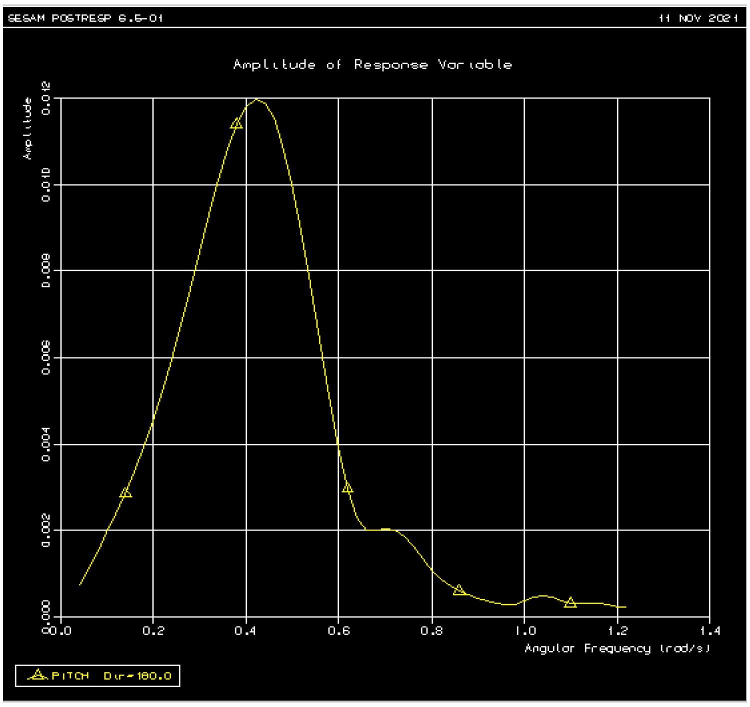
Table wavesets for comparison time domain and frequency domain



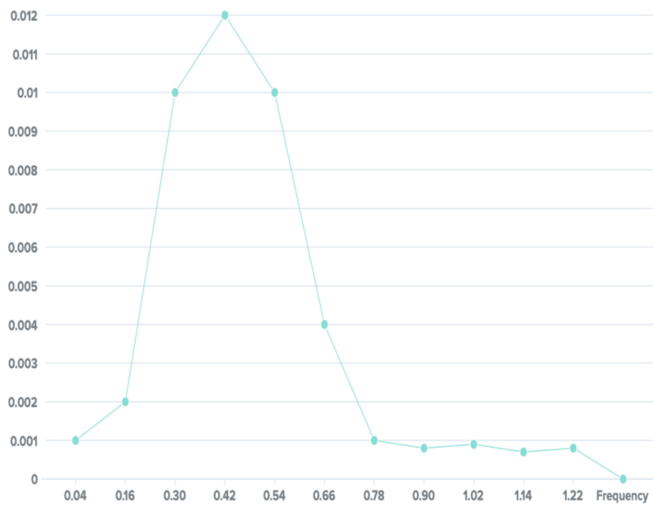

SESAM POSTRESP 6.5-01
11 NOV 2021
Amplitude of Response Variable
Amplitude
2.0
1.5
1.0
0.5
0.0
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
Angular Frequency (rad/s)
HEAVE Dir=180.0

WASIM HEAVE


1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0.04
0.16
0.30
0.42
0.54
0.66
0.78
0.90
1.02
1.14
1.22
Frequency



WASIM PITCH



We can see from the comparison of the four graphs that in the transfer of the time domain to the frequency domain, both curves are generally identical, with distinct amplitudes at low frequencies but adapting to the same shape as the x-axis is increased.

The graphs follow the same style, with minor deviations that might have been avoided if the number of points had been higher. Overall, the procedure for transferring domains is acceptable.

Task 2B : Time domain analysis of responses of a ship in irregular (WASIM)

2B(1,2,3)

With this section, the reactions of a ship in rough seas will be explored, as was the case with Wasim, but with the addition of a three Bretschneider Spectra were named in order.

The Bretschneider spectrum is yet another spectrum for defining irregular waves. The formula for the Bretschneider ocean wave spectrum is:

$$S(\omega) = \frac{5}{16}\frac{\omega_m^4}{\omega^5} H_{1/3}^2 e^{-5\omega_m^4/4\omega^4}$$

Where ω is the frequency in radians per second, ω_m is the modal frequency of any given wave, and $H_{1/3}$ is the significant wave height.

Wave Spectrum of Bretschneider has the parameters of H=8 and T=10. The six degrees of motion in three directions will be studied once more.

Wave irregular for Bretschneider spectrum	Direction [deg]
WS1	45°
WS2	90°
WS3	180°

We'll use the same approach as in the last exercise, but because we're operating with an irregular wave sea condition, there will be some adjustments between how we set up our software for analysis.

We'll still use a panel model (with the motion control springs and critical damping matrix) in the first setup, but this time we'll additionally choose the wave spectrum.

We'll utilize the similar location parameters as in the previous exercise (Task 2A), as well as a simplified direction set to just account for beam and head waves (180° and 90° direction waves), but this time we'll create a wave spectrum. We'll utilize a Bretschneider spectrum (also known as a 2 parameter Pierson-Moskowitz spectrum) with the given significant wave height and the peak period from the statement of work for our wave spectrum.

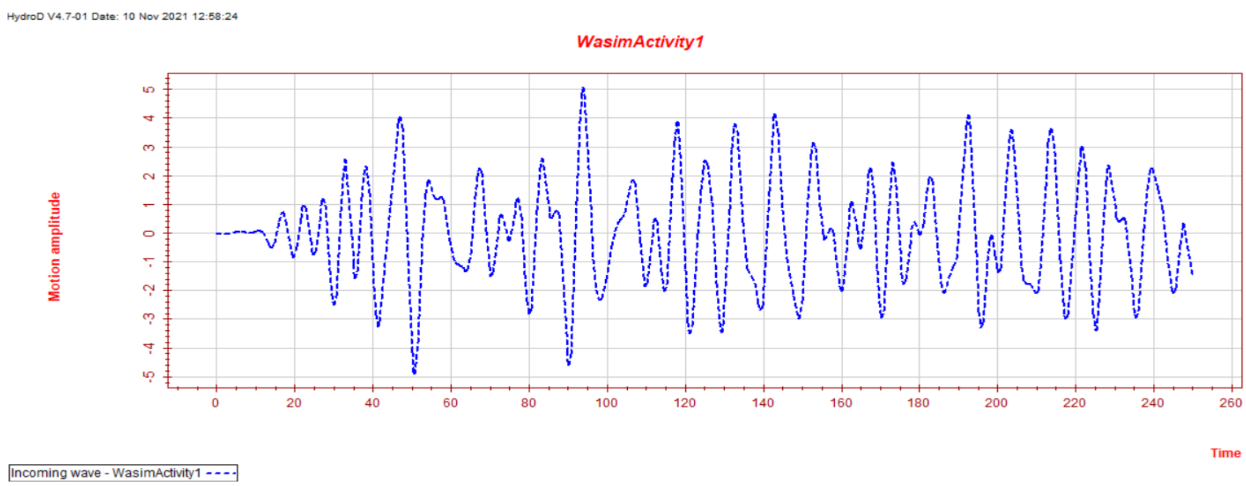
We shall also exclude short crested waves from this study.

As a result, none spreading function will be defined. We'll start with a 180° wave direction for the first wave direction we'll investigate in.

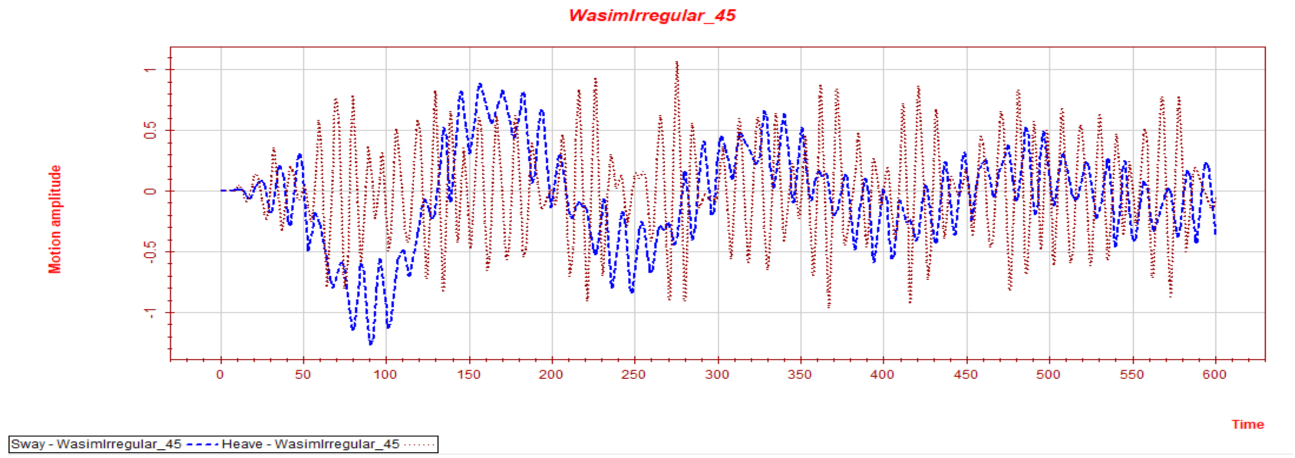
We'll maintain the same WASIM wizard settings as in the last exercise for the rest of the WASIM wizard setup so we can compare our conclusions.

