International Journal of Marine Engineering Innovation and Research, Vol. 10(1), March. 2025. 68-77
(pISSN: 2541-5972, eISSN: 2548-1479)

The Feasibility Study of Rectangular Floating Solar Panel Motion in Semangka Bay Waters

Berlian Arswendo Adietya[1], Yudy Gunawan[2], Ahmad Fauzan Zakki[3], Ocid Mursid[4] ,Tuswan[5]
(Received: 05 January 2025 / Revised: 19 January 2024 /Accepted: 28 January 2025 / Available Online: 21 March 2025)

Abstract-- **With the depletion of mineral resources in Indonesia, the need for effective renewable energy alternatives has become critical. Solar energy, harnessed through photovoltaic panels, presents significant potential. However, the widespread adoption of solar panels remains limited due to their large land area requirements and susceptibility to damage. Floating solar panels, installed on water surfaces, offer a promising solution by enhancing energy efficiency through natural cooling while addressing land constraints. This study aims to analyze the motion dynamics of floating solar panels in Semangka Bay and identify the most effective design for open water conditions. Three models were tested: rectangular, kite-shaped, and perforated, using 3D simulation software. The analysis focused on the Response Amplitude Operator (RAO) under regular wave conditions at a 180° angle. The results revealed that Model 3, with 8 mooring points, exhibited the best performance in mitigating rolling, pitching, and heaving motions. The maximum rolling value reached 826.24 cm at 81 seconds, with a minimum of -735.36 cm at 86.7 seconds. Pitching peaked at 390.30 cm at 61.4 seconds and fell to -376.42 cm at 63.9 seconds. Heaving values ranged from a maximum of 17.64 cm at 62.8 seconds to a minimum of -220.94 cm at 83 seconds. This study concludes that Model 3 with 8 moorings offers superior stability, making it the optimal design for floating solar panels in open waters like Semangka Bay. By addressing environmental and implementation challenges, this research contributes significantly to advancing floating solar energy technology in Indonesia. The findings highlight the potential of efficient and resilient designs to harness Indonesia's abundant solar energy resources effectively.**

Keyword- Floating Solar Panel, Photovoltaic, Motion, Hydrodynamic Diffraction

I. INTRODUCTION

The electricity in Indonesia is not yet 100% widespread to all regions. According to electricity data, the electrification ratio reached 99.63% by the end of 2022, compared to 99.45% in 2021. The electrification ratio is the comparison between households with electricity and the total number of households. Nearly all of this electricity is still sourced from conventional energy sources[1]. However, according to an analysis conducted by Pambudi et al[2]., based on data from official government institutions, Indonesia has significant potential for renewable energy. According to the data from table 1., the greatest potential is solar energy (solar panels). The potential for solar energy development is immense, with Indonesia recorded to have a solar energy potential of 207.898 MW per day[3]. A solar panel is a semiconductor element that can convert solar energy into electrical energy through the photovoltaic principle[4]. However, in reality, the use of solar panels is still very limited in Indonesia, aside from the area required and other factors such as vulnerability to damage and output reduction from the solar panels themselves.

TABLE 1.
POTENTIAL ENERGY IN INDONESIA

Energy Type	Potency (GW)
Hydro *energy*	75
Geothermal	23.7
Bio*energy*	32.6
Solar	207.8
Wind	60.6
Micro-hydro	19.3
Total	419

One alternative that can be implemented is installing solar panels on the surface of water bodies such as rivers, lakes, or seas, commonly known as floating solar panels. Compared to land-based solar panels, floating solar panels are more effective

Berlian Arswendo Adietya Department of Naval Architecture Diponegoro University, Semarang, 50275. E-mail: berlianarswendokapal@gmail.com
Yudy Gunawan Department of Naval Architecture Diponegoro University, Semarang, 50275. E-mail: yudygun23@gmail.com
Ahmad Fauzan Zakki Department of Naval Architecture Diponegoro University, 50275. E-mail: ahmadfzakki@yahoo.com
Ocid Mursid Department of Naval Architecture Diponegoro University, 50275. E-mail: ocidmursid@lecturer.undip.ac.id
Tuswan Department of Naval Architecture Universitas Diponegoro, Semarang, 50275. E-mail: Tuswan@lecturer.undip.ac.id

because they produce higher output and more efficient electricity distribution[5]. Supported by the research conducted by Trapani and Santafé (2015), the energy produced by floating systems is more efficient than land-based systems due to natural cooling provided by the water[6]. Floating solar panels have become a focus and have been used in several developed countries, such as Japan, the United States, and South Korea, since 2007[7].

Lampung is also considered suitable for solar energy applications because it has a more dominant direct radiation component than diffuse radiation[10].

