International Journal of Advances in Engineering and Management (IJAEM)
Volume 6, Issue 09 Sep. 2024, pp: 27-41 www.ijaem.net ISSN: 2395-5252

Comparative Analysis of the Motion Behavior for an FPSO Moored in Gulf of Guinea

[1]Uchenna Azubuike Robinson, [2]Charles Ugochukwu Orji and [3]Morrison Inegiyemiema
[1,2,3]Rivers State University, Port Harcourt, Nigeria
Corresponding Author: Uchenna Azubuike Robinson

Date of Submission: 01-09-2024 Date of Acceptance: 10-09-2024

ABSTRACT: The study investigates the surge, heave, and pitch motions of the EGINA FPSO, which is moored in the deep sea and experiences head sea conditions. The research comprises a linear wave analysis of the vessel's motion utilising strip theory and Airy's wave model to calculate the hydrodynamic coefficients, response amplitude operators, and excitation forces. The modified Pierson-Moskowitz wave energy density spectrum was used in a spectral analysis based on the 100-years of storm data of the West Africa Sea shore in order to explain the roughness connectedto the normal ocean water and to predict the vessel's response.The study aims to predict and compare the motion behaviour of an FPSO operating in Gulf of Guinea using MATLAB and ORCAFLEX computer software. In both instances, it is evident that the surge RAO dramatically increased at a frequency of 0.2 Hz and tended to hold a steady peak value of unity as the wave frequencies tended towards zero.The maximum value of surge occurred at a frequency very close to 0.1Hz. The R-square value of 0.9357. In heave, the highest value is obtained at a frequency that is very close to 0 Hz in both cases. While MATLAB's top value was 1 m/m, ORCAFLEX's reached 1.2 m/m; still, both charts show similar tendencies. MATLAB appears to have correctly accounted for 95% of the results generated by the ORCAFLEX tool, with an R-square score of 0.9498.Pitch responses grows quickly to reach the maximal value of 1.6 deg/m as the frequency gets closer to 0 Hz. Because there are several crest and trough, the waves can no longer affect the FPSO's pitch motion in the low frequency area, where frequency is less than 0.5Hz. The MATLAB has appropriately accounted for 83.9% of the findings produced by the ORCAFLEX tool, according to the R-square value of 0.8387.

Furthermore, as demonstrated by the descriptive statistics results in Tables 3, 4, and 5, the average response in a surge was 0.0841 m/m for ORCAFLEX and 0.074 m/m for MATLAB, with a percentage variation of ±11.8%. The standard deviation was 0.2229 m/m for ORCAFLEX and 0.1996 m/m for MATLAB, with a percentage variation of ±12.1%. The coefficient of skewness was 2.9173 for MATLAB and 3.1252 for ORCAFLEX, with a percentage variation of 7.7%. The average response in heave is 0.0967 m/m from ORCAFLEX and 0.1017 m/m from MATLAB, with a variance of ±10.7% in percentage. The coefficient of skewness is 2.763 and 2.747, respectively, with a percentage fluctuation of ±1.03%, and the standard deviation is 0.2497 m/m for ORCAFLEX and 0.2585 m/m for MATLAB. Regarding pitch, the mean response obtained from ORCAFLEX and MATLAB is 0.1867 degrees/meter and 0.2052 degrees/meter, respectively, with a percentage variation of 9.9%. The standard deviation for both ORCAFLEX and MATLAB is 0.3356 degrees/meter and 0.2999 degrees/meter, respectively, with a percentage variation of 10.7%. The coefficient of skewness is 2.6955 and 2.9107, respectively, with a percentage variation of 7.07%.

KEYWORDS: FPSO, Heave, Pitch, Surge, MATLAB, ORCAFLEX, RAO, Response

I. INTRODUCTION:

Ship-shaped offshore units have shown to be a rather dependable option for deep-sea offshore fields throughout this period of the last 4 decades. These comprise FPSOs and FSOs that operate in challenging environments and in oceans deeper than 1500 meters. Although shuttle tanker-mooring facilities and oil storage facilities employing repurposed trading tankers were present in the late 1960s, it is unclear when ship-shaped units first entered the offshore sector.

Now that floating production systems have developed into a mature technology, as opposed to their early days, this could allow the development of offshore oil and gas deposits that would otherwise be unfeasible or prohibitively expensive to access. Production is now possible much more than the sea-depth limitations of immovable offshore platforms thanks to technology, which also offers a flexible way to develop short-lived fields with marginal reserves and fields in remote areas where it would be challenging to establish a fixed facility.

[1]contrasted the findings of the coupled and uncoupled analyses for a tethered FPSO in hostile locations and they recommended using the uncoupled analysis results early in the mooring mechanism's development stage. Though the maximum values varied, there was a fair amount of agreement between the uncoupled and coupled analytical results; however,[2] proved the necessity of considering coupling effects between FPSO hull and mooring lines as well as the influence of viscous damping. [2] neglected the inertia and damping impact of mooring lines in favour of a thorough investigation of computer models of a turret-moored FPSO in variable swells with storms and winds.

The reaction of a ship-shaped vessel can be greatly affected by quartering or beam seas, which are occasionally caused by waves, winds, and currents that are highly non-parallel. Apart from knowing the wave loads acting on the structure, one must also know how the structure moves in order to calculate the stress distribution on it. The spread mooring unit helps maintain the FPSO's position in an entire coordinate during clear-sky circumstances, while the turret mooring unit helps arrange the mooring cables optimally under adverse atmospheric conditions to prevent additional damage to the ropes [3]

While[4] focused on the FPSO responses motion in many mild environmental conditions with a 100-year period of return,[5] considered prolonged FPSO responses as meticulous when compared to different sea conditions. [6] examined the modified configuration approaches for FPSO and re-examined the dependability of the mooring arrangement of an existing FPSO in West Africa using field meteorological conditions.

Problem Statement: The necessity of looking at an FPSO's motion response has raised questions and concerns over the years. This has prompted a number of academics to conduct research in this field, with the goal of eventually producing practical operational data that businesses and operators may use. Even with this set of studies on motion response, more research on the subject is still required, particularly in the Gulf of Guinea where it will be easier for anyone who want to construct or run an FPSO there to acquire the findings. This study used MATLAB programming and ORCAFLEX to examine how the FPSO responded to an external force. A comparative study was conducted to verify the accuracy of the outcomes in each scenario.

AIM: The study aims to predict and compare the motion behaviour of an FPSO operating in Gulf of Guinea using MATLAB and ORCAFLEX computer software.

II. MATERIALS AND METHODS

A. MATERIALS: With the realm of simulating marine and offshore structures' response to environmental forces, ORCAFLEX stands as a special software solution to perform response analysis, offering extensive array of features. ORCAFLEX primary focus is on static and dynamic analysis; particularly concerning how marine structure reacts to diverse environmental conditions encompassing the effects of wave load, currents and winds.

We are able to ascertain the response characteristics for each ORCAFLEX result because to its spectral analysis capacity. This feature uses a random wave time domain simulation as the basis for the calculation, yet it yields results similar to a frequency domain solver. After utilising a fast Fourier transform (FFT) to convert the simulation output into the frequency domain, the spectral response is computed. The analysis's final conclusion is the response amplitude operator (RAO) for the desired outcome.

