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ORIGINAL ARTICLE

Strucure Vulnerability and Risk Analysis of 4-Legged Offshore Structure

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ABSTRACT – Offshore structures are commonly used in oil and gas collecting sector. This industry is one of the major economic sector in Malaysia. Since distant earthquakes from neighbour countries (Indonesia and Philippines) had caused significant structural damages in the past few years, the perfomance level of offshore due to seismic effect need to be undergone detailed investigation. Therefore, this research aims to investigate the vulnerability and analyze the risk of 4-legged fixed offshore structure under different excitations. In order to achieve the objectives, SAP 2000 was chosen to analyze the offshore structure modelling by referring to the API (American Petroleum Institute) criteria. Time history, response spectrum and free vibration analysis have been performed. The behaviour of the offshore structure was observed and evaluated through the natural frequencies and periods. Meanwhile, results outcome of the joint displacement, velocity, and acceleration represented the dynamic characteristic of the structure. The 4-legged fixed offshore structure categorized as Immediate Occupancy (IO) based on FEMA 356 guidelines. From the results, it showed that existing 4-legged offshore structures in Malaysia are capable to resist seismic loads and in stable condition.

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INTRODUCTION

Earthquakes are categorized as one of the most dangerous natural disasters in the world. It is unpredictable and it has probability to occur at anytime and anywhere. The worst situation such as tsunami, landslide, destruction of buildings, seiches, and liquefaction may occur after an earthquake event [1]. Earthquakes occur when the stress produced and released due to the movement and friction between the tectonic plate. However, the classification of earthquake hazard in Malaysia consider between low to moderate seismicity region according to the distance from the fault line[2,3]. Since Malaysia is not located near to the active seismic fault zone, so most of Malaysian perceive that they are free from the life-threatening seismic crisis which it is totally a wrong perception. On 5th June 2015, the Ranau earthquake with a magnitude of Mw 5.9 has been recorded as the strongest tremors to affect Malaysia for the last 45 years[3]. It caused substantial damage to the structural buildings in Ranau [4]. Therefore, the structural performances and life safety of any civil engineering work in Malaysia were to pay more concern and attention due to the significant hazard occur in this earthquake[5].Other than that, the construction industry to come out with a risk analysis and vulnerability of structure under earthquake loading has given a very big challenge due to this incident.

Offshore drilling is widely used to collect the oil deposit under the deep ocean around the world. It is normally constructed in countries which rich in resources such as petroleum, gas, and others.There are three offshore regions in Malaysia which are East Malaysia, Sabah, and Sarawak Operation (SBO and SKO), and Peninsula Malaysian Operation (PMO) [6]. With the escalated number of high rise buildings and offshore structures in Malaysia, ignoring the seismic design is starting to become an arguable point by design engineers in Malaysia. So, earthquakes should be taken as a serious issue because it will destroy a country or city which consequently will results in extensive loss of life [7]. However, seismic design is still considered relatively new knowledge to civil engineer society in Malaysia. This research contributes to the social by evaluating the structural system's existing structural performance and stability under different seismic loads. Besides, related parties would have the opportunity to revisit the seismic hazards in Malaysia and also promote the importance of seismic design for the construction industry in Malaysia.

LITERATURE REVIEW

Offshore structure

Offshore is a special type of complex structures consisting offshore oil platforms used for drilling, extracting, and processing oil and natural gas. These kinds of large-scale structure are continuosly exposed to the sea water and caused corrosion of offshore structure [8,9]. Malaysia having over 250 installation of offshores, which have been operating more than 20 years, 48% of these platform have already exceed its design life of 20-25years [10]. Thus, safety is the key factor for offshore structure and regular maintenance required to ensure the structure system performes well. Also, offshore structures face the lateral loads where wave load, wind load, seismic load, and water pressure during operating [11]. Thus,

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stable platform of the offshore is very important to prevent failure effect by the external loads or enviroment factor.There are few number of offshores constructed in Malaysia as shown in Figure 1.

Figure 1. Location of offshore in Malaysia [6].