Floating solar panels are usually installed in closed water bodies such as reservoirs, lakes, etc. As in the research conducted by Junianto (2020) on the installation of floating solar panels in Palembang, North Sumatra [11]. However, with a wider sea area, the application of floating solar panels can be

TABLE 2.
SPECIFICATION OF FLOATING SOLAR PANEL [16]

Properties	Value
Type	125x156 mm crystalline silicon
Watt peak	280 W
Cell efficiency	16 %
Area of Photovoltaic	1.4 m2
Performance ratio	0.72

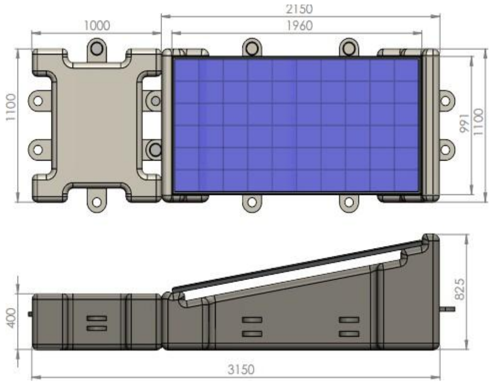

Figure 1. Dimension of Floating Solar Panel

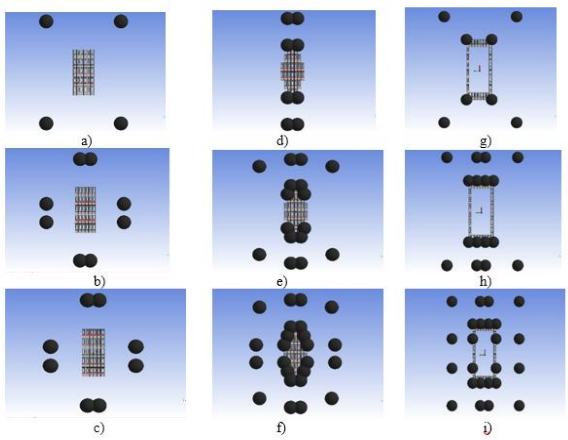

Figure 2. Design Variation Floating Solar Panel

The use of floating solar panels in Indonesia can be said to be a huge potential, seeing the geography of Indonesia which has a lot of water surface. Supported by research conducted by Tia Mariatul, et al (2024) on the potential of floating solar power plants in Indonesia [8]. One area in Indonesia with the largest solar energy potential is Sumatra, with a potential of 7.15 GW out of a total of 12 GW in Indonesia. Data shows that Lampung has solar energy potential. GIS polygon data for solar insolation in Lampung for each month throughout 2012 shows an average value of 4.81 kWh/m², with a minimum of 4.43 kWh/m² in December and a maximum of up to 5.12 kWh/m²[9].

maximized. Installing them in open waters such as the sea requires attention to many factors, such as waves, currents, and wind, which can hinder the performance of floating solar panels in the future. A study by Ray Yeng Yang on the analysis of floating solar panels in tidal zones explains that sea conditions, both normal and extreme, greatly affect the movement and durability of floating solar panels[12].

To prevent this, it is necessary to calculate the hydrodynamic response when installing floating solar panels by understanding the RAO characteristics of floating solar panels.

RAO (Response Amplitude Operator) is used to transfer external loads, in this case, waves in the frequency range, into a form of response that is received[13]. The response can be in the form of vibrations, movements, and stresses. The validity of this operator is based on the assumption of linearity between the wave excitation and the system's response[14]. By understanding the RAO value, the characteristics of the most suitable floating solar panels for a given location can be determined.

In other comparative studies, it is explained that floating solar panels installed in open waters or the open sea tend to experience more dominant heave and pitch movements. This occurs due to the connections between each solar panel unit and the possibility of more complex movements depending on the wave conditions[15].

Compared to previous research, this study focuses on the installation of floating solar panels in open waters, specifically in Semangka Bay, addressing gaps in prior research with in-depth environmental and implementation insights.

II.METHOD

A. *Research object*

The object studied in this research is a floating solar panel with variations in model design and the number of mooring lines. The dimensions of the floating solar panel were adopted from previous research based on table 2.

B. *Research Parameter*

This research focuses on finding the most optimal layout design for floating solar panels by using three different layout models, each with variations in the number of mooring lines. The floating solar panel models were created and further modified using 3D software. The simulation conducted in this study utilized specific boundary conditions to analyze the motion dynamics of floating solar panel models. Regular wave conditions were simulated at a 180° angle to represent open sea environments, such as in Semangka Bay. The models were designed with variations in geometry and mooring configurations to assess their stability under these conditions. Key parameters, such as wave height, wave period, and their interactions with the floating structures, were carefully considered. The simulation used a wave height of 0,25 m with a period of 11 s, derived from the average wave height observed in Semangka Bay. However, certain limitations were noted, including the exclusion of wind and current forces, which are crucial in real-world scenarios. Additionally, the model size was scaled down for simulation purposes, potentially affecting the accuracy of extrapolated results. These constraints highlight the need for further studies incorporating comprehensive environmental factors, such as wind and current influences, to enhance the applicability of the findings to actual marine conditions.

