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SUSTAINABLE SHIP AND SHIPPING 4.0

Erasmus Mundus Joint Master Degree

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SHIP SEAKEAPING ASSIGNMENT-3

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INTRODUCTION

The aim of this study is to obtain the ship motions (heave and pitch) and compare the results obtained with the variance preserving method. It is also aimed to obtain acceleration values that occur in the center of gravity and bow part of the ship, depending on the values obtained after calculating the heave and pitch motion.

METHODS

1. RMS CALCULATION

1.1. Approaching Using Encounter Frequency

First of all, it is necessary to select a sample ship in order to calculate the ship motions. Ship number 4 was determined as the sample ship and main dimension values were obtained. (Table 1.) Apart from determining the main values, it was stated that the heading angle was 30° and the ship speed was 3 m/s and at the same time, in order to find the RMS values, the significant wave height($H_{1/3}$) and zero crossing period(T_z) values in the sea state are given as 2.3 m and 8.5 s, respectively.

Table 1. Main Dimensions

L	B	T	Cb	∇	KG	GM
232.5	32.2	10.8	0.67	53910.55	7.28	0.6
[m]	[m]	[m]		[t]	[m]	[m]

After the main dimensions were determined, the RAO values for the sample ship model were specified. (Table 2.) RAO values for heave and pitch corresponding to the ratio of each wavelength to ship length are given in the table.

Table 2. RAO Values

λ / L	η_3/A	η_5/kA
0.25	0.08	0.06
0.4	0.24	0.37
0.5	0.56	0.56
0.75	0.95	0.74
0.9	1.22	1.19
1	1.47	1.36
1.25	1.33	1.18
1.5	1.15	1.1
1.75	1.09	1.05
2	1.03	1.03

First, the range of values was increased by interpolation before obtaining the values because the number of values given may not be enough to converge to the result. After increasing the value range, wavelength values were calculated first. Then, depending on the wavelength, k values were calculated according to equation 1.

$$k = \frac{2\pi}{\lambda} \qquad \text{(Eq-1)}$$

Then, the frequency range was determined and the encounter frequency values were calculated for the determined range. (Eq-2) Normally, the frequency values should have been calculated according to the number of waves, but the given interval was not sufficient to obtain the wave spectrum, and the frequency values were determined since interpolation could not be applied after the start and end values.

$$W_e = W - (\frac{W^2 V cos(\beta)}{g}) \quad \text{(Eq-2)}$$

Then, first of all, A and B values were calculated in order to calculate the wave spectrum, and then the observed wave spectrum values were calculated for the A and B values.

$$A = \frac{123.8 H_{\frac{1}{3}}^2}{T_z^4} \quad \text{(Eq-3)}$$

$$B = \frac{495}{T_z^4} \quad \text{(Eq-4)}$$

$$S(w) = \frac{A}{w^5} \exp^{-\frac{B}{w^4}} \quad \text{(Eq-5)}$$

After calculating the wave spectrum, its derivative was taken to calculate the encounter spectrum. (Eq-6)

$$\frac{dW_e}{dW} = 1 - \frac{2WVcos(\beta)}{g} \quad \text{(Eq-6)}$$

$$S(W_e) = \frac{S(W)}{1 - \frac{2WVcos(\beta)}{g}} \quad \text{(Eq-7)}$$

After the calculation of the encounter spectrum, the first moment value for control purposes was compared with the first moment value of the wave spectrum and verified. Then, the change of the encounter frequency values was obtained. The encounter frequency change is necessary to obtain the RMS value. Then, to obtain the RMS value, the RAO values were squared for the heave and pitch, respectively, and multiplied by the spectrum data. For the pitch, in addition to the heave, the wavenumber (k) was multiplied by the square. After taking the square root of the sum of the obtained values, the obtained value gives the RMS result. (Eq-8, 9, 10)