METHODOLOGY

Selected offshore structure

Two types of analysis were adopted; time history analysis and response spectrum analysis using SAP 2000 software. The 4-legged offshore structure is selected to investigate the structure's vulnerablity and risk anlaysis. The height of the offshore fixed platform is 53.210m and having the square dimension showed in Figure 2 to Figure 4. Meanwhile, Table 1 showed the summary of the structural member properties.

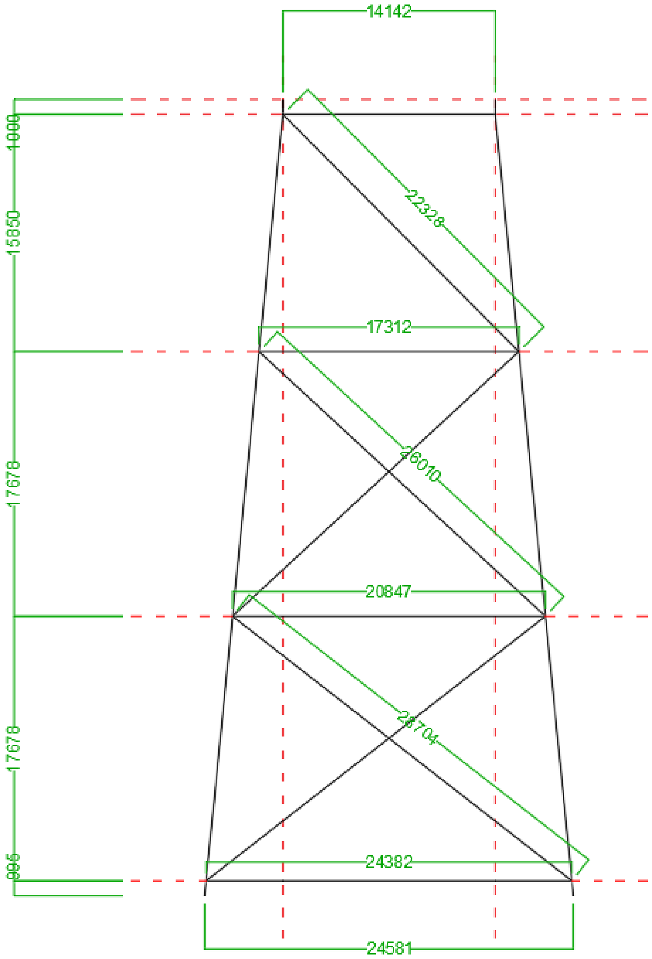

Figure 2. Elevation view of 4-legged offshore structure.

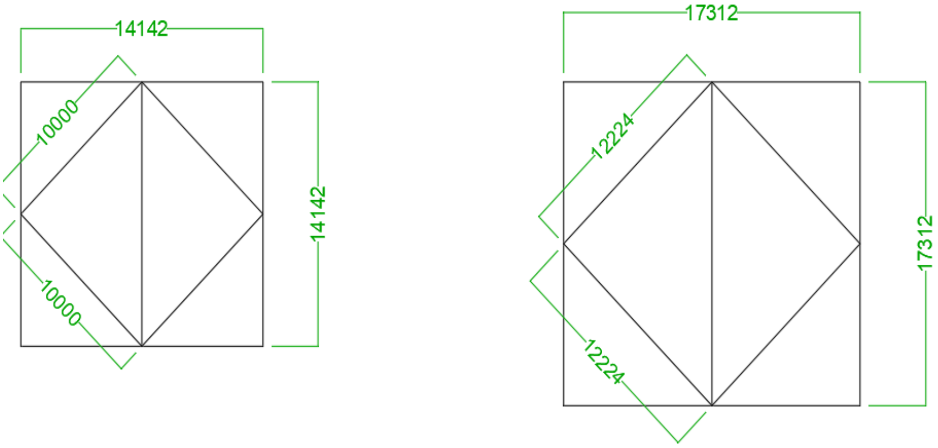

Figure 3. Square dimension at level 3 and 4.

