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Seismic Effect of the Offshore Structure Under Different Earthquake Loadings

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Abstract: Peninsular Malaysia is most affected by the distant Sumatra subduction zone earthquake. Meanwhile, Eastern Malaysia was subjected to major Philippine and Indonesian earthquake. Most of the offshore platform is at Terengganu, Sabah, and Sarawak. More than 65% of the offshore platform structure exceed the range of design between 20-30 years. This research aims to determine the vulnerability and risk analysis for the existing 3-legged offshore platform under earthquake load, study the behaviors of an offshore platform under major or minor earthquake loading, and study the dynamic characteristic of an offshore platform. SAP 2000 is use to analyses and modelling the 3-legged offshore platform. In SAP 2000, the response spectrum, time history, and free vibration will be performed. The mixed load of the platform consists of dead load, imposed load, environment loads, and earthquake load. The position of the offshore platform has referred to American Petroleum Institute (API) standard. The major earthquake under off-shore platform is El-Centro and the minor is Aceh compared to time history. Based on this study, Malaysia can withstand this low seismic activity, overall joint acceleration, velocity and displacement.

Keywords: Offshore structure, Aceh, El-Centro, response spectrum, SAP 2000

1. Introduction

Earthquake is a natural disaster, the world's most destructive and intimidating. An earthquake harms nobody but as a result of the movement of the tectonic plate, it can destroy infrastructure and victims particularly strongly and severely [1]. The physical damage caused by the earthquake is building damage either caused by the environmental condition or poor quality of the building material [2]. Hence the earthquake effects that cause buildings to collapse that also affect engineers and architects. While Malaysia was considered a low seismic region, peninsular Malaysia is most affected by the distant Sumatra subduction zone earthquake. At the same time, Eastern Malaysia was subjected to major Philippine and Indonesian earthquakes [3], [4]. Besides that, an offshore platform is a massive structure that is floating or fixed on the ocean, it is used to drill wells in the ocean bed, which extracts oil and natural gas [5], [6]. There are few types of offshore platforms: Fixed platform, Compliant tower, Sea star platform, Floating production system, Tension leg platform, Sub- Sea system, and SPAR platform. Fixed offshore platforms are the best choice due to a massive amount of extraction of oil and gas platforms in Malaysia.

In Malaysia, there have most of the offshore platform structures is operate 24 hours per day. Most of the offshore platforms are at Terengganu, Sabah, and Sarawak. This offshore platform is classified into two types of offshore

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platforms: shallow-water offshore and deep-water offshore platforms [7], [8]. Additionally, there are two categories for offshore structure platforms, drilling offshore and offshore storage platforms. Specifically, more than 65% offshore platform structure exceeds the range of design life, ranging from 20-30 years [9]. The offshore platforms might be vulnerable to the earthquake effect, but it must verify with the research data and use the prototype offshore structure to support the research.

2. Literature Review

An offshore platform is a structure that is built on the seabed and used for various purposes around the world, including oil and gas exploration and production [10] - [12]. The design engineer must analyses whether the offshore structure can operate for more than 25 years while susceptible to sea waves. Waves and wind load are two important aspects to consider while designing an offshore building. The fixed offshore structure is a one-of-a-kind design since it can be built out in the middle of the ocean, and its primary function is to process oil and gas production [16].

There are three types of loads on the offshore structure: gravity loads, environmental loads, and other loads. The offshore platform and the quality of the construction materials bear the brunt of the pressure. Wind loads, wave loads, and earthquake loads are examples of environmental loads that operate on the platform structure as a result of geological and climate circumstances. Seismic waves are caused by the movement or shaking of the Earth's tectonic plates, which are discharged from the earthquake's focal point. Once the energy of the shockwave has been unleashed, natural disasters such as volcanoes, landslides, and tsunamis may occur. In addition, it briefly transforms into liquefaction when the earth shakes, such as clay [19].

The time history study was carried out using seismic data from the Malaysian Meteorological Department, and the response spectrum analysis was carried out using response spectra curves of Eurocode 8. It has contrasted the findings of the response spectrum and time history analyses. Results of the mode shape and the natural period of the offshore structure were derived and discussed in detail.