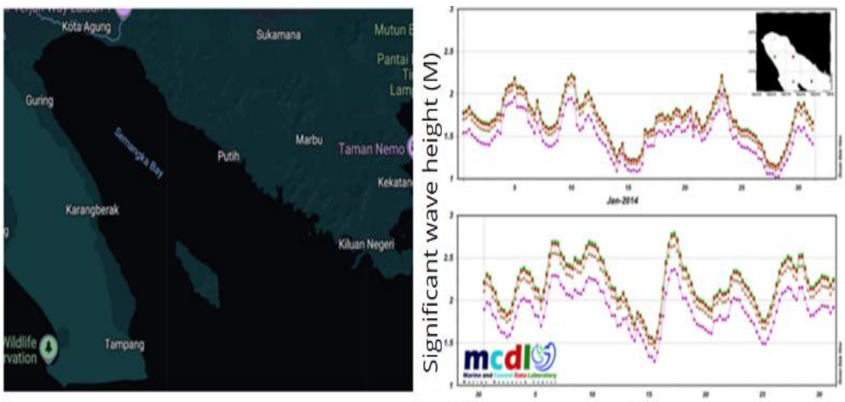

Figure 3. Condition of Semangka Bay

Model	Number Mooring	Number of Solar Panel
Model 1	4	30
Model 1	8	30
Model 1	12	30
Model 2	4	30
Model 2	8	30
Model 2	12	30
Model 3	4	30
Model 3	8	30
Model 3	12	30

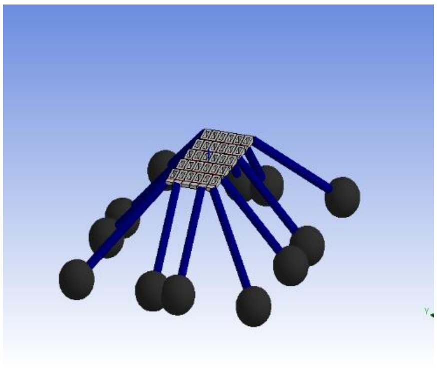

Figure 4. *Catenary System*

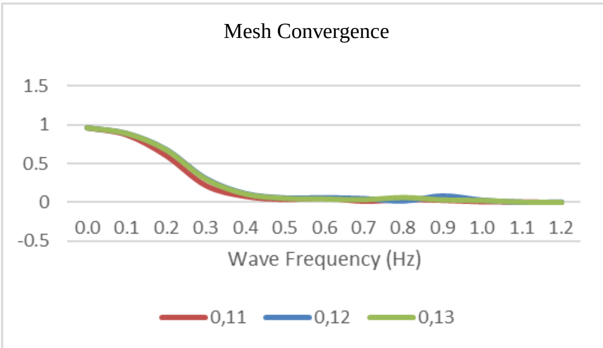

Figure 5. Mesh Convergence

C. *Motion*

The motion analysis of a floating object refers to the movement caused by external factors such as waves, wind, and others. When subjected to wave forces, the floating object undergoes two types of motion: rotational motion, which includes rolling, pitching, and yawing, and linear motion, which includes surging, swaying, and heaving. However, in this research, only rolling, heaving, and pitching motions were analyzed.

D. *Respons Amplitude Operator* (RAO)

The response of a vessel's motion to regular waves is expressed in RAO (Response Amplitude Operator), where RAO is the ratio between the amplitude of the vessel's motion (both translational and rotational) and the wave amplitude at a specific frequency[17].

$$S\zeta r\,(\omega) = RAO2 \times S\zeta\,(\omega) \quad (1)$$

Referring to the research conducted by J Lee et al. (2022), which analyzes the dynamic response of floating solar panel systems, it shows that the dynamic response experienced by floating solar panels is influenced by external environmental conditions such as waves, whether normal or extreme waves[18].

E. *Semangka Water Bay*

Lampung is considered suitable for the application of solar energy technology due to its characteristics, where the direct radiation component is more dominant than the diffuse radiation component[19]. The wave characteristics in Semangka Bay are significantly higher during the East/Southeast Wind Season (1.25 – 3 m) compared to the West Wind Season (1 – 2.3 m). According to Figure 3. Based on research conducted by Hasanah (2022), the maximum wave height occurs during the western season in December, reaching 2.35 meters, while the lowest wave height occurs during the first transition season in April, at 0.12 meters. [20].

F. *Mooring System*

The mooring system is used to dampen the movement of floating objects that are free-moving, To assist the weathervaning process, ensuring that operations run safely[21]. The configuration of the mooring system used is the catenary spread system such as figure 4. The formula used in RAO (Response Amplitude Operator) is as follows[22] :

(2)

The research conducted by Gokale and Pathil (2021) explains that the mooring configuration has a significant impact on the stability of floating panels, particularly in reducing pitching and rolling motions in open waters[23]. And research conducted by Ghofar (2023) on the use of catenary lines type spread mooring design on floating solar power plants. [24].

III.RESULT AND DISCUSSION

A. *Mesh Convergence*

The 3D model underwent mesh convergence to determine whether the model used is valid for 3D diffraction analysis[25]. This mesh convergence was performed in hydrodynamic diffraction using Ansys Aqwa. For all three models, mesh variations were applied with sizes of 0.11, 0.12, and 0.13. The mesh convergence graph can be seen in figure 5. Based on the graph, the meshes with sizes 0.11, 0.12, and 0.13 yield convergent results, so the author used the model with a mesh size of 0.11.