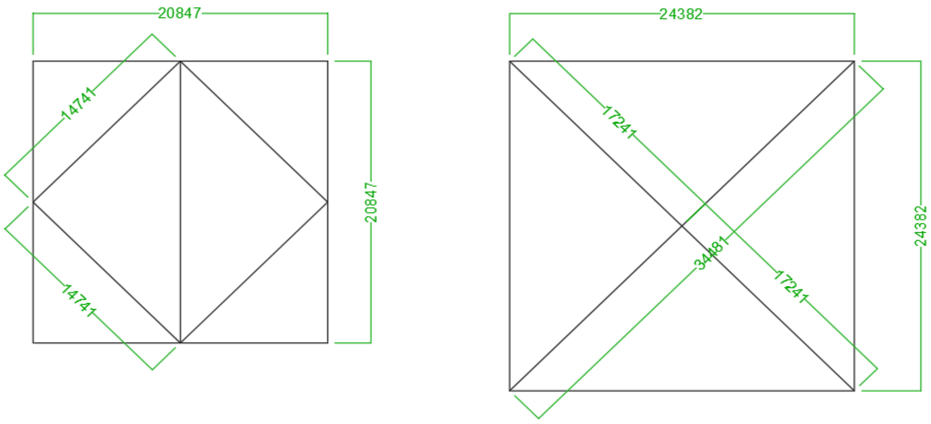

Figure 4. Square dimension at level 1 and 2.

Table 1. Structures properties.

Parameter	Label	Details
Circular hollow section	1168 OD x13 mm	-
Ultimate stress	Fu	510N/mm^2
Possion' ratio	U	0.3
Modulus of elasticity	E	210000N/mm^2
Minimun yield stress	Fy	355N/mm^2
Steel density	Density	7849kn/m^3
Shear modulus	G	80769.2N/mm^2

Time history analysis

In Malaysia, earthquake hazards are still poorly understood and have yet to be thoroughly quantified due to lack of basic scientific data [12,13]. Moreover, time history data of Malaysia are not well documented and archieved. Therefore, the time history data of El-Centro (major earthquake) and Aceh (minor earthquake) have been selected for the analysis as shown in Table 2.

Table 2. Time history data.

Earthquake	Description	Magnitude,Mw	Date	PGA,g
Aceh	Minor Earthquake	6.1	2 July 2013	0.2
El Centro	Major Earthquake	6.9	18 May 1940	0.357

Response specturm analysis

According to [14], the authors advised that minimum reference PGA value of 0.07g for Peninsular Malaysia and 0.12g for CNE Sabah to address the modelling of uncertainties, even though more than conventional PSHA would indicate. The highest PGA value recommended in NA-2017 to MS EN1998-1:2015, had been selected to represent the seismic hazards among all the location of offshore in Malaysia as shown in Table 3.

Table 3. Response specturm input details.

Parameter	Detail
Spectrum Type	I
Ground Type	D
Soil Factor	1.35
Behaviout Factor,q	1.5
Peak ground acceleration,a_{gr}	16%
Damping Ratio	5%

RESULT AND DISCUSSION

To validate the accuracy of the analysis results; atleast 90% of total mass participation ratio, eigenvalues equal to 0, translation in mode shape 1 and 2, and torsional in mode shape 3 should be achieved [15,16]. The joint displacement, joint velocity, joint acceleration, maximum shear and bending as well as the maximum unity check were taken as observations to meet the study's objectives. The assumption for the support of the offshore modelling considered as fixed support was made.

Free vibration analysis

Mode shape of offshore structure have been obtained in this analysis to prevent resonance effect due to structures have their own frequency and period in modal anlaysis [17]. Results output for twelve mode shape of offshore structures were summarized in Table 4. Meanwhile, only the first three mode shape were considered in the analysis due to the other mode shapes are small and it can be neglected. Figure 5 and Figure 6 show first three mode shape of offshore structure, where the translation direction and torsional, were almost similar with previous research [16,18,20].

Table 4. Natural period and frequency.