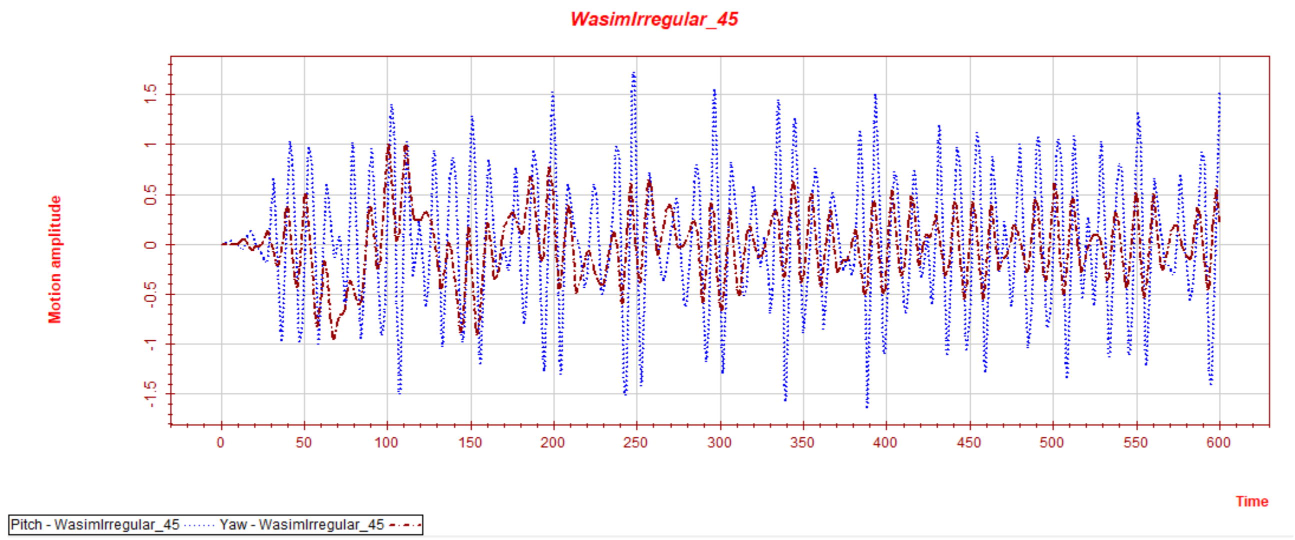
For the WASIM activity, we'll also make sure that our time step is at least 1/20th of the minimum period of the defined wave spectrum, so that we can get an adequate resolution, and that our analysis time is at least 250 seconds, so that we can properly evaluate our ship's response to the incoming sea state over a longer period of time.

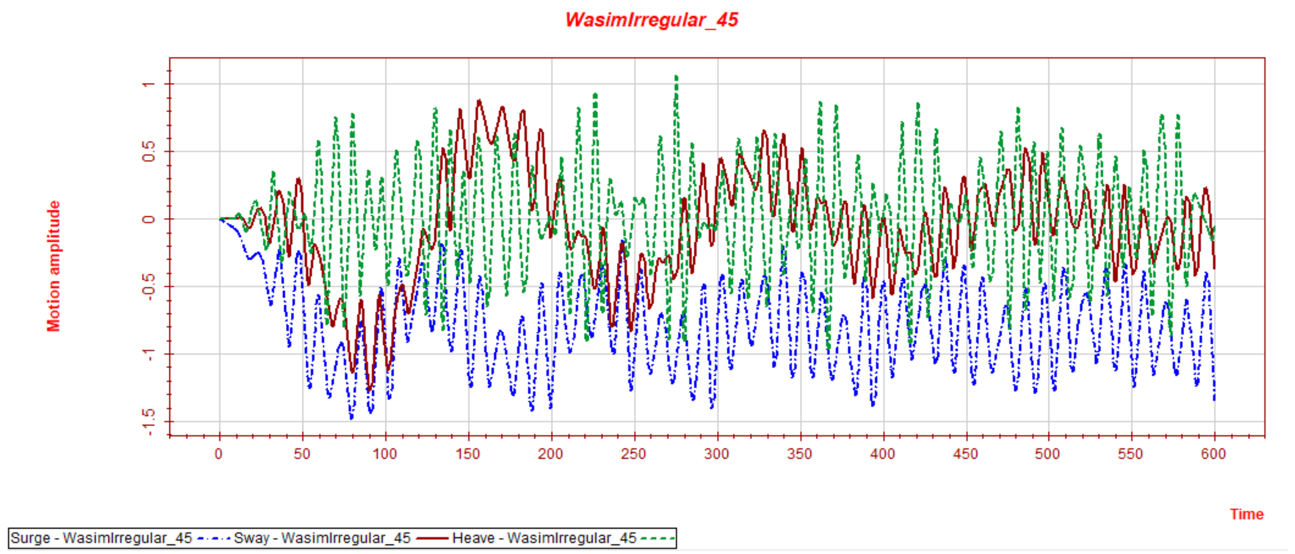
We can now obtain the data for our ship's reaction in the time domain for a sea condition with irregular waves. The following graph depicts the incoming wave's displacement amplitude throughout time.

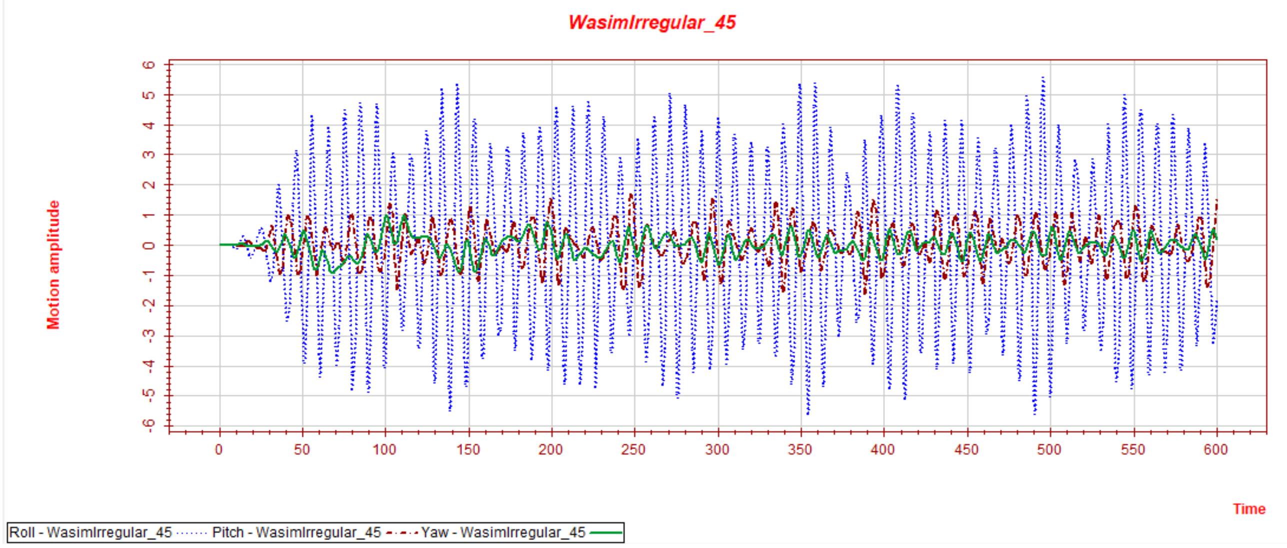


For 45°:

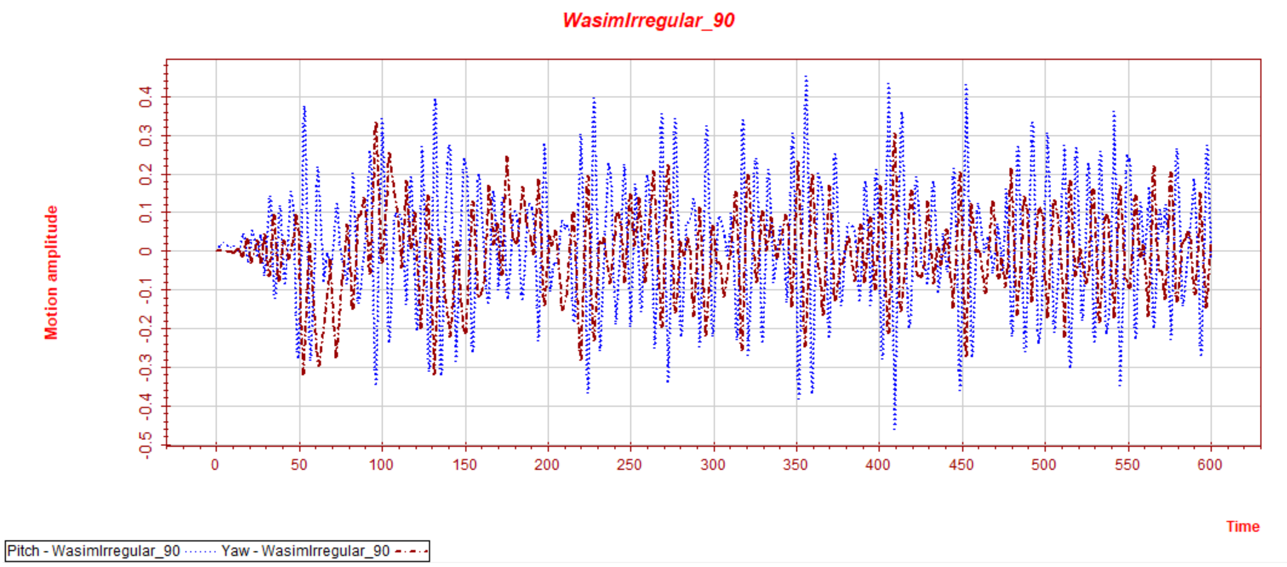

WasimIrregular_45
Motion amplitude
Time
Sway - WasimIrregular_45
Heave - WasimIrregular_45