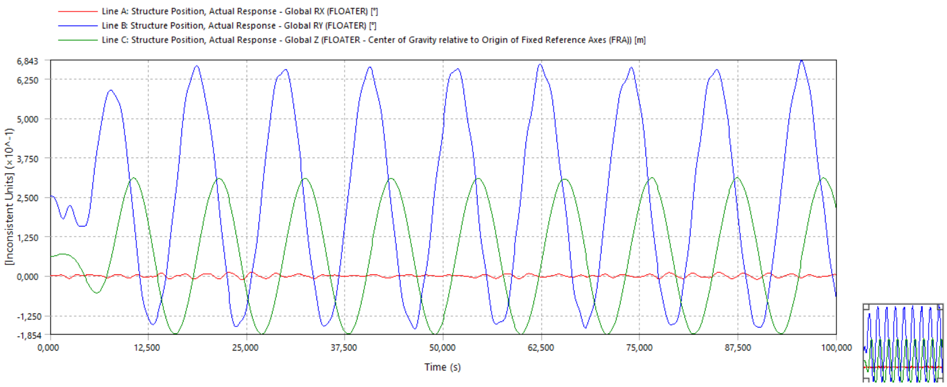

Figure 6. *Time Domain* Graph Model 1 4 *Mooring*

TABLE 4.
TIME DOMAIN VALUE MODEL 1 4 MOORING

	Max (cm)	Time Step (s)	Min (cm)	Time Step (s)
Rolling	1.19	25.6	-1.26	24.4
Pitching	68.43	95.6	-16.87	46.3
Heaving	31.08	87.4	-18.54	70.8

B. *Motion Analysis*

The motion analysis of the floating solar panel was carried out using hydrodynamic diffraction in the ANSYS AQWA software. The analysis was performed with several variations, including layout models and the number of moorings. The results of the analysis were in the form of RAO (Response Amplitude Operator) for pitch, heave, and roll motions, considering wave direction at 180° with regular waves. The analysis with variations in layout design and the number of moorings, considering wave direction at 180° with regular waves, resulted in the pitch, heave, and roll graphs shown in Figure 6. Based on Table 4. the RAO data shows that the maximum rolling value is 1.19 cm at 25.6 seconds, and the minimum rolling value is -1.26 cm at 24.4 seconds. The maximum pitching value is 68.43 cm at 95.6 seconds, and the minimum pitching value is -16.87 cm at 46.3 seconds. The maximum heaving value is 31.08 cm at 87.4 seconds, and the minimum heaving value is -18.54 cm at 70.8 seconds.Based on Table 5. the RAO data shows that the maximum rolling value is 2.45 cm at 78.9 seconds, and the minimum rolling value is -2.53 cm at 96.7 seconds. The maximum pitching value is 61.46 cm at 40.5 seconds, and the minimum pitching value is –23.95 cm at 23.9 seconds. The maximum heaving value is 31.13 cm at 54.2 seconds, and the minimum heaving value is -18.12 cm at 48.7 seconds.Based on Table 6. the RAO data shows that the maximum rolling value is 1.19 cm at 25.6 seconds, and the minimum rolling value is -1.26 cm at 24.4 seconds.The maximum pitching value is 68.43 cm at 95.6 seconds, and the minimum pitching value is -16.87 cm at 46.3 seconds. The maximum heaving value is 31.08 cm at 87.4 seconds, and the minimum heaving value is -18.54 cm at 70.8 seconds.

Based on Table 7. the RAO data shows that the maximum rolling value is 2.29 cm at 46.8 seconds, and the minimum rolling value is -2.10 cm at 95.2 seconds. The maximum pitching value is 63.39 cm at 51.3 seconds, and the minimum pitching value is -20.57 cm at 78.8 seconds. The maximum heaving value is 23.76 cm at 65.1 seconds, and the minimum heaving value is -25.55 cm at 26.6 seconds.

Based on Table 8. the RAO data shows that the maximum rolling value is 2.30 cm at 33.8 seconds, and the minimum rolling value is -3.15 cm at 13.7 seconds. The maximum pitching value is 62.93 cm at 51.3 seconds, and the minimum pitching value is –23.60 cm at 90 seconds. The maximum heaving value is 23.56 cm at 10.5 seconds, and the minimum heaving value is -25.99 cm at 48.8 seconds.

Based on Table 9. the RAO data shows that the maximum rolling value is 2.30 cm at 33.8 seconds,

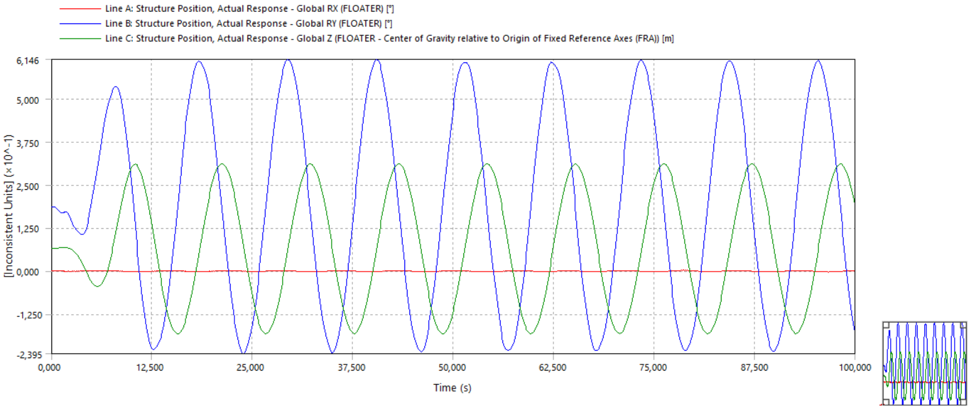

Figure 7. Time Domain Graph Model 1 8 Mooring

TABLE 5.
TIME DOMAIN VALUE MODEL 1 8 MOORING

	Max (cm)	Time Step (s)	Min (cm)	Time Step (s)
Rolling	2.45	78.9	-2.53	96.7
Pitching	61.46	40.5	-23.95	23.9
Heaving	31.13	54.2	-18.12	48.7