Mode	Natural Period,T (sec)	Natural Frequency,f (Hz)
1	0.3453	2.8960
2	0.3451	2.8977
3	0.1826	5.4762
4	0.1272	7.8631
5	0.1138	8.7874
6	0.1124	8.8978
7	0.1100	9.0852
8	0.1100	9.0862
9	0.1067	9.3766
10	0.1057	9.4647
11	0.1049	9.5371
12	0.0941	10.6316

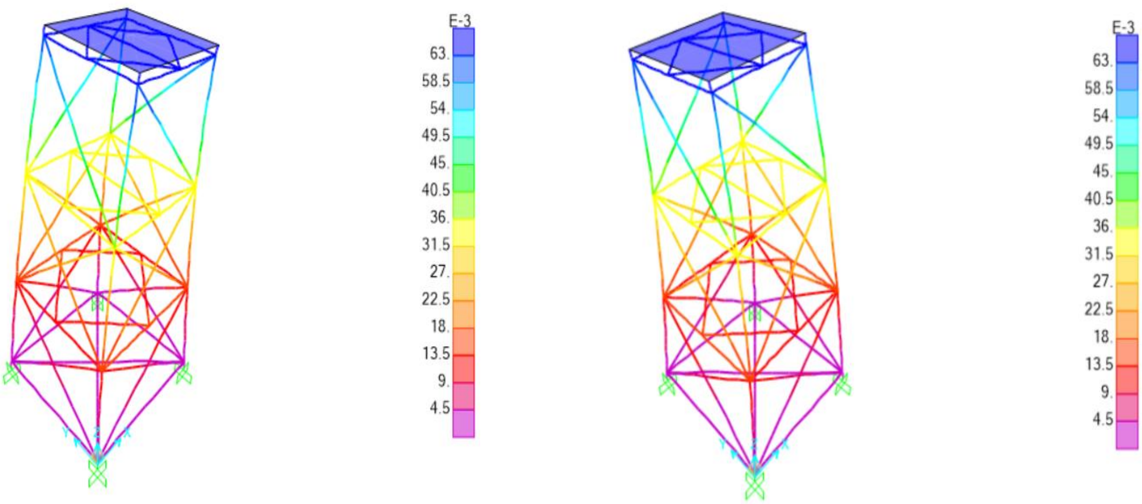

Figure 5. Mode shape 1 and 2 (translation).

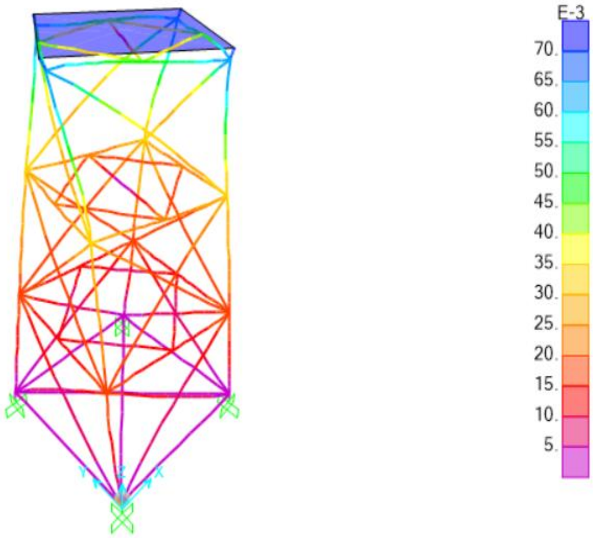

Figure 6. Mode shape 3 (torsional).

Joint displacement,velocity and acceleration

For this study,results output of joint displacement, velocity and acceleration were observed under time history and response spectrum analysis. Joint in steel structures system considered as one of the most important element to determine the stabiliy and strength. From figure 7 to Figure 9, it showed the results of joint displacement, velocity and acceleration for each load case combination in 3-direction. Among all of the load case combination, it can be observed that El Centro having the highest results value, followed by Aceh which ranked second and then third by response spectrum. The effect of the PGA and earthquake's magnitude can be seen, where the higher the intensities, the higher the joint displacement, joint velocity and joint acceleration.