The Gulf of Guinea's sea state characteristics are shown in the table below. Wave period and significant wave height (Hs) and (Ts) determine characteristics. The return period features must be considered while examining the motion response of the FPSO in the chosen degree of freedom. The different sea spectrum representative models and the return period spanning the last 100 years will be employed. An acceptable range of wave frequencies will be used in the analysis.

Table 1: Wave Parameter [7]

A wave frequency range of 0.01rad/s to 2.51rad/s was chosen to be used. The fact that wave spectra containtiny bands, a regular distribution, and are not overly broad suggests this[8].

The analysis in this study will be conducted using the Egina FPSO features, The largest FPSO in the Gulf of Guinea, with a capacity of 2.3 million barrels. It is located about 200 kilometres off the coast of Port Harcourt, Nigeria, at a depth of 2200 meters in the water. The parameters of the FPSO are displayed in Table 2 below.

Table 2: FPSO Particular[9]

Properties	**Full Load Condition**	**Unit**
Length, L_{OA}	330.00	M
Breadth, B	61.00	M
Depth, D	33.50	M
Equivalent Level Keel Draft, T	25.80	M
Mass Displacement, M	499155.60	Tonnes
Centre of Gravity Above Baseline (CG) x, y&z	170.48, 0.00 and 19.98	M
Transverse Metacentric Height	5.63	M
Roll Inertia	22.37	m^4
Pitch Inertia	88.27	m^4

METHODS: The sea bottom and free-surface conditions are used to calculate the velocity along with the Laplace equation possibilities for head wave propagation Thus, the profile displayed as:

(1)

The deep-water dispersion characteristics is obtained as:

(2)

Using the parameter of motion of water particle, we have;

vertical particle velocity is:

(3)

The derivative of equation (3) gives the vertical particle acceleration as;

(4)

The dynamic pressure of waveis given as:

(5)

In 6-DOF, motion equation is defined as;

(6)

Surge Force and RAO: The equation for surge motion is given as;

(7)

To properly solve the equation, we must ascertain the hydrodynamic coefficients of added mass, stiffness, and surge exciting force.

The Froude-Krilov Force is out of phase with the acceleration of added mass force in the surge mode of motion. Algebraically adding them together would be erroneous. The surge excitation force amplitude, F_1, is typically regarded to be roughly equal to the amplitude of the Froude-Krilov (pressure force), as given in Equation (7) because the extra mass force is relatively small in comparison to the Froude-Krilov force, especially within the relevant frequency range.

(8)

Therefore, theResponse Amplitude Operator in surge, RAO_1, is:

(9)

The stiffness matrix components; C_{11} is defined as:

(10)

Where the surge magnification factor; is,

(11)

Surge natural frequency is given as;

(12)

(13)

damping factor and this have a range of value of; .

The surge response is provided as follows because a harmonic load typically results in a response of the same harmonics and type:

(14)

From equation (14), we can obtain the response velocity and acceleration as follows:

(15)

(16)

The product of the vessel's static displacement and magnification factor yields the response amplitude. Thus,

(17)

We can write the linear acceleration RAO as:

(18)

Heave Force and RAO: The equation for heave motion is given as;

(19)

The sum of the increased mass forces (dF_3) and pressure (Froud-Krylov) on each ship frame strip throughout the length of the vessel equals the overall heave force. Consequently, (20)

Added mass in 2-dimension for heave is given as:

(21)

[10] derived the added mass coefficient for a rectangular-shaped vessel as:

(22)

Thus, the heave force amplitude is:

(23)

From equations (14), (15) and (16), we have

(24)

And the magnification factor in factor in heave is defined as:

(25)

While in heave,

(26)

Hence, the Response Amplitude Operator in heave motion is defined as the heave response amplitude per wave amplitude and it can be expressed as:

(27)

(28)

Referring to the 17th equation containing the response in terms of acceleration, the RAO of the linear acceleration can be written as:

(29)

Pitch Moment and RAO: The equation for pitch motion is given as;

(30)

The total product of the heave forces and their trimming arms across the vessel's length is the pitch moment. On the 2-D strips, the pitch moment would be:

(31)

After expanding and simplifying the terms, the pitch moment is obtained as:

(32)

(33)

The pitch moment amplitude is thus written as:

(34)

Where is the lever arm of the pitching moment and it can be obtained as is defined as;

(35)

Just as the case of the heave, the pitch response has been defined as;

(36)

Hence, the Response Amplitude Operator in pitch is then given as;

(37)

Where the magnification factor in pitch has been obtained as;

(38)

And;

(39)

Where pitch natural frequency is given as;

(40)

And; (41)

(42)

Spectral Analysis: A spectral analysis with a suitable wave spectrum will be performed to investigate the FPSO's motion response in a realistic sea state. A response spectrum, which is the square of the response amplitude operator and

the product of the wave spectrum, would be the result of the study. The FPSO will use the Gulf of Guinea for all hydrodynamic assessments. For the Gulf of Guinea, a modified Pierson-Moskowitz wave spectrum—appropriate for analysing an open sea—will be used. This spectrum is provided with the zero up-crossing period and significant wave height indicated.
as:

(43)

Wave Spectral and Surge Motion: According to [11], the following is the relationship between the spectral density of the wave and the ship responses:

(44)

The response spectral of the nth moment is given as;

(45)

Considering equations (44) and (18) we can define the surge response spectrum as;

(46)

The zeroth moment of surge , (at is the area enclosed by the surge spectrum curve and given by;

(47)

The following is the most likely maximum surge amplitude:

(48)

Wave Spectral and Heave Motion: In the same way, for heave response spectrum we can define it as;

(49)

The heave zeroth moment , is;

(50)

And the most likely highest heave amplitude is;

(51)

Wave Spectral and Pitch Motion: Also, we can define the pitch response spectrum as;

(52)

The pitch zeroth moment , is;

(53)

And the most likely highest pitch amplitude is;

(54)

Numerical Development Using ORCAFLEX: A mooring and Wave Energy Converter (WEC) dynamic solver is ORCAFLEX from Orcina. This section only addresses the dynamic solver. One of the most widely used programs in the offshore industry is ORCAFLEX. Using the data previously mentioned in Tables 1 and 2, the model has been constructed on an experimental scale. Figure 1 and 2 below shows the FPSO model setup and the data input interface for simulation respectively.