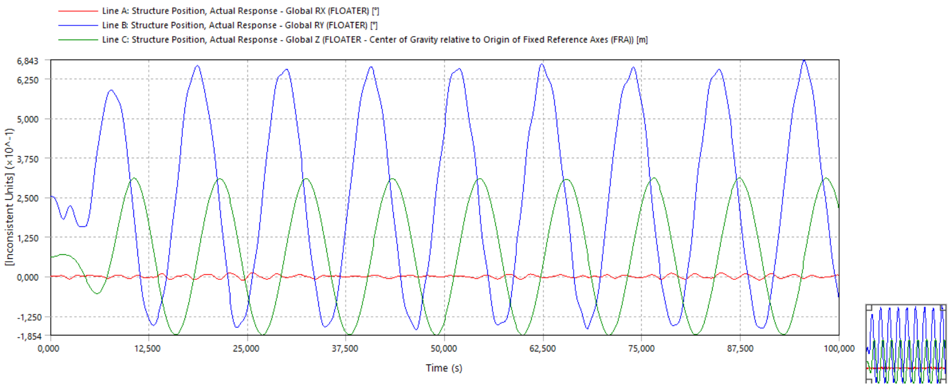

Figure 8. Time Domain Graph Model 1 12 Mooring

TABLE 6.
TIME DOMAIN VALUE MODEL 1 12 MOORING

	Max (cm)	Time Step (s)	Min (cm)	Time Step (s)
Rolling	1.19	25.6	-1.26	24.4
Pitching	68.43	95.6	-16.87	46.3
Heaving	31.08	87.4	-18.54	70.8

and the minimum rolling value is -3.15 cm at 13.7 seconds. The maximum pitching value is 62.93 cm at 51.3 seconds, and the minimum pitching value is -23.60 cm at 90 seconds. The maximum heaving value is 23.56 cm at 10.5 seconds, and the minimum heaving value is -25.99 cm at 48.8 seconds.

Based on Table 10. the RAO data shows that the maximum rolling value is 826.24 cm at 81 seconds, and the minimum rolling value is -735.36 cm at 86.7 seconds. The maximum pitching value is 381.28 cm at 74.2 seconds, and the minimum pitching value is -370.95 cm at 78 seconds. The maximum heaving value is 17.45 cm at 84.6 seconds, and the minimum heaving value is -215.21 cm at 71.4 seconds.

Based on Table 11. the RAO data shows that the maximum rolling value is 661.77 cm at 37.4 seconds, and the minimum rolling value is -581.67 cm at 58.4 seconds. The maximum pitching value is 390.30 cm at 61.4 seconds, and the minimum pitching value is -376.42 cm at 63.9 seconds. The maximum heaving

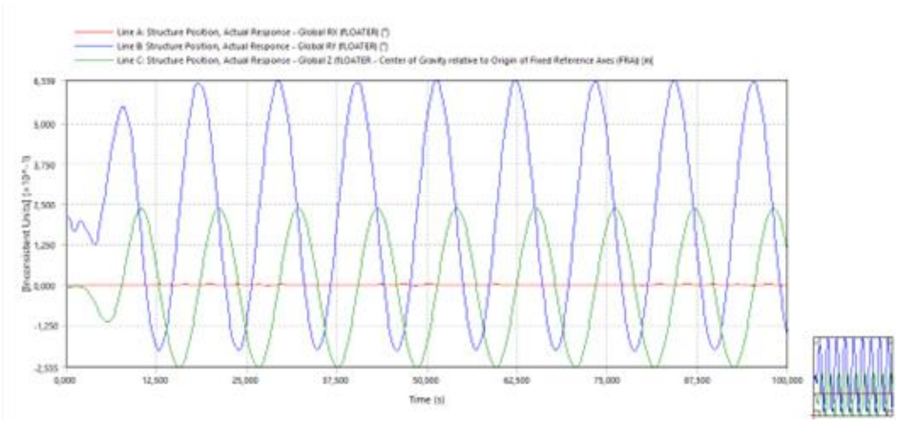

Figure 9. Time Domain Graph Model 2 4 *Mooring*

TABLE 7.
TIME DOMAIN VALUE MODEL 2 4 MOORING

	Max (cm)	Time Step (s)	Min (cm)	Time Step (s)
Rolling	2.29	46.8	-2.10	95.2
Pitching	63.39	51.3	-20.57	78.8
Heaving	23.76	65.1	-25.55	26.6