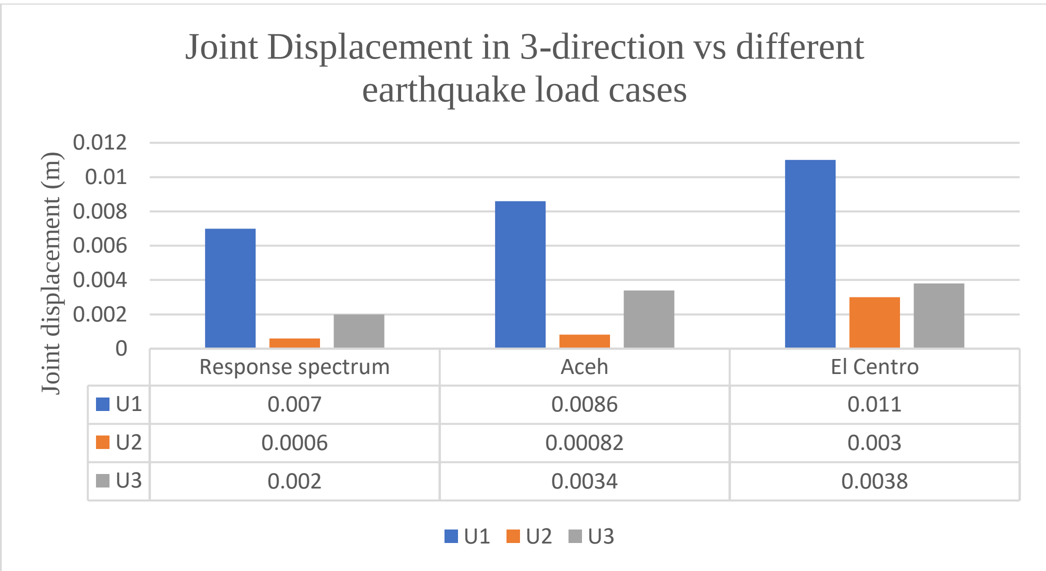

Figure 7. Joint displacement in 3-direction for different load cases.

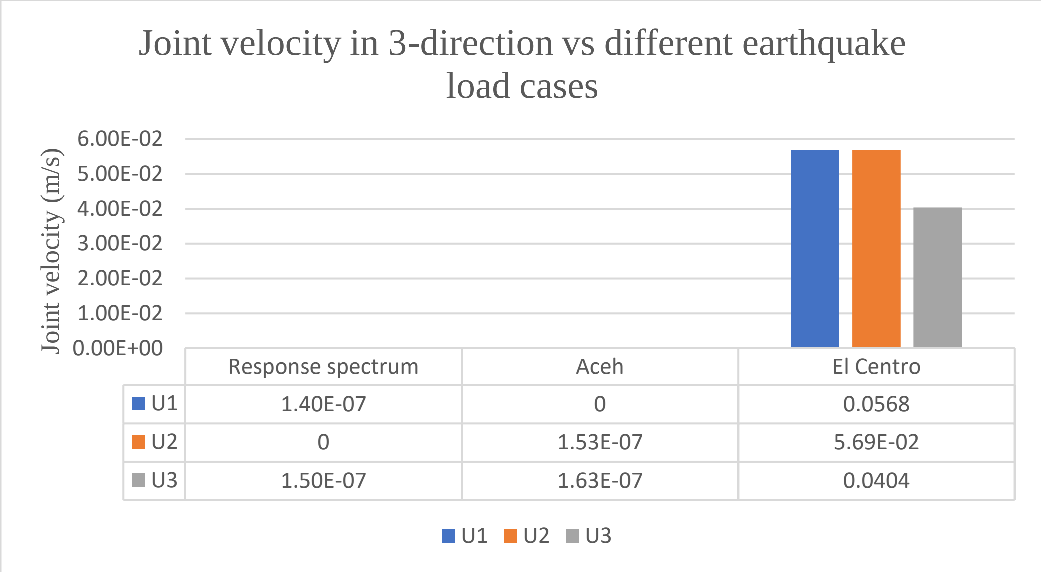

Figure 8. Joint velocity in 3-direction for different load cases.