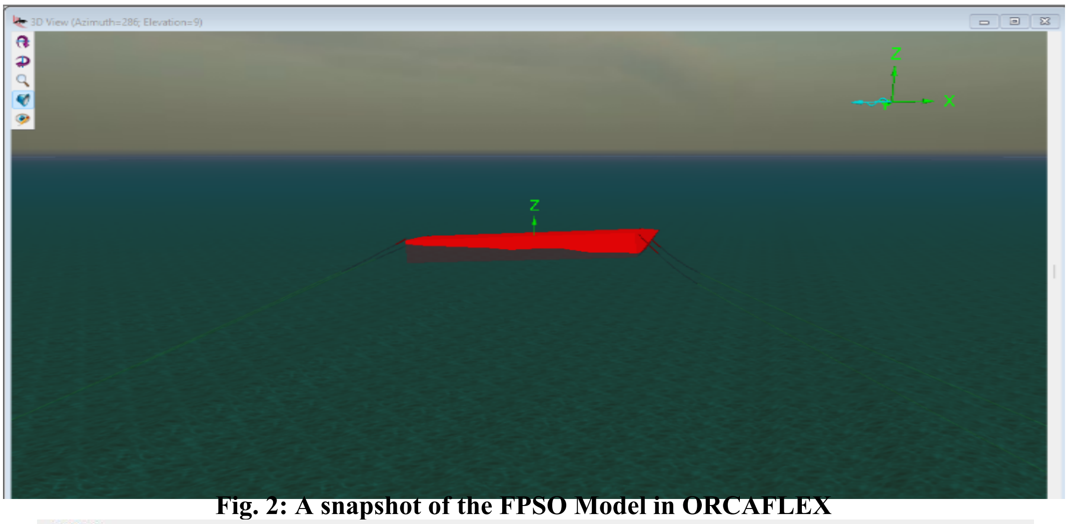
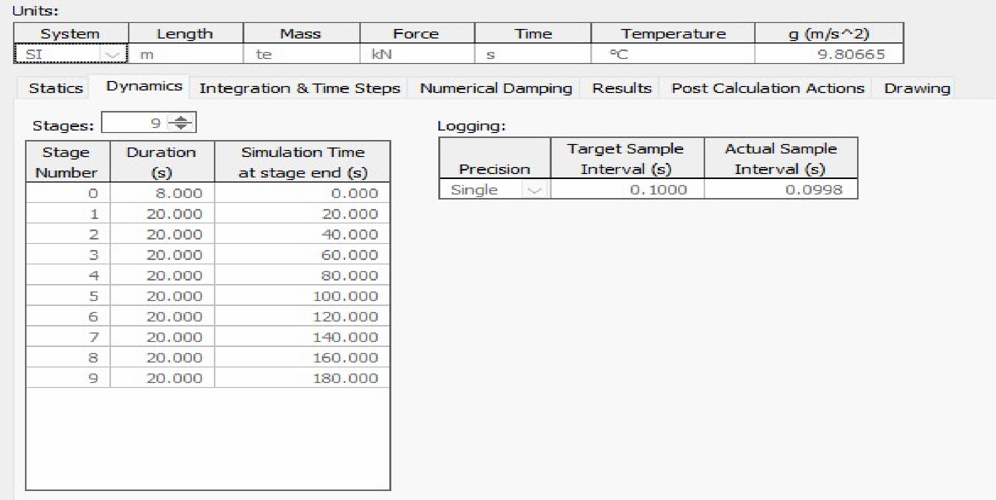


Fig. 2: A snapshot of the FPSO Model in ORCAFLEX



Units:

System	Length	Mass	Force	Time	Temperature	g (m/s^2)
SI	m	te	kN	s	°C	9.80665

Stages: 9

Stage Number	Duration (s)	Simulation Time at stage end (s)
0	8.000	0.000
1	20.000	20.000
2	20.000	40.000
3	20.000	60.000
4	20.000	80.000
5	20.000	100.000
6	20.000	120.000
7	20.000	140.000
8	20.000	160.000
9	20.000	180.000

Logging:

Precision	Target Sample Interval (s)	Actual Sample Interval (s)
Single	0.1000	0.0998

Fig. 3: Data Input Interface

III. RESULTS AND DISCUSSION

Mooring Analysis: The diagram below in figure 3 depicts the bending moment behaviour of the lines used to secure the floater against the sea environmental forces. As can be seen in the diagram, the floater was secured using four mooring lines. Line 1 and 2 shows a similar trend while line 3 and 4 shows similar trend this is because they are grouped in that order for forward and aft. The results show that the allowable bending moment for line 1 and 2 are within the limits of 0.0004kNm to 0.0005kNm while that of line 3 and 4 are staggering around 0.0005kNm. Also, the maximum bending moment for line 1 and 2 are respectively 0.0015kNm and 0.0011kNm while for line 3 and 4, we have 0.0025kNm and 0.0027kNm respectively.

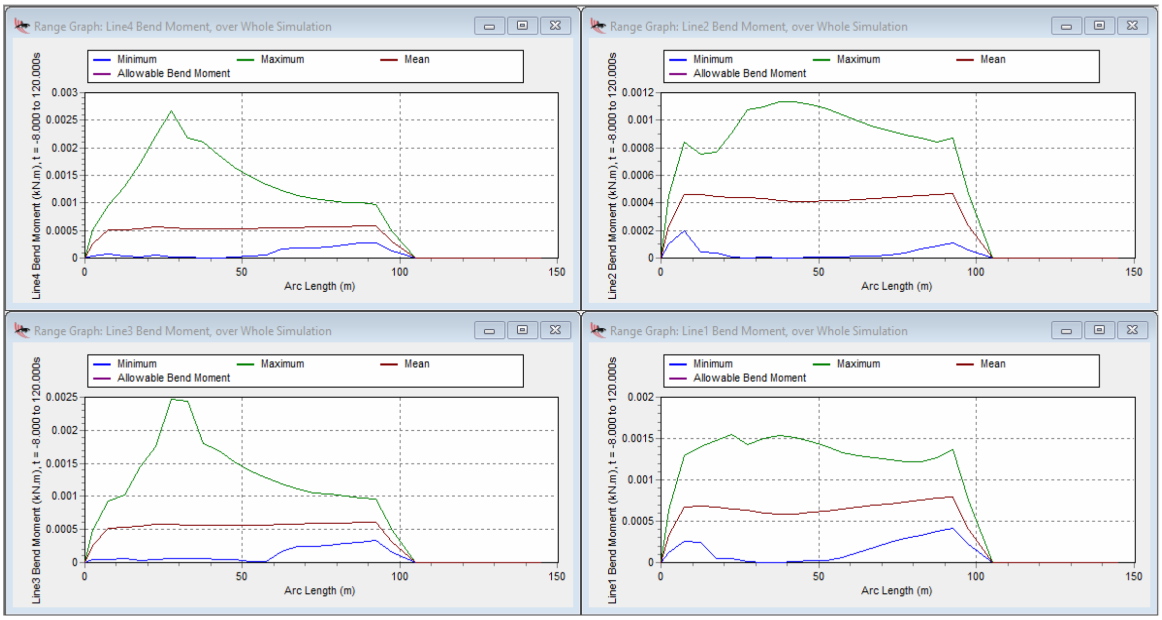


Fig. 3: Line Bending Moment in head sea

Surge Response: The Heave RAO for the FPSO in the Head Sea is compared to that from ORCAFLEX in Figures 4 and 5. The MATLAB software developed in this work is validated by ORCAFLEX for the purpose of determining the RAOs in the Head Sea when the FPSO responds to a sinusoidal wave. It can be observed for both cases that the surge RAO increased significantly at a frequency of 0.2Hz and moves to continue with a steadymaximum value of unity as the wave frequencies tends to zero. The maximum value of surge occurred at a frequency very close to 0.1Hz.