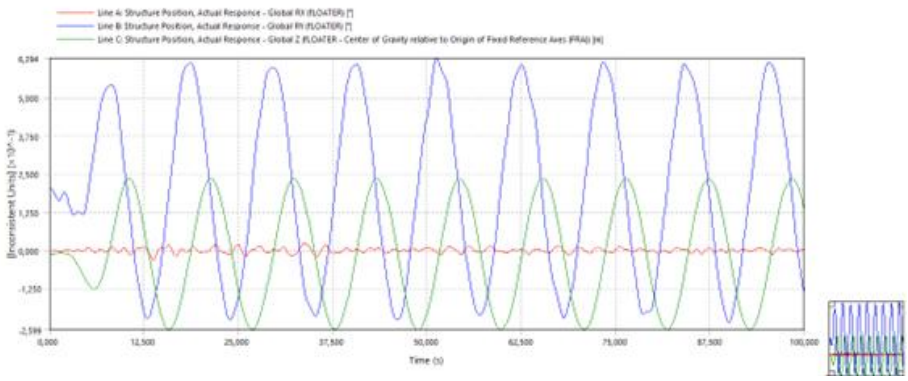

Figure 10. Time Domain Graph Model 2 8 Mooring

TABEL 8.
TIME DOMAIN VALUE MODEL 2 8 MOORING

	Max (cm)	Time Step (s)	Min (cm)	Time Step (s)
Rolling	2.30	33.8	-3.15	13.7
Pitching	62.93	51.3	-23.60	90
Heaving	23.56	10.5	-25.99	48.8

value is 17.64 cm at 62.8 seconds, and the minimum heaving value is -220.94 cm at 83 second.

Based on Table 12. the RAO data shows that the maximum rolling value is 826.24 cm at 81 seconds, and the minimum rolling value is -735.36 cm at 86.7 seconds. The maximum pitching value is 381.28 cm at 74.2 seconds, and the minimum pitching value is -370.95 cm at 78 seconds. The maximum heaving value is 17.45 cm at 84.6 seconds, and the minimum heaving value is -215.21 cm at 71.4 seconds.

Based on the research conducted on the 3D floating solar panel model using ANSYS AQWA, it can be concluded that the results of the motion analysis through the Response Amplitude Operator (RAO) graph in experiments with regular wave indicate the following.The highest and lowest rolling values are found in model 3 with 12 moorings, where the highest rolling value is 826.24 cm at 81 seconds, and the lowest rolling value is -735.36 cm at 86.7 seconds.The highest and lowest pitching values are found in model 3 with 8 moorings, where the highest

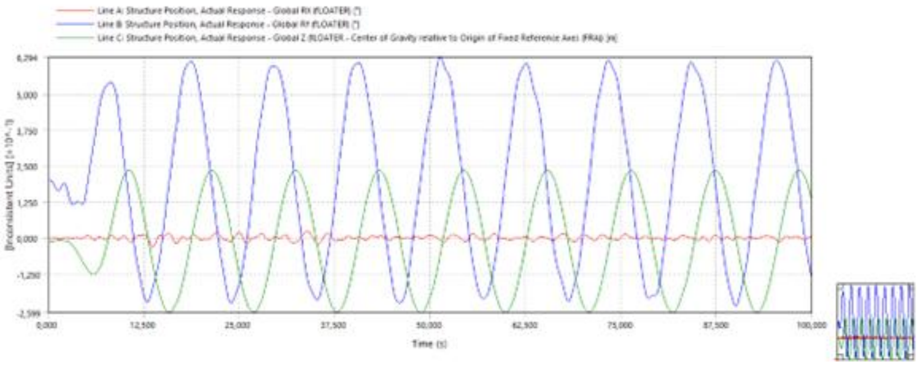

Figure 11.Time Domain Graph Model 2 12 *Mooring*

TABLE 9.
TIME DOMAIN VALUE MODEL 2 12 *MOORING*

	Max (cm)	Time Step (s)	Min (cm)	Time Step (s)
Rolling	2.30	33.8	-3.15	13.7
Pitching	62.93	51.3	-23.60	90
Heaving	23.56	10.5	-25.99	48.8

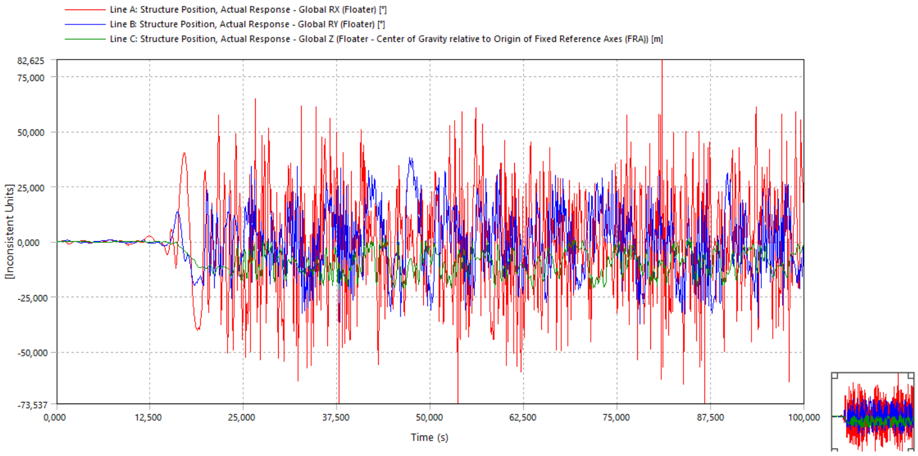

Figure 12. Time Domain Graph Model 3 4 Mooring

TABLE 10.
TIME DOMAIN VALUE MODEL 3 4 *MOORING*

	Max (cm)	Time Step (s)	Min (cm)	Time Step (s)
Rolling	826.24	81	-735.36	86.7
Pitching	381.28	74.2	-370.95	78
Heaving	17.45	84.6	-215.21	71.4

pitching value is 390.30 cm at 61.4 seconds, and the lowest pitching value is -376.42 cm at 63.9 seconds.The highest and lowest heaving values are found in model 3 with 8 moorings, where the highest heaving value is 17.64 cm at 62.8 seconds, and the lowest heaving value is -220.94 cm at 83 seconds.