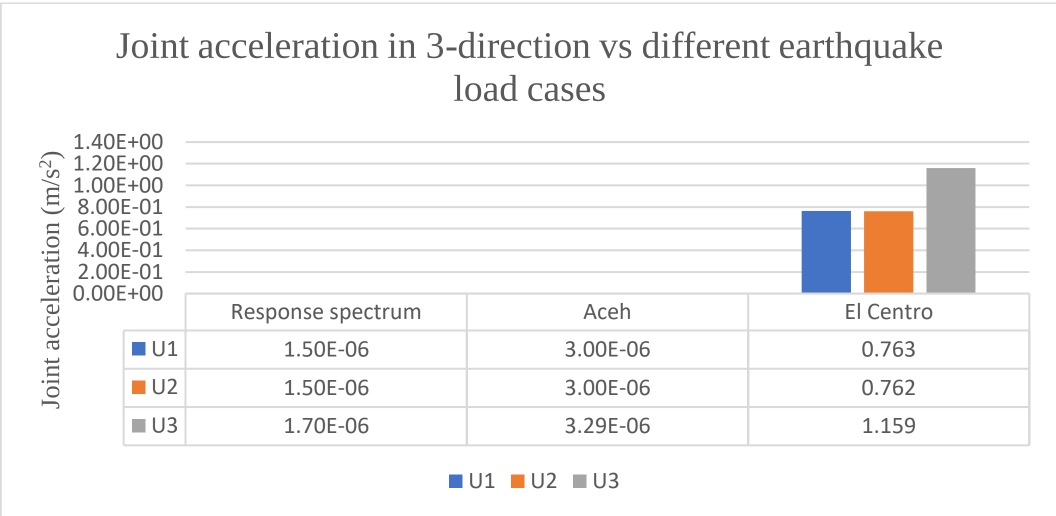

Figure 9. Joint acceleration in 3-direction for different load cases.

Maximum unity check for all strucuture member

Figure 10 shows the unity check results of the structural members under two analysis methods due to gravitational and environmental loads. It can be observed that the highest P-M ratio of the structural members with value 0.729 is within the allowable limit according to API RP 2A WSD. Therefore, offshore structures are safe to support the various combined load cases and met components structural adequacy [16,19].

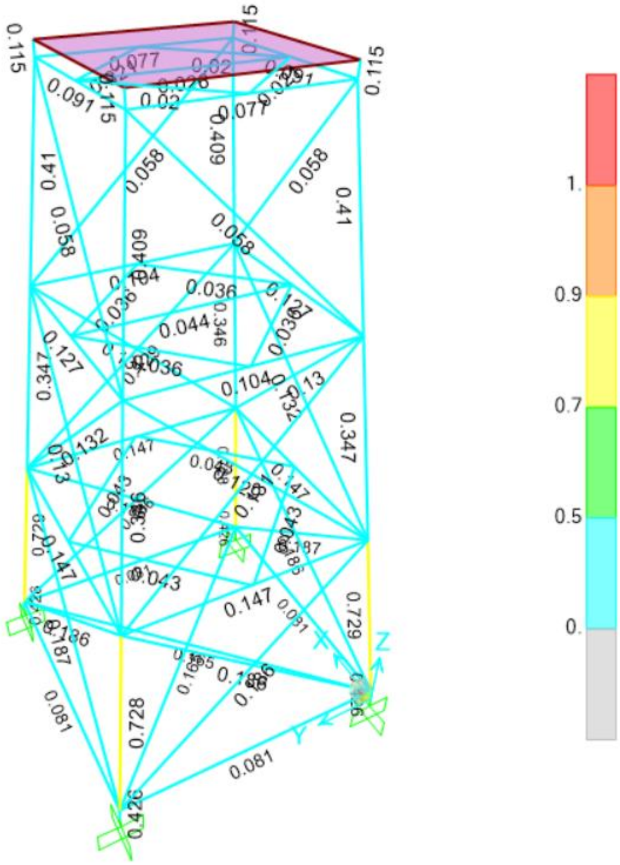

Figure 10. Unity check ratio.

Maximum shear force and bending moment of the member

Local strength of the structures member were gained through the maximum shear force and bending moment based on several load cases combination. The structure member with highest unity check value having the maximum shear force and bending moment are concluded as the most critical member. From Figure 11 and Figure 12, El Centro load combination having the highest shear force and bending moment among all load combination which are 1091.131kN and 929.68kNm respectively.