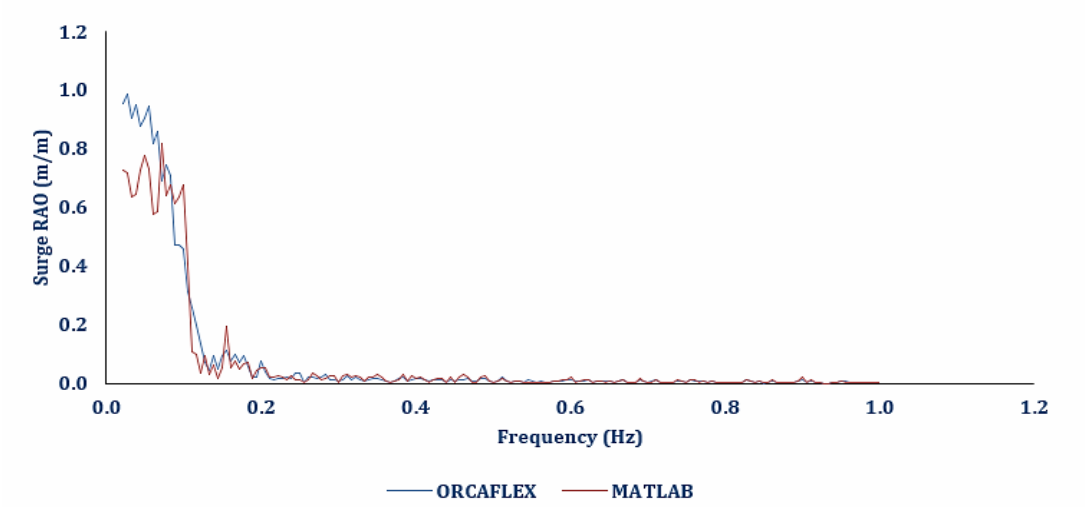


Fig. 4: Comparison of MATLAB and ORCAFLEX Surge RAO

In general, the predictions produced by ORCAFLEX and the MATLAB source code agree. This implies that the suggested model may predict the RAO of surge in head seas, especially at low frequencies. An R-square value near unity is another sign of a strong model for additional research.

It is evident that in both situations, a peak response is reached at a frequency that is extremely near to 0 Hz. This implies that the suggested model may predict the RAO of pitch in head seas, especially at low frequencies. With an R-square score of 0.9357, MATLAB appears to have appropriately accounted for 93.6% of the results produced by the ORCAFLEX tool.

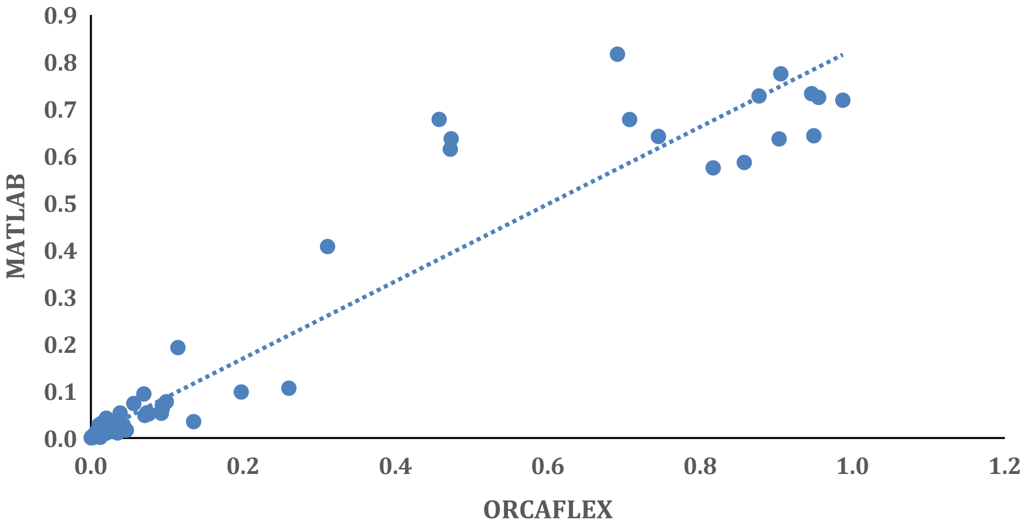


Fig. 5: Scatter plot of MATLAB and ORCAFLEX SURGE RAO

Table 3 displays the findings of the descriptive statistics analysis conducted on surge responses. It is evident that the average surge response measured by ORCAFLEX is 0.0841 m/m, while the MATLAB measurement is 0.074 m/m. We can see that there is some variation in the data response that solvers projected due to these closed values. The variance came to a variation of ±11.8%, a percentage that is often appropriate for analysis.

Table 3: Descriptive Statistical Results for Surge RAO

Surge RAO (m / m)	ORCAFLEX	MATLAB	% Variation
Mean	0.08419774	0.074254802	-11.8090317

Standard Error	0.016756819	0.014217695	-15.1527843
Median	0.0093	0.0097	4.301075269
Mode	0.0041	0.005	21.95121951
Standard Deviation	0.222934982	0.199654125	-12.1527843
Sample Variance	0.049700006	0.035779283	-28.0094999
Kurtosis	8.501360159	6.916230595	-18.6455995
Skewness	3.125228281	2.917267276	-6.65426605
Range	0.9868	0.8161	-17.2983381
Minimum	0.0005	0.0004	-20
Maximum	0.9873	0.8165	-17.2997063
Sum	14.903	13.1431	-11.8090317
Count	177	177	0
Largest(1)	0.9873	0.8165	-17.2997063
Smallest(1)	0.0005	0.0004	-20
Confidence Level(95.0%)	0.033070159	0.028059109	-15.1527843

Furthermore, another statistical outcome that shows us how close our results are to the mean value is the standard deviation. The data points cluster closer to the mean when the standard deviation is less. In other words, the values in the dataset are strongly correlated. It is possible to conclude that the data result, which is clustering around the mean, is consistent based on the standard deviation, which has values of 0.2229 m/m and 0.1996 m/m for both ORCAFLEX and MATLAB. The percentage variance is ±12.1%.

A distribution is also said to be skewed visually if the mean and median fall at different points in the distribution and the balance is moved to the left or right. Figure 4 shows that on the high-value end of the curve, or the right side, the data set is distributed over a wider range of values. The research conducted in MATLAB and ORCAFLEX shows that the surge RAO has a percentage fluctuation of ±6.7% and a positively skewed coefficient of skewness of 2.9173 and 3.1252 correspondingly.

This outcome demonstrates that there is little overlap between the two curves' looks and shapes. As seen by the percentage variance, they so generally follow the same trend for both Orcaflex and MATLAB with little deviation.

Heave Response: The MATLAB software developed in this study to determine the RAOs in Head Sea when the FPSO responds to a sinusoidal wave is validated by the ORCAFLEX. Figures 6 and 7 present a comparison between the Heave RAO obtained by ORCAFLEX and MATLAB software for the FPSO located in the Head Sea.