3. Methodology

3.1 3-Legged Offshore Structure

The vulnerability and risk analysis for an existing three-legged offshore platform under seismic loading is the method used in this study. SAP 2000 modelled and analyzed on a three-legged offshore platform. Response spectrum, time history, and free vibration will be analyzed once the offshore platform modelling is finalized. Deadload, imposed load, and environmental loads all make up the platform mix load [15]. The position of the offshore structure must correspond to the American Petroleum Institute (API) standard after integrating environmental factors such as wind loads, wave loads, earthquake loads, and loads related to the structure. Moreover, free vibration analysis, timeframe, and structure mode shape will all be obtained as part of this investigation. The 3- legged offshore platform is 120m in height and has a triangle shape as shown in Fig. 1. Fig. 2 and Table 1 show the spacing of the frame and the size of the members in detail.

3.2 Earthquake Loads

This study contained a free vibration analysis, earthquake analysis and earthquake reaction continuum research. The response spectrum study will be carried out for the earthquake load using the response spectrum curves of EuroCode8 2004 via SAP2000 computation tools [13,14]. There are two types of analysis, Aceh and El-Centro, which are time history analysis. Besides that, the load combinations for this study will be as follows:

- Dead Load + Live Load + Environmental Load (wind & wave load) + Time history analysis (Aceh)
- Dead Load + Live Load + Environmental Load (wind & wave load) + Time history analysis (El- Centro)
- Dead Load + Live Load + Environmental Load (wind & wave load) + Time history analysis (Rapid KL)
- Dead Load + Live Load + Environmental Load (wind & wave load) + Response spectrum analysis.

In prior microzonation assessments, the actual time history was used to determine the seismic ground motion. For Aceh, El Centro, and Rapidkl, respectively, the ground motion intensities are 0.20g, 0.357g, and 0.19g which show in Table 2. From Table 3, there was the selected response spectrum data that was analyzed in this study and this data is referred from the Eurocode 8 2004. Lastly, a detailed comparison and evaluation of the two types of seismic loadings that were applied in the simulation will be analyzed.