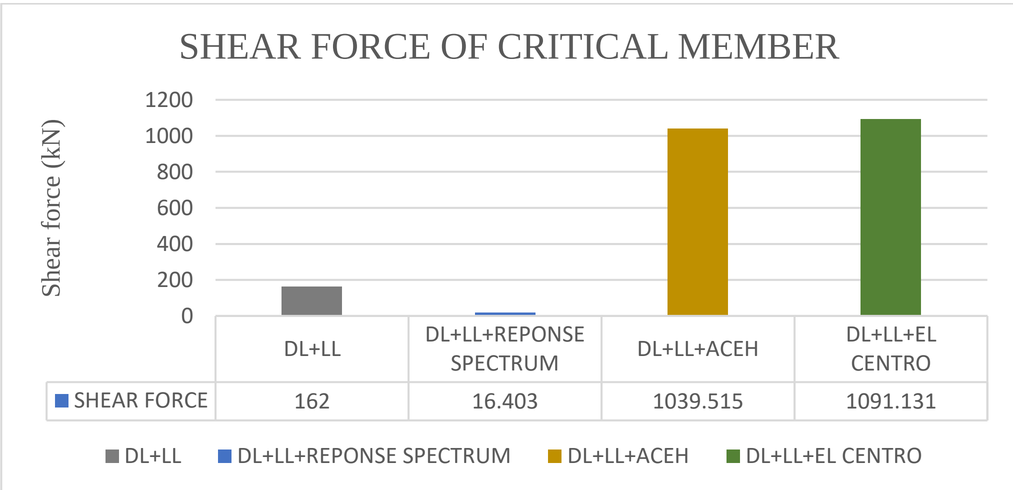

Figure 11. Shear force under different load cases.

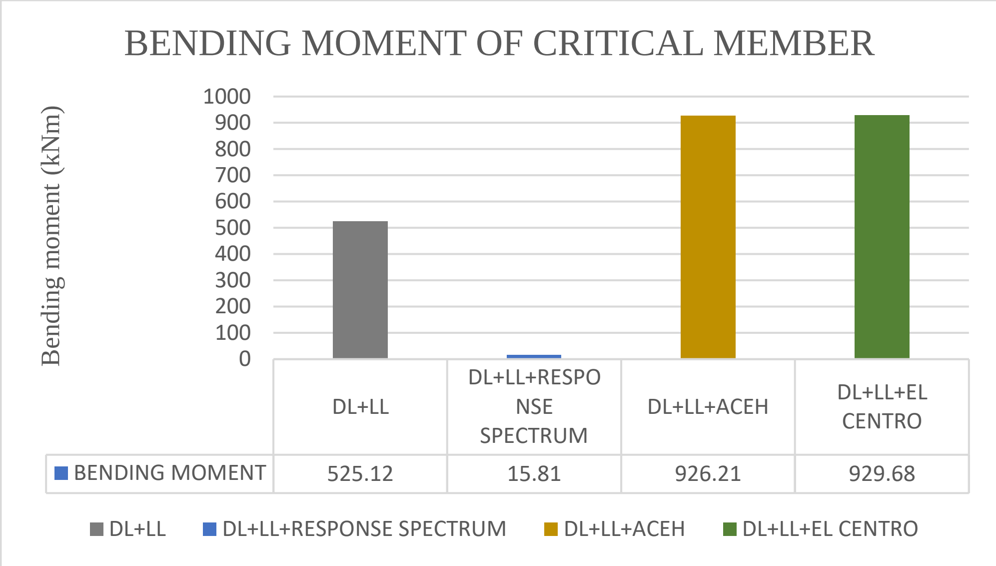

Figure 12. Bending moment under different load cases.

Perfomance level of the structural system

To determine the status of the safety of building after an earthquake events, performance of offshore structures evaluate based on the interstorey drift ratio (IDR) according to the FEMA 356 (2000) [21]. There are three main structural performance levels namely as Immediate Occupancy (IO), Life Safety (LS), and Collapse Prevention (CP). Table 5 showed the deformation criteria for braces with circular hollow section. From the results showed in Figure 13, El Centro is having the highest interstorey drift ratio among the different load cases which are 8mm. Based on the Figure 13, the interstorey drift ratio of all different load cases within the acceptance criteria of Immediate Occupancy (IO). Therefore, the perfomance level of the offshore structure categoraized as Immediate Occupancy (IO).