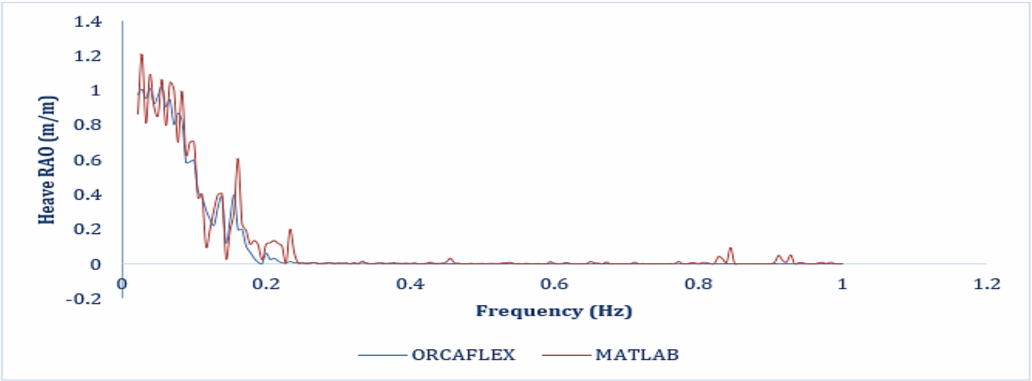


Fig. 6: Comparison of MATLAB and ORCAFLEX Heave RAO

In general, the predictions produced by ORCAFLEX and the MATLAB source code agree. This implies that the suggested model may predict the RAO of heave in head seas, notably at small frequencies.

It is evident that in both situations, the peak value is reached at a frequency that is extremely near to 0Hz. Despite the fact that ORCAFLEX reached a peak value of 1.2 m/m while MATLAB reached a peak value of 1 m/m, both plots display comparable tendencies. This implies that the suggested model may predict the RAO of heave in head seas, notably at small frequencies. With an R-square value of 0.9498, MATLAB appears to have appropriately accounted for 95% of the results produced by the ORCAFLEX tool

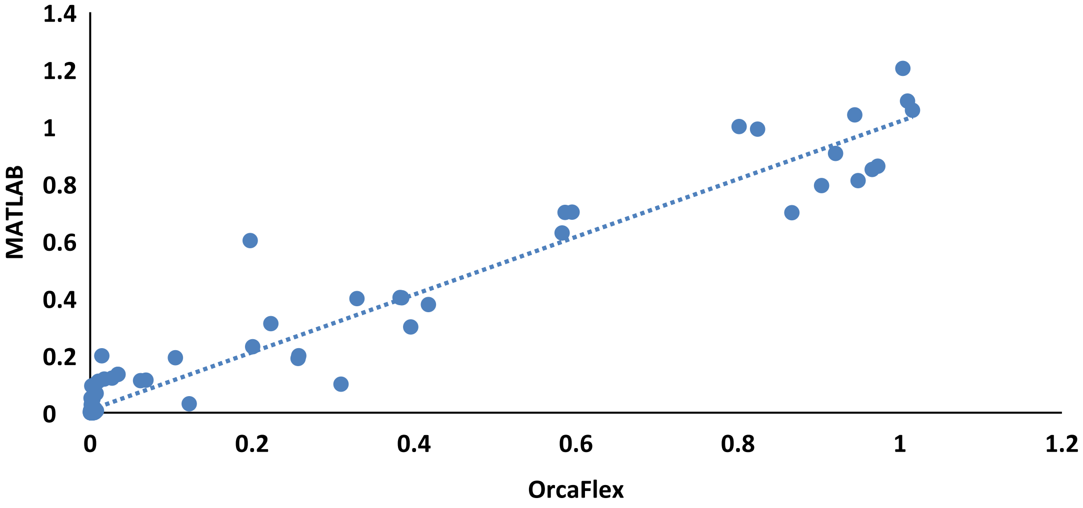


Fig. 7: Scatter plot of MATLAB and ORCAFLEX Heave RAO

The responses were analysed using descriptive statistics, as shown in table 4 for heave.

It is evident that the average heave response from ORCAFLEX is 0.0967 m/m, while the average heave response from MATLAB is 0.1017 m/m. We can see that the data response that solvers expected has some fluctuation due to these closed values. Thediscrepancy came to a variation of ±10.7%, which is generally appropriate for analysis.

Table 4: Descriptive Statistical Results for Heave RAO

	Heave RAO (m / m)		
	ORCAFLEX	MATLAB	% Variation
Mean	0.096724459	0.107159504	10.788425
Standard Error	0.018769159	0.019426834	3.5040246
Median	0.002334046	0.002524897	11.144727
Mode	#N/A	#N/A	#N/A
Standard Deviation	0.249707413	0.258457222	3.5040246
Sample Variance	0.062353792	0.066800136	7.1308311
Kurtosis	6.427968386	6.507676913	1.2400267
Skewness	2.763248211	2.734730362	-1.0320408
Range	1.015269897	1.203553592	18.545186
Minimum	0.000203467	0.000009287	-95.435623
Maximum	1.015473364	1.203562879	18.522348
Sum	17.12022918	18.96723221	10.788425
Count	177	177	0
Largest(1)	1.015473364	1.203562879	18.522348
Smallest(1)	0.000203467	0.000009287	-95.435623
Confidence Level(95.0%)	0.03704158	0.038339526	3.5040246

Furthermore, another statistical outcome that shows us how close our results are to the mean value is the standard deviation. The data points cluster closer to the mean when the standard deviation is less. In other words, the values in the dataset are strongly correlated. Based on the standard deviation, which is presented in table 4 and has values of 0.2497 m/m and 0.2585 m/m for both MATLAB and ORCAFLEX, respectively, and a percentage variation of ±3.5%, it can be inferred that the data results, which cluster around the mean, are consistent. Additionally, a distribution is considered skewed visually when the mean and median fall at opposite points in the distribution and the balance is shifted to the left or right. The data set is dispersed over a wider range of values on the high-value end of the curve, or the right side, as shown in Figure 6. The analysis in appendix F for both MATLAB and ORCAFLEX shows that the RAO in heave is positively skewed, with a percentage variation of ±1.03% and a coefficient of skewness of 2.763 and 2.747, respectively. This outcome demonstrates that there is little overlap between the two curves' looks and shapes.

Pitch Response: Additionally, the pitch RAO from ORCAFLEX and the MATLAB program are contrasted in Figures 8 and 9. As demonstrated in the figures below, the predictions produced by ORCAFLEX and the MATLAB source code often agree.

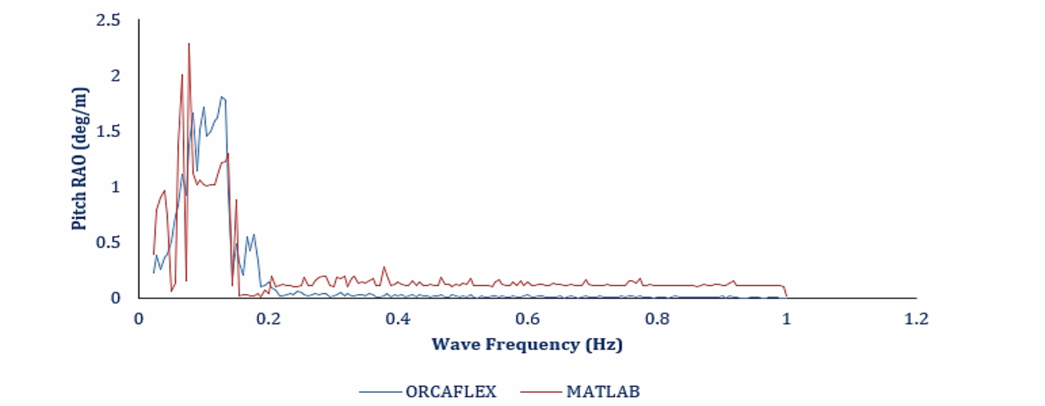


Fig. 8: Comparison between MATLAB and ORCAFLEX Pitch RAO

Even though the charts' peaks rise and fall slightly differently, it is still possible to see that the graphs exhibit a striking similarity in behaviour. It is evident that in both situations, resonance is reached at a frequency extremely near to zero. This implies that the suggested model may predict the RAO of pitch in head seas, especially at low frequencies. With an R-square score of 0.8387, MATLAB appears to have appropriately accounted for 83.9% of the data produced by the ORCAFLEX tool.