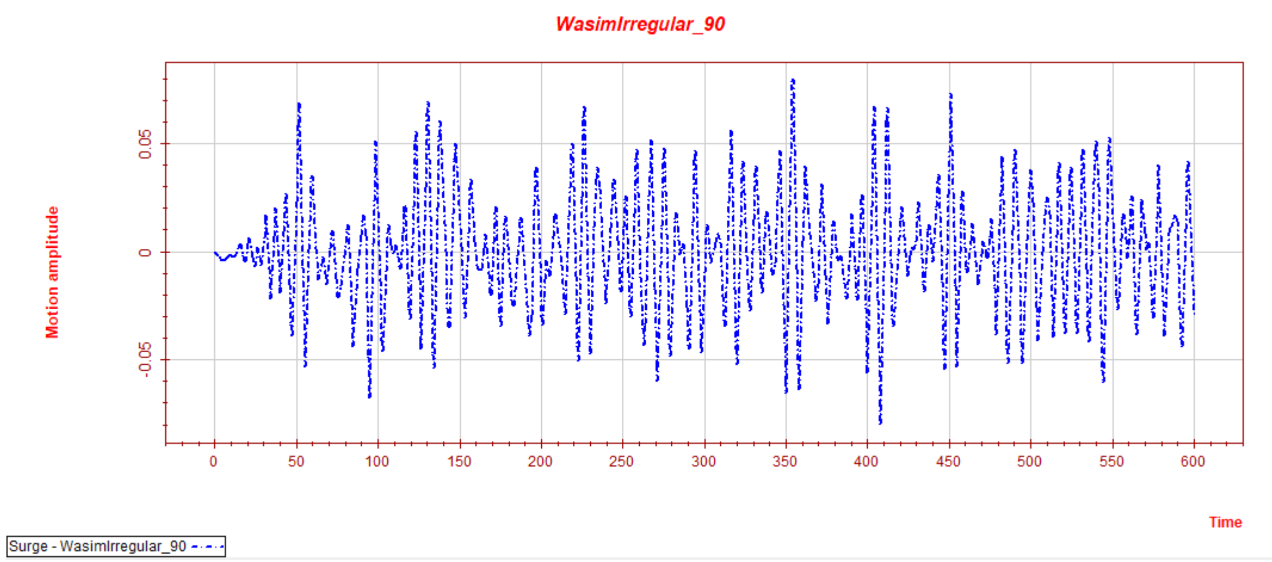

WasimIrregular_45
Motion amplitude
Time
Pitch - WasimIrregular_45
Yaw - WasimIrregular_45

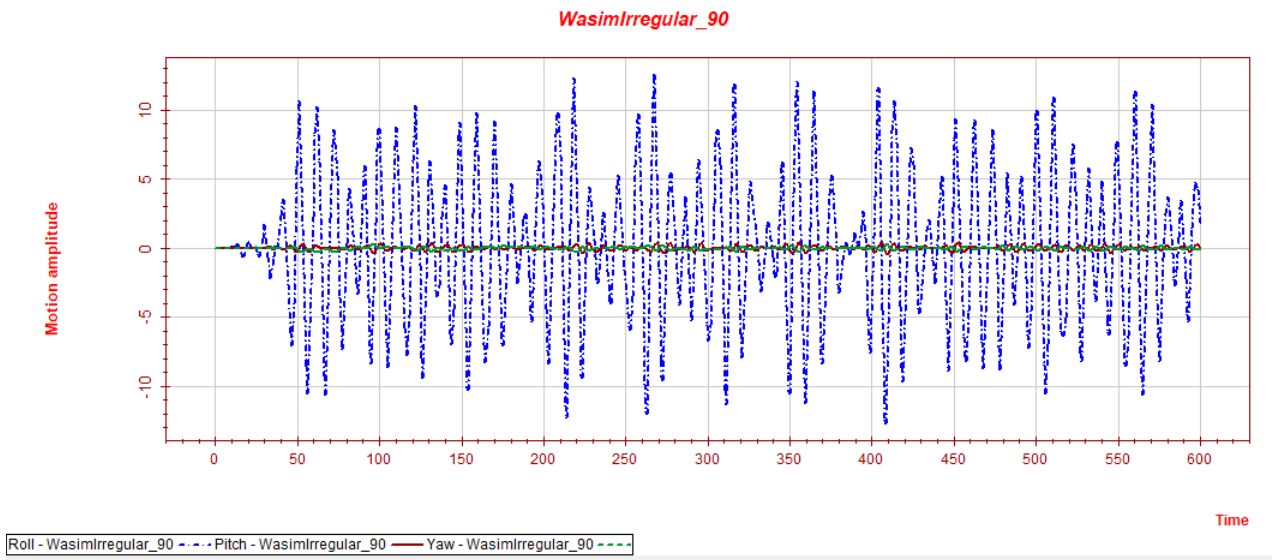

WasimIrregular_45
Motion amplitude
Time
Surge - WasimIrregular_45
Sway - WasimIrregular_45
Heave - WasimIrregular_45

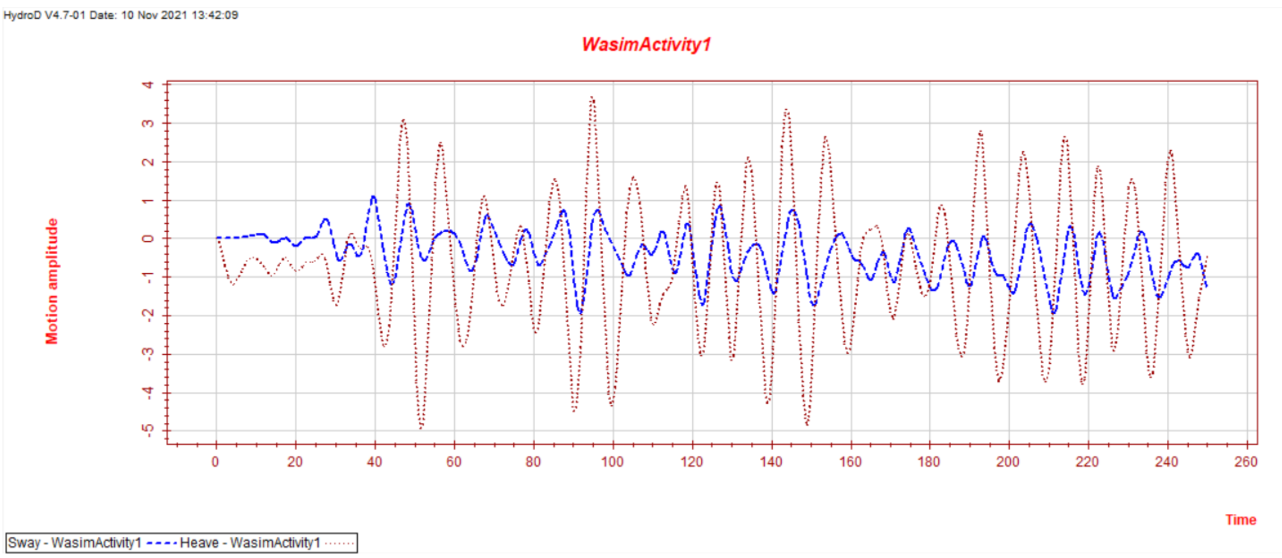

WasimIrregular_45
Motion amplitude
Time
Roll - WasimIrregular_45
Pitch - WasimIrregular_45
Yaw - WasimIrregular_45

For 90°:

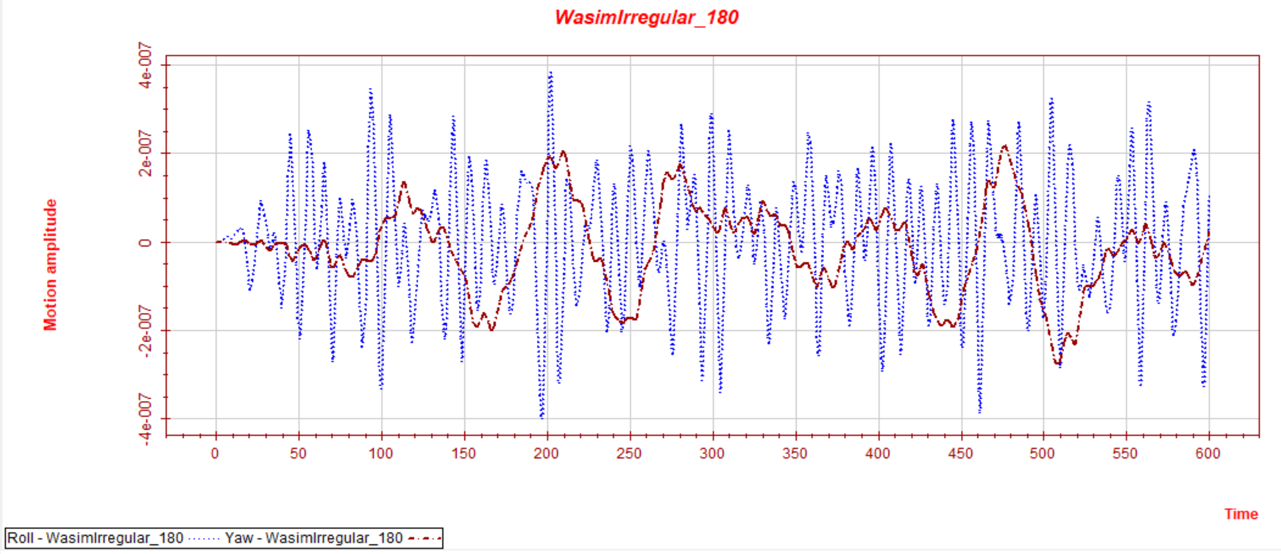

WasimIrregular_90
Motion amplitude
Time
Pitch - WasimIrregular_90
Yaw - WasimIrregular_90


WasimIrregular_90
Motion amplitude
0.05
0
-0.05
0
50
100
150
200
250
300
350
400
450
500
550
600
Time
Surge - WasimIrregular_90

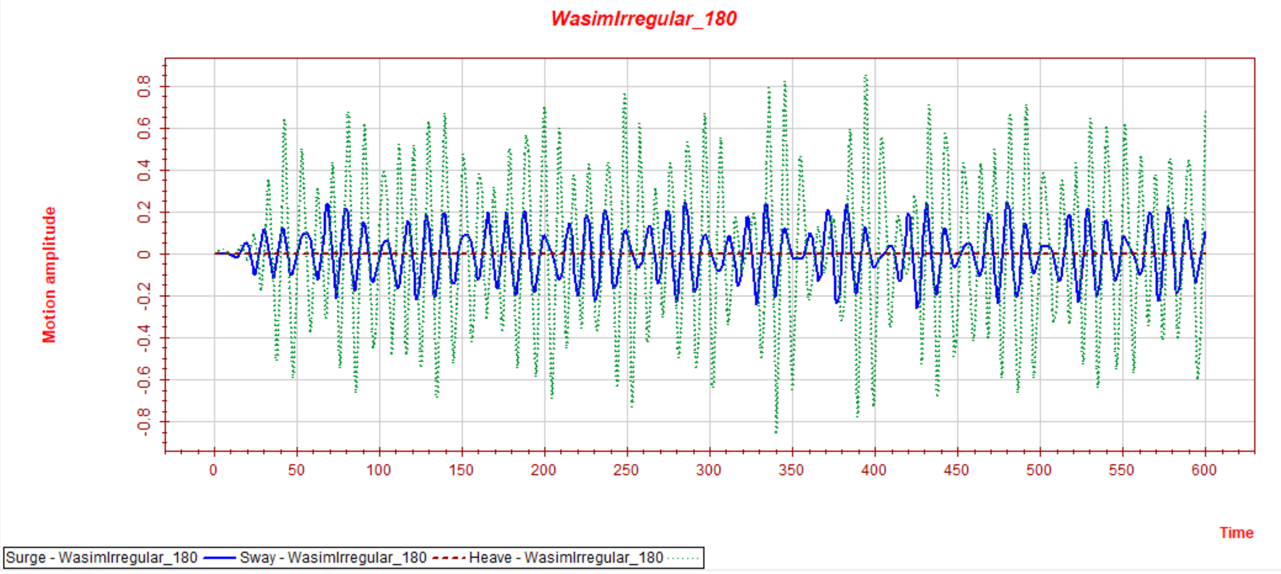

WasimIrregular_90
Motion amplitude
10
5
0
-5
-10
0
50
100
150
200
250
300
350
400
450
500
550
600
Time
Roll - WasimIrregular_90
Pitch - WasimIrregular_90
Yaw - WasimIrregular_90


HydroD V4.7-01 Date: 10 Nov 2021 13:42:09
WasimActivity1
Motion amplitude
4
3
2
1
0
-1
-2
-3
-4
-5
0
20
40
60
80
100
120
140
160
180
200
220
240
260
Time
Sway - WasimActivity1
Heave - WasimActivity1

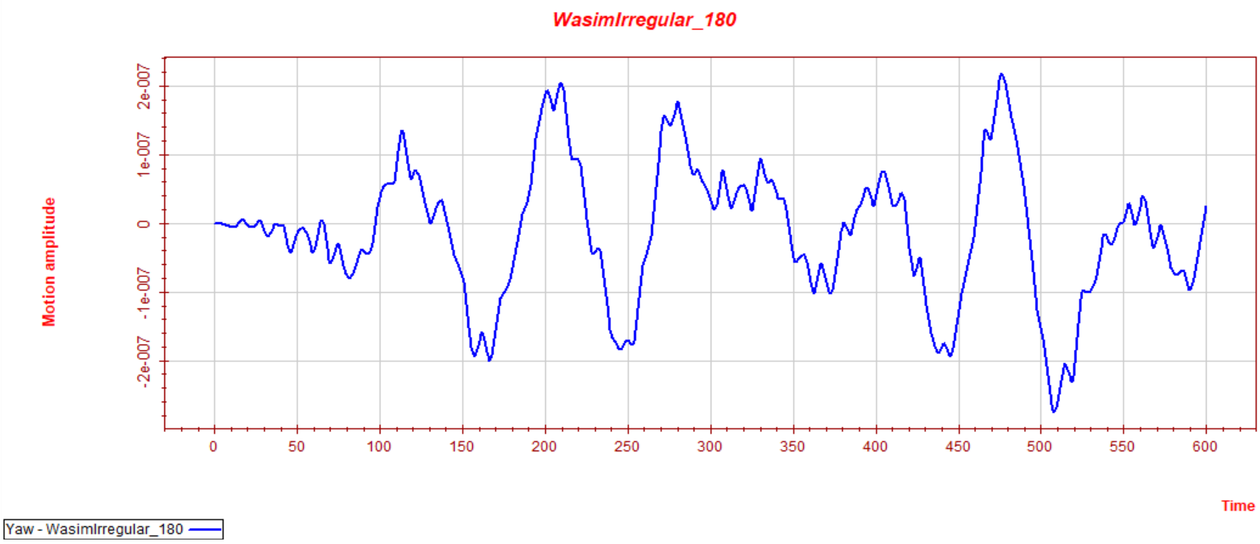
For 180°:



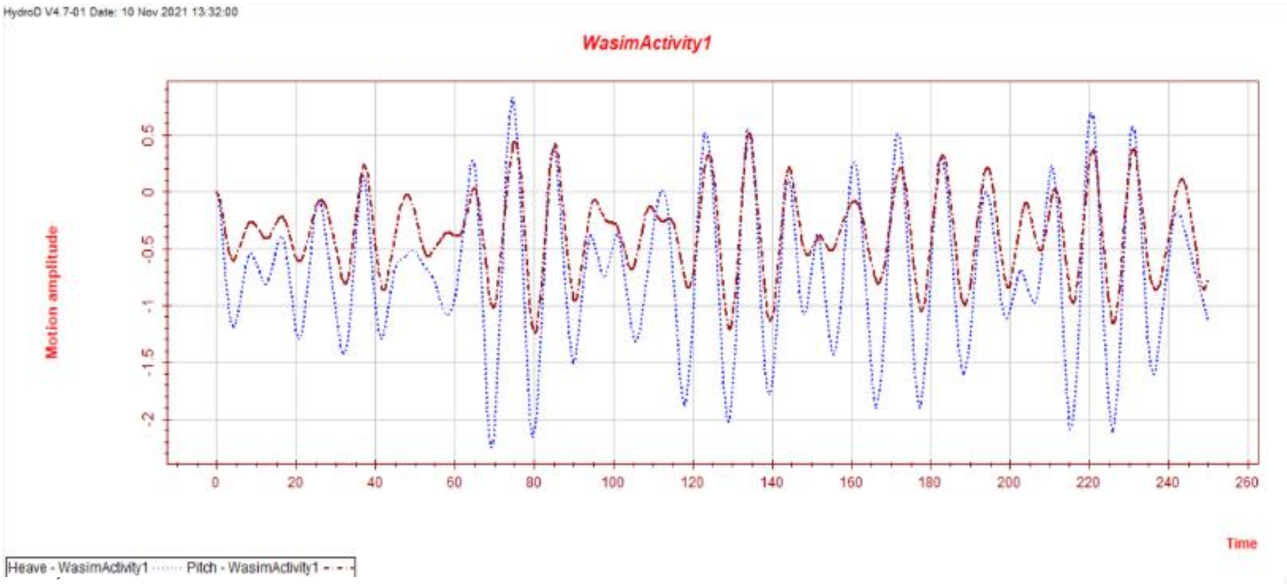
WasimIrregular_180
Motion amplitude
4e-007
2e-007
0
-2e-007
-4e-007
0
50
100
150
200
250
300
350
400
450
500
550
600
Time
Roll - WasimIrregular_180
Yaw - WasimIrregular_180