$$RMS_3 = \sqrt{\sum RAO_3 \Delta W_e S(W_e)} \quad \text{(Eq-8)}$$

$$RMS_5 = \sqrt{\sum RAO_5 \Delta W_e S(W_e)} \quad \text{(Eq-9)}$$

$$\Delta W_e = W_{e_{i+1}} - W_{e_i} \quad \text{(Eq-10)}$$

1.2. Variance Preserving Transformation

In the variance transforming method, the operations are performed in the same order without considering the encounter frequencies and the results are calculated in order to be able to compare. Therefore, the obtained RMS values were obtained independently of the encounter frequency. (Eq-11, 12)

$$RMS_3 = \sqrt{\sum RAO_3 \Delta W S(W)} \quad \text{(Eq-11)}$$

$$RMS_5 = \sqrt{\sum RAO_5 \Delta W S(W)} \quad \text{(Eq-12)}$$

2. ACCELERATIONS

In order to calculate accelerations on the center of gravity and ship bow DNV rules [1] has used. For the heave acceleration in the center of gravity, equation 13 has performed for ships over the 150 meters length. In this equation a_0 is acceleration parameter and f_p is coefficient.

$$a_{heave} = \left(1.15 - \frac{6.5}{\sqrt{gL}}\right) f_p a_0 g \quad \text{(Eq-13)}$$

After that in order to calculate vertical and lateral acceleration at bow DNV regulations has been used. First assumption is acceleration from sway equals to 0 and after that roll acceleration at lateral axis has calculated according to equation 15.

$$a_y = \left(1 - e^{-\frac{BL}{215GM}}\right)\sqrt{a_{sway}^2 + \left(gsin\theta + a_{roll-y}\right)^2} \quad \text{(Eq-14)}$$

$$a_{roll-y} = a_{roll}(z - R) \quad \text{(Eq-15)}$$

Lastly, vertical acceleration has calculated according to equation-16. In order to calculate vertical acceleration first pitch and roll acceleration for vertical axis has to calculate first. (Eq-17, 18)

$$a_z = \sqrt{a_{heave}^2 + \left(\left(0.95 + e^{-\frac{L}{15}}\right)a_{pitch-z}\right)^2 + (1.2a_{roll-z})^2} \quad \text{(Eq-16)}$$

$$a_{pitch-z} = a_{pitch}(1.08x - 0.45L) \quad \text{(Eq-17)}$$

$$a_{roll-z} = a_{roll}y \quad \text{(Eq-18)}$$

RESULTS

Firstly in order to increase number of the samples, interpolation has performed between variables at Table 1. After the interpolation total amount of the samples determined as 100. After that wavelength, wave number, frequencies and encounter frequencies has calculated. After calculating the encounter frequencies (Eq-2) first, the frequency-encounter frequency curve (Fig 1.) was obtained by considering the angle at which the ship received the wave.

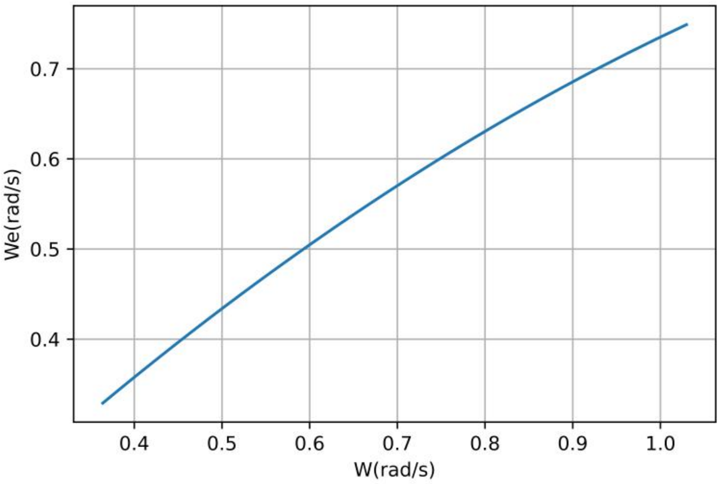

Figure 1. Frequency – Encounter Frequency Curve

Then, spectrum values were calculated according to the frequency values. (Fig 2.) After the graph was obtained, the moment value was calculated. It was an expected result that the calculated moment value was close to the significant wave height value and the calculation met this result. (Table 1.)