IV.CONCLUSION

This study successfully examined the motion and performance of a rectangular-shaped Floating Solar Panel in the waters of Semangka using a 3D simulation model and the Response Amplitude Operator (RAO) method. The analysis was conducted on three panel design models with variations in the number of moorings (4, 8, and 12) to evaluate stability against three main types of motion: rolling, pitching, and heaving.

The main results of this study are about the maximum value of Rolling is 826.24 cm occurred in model 3 with 12 moorings at 81 seconds, and the

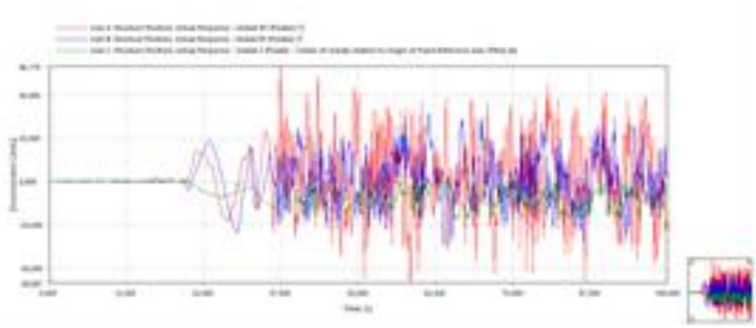

Figure 13. Time Domain Graph Model 3 8 Mooring

TABLE 11.
TIME DOMAIN VALUE MODEL 3 11*MOORING*

	Max (cm)	Time Step (s)	Min (cm)	Time Step (s)
Rolling	661.77	37.4	-586.67	58.4
Pitching	390.30	61.4	-376.42	63.9
Heaving	17.64	62.8	-220.94	83

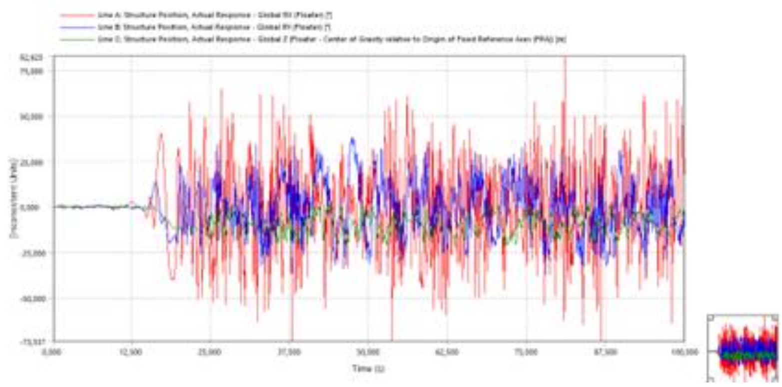

Figure 14. Time Domain Graph Model 3 12 *Mooring*

TABLE 12.
TIME DOMAIN VALUE MODEL 3 12 *MOORING*

	Max (cm)	Time Step (s)	Min (cm)	Time Step (s)
Rolling	826.24	81	-735.36	86.7
Pitching	381.28	74.2	-370.95	78
Heaving	17.45	84.6	-215.21	71.4

minimum value of -735.36 cm occurred at 86.7 seconds. Pitching, the maximum value of 390.30 cm occurred in model 3 with 8 moorings at 61.4 seconds, and the minimum value of -376.42 cm occurred at 63.9 seconds. Heaving**, t**he maximum value of 17.64 cm occurred in model 3 with 8 moorings at 62.8 seconds, and the minimum value of -220.94 cm occurred at 83 seconds.

This study shows that model 3 with 8 moorings provides optimal results in responding to the conditions of open waters, such as those in Semangka bay. The better stability of this design makes it the best option for implementing Floating Solar Panels, particularly in locations with significant wave and ocean current challenges. Slightly different from previous research wich recorded a maximum pitching value of about 250cm in moderate waters.

These findings make an important contribution to the development of floating solar energy technology in Indonesia, supporting the utilization of the vast potential of renewable energy with a more efficient design that is resilient to open sea environmental conditions.

ACKNOWLEDGMENTS

The content of this paper is a part of research supported by laboratory of ship piping and machinary system Diponegoro University.

REFERENCES

[1] Kementerian Energi dan Sumber Daya Mineral, *Statistik Ketenagalistrikan 2022*. Jakarta: Direktorat Jenderal Ketenagalistrikan, 2022.

[2] N. A. Pambudi, R. A. Firdaus, R. Rizkiana, D. K. Ulfa, and M. S. Salsabila, “Renewable *Energy* in Indonesia : Current Status , Potential , and Future Development,” 2023.

[3] D. Govindasamy and A. Kumar, "Experimental analysis of solar panel efficiency improvement with composite phase change materials," Renewable Energy, vol. 212, pp. 175-184, 2023.

[4] Suryana. D, “Pengaruh Temperatur / Suhu Terhadap Tegangan Yang Dihasilkan Panel Surya Jenis Monokristalin,” (Studi Kasus: Baristand Industri Surabaya), vol. 2, no. 1, 2016

[5] M. Iswahyudi and T. Wati, "Planning of Solar Power Plants at Surya Market Regional Companies," Procedia Engineering and Life Sciences, vol. 2, no. 1, pp. 4–8, 2021.