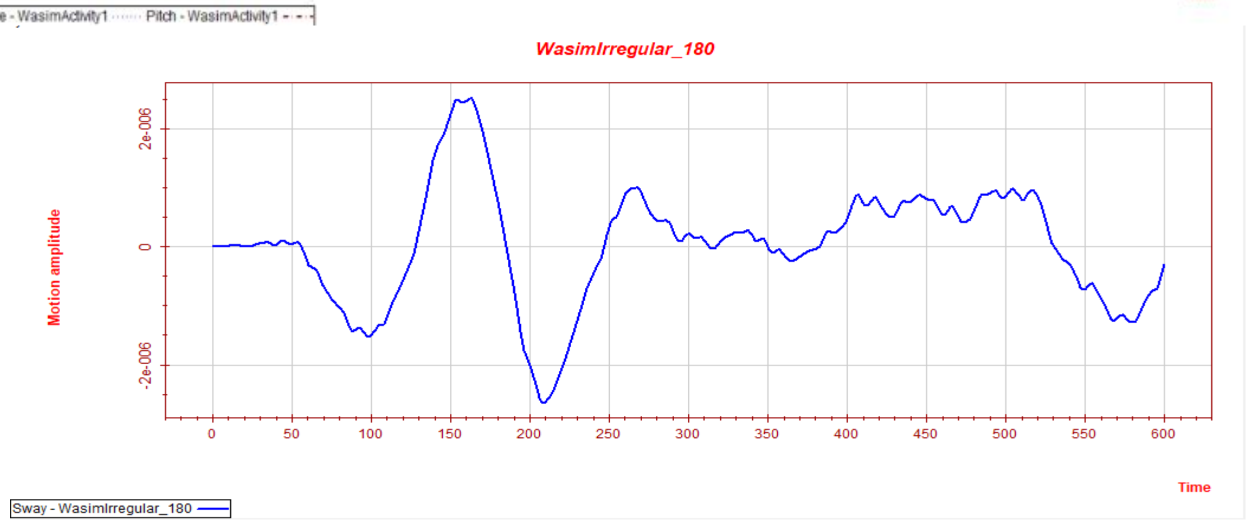


WasimIrregular_180
Motion amplitude
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
0
50
100
150
200
250
300
350
400
450
500
550
600
Time
Surge - WasimIrregular_180
Sway - WasimIrregular_180
Heave - WasimIrregular_180



WasimIrregular_180
Motion amplitude
2e-007
1e-007
0
-1e-007
-2e-007
0
50
100
150
200
250
300
350
400
450
500
550
600
Time
Yaw - WasimIrregular_180



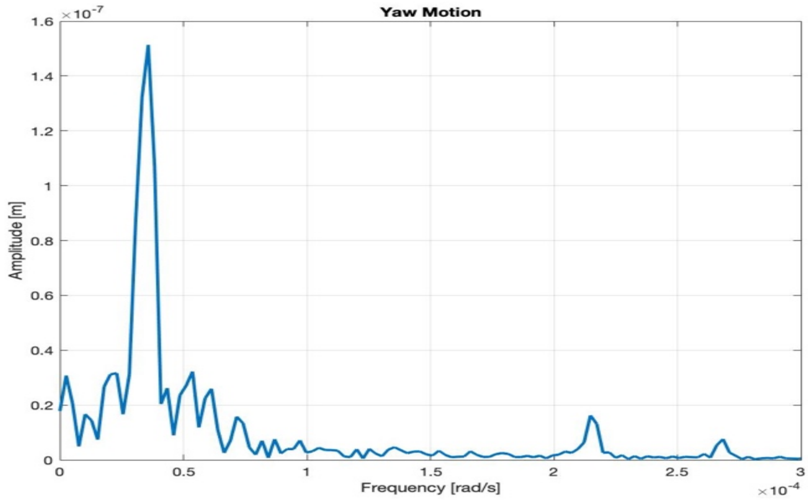


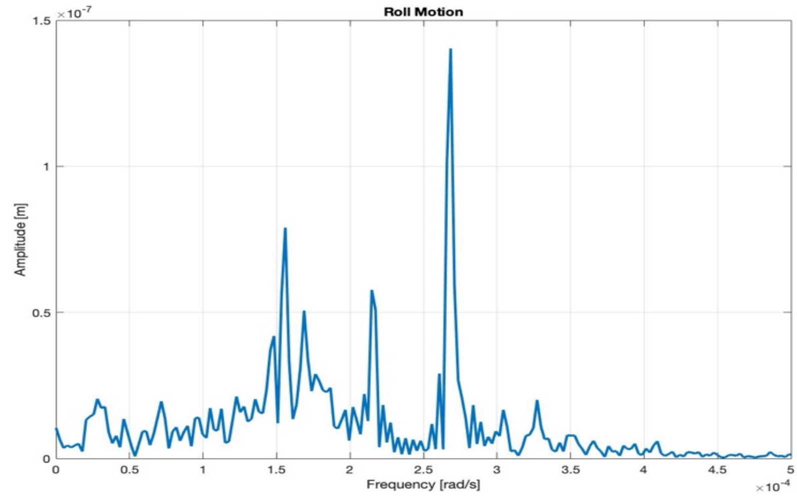
We can draw the same conclusions from these data as we did from the previous jobs about how different wave directions influence our ship's 6 degrees of motion differently (90° waves cause a larger amplitude roll motion).

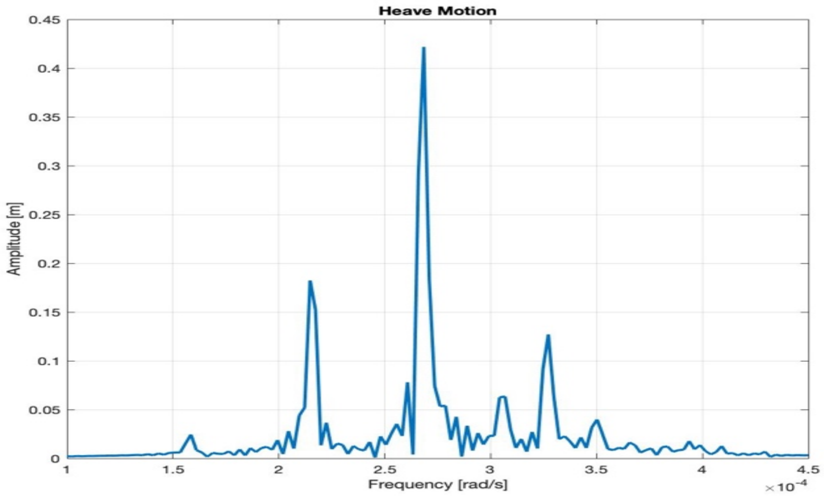
2B(4)

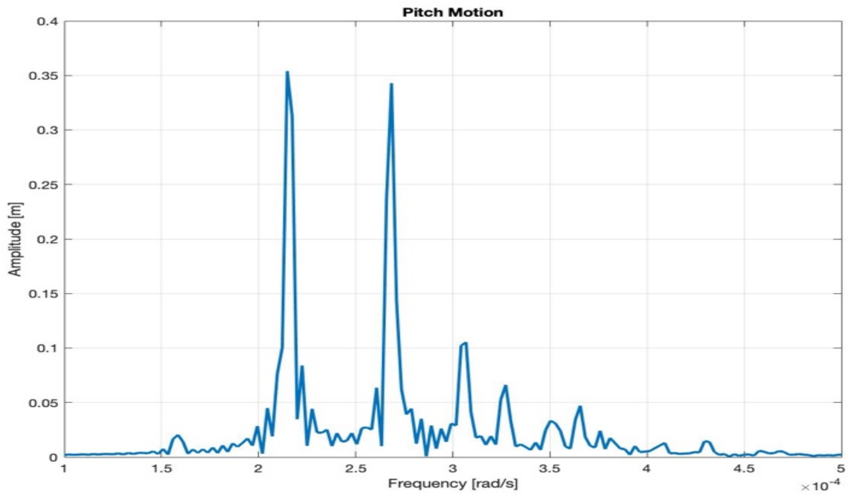
The corresponding amplitude spectra are plotted below by using an important transformation related from the time domain to the frequency domain using Matlab: Fast Fourier Transform (FFT): A fast fourier transform is an algorithm that calculates the discrete Fourier transform (DFT) or its inverse (IDFT).

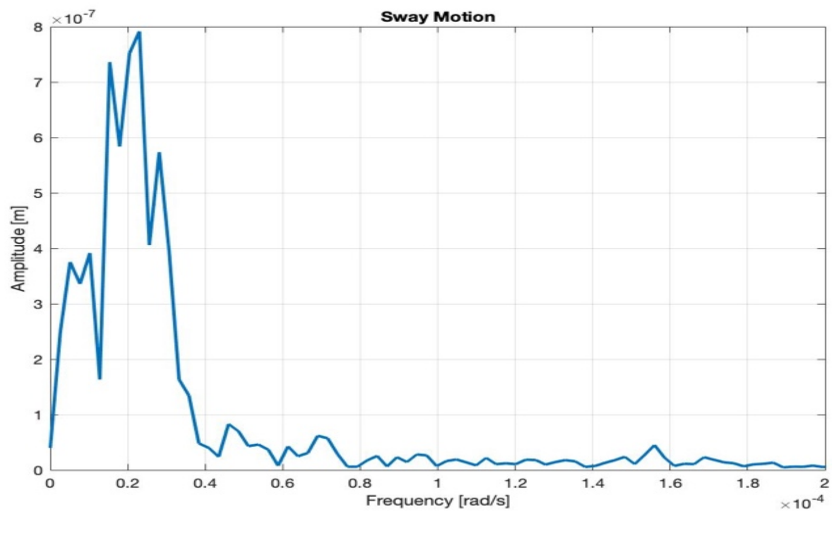
This algorithm allows us to convert a signal from its original domain (often time or space) to a representation in the frequency domain and vice versa.