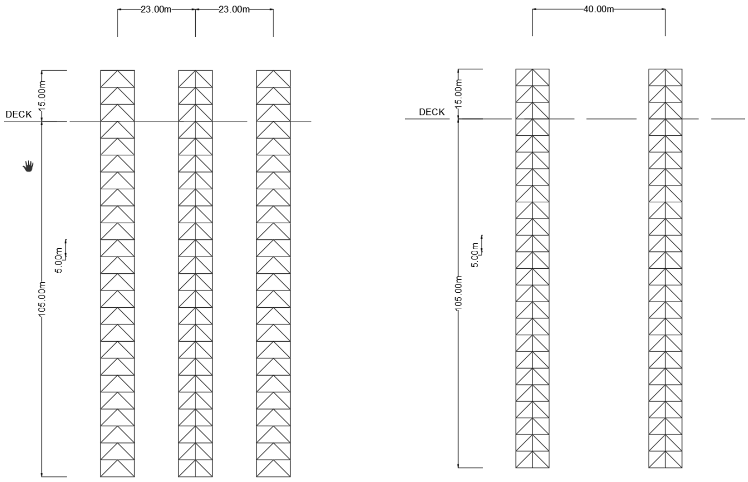


Fig. 1 - Elevation view

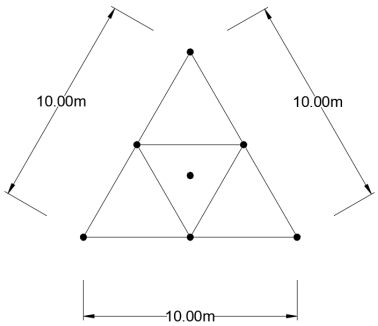


Fig. 2 - Spacing of members

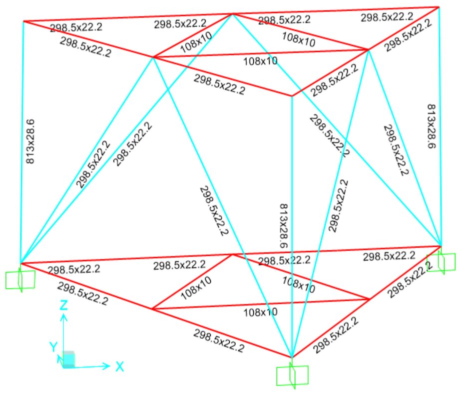


Fig. 3 - Size of members

Table 1 - Properties of material, mechanical of 3-legged offshore platform

	LCHS 813 mm x 28.6 mm	CHS 298.5 mm x 22.2 mm	CHS 108 mm x 10 mm
Young's modulus (GPA)	210	210	210
Yield stress (MPA)	686	353	353
Shear modulus (GPA)	80.77	80.77	80.77
Axial rigidity (MN)	3.0125×10^4	8.414×10^3	1.359×10^3
Torsional rigidity (MNm^2)	7.394×10^4	2.677×10^2	5.555
Flexural rigidity (MNm^2)	113.98×10^4	217.62 X 102	51.23

Table 2 - Time history considered in the study

Date	Earthquake	Magnitude	PGA (g)
2 July 2013	Aceh	6.1	0.20
18 May 1940	El-Centro	6.9	0.357
	RapidKL		0.19

Table 3 - Response spectrum considered in the study

Description	Data
Ground type	C
Peak ground acceleration	8%
Behavior Factor, q	1.5

4. Result and Discussion

4.1 Free Vibration Analysis

A linear static analysis is the same as a free vibration analysis (FVA). Based on material attributes, it would describe the modulus, mass density, yield stress, shear module and others. According to the research, there are 12 modes, and the time of each model is shown in Table 4.

Table 4 - Modal periods and frequency

Mode	Natural Period, T (Sec)	Natural Frequency, f (Hz)
1	0.270919	3.69113
2	0.270917	3.69116
3	0.137658	7.26437
4	0.090313	11.07255
5	0.090309	11.07311
6	0.054069	18.49503
7	0.054062	18.47939
8	0.046156	21.66580
9	0.038706	25.83555
10	0.038697	25.84155
11	0.030236	33.07366
12	0.030225	33.08534

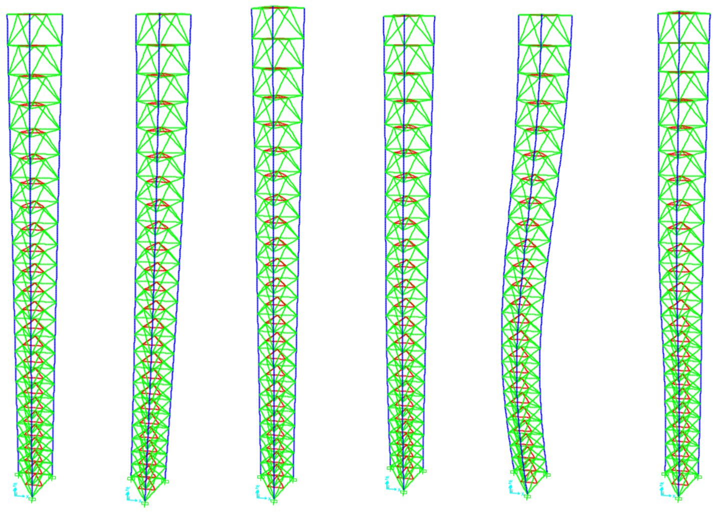


Fig. 4 - Mode shape 1 to 6 (left to right)