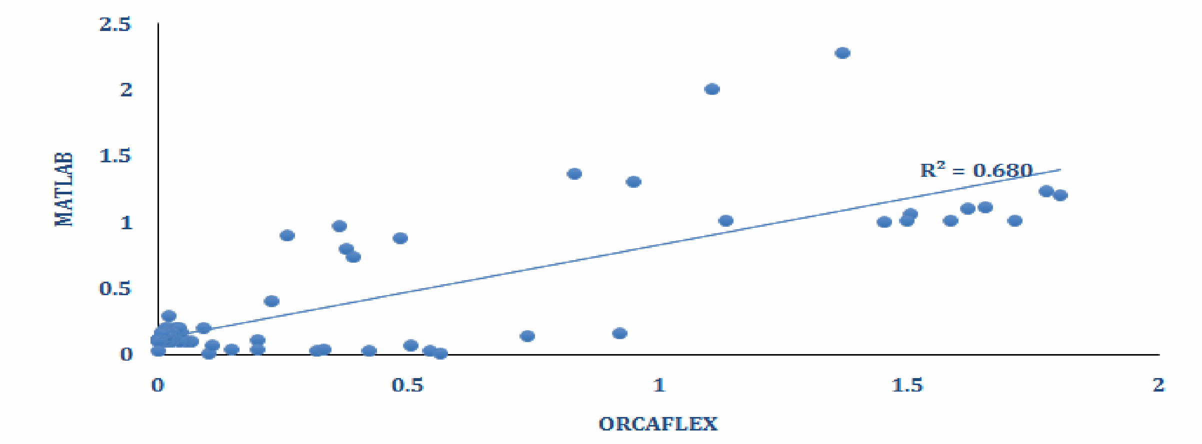


Fig. 9: A Scatter plot of MATLAB and ORCAFLEX Pitch RAO

It is evident from the examination of the responses using descriptive statistics, as shown in table 5 for pitch that the average pitch response from ORCAFLEX is 0.1867 deg/m and that from MATLAB is 0.2052 deg/m. We can see that there is some variation in the data response that solvers predicted due to this closed value. With an average allowable variation of ±9.9%, the difference was found to be suitable for analysis.

Furthermore, another statistical outcome that shows us how close our results are to the mean value is the standard deviation. The data points cluster closer to the mean when the standard deviation is less. In other words, the values in the dataset are strongly correlated. Based on the standard deviation, which is displayed in Table 5 with values of 0.3356 deg/m and 0.2999 deg/m for MATLAB and ORCAFLEX, respectively, and a percentage variation of ±10.7%, it can be inferred that the data results are consistent in that they cluster around the mean.

Table 5: Descriptive Statistical Results for Pitch RAO

Pitch RAO (m / m)	ORCAFLEX	MATLAB	% Variation
Mean	0.186726033	0.205230435	9.909920814
Standard Error	0.030267361	0.022384436	-26.04431142
Median	0.208953782	0.1870809	-10.46780862
Mode	#N/A	#N/A	#N/A
Standard Deviation	0.335681054	0.299905546	-10.6575892
Sample Variance	0.162152031	0.088688143	-45.30556127
Kurtosis	7.455651734	6.462864009	-13.31590799
Skewness	2.900710062	2.695506182	-7.074263735
Range	1.803043759	1.5779113	-12.48624488
Minimum	0.000814932	0.0019112	134.522635
Maximum	1.803858691	1.5798225	-12.41983045
Sum	29.60507844	36.325787	22.70120166
Count	177	177	0
Largest(1)	1.803858691	1.5798225	-12.41983045
Smallest(1)	0.000814932	0.0019112	134.522635
Confidence Level(95.0%)	0.059733679	0.044176453	-26.04431142

A distribution is also seen as skewed in terms of how it appears when the mean and median fall at different points in the distribution and the balance is moved to the left or right. The data set is more widely distributed on the high-value end of the curve (i.e., the right side), as seen in Figure 8. The analysis in table 5 for both MATLAB and ORCAFLEX shows that the pitch RAO has a percentage fluctuation of ±7.07% and a positive skewness, with coefficients of skewness of 2.6955 and 2.9007, respectively. This outcome demonstrates that there is little overlap between the two curves' looks and shapes.

IV. CONCLUSION:

Our comprehension of responses under irregular sea conditions has greatly increased as a result of the research, which also provides a reasonable perspective on the study of maritime and ocean engineering. Utilising ORCAFLEX software to analyse the dynamic response of the FPSO and derive surge, heave, and pitch RAO, as well as benchmarking the developed algorithm against the ORCAFLEX results, was our approach to investigating the dynamic response of an FPSO numerically and developing a coded solution algorithm.

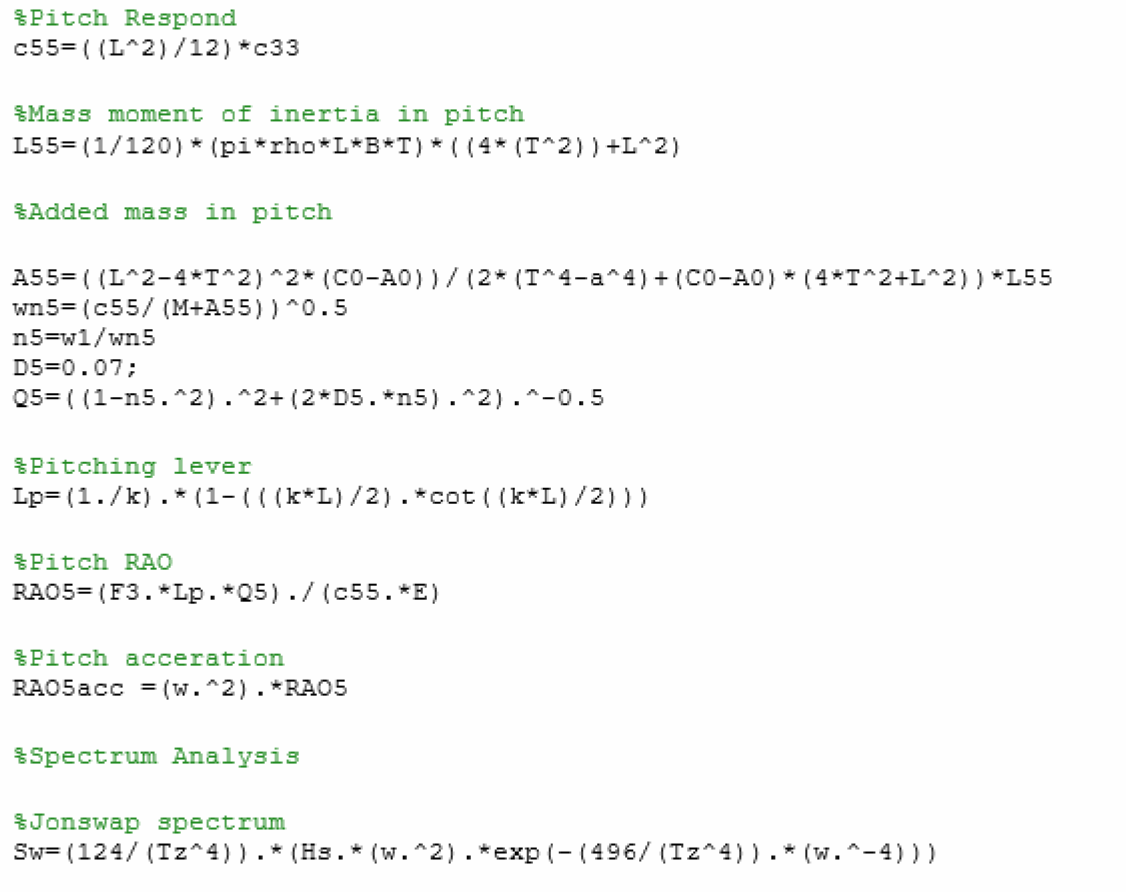
Our study's backdrop was established by the creation of MATLAB, a program used for analysis. With the use of the relevant formulas and the Modified Pearson-Moskowitz spectrum, we were able to precisely construct the producing surge, heave, and pitch RAO.