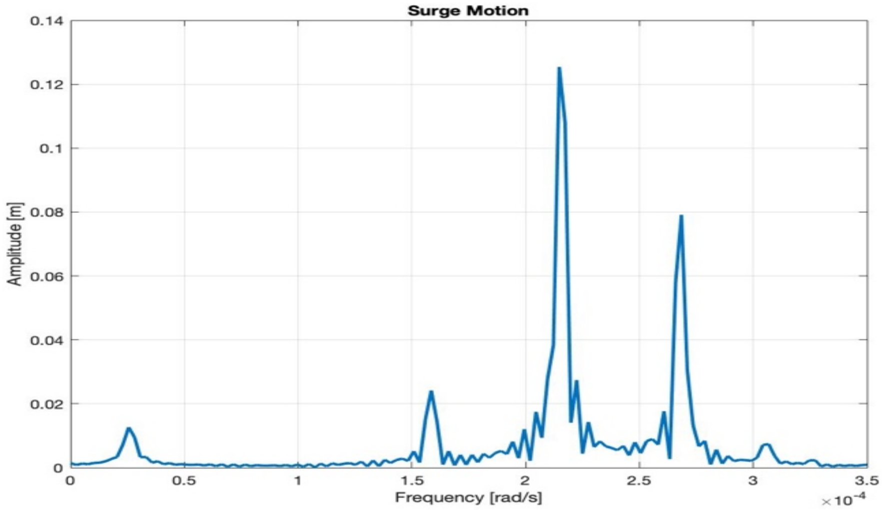





Heave Motion
Amplitude [m]
Frequency [rad/s]
×10^-4


Pitch Motion
Amplitude [m]
Frequency [rad/s]
×10^-4


Sway Motion
×10^-7
Amplitude [m]
Frequency [rad/s]
×10^-4



We can notice that the amplitude of response provide by the different directions of the wave, is significative for Heave and Pitch, that correspond to the same past results obtained, and give us the important relation between the degree of motion analyzed and the direction of the wave in a frequency domain.

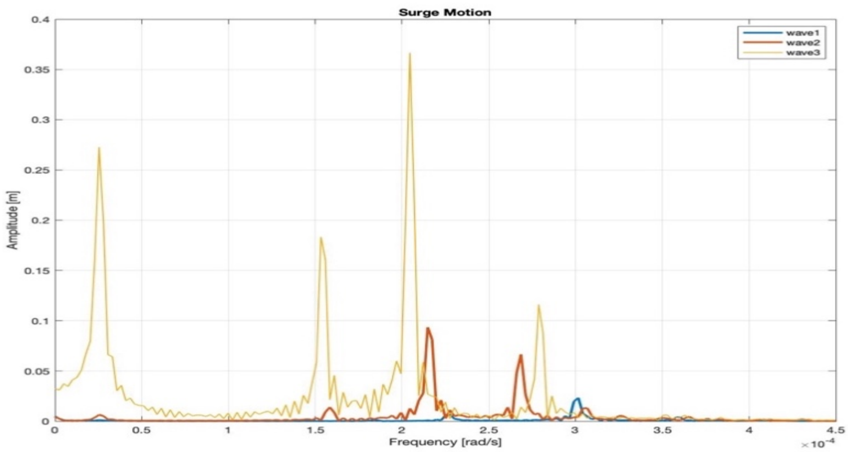
In terms of the ship's amplitude spectra in rough seas, the existence of second order forces can be observed in the many peaks of each curve, as well as the amplitude envelopes of the time-domain responses, for every motion at every wave spectrum. These forces, also known as drift forces, are proportional to the input wave amplitude squared. Because of the irregularity of the incident waves, irregular second order forces are generated, which are transferred onto the response signals. They are caused by the non-linear interaction of waves with the floating body, namely wave reflection and diffraction, as well as waves created by the body itself when oscillating. These non-linear effects are amplified since the ship is anchored.

2B(5)

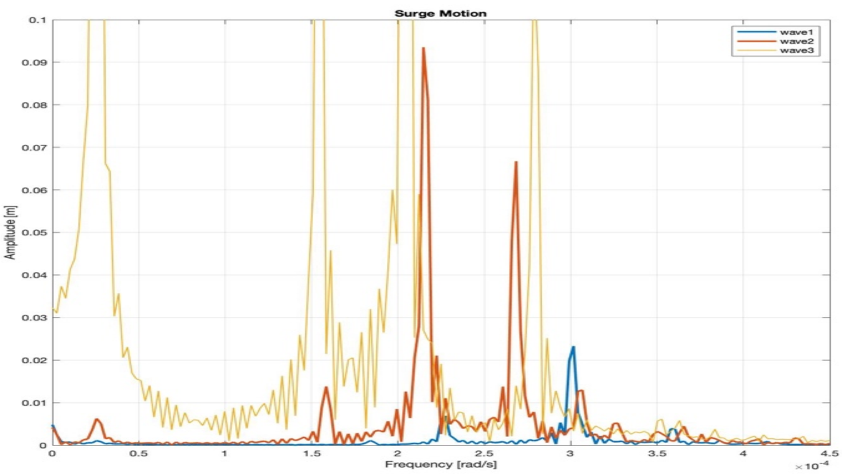
Using different values of Hs and Tp permit us to understand, through simulation, the comparison between time series of motion and amplitude of the spectra, that is provide by the Matlab code given in class.

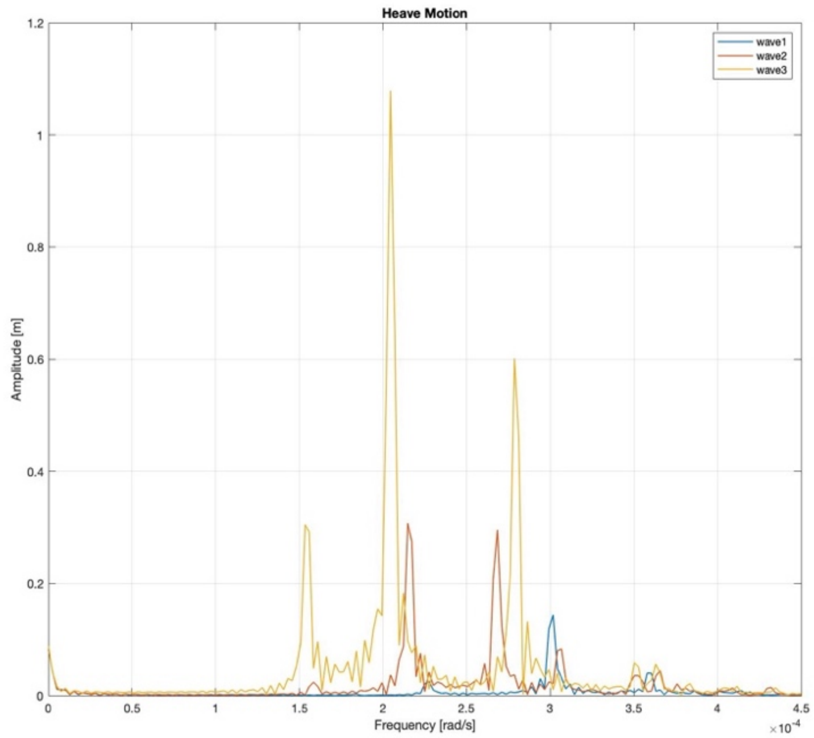
The values chosen for that simulation are valid only for the wave direction of 180°.