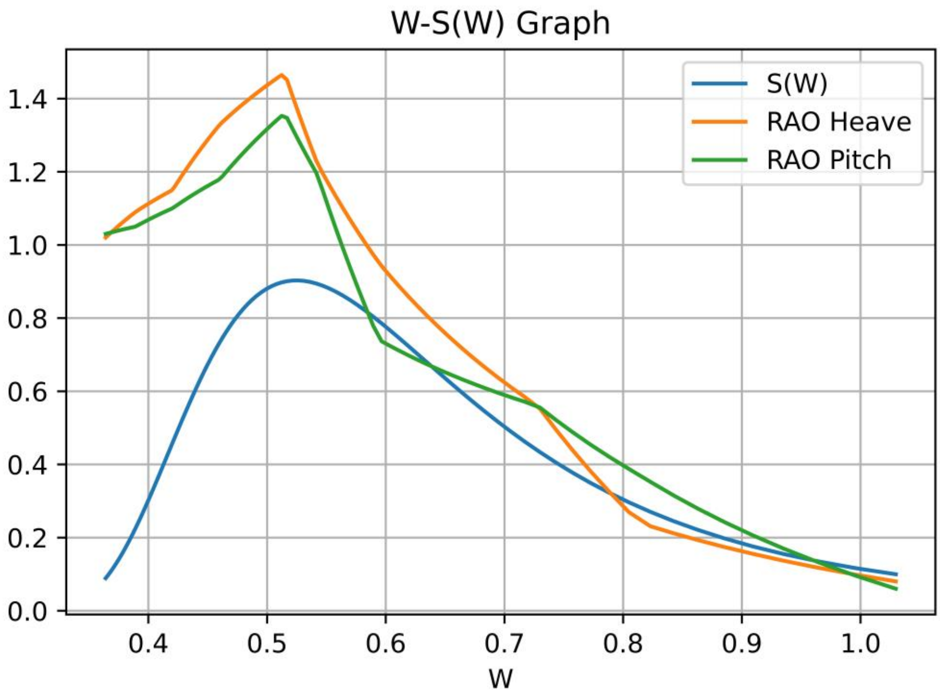

Figure 2. Frequency – ITTC Spectra

Table 3. SWH – Moment Value Comparison from ITTC Spectra

Significant Wave Height(m)	2.3
$\boldsymbol{m_0}$	2.20006
Failure Rate (%)	4.34

After the calculation of ITTC spectra, in order to observe effect of waves spectra for encounter frequency has to be calculate. Firstly derivative of equeation-2 has calculated then in order to calculate encounter frequency spectra, ITTC spectra divide to derivative equation. (Eq-7) Then same like ITTC spectra moment value has calculated and compared with both ITTC moment and significant wave height value. (Table 4.)