It was observed that for both cases that the RAO in surge increased significantly at a frequency of 0.2Hz and moves until it maintained a steady peak value of unity as the wave frequencies tends to zero. The maximum value of surge occurred at a frequency very close to 0.1Hz. The R-square value of 0.9357 suggest that 93.6% of the results generated by ORCAFLEX tool has been properly accounted for by the MATLAB. In heave, the highest value is obtained at a frequency that is very close to 0 Hz in both cases. While MATLAB's top value was 1 m/m, ORCAFLEX's reached 1.2 m/m; still, both charts show similar tendencies. This suggests that the proposed model, especially at low frequencies, would be able to forecast the RAO of pitch in head seas. MATLAB appears to have correctly accounted for 95% of the results generated by the ORCAFLEX tool, with an R-square score of 0.9498.Pitch responses are larger at frequencies near resonance. The motion equation's damping term dominates the resonance area. The reaction grows quickly to reach the maximal value of 1.6 deg/m as the frequency gets closer to 0 Hz. Because there are several crest and trough, the waves can no longer affect the FPSO's pitch motion in the low frequency area, where frequency is less than 0.5Hz. This implies that the suggested model may predict the RAO of pitch in head seas, notably at a very small frequencies. The MATLAB has appropriately accounted for 83.9% of the findings produced by the ORCAFLEX tool, according to the R-square value of 0.8387.

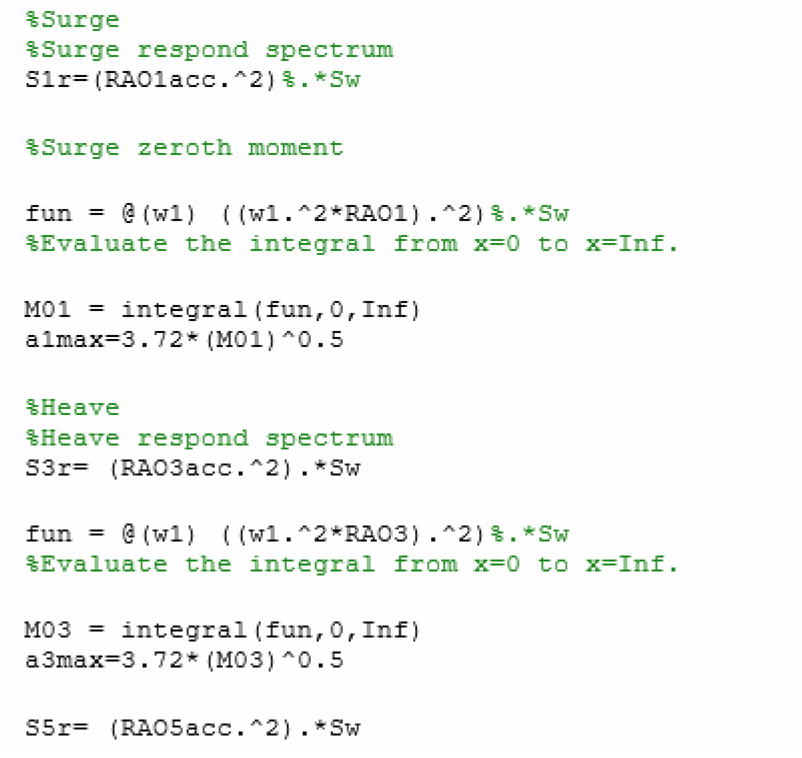
Furthermore, as demonstrated by the descriptive statistics results in Tables 3, 4, and 5, the average response in a surge was 0.0841 m/m for ORCAFLEX and 0.074 m/m for MATLAB, with a percentage variation of ±11.8%. The standard deviation was 0.2229 m/m for ORCAFLEX and 0.1996 m/m for MATLAB, with a percentage variation of ±12.1%. The coefficient of skewness was 2.9173 for MATLAB and 3.1252 for ORCAFLEX, with a percentage variation of 7.7%. The average response in heave is 0.0967 m/m from ORCAFLEX and 0.1017 m/m from MATLAB, with a variance of ±10.7% in percentage. The coefficient of skewness is 2.763 and 2.747, respectively, with a percentage fluctuation of ±1.03%, and the standard deviation is 0.2497 m/m for ORCAFLEX and 0.2585 m/m for MATLAB. Regarding pitch, the mean response obtained from ORCAFLEX and MATLAB is 0.1867 degrees/meter and 0.2052 degrees/meter, respectively, with a percentage variation of 9.9%. The standard deviation for both ORCAFLEX and MATLAB is 0.3356 degrees/meter and 0.2999 degrees/meter, respectively, with a percentage variation of 10.7%. The coefficient of skewness is 2.6955 and 2.9107, respectively, with a percentage variation of 7.07%.