Table 5. Deformation criteria fo brace with circular hollow section.

Component/action	Acceptance criteria (plastic deformation)		
Braces in compression	IO	LS	CP
$\frac{d}{t} \leq \frac{1500}{Fy}$	$0.25\Delta_c$	$4\ \Delta_c$	$6\ \Delta_c$
$\frac{d}{t} \geq \frac{6000}{Fy}$	$0.25\ \Delta_c$	$1\ \Delta_c$	$2\ \Delta_c$
Braces in tension	$0.25\ \Delta_T$	$7\ \Delta_T$	$9\ \Delta_T$

1. Δ_C is the axial deformation at expected buckling load.
2. Δ_T is the axial deformation at expected tension yielding load.

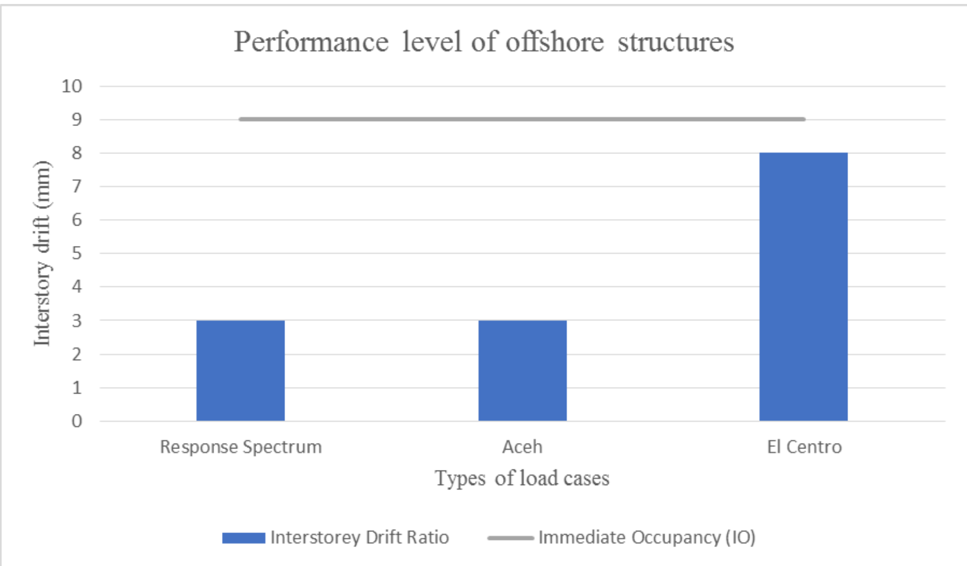

Figure 13. Perfomance level of offshore strucutures.

CONCLUSION

This study investigated the structural vulnerability and risk analysis of 4-legged offshore structures under different earthquakes occurred in Malaysia. In brief, this study of the data led to the following conclusions:

1. Structural vulnerability and risk analysis of 4-legged offshore structures are defined by unity check of every steel member based on the critical load case combination. As a result, the P-M interaction ratio of all steel member are within the allowable capacity, which shall be less than 1, indicating that the offshore in stable condition. Frame member 28 was the most critical frame member with the P-M interaction ratio of 0.729.
2. From the finding, the major earthquake has caused more significant effect to the offshore structures compare to the minor earthquake. This can be proven by comparing the results of joint displacement, joint velocity, joint acceleration, shear forces, and bending moments under El Centro load combination, having highest value compared to other earthquakes.
3. The highest value of the natural periods is 0.3453sec with the natural frequency of 2.896Hz in free vibration analysis. Other than that, the first three modes with two orthogonal translational modes and third torsional modes indicated the structural system of 4-legged offshore structures is effective and symmetrical [20].
4. From the result, Interstorey Drift Ratio (IDR) of all different load cases are within the limit of Immediate Occupancy (IO). So, the performance level of 4-legged offshore structures categorized as Immediate Occupancy (IO) according to the FEMA 356 (2000) guideline [21].

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