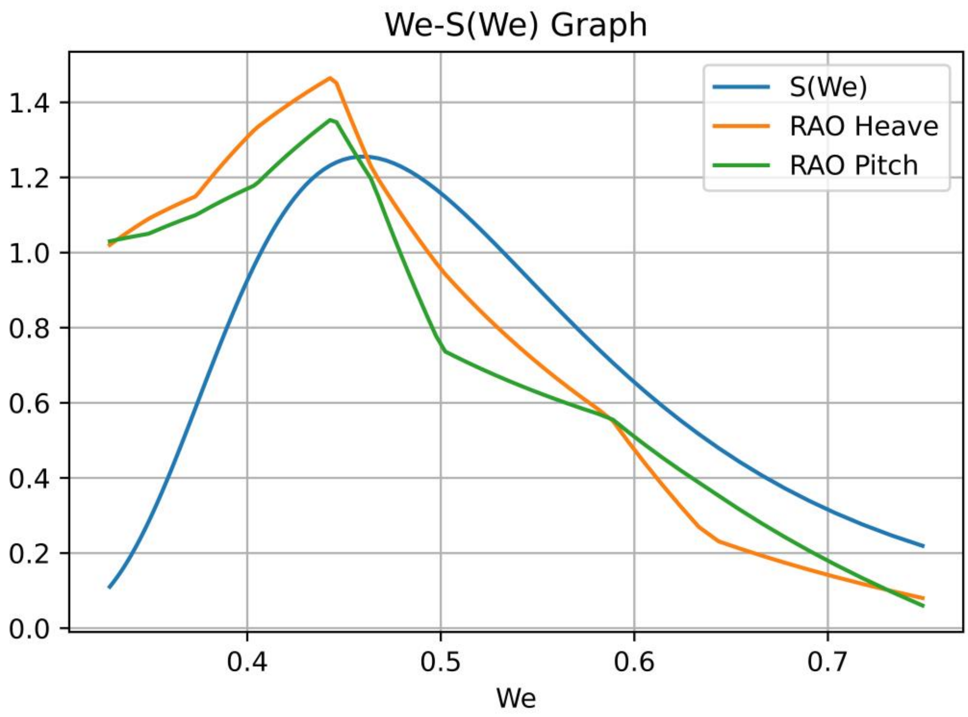

Figure 3. Encounter Frequency Spectra

Table 4. SWH – Moment Value Comparison from Encounter Frequency Spectra

Significant Wave Height(m)	2.3
$\boldsymbol{m_0}$	2.20005
Failure Rate (%)	4.34

Then RAO values for heave and pitch has multiplied with encounter spectra values but for pitch motion it also has multiplied with wave number square. (Figure-4) After performing this calculation, the change between encounter frequencies has calculated according to number of samples. (Eq-10) Then lastly RMS values has calculated according to equation-11, 12 for encounter frequency approach.

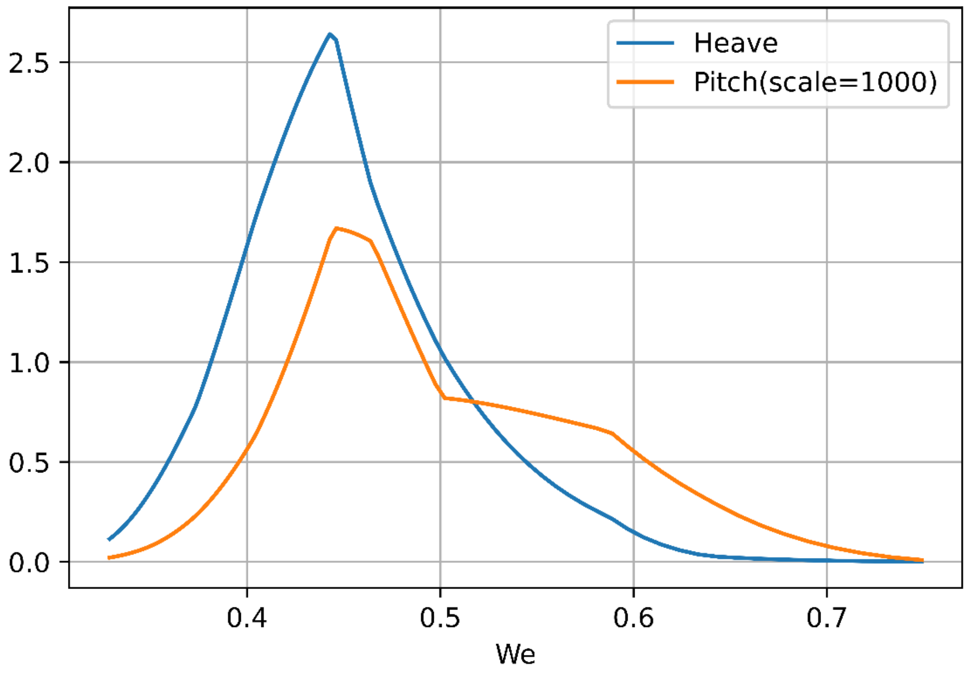

Figure 4. Characteristic of Heave and Pitch

Table 5. RMS Values for encounter frequency approach

$\boldsymbol{m_{0-3}}$	0.5492802	[m]
$\boldsymbol{m_{0-5}}$	0.0158955	[rad]

After that, same calculation has performed using variance preserving transformation method same like encounter frequency. Difference between these 2 method is in variance preserving transformation method calculation has performed with frequency values.