MATLAB CODE

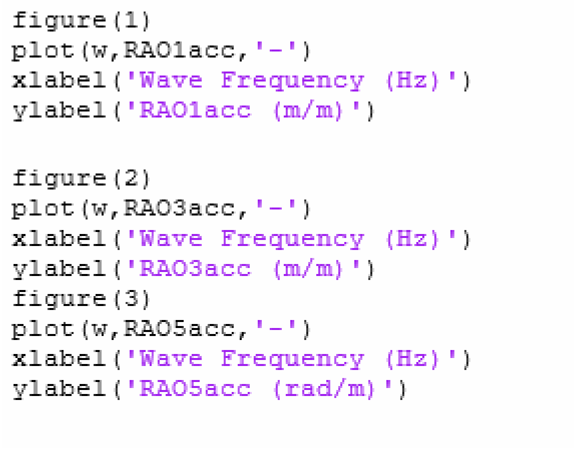
```
 clear
 clc
 L = 330%length overall = 330 m
 T = 13%draft = 13 m
 B = 61%breadth = 61 m
 D = 33.5%depth = 33.5 m
 rho = 1.025%density of sea water = 1.025 kg/m3
 g = 9.81%acceleration due to gravity = 9.81 m/s2
 Hs = 2.7%significant wave height = 2.7 m
 Hm = 5.1%maximum wave height = 5.1 m
 Tz = 7.6%Zero up crossing period = 7.6 s


 w =[.01:.2:2.51]'
 w1=sqrt((2*pi)/(g*L))

 E  =Hs/2
 b=B/2
 l=L/2
 k=(w1.^2)/g
 lamda=(2*pi*g)./w1.^2
 W=1000
 Tm=4
 TH=300 %Tm*cos(thetha_W)
 a=TH/W
 h=250;
 M=499155600;
 c11=W*(acosh(1+(h/a))-2*(1+(2*a)/h)^-0.5)^-1
 r=sqrt(1-((b^2)/(l^2)))
A0=2*((1-(r^2))/(r^3))*(0.5*log((1+r)/(1-r))-r)
A11=(A0/(2-A0))*M
wn1=(c11/(M+A11))^0.5
n1=w1./wn1
D1=0.07;
Q1=(((1-(n1.^2)).^2)+((2*D1.*n1).^2)).^-0.5
RAO1=((2.*Q1)/c11).*((rho*g*B)./k).*(1-exp(-k*T)).*sin((k*L)/2)
RAO1acc=(w.^2).*RAO1
c33=rho*g*B*L
C0=(1/r^2)-((1-r^2)/(2*(r^3)))*(log((1+r)/(1-r)))
A33=(C0/(2-C0))*M
wn3=(c33/(M+A33))^0.5
n3=w1/wn3
D3=0.07;
Q3=(((1-n3.^2).^2)+(2*D3.*n3).^2).^-0.5

%Heave force amplitude
F3=(rho*g*E).*(((2*B)/k)-A33*(2/(g*L))).*(exp((-
2*pi*T)./lamda).*sin((pi*L)./lamda))

%Heave RAO
RAO3=((rho*g.*E)./c33).*(((2*B)./k)-(A33)*(2/(g*L))).*(exp((-
2*pi*T)./lamda).*sin((pi*L)./lamda))

RAO3acc=(w.^2).*RAO3
```



```
%Pitch Respond
c55=((L^2)/12)*c33

%Mass moment of inertia in pitch
L55=(1/120)*(pi*rho*L*B*T)*((4*(T^2))+L^2)

%Added mass in pitch

A55=((L^2-4*T^2)^2*(C0-A0))/(2*(T^4-a^4)+(C0-A0)*(4*T^2+L^2))*L55
wn5=(c55/(M+A55))^0.5
n5=w1/wn5
D5=0.07;
Q5=((1-n5.^2).^2+(2*D5.*n5).^2).^-0.5

%Pitching lever
Lp=(1./k).*(1-(((k*L)/2).*cot((k*L)/2)))

%Pitch RAO
RAO5=(F3.*Lp.*Q5)./(c55.*E)

%Pitch acceration
RAO5acc =(w.^2).*RAO5

%Spectrum Analysis

%Jonswap spectrum
Sw=(124/(Tz^4)).*(Hs.*(w.^2).*exp(-(496/(Tz^4)).*(w.^-4)))
```



```
%Surge
%Surge respond spectrum
S1r=(RAO1acc.^2)%.*Sw

%Surge zeroth moment

fun = @(w1) ((w1.^2*RAO1).^2)%.*Sw
%Evaluate the integral from x=0 to x=Inf.

M01 = integral(fun,0,Inf)
a1max=3.72*(M01)^0.5

%Heave
%Heave respond spectrum
S3r= (RAO3acc.^2).*Sw

fun = @(w1) ((w1.^2*RAO3).^2)%.*Sw
%Evaluate the integral from x=0 to x=Inf.

M03 = integral(fun,0,Inf)
a3max=3.72*(M03)^0.5

S5r= (RAO5acc.^2).*Sw
```



```
figure(1)
plot(w,RAO1acc,'-')
xlabel('Wave Frequency (Hz)')
ylabel('RAO1acc (m/m)')

figure(2)
plot(w,RAO3acc,'-')
xlabel('Wave Frequency (Hz)')
ylabel('RAO3acc (m/m)')
figure(3)
plot(w,RAO5acc,'-')
xlabel('Wave Frequency (Hz)')
ylabel('RAO5acc (rad/m)')
```

REFERENCES

[1]. J. M. Heurtier, P. Buhan, E. Fontane, C. Cuniff, F. Biolley and C. Berhault, “Coupled Dynamic Response of Moored FPSO with Risers.,” Proceedings of eleventh ISSOPE Conference 1, pp. 319-326, 2001.

[2]. J. E. W. Wichers and P. Davlin, “Effect of Coupling of Mooring Lines and Risers on the Design Values for a Turret Moored FPSO in Deep Water of the Gulf of Mexico,” in Proceeding Eleventh International Offshore Polar Engineering Conference, Stavanger, Norway, 2001.

[3]. L. T. England, A. S. Duggal and L. A. Queen, “A Comparison Between Turret and Spread Moored FPSO for Deep Water Field Developments,” Journal of Deep Offshore and Technology, pp. 1-23, 2001.

[4]. Y. Rho, K. Kim, C. Jo and D. Kim, “Static and dynamic mooring analysis - Stability of floating production storage and offloading (FPSO) risers for extreme environmental conditions,” International Journal of Naval Architecture and Ocean Engineering, vol. 5, pp. 179–187, 2013, pp. (5) 179-187, 2013.

[5]. A. O. Vazquez-Hernandez, G. B. Ellwanger and L. Sagrilo, “Long-term response analysis of FPSO mooring systems,” Journal of Applied Ocean Resources, pp. 375-383, 2011.

[6]. E. Fontaine, P. Orsero, A. Ledoux, R. Nerzic, M. Prevosto and V. Quinious, “Reliability analysis and Response Based Design of a moored FPSO in West Africa,” Journal of structural Safety, pp. (41) 82-96, 2013..

[7]. J. K. Paik and A. K. Thayamballi, “Ship Shaped Offshore Installations Design, Building and Operation,” Cambridge University Press, 2007.

[8]. E. Akandu and K. N. Wugha, “Analysis of Vertical Motions of Bonga FPSO in Harsh Environmental Conditions.,” Journal of Subsea and Offshore-Science and Engineering, pp. 15, 13-19, 2018.

[9]. Marine Traffic, “Vessel Characteristics: Ship Egina FPSO,” https://www.marinetraffic.com.

[10]. E. Akandu, A. Incecik and N. Barltrop, “The Floating Production, Storage and Offloading Vessel Design for Oil Filed Development in Harsh Marine Environment,” Journal of Ocean, Mechanical and Aerospace-Science and Engineering, pp. 15, 18-24, 2015.

[11]. L. Bergdahl, “Wave-Induced Loads and Ship Motions.,” Department of Civil and Environmental Engineering, Division of Water Environmental Technology, Chalmers Univeristy of Technology, Goteborg, Sweden., pp. 30-36, 2009.