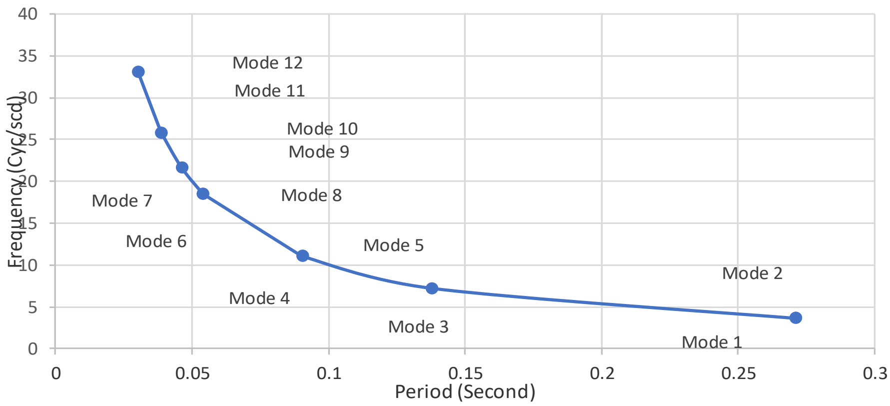


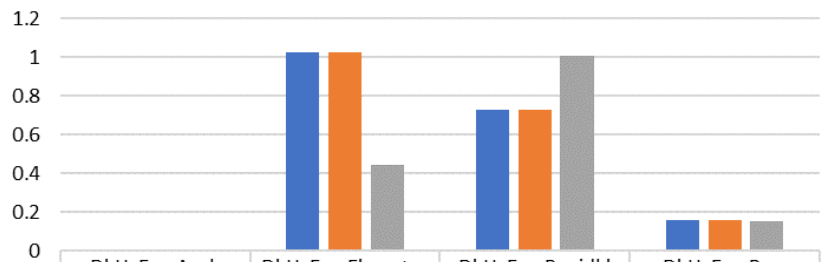
Fig. 5 - Frequency vs period

Based on Fig. 4, there are 12 modal types, but 3 modal forms were chosen from this study, which are modal 1, 2 and 3, since the value of those 3 modals has a longer period of time and a lower frequency of the offshore platform. According to the graph above the lower frequency would occur over the longer duration of the model. The frequency formula is 1 divided by period and the frequency unit is cycles per second (Hz). For instance, the period of mode shape 1 is 0.270919 seconds, so the mode shape frequency is 3.6911 Hz. From this graph, as the model period decreases, the frequency of the model will increase due to the frequency wave. The 3-legged offshore platform mode shape is analysed and listed in Fig. 5. Besides that, the swaying mode shape associated with the natural era of the offshore platform is the warped shape of the platform when shaken during the natural time. Therefore, an offshore has several modes formed as the quantity of cycles. In short, each type of mode shape is independent, which means that incorporating this or any other mode shape, it cannot be accomplished.

4.2 Time History Analysis and Response Spectrum

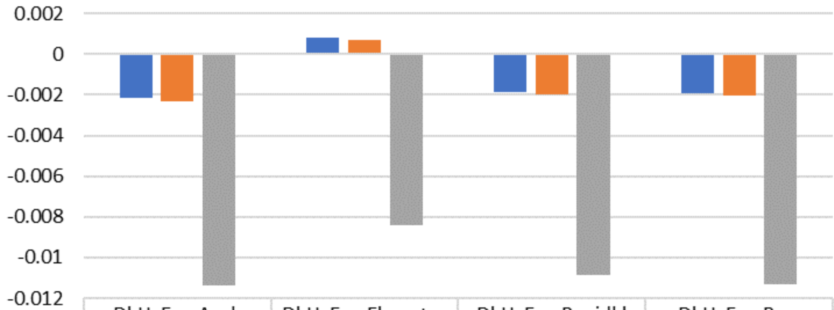
Time history analysis is also an important seismic structural technique known as nonlinear dynamic analysis. It is analyzed particularly if the analyzed systemic reaction is nonlinear dynamic analysis. For such an analysis, the offshore platform needs a representative earthquake background. Furthermore, time history is one of the research projects that demonstrates several stages of the dynamic response of the structure to the load that can vary over time.