Table 6. RMS Values for variance preserving transformation

$\boldsymbol{m_{0-3}}$	0.5491447	[m]
$\boldsymbol{m_{0-5}}$	0.0157630	[rad]

Table 7. RMS Values Comparison

Using Encounter Frequency	m_{0-3}(m)	0.5492802
	m_{0-5}(rad)	0.0158955
	m_{0-5}(degree)	0.9107451
Variance Preserving Transformation	m_{0-3}(m)	0.5491447
	m_{0-5}(rad)	0.0157630
	m_{0-5}(degree)	0.9031534

After the calculation of RMS values, ship accelerations on center of gravity and ship bow has calculated according to DNV rulebook. [1] Heave acceleration can be found according to equation 13.

If we calculate pitch motion at center of gravity according to DNV rules, results gives us to value that approximate 0.

Table 8. Acceleration at Center of Gravity

Heave Acceleration At Center Of Gravity($\frac{m}{s^2}$)	0.884
Heave Acceleration At Center Of Gravity(g)	0.09

After that, lateral acceleration at ship bow has calculated according to equation-14. The acceleration of the ship for the sway is assumed to be 0. Later, in order to make the calculation, the roll value in the lateral direction was calculated according to the equation 15.

Table 9. Lateral Acceleration at Bow

	$\frac{m}{s^2}$	g
Total Lateral Acceleration	1.02542	0.105

Finally, vertical acceleration at ship bow has calculated according to equation-16. In order to calculate vertical acceleration first, vertical pitch and roll acceleration has also calculated.

Table 10. Vertical Acceleration at Bow

	$\frac{m}{s^2}$	g
Total Vertical Acceleration	1.29921	0.1325

Finally, the data are shown in the same table in order to compare the acceleration data obtained at ship bow and center of gravity. (Table-11)

Table 11. Acceleration Values

Center of Gravity	Heave Acceleration(g)	0.09
Bow	Lateral Acceleration(g)	0.105
	Vertical Acceleration(g)	0.1325

CONCLUSION

- First of all, when the encounter frequency values corresponding to the wave frequency are examined, considering that the ship received the wave at an angle of 30°, it continued to increase approximately linearly. This relationship would have tended to peak at some point and decrease if the ship had started to pick up the wave at higher angles.
- When the primary moments obtained by using the ITTC spectrum and the encounter frequency spectrum were calculated, it was observed that the values obtained were close to each other and also close to significant wave height. Therefore, a check of the obtained spectrum values was also made. However, it has been observed that this convergence begins to disappear when progressing from primary moments to secondary tertiary or even quaternary moments
- When the values obtained with the encounter frequency and variance preserving transformation were compared, it was observed that the values obtained were very close to each other, and it was showed that this convergence was even greater when the number of samples increased. It was accepted that sufficient convergence was achieved when the number of samples was 100 and it was decided that it was not necessary to do more interpolation, but if the number of samples were increased, the amount of convergence would also increase in small proportions.
- When the heave and pitch characteristics are examined (Fig 4.), both motions reach their maximum at the same encounter frequency value and begin to decrease at approximate points. For this reason, it can be interpreted that the two motions are couples with each other. In the pitch motion, unlike the heave, when it starts to decrease after the peak point, breaks occur. In the heave, the curve converges to 0 smoothly. For these breaks in the pitch motion, it can be interpreted that the pitch values that occur when the ship encounters the wave are more unstable than the heave.
- First of all, it should be noted that the acceleration source is the heave when calculating the acceleration values at the center of gravity. Because there will be no acceleration due to pitch in the center of gravity of the ship.
- When the acceleration values obtained in the bow of the ship are examined, it is observed that the vertical acceleration value is more than the lateral acceleration value. The longitudinal acceleration value obtained at the bow of the ship is 0. Considering this observation, the definition of heavy manual work on the ship can be made according to Faltinsen.

REFERANCES

[1] DNV Rules for Classification Ships, Part 3 Hull, Chapter 4 Loads, July 2022

[2] Faltinsen, Sea Loads on Ships and Offshore Structures, p.8