Bretschneider Spectrum wave	Hs [m]	Tp [s]
WS1	3	9
WS2	5	11
WS3	7	13

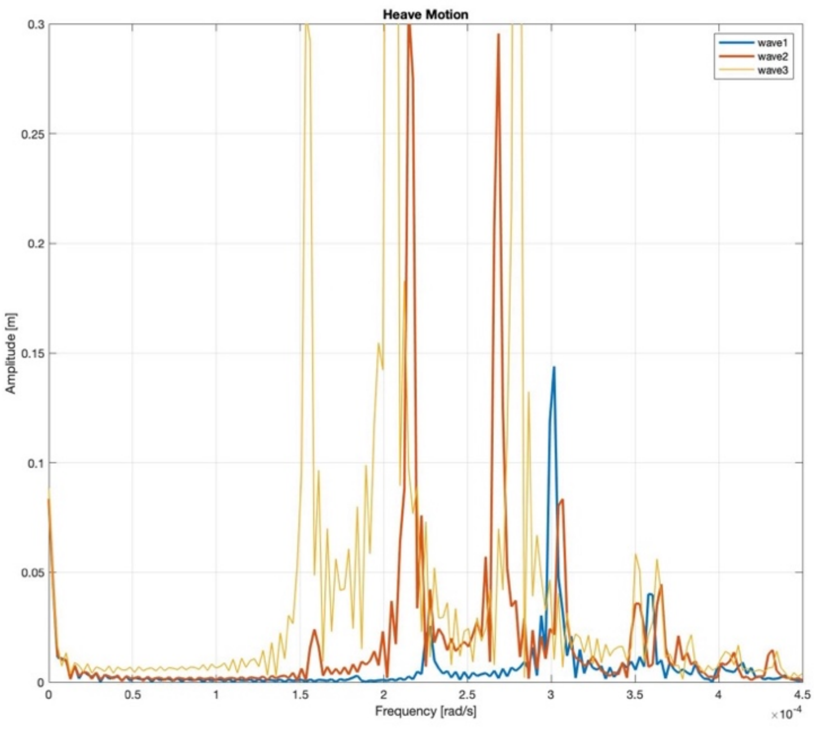


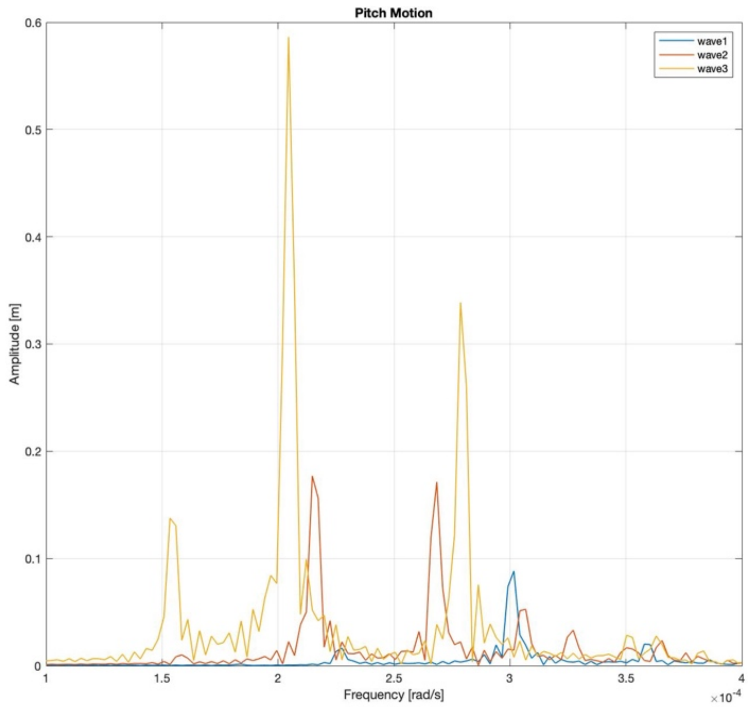
Surge 180°



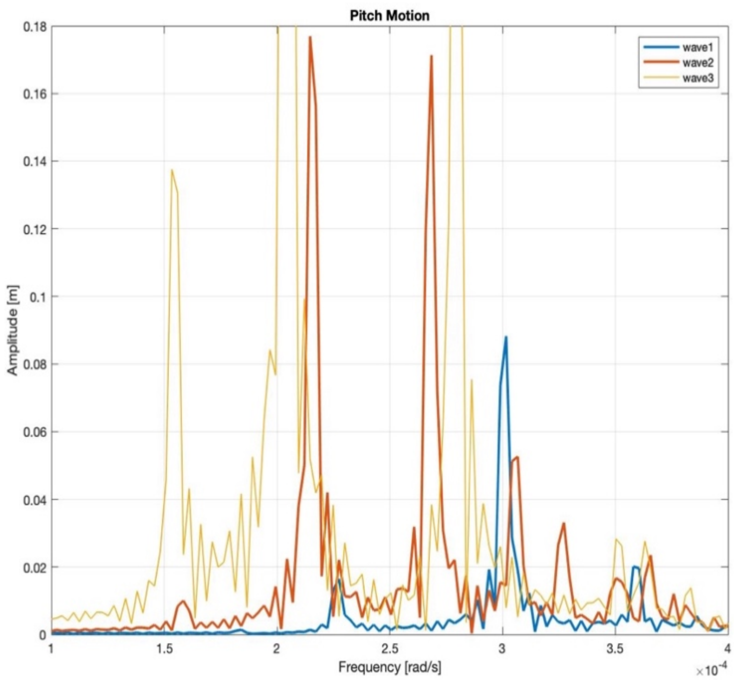

Heave Motion
wave1
wave2
wave3
Amplitude [m]
Frequency [rad/s]
$\times 10^{-4}$

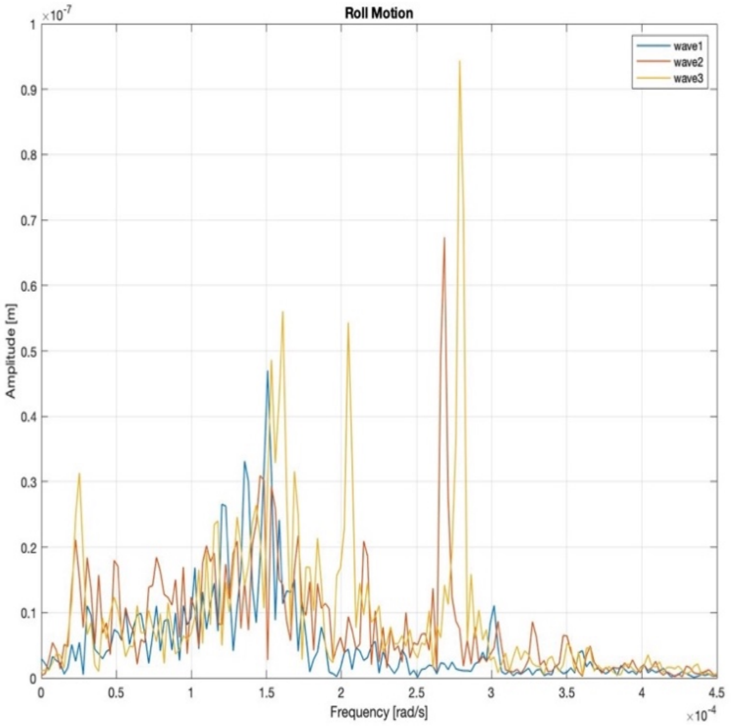
Heave 180°


Heave Motion
wave1
wave2
wave3
Amplitude [m]
Frequency [rad/s]
$\times 10^{-4}$

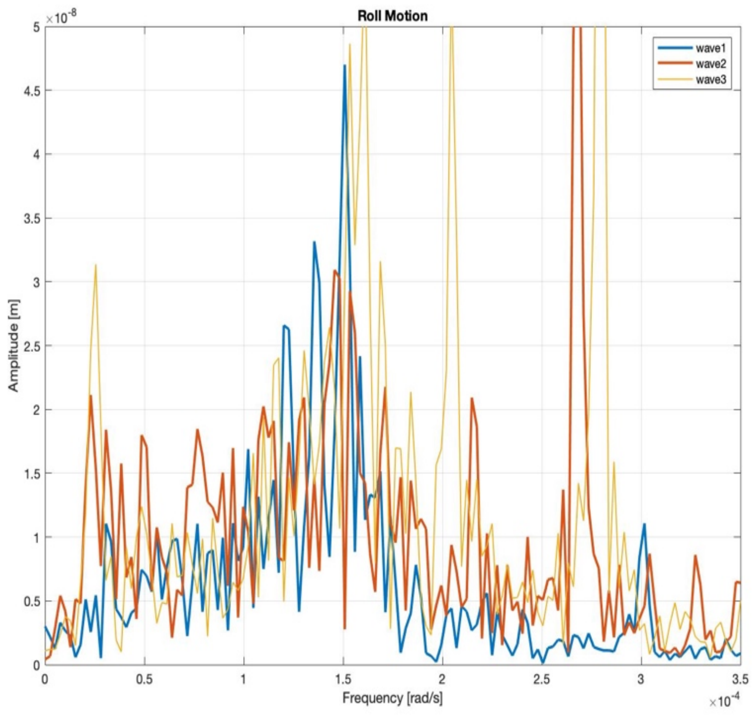

Pitch Motion
wave1
wave2
wave3
Amplitude [m]
Frequency [rad/s]
$\times10^{-4}$

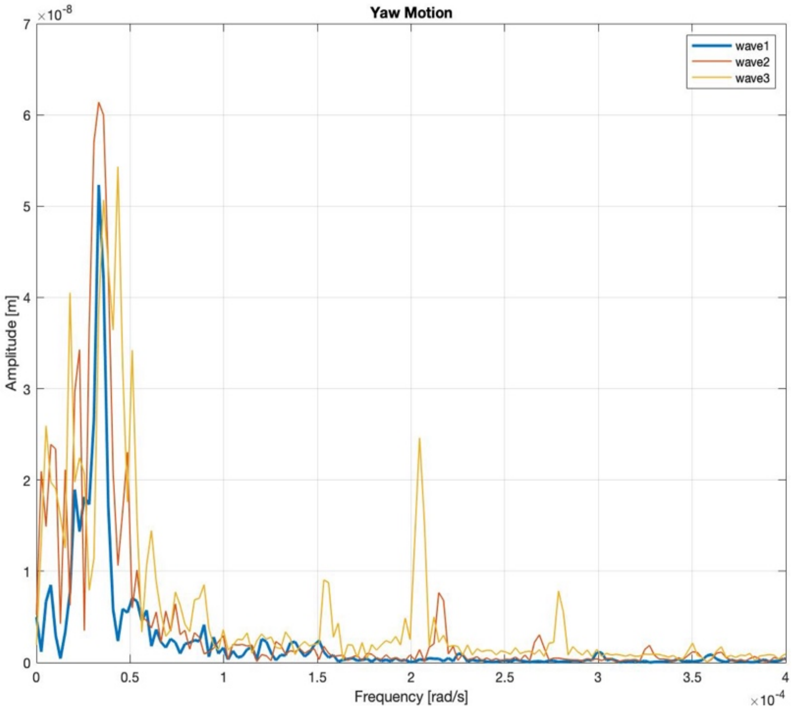
Pitch 180°


Pitch Motion
wave1
wave2
wave3
Amplitude [m]
Frequency [rad/s]
$\times10^{-4}$


Roll Motion
wave1
wave2
wave3
Amplitude [m]
Frequency [rad/s]
×10^-7
×10^-4

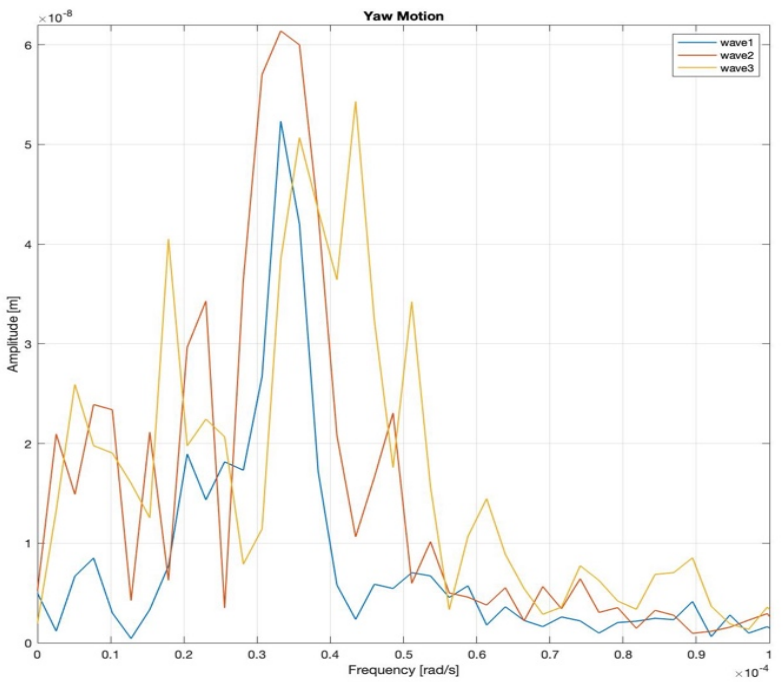
Roll 180°


Roll Motion
wave1
wave2
wave3
Amplitude [m]
Frequency [rad/s]
×10^-8
×10^-4

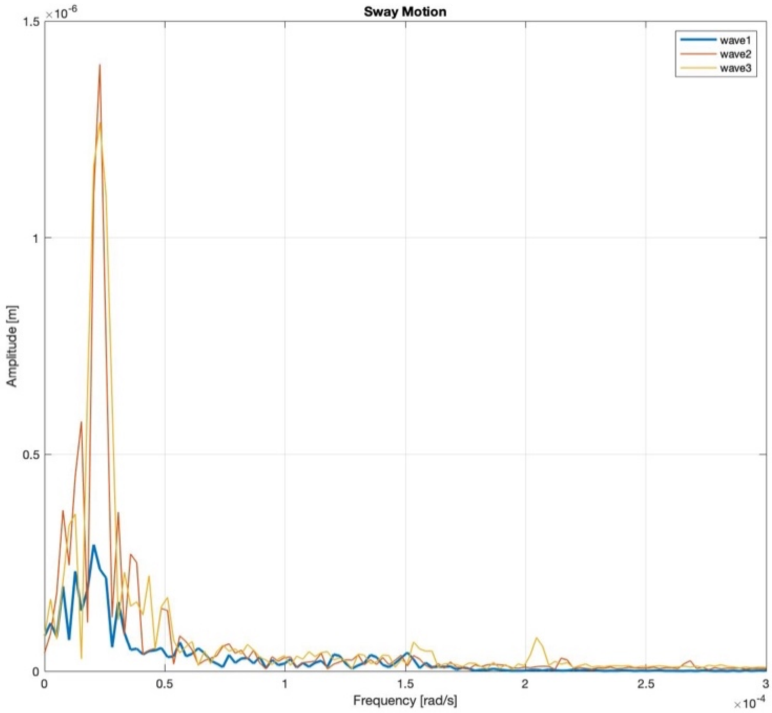


Yaw Motion
wave1
wave2
wave3
Amplitude [m]
Frequency [rad/s]

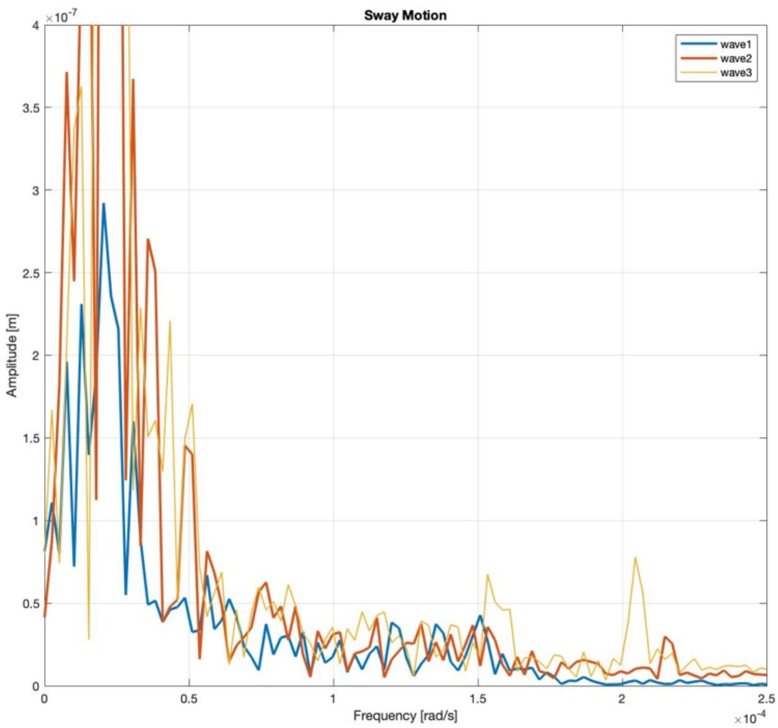
Yaw 180°



Yaw Motion
wave1
wave2
wave3
Amplitude [m]
Frequency [rad/s]


Sway Motion
wave1
wave2
wave3
Amplitude [m]
Frequency [rad/s]
×10^-6
×10^-4

Sway 180°


Sway Motion
wave1
wave2
wave3
Amplitude [m]
Frequency [rad/s]
×10^-7
×10^-4

3.Analysis and conclusion

The investigation of the reactions of floating bodies in various sea conditions is critical for understanding the loads operating on the structure, maintaining its operational integrity, and devising methods to mitigate the consequences.

It was possible to comprehend the significance of estimating the natural frequency of the body in order to avoid similar sea conditions that might cause structural harm. Floating bodies exhibit considerable movements when oscillating near their natural frequency. This might be minimized by damping, the effect that absorbs energy, causing the displacement to be less and decrease faster. If the RAOs are taken into account, they will peak at a distinct value for each wave direction, lowering the chance of resonance.

Depending on the motion, the direction of the waves has a considerable impact on the response:

The most important direction for the roll motion is 90°. The RAO for roll has the maximum value at this angle, as seen in the findings. The results may have been different if a roll damping coefficient had been used. The 90° incident wave, on the other hand, would continue to be the most crucial for this motion.

In low-frequency waves, the floating body follows the wave height, hence the RAO is equal to 1 for every wave incidence direction. The ratio between the beam of the body and the wavelength is significant for the resonance at beam waves (i.e., angle of incidence of 90o).

As a result, the peak of the heave motion is greater for 90o incident waves. In terms of pitch motion, the impact of the body's asymmetry is a significant factor that alters the RAO; because the body is symmetric, the amplitude of this motion for each angle of incidence is very small.

In terms of wave spectra, the greater the significant wave height, the greater the frequency at which the spectrum achieves its maximum value. As a result, the period has an effect on the form of the wave spectrum. The impact of the shape on spectra with the same period depends only on the wave height, which is squared in the spectra equation.

As a representation of wind-generated sea waves, the spread function replicates how waves at different frequencies propagate. As previously stated, the pitch motion is mostly caused by asymmetry. Because of the symmetry, pitch motion is not important in long crested wave incidence over a symmetric body. However, depending on the spreading function, a portion of this symmetry is lost in short crested waves. As a result, the pitch motion with dispersed waves is greater.

With these results, we can see that as we increase our wave height, the amplitude peaks of our time domain response plots rise. These, however, do not rise in a linear pattern, but rather dependent on the direction of wave propagation. In this situation, when the wave height increases, movements like heave and pitch increase substantially faster than the others.
Thus, the predominant motion that is driven by the wave direction will become far more dominant when compared to the others (notice how larger the pitch motions looks for the larger wave height when compared to the original conditions).