[6] K. Trapani and M. R. Santafé, "A review of floating photovoltaic installations: Performance and environmental impacts," *Renewable and Sustainable Energy Reviews*, vol. 51, pp. 1264–1271, 2015.

[7] Rosa-Clot, M., Tina, GM. dan Nizetic, S., 2017. Pembangkit listrik fotovoltaik terapung dan cekungan air limbah: sebuah proyek Australia. Procedia Energi, 134, hal.664-674.

[8] Kibtiah, T. M. (2021). Floating Solar Power Plants Potential in Indonesia. *Journal of Renewable Energy and Environmental Sustainability*, 6(1), 45-52. Retrieved from researchgate.net

[9] Rumbayan, Meyta. Asifujiang Abudureyimu., Ken Nagasaka. 2012. Mapping of Solar energy potensial in Indonesia using artificial neural network and geographical information system. Renewable and sustainable energy reviews 16 (2012) 1437-1449.

[10] Utomo, Yusuf Suryo., Sugiyatno. 2012. Studi Potensi Energi Surya Provinsi Lampung. Seminar Nasional Fisika 2012 Pusat Penelitian Fisika –LIPI Serpong, 4 - 5 Juli 2012 ISSN: 2088-4176 No. Arsip : LIPI-12063.

[11] B. Junianto, T. Dewi, and C. R. Sitompul, "Development and Feasibility Analysis of Floating Solar Panel Application in Palembang, South Sumatra," *Journal of Physics: Conference Series*, vol. 1500, p. 012016, 2019, 3rd Forum in Research, Science, and Technology (FIRST 2019) International Conference, 9-10 Oct. 2019, South Sumatera, Indonesia.

[12] Yang, R. -Y., & Yu, S. -H. (2021). A Study on a Floating Solar Energy System Applied in an Intertidal Zone. *Energies*, *14*(22), 7789.

[13] M. E. McCormick, Dynamics of Marine Vehicles by Rameswar Bhattacharya. 1978.

[14] Journée, J.M.J. and Massie, W.W. (2001) Offshore Hydromechanics. Delft University of Technology, Delft, Netherlands.

[15] Lee, J. -H., Paik, K. -J., Lee, S. -H., Hwangbo, J., & Ha, T. -H. (2022). Experimental and Numerical Study on the Characteristics of Motion and Load for a Floating Solar Power Farm under Regular Waves. *Journal of Marine Science and Engineering*, *10*(5), 565.

[16] Mursid, O., Malau, K. R., Huda, N., Abidin, A. M. A., & Sutarno, G. (2021). Design and Feasibility Studies A Floating Photovoltaic to Supply Electricity for Isolated Island Village in Indonesia. *IOP Conference Series: Earth and Environmental Science*, *698*(1).

[17] I. Ibinabo dan D. T. Tamunodukobipi, “Determination of the Response Amplitude Operator(s) of an FPSO,” Engineering, vol. 11, no. 09, hlm. 541–556, 2019.

[18] Song, J., Kim, J., Lee, J., Kim, S., & Chung, W. (2022). Dynamic Response of Multiconnected Floating Solar Panel Systems with Vertical Cylinders. *Journal of Marine Science and Engineering*, 10(2), 189.

[19] Utomo, Yusuf Suryo., Sugiyatno. 2012. Studi Potensi Energi Surya Provinsi Lampung. Seminar Nasional Fisika 2012 Pusat Penelitian Fisika –LIPI Serpong, 4 - 5 Juli 2012 ISSN: 2088-4176 No. Arsip : LIPI-12063.

[20] M. Hasanah, "Pemodelan Gelombang di Perairan Teluk Lampung," Skripsi, Universitas Lampung, 2022. [Online]. Available: https://digilib.unila.ac.id/76635/.

[21] Afdhal, M. I.,U. Budiarto, and I. P. Mulyatno, "Optimasi Disain Spread Mooring Dengan Konfigurasi Variasi Line Terhadap Six Degrees Of Freedom (DOF) Olah Gerak Pada Kapal Floating Storage And Offloading (FSO)," Jurnal Teknik Perkapalan, vol. 7, no. 1, 2019. [Online]. Available: https://ejournal3.undip.ac.id/index.php/naval/article/view/22313.

[22] E. B. Djatmiko, “Perilaku dan Operabilitas Bangunan Laut di Atas Gelombang Acak,” ITS Press, no. September, pp. 1–27, 2012.

[23] A. A. Gokhale and S. S. Patil, "Optimization of Mooring Systems for Floating Solar Farms in Offshore Conditions," *Ocean Engineering*, vol. 234, p. 109178, 2021.

[24] Z. A. Ghofar, "Desain Spread Mooring tipe Catenary Lines pada Pembangkit Listrik Tenaga Surya Terapung," *Bachelor thesis*, Institut Teknologi Kalimantan, 2023. *Repository ITK*.

[25] F. Liu, W. W. Hager, and A. V. Rao, “Adaptive mesh refinement method for optimal control using nonsmoothness detection and mesh size reduction,” J. Franklin Inst., vol. 352, no. 10, pp. 4081–4106, 2015.