Response spectrum analysis (RSA) is a form of linear-dynamic statistical analysis that evaluates the contribution of each natural vibration mode to demonstrate the possible maximal seismic response of a system that is basically elastic. Response-spectrum research gives insight into complex behaviour by calculating pseudo-spectral acceleration, velocity, or displacement for a defined time span and the degree of damping as a feature of the structural duration. Envelope reaction spectra are functional, such that a smooth curve reflects the peak response for each structural time realization. For design decision-making, response-spectrum research is beneficial since it links structural type selection to dynamic results. Shorter-period systems undergo greater acceleration, whereas longer-period ones' experience greater displacement.



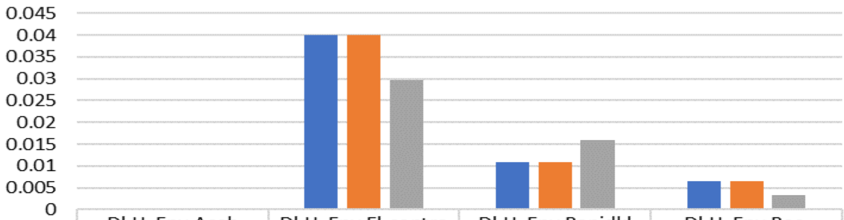
	Dl,LL,Env,Aceh	Dl,LL,Env,El-centro	Dl,LL,Env,Rapidkl	Dl,LL,Env,Res.
U1	0.000002199	1.02549	0.73095	0.15949
U2	0.000002187	1.02522	0.72952	0.15927
U3	0.00000176	0.44381	1.00748	0.15429

Fig. 6 - Joint accelerations under different earthquake loadings



	Dl,LL,Env,Aceh	Dl,LL,Env,El-centro	Dl,LL,Env,Rapidkl	Dl,LL,Env,Res.
U1	-0.002166	0.000829	-0.001838	-0.001893
U2	-0.002304	0.000692	-0.001976	-0.00203
U3	-0.011359	-0.008408	-0.010846	-0.011289

Fig. 7 - Joint displacement under different earthquake loadings



	Dl,LL,Env,Aceh	Dl,LL,Env,El-centro	Dl,LL,Env,Rapidkl	Dl,LL,Env,Res.
U1	1.354E-07	0.04	0.0109	0.0064
U2	1.354E-07	0.04	0.0109	0.0064
U3	1.289E-07	0.0296	0.016	0.0032

U1 U2 U3

Fig. 8 - Joint velocities under different earthquake loadings

Based on the results analyzed, the path of these three-earthquake loads (U1, U2, U3) showed a significant difference. Node 200 was selected because the importance of the outcome is the main component of the offshore platform. Therefore, it has been chosen to be a comparison member. Meanwhile the figure below shows the comparison between 'Aceh',' El-Centro', 'Rapid KL' and Response Spectrum.

The software's results showed node 200, which is shown in Fig. 6 to Fig. 8. is the most important node element in this structure. This is because these joints enable to sustain the weight of the pipe equipment, topside dead load, and jacket appurtenances. Furthermore, the output from the result from the various load combination cases for the particular element have been determined that consist of joint acceleration, joint displacement, and joint velocity. Based on the figure, the seismic wave of El-Centro, which has the highest magnitude among the three-earthquake load in our research, and it has impact on the offshore platform in terms of acceleration, displacement and velocity.

5. Conclusion

Based on the analysis from SAP 2000, the highest value of free vibration analysis (FVA), the natural period is 0.270919 second for mode shape 1, 0.270917 second for mode shape 2 and 0.13766 second for mode shape 3. From this result, the natural period decreases from every mode, but the frequency of the mode increases. Besides that, the region of Malaysia can withstand this low seismic, as the overall joint acceleration, joint velocity and joint displacement are below the permitted capability controls after a few types of load combination have been assigned. The major earthquake under the offshore platform is 'El-Centro' and the minor is 'Aceh' compared to the time history of 'Aceh',' El-Centro', 'Rapid kl' and Response spectrum. The result shown node 200 is the vital steel member. Therefore, this analysis contrasted the 4-earthquake loading with select node 200.

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