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Unity check of typical offshore wellhead platform in Malaysia using Aceh earthquake loading data and SAP2000

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Abstract. One of the most significant regional earthquakes which brought catastrophic impacts is the magnitude of Mw= 9.1 earthquake which occurred on the western coast of Banda Aceh, North Sumatera had generated a massive Indian Ocean tsunami on December 26th, 2004. Apart from that, several local earthquakes also occurred in Bukit Tinggi, Pahang and Ranau, Sabah according to Malaysian Meteorological Department (METMalaysia). However, oil and gas industry plays a vital role in Malaysian economy due to the significant contribution to the country's gross domestic product. In fact, the existing fixed offshore structure in Malaysia region only take into considerations the wind load, wave load, and current load rather than earthquake load. The objective of this study is to perform unity check for every element of offshore wellhead platform when subjected to 2004 Aceh earthquake loading. All the environmental loads such as wave, wind, and current load have been designed by referring the American Petroleum Institute (API) design criteria. The computer software SAP2000 is selected to model and analyse the offshore structure. There are three types of analysis that have been performed in this study which are the free vibration analysis, time history analysis, and response spectrum analysis. The time history of earthquake data from 2004 Aceh earthquake has been used in performing time history analysis. For the response spectrum analysis, the analysis was performed by using response spectra curves in Eurocode 8. As a result, the offshore wellhead platforms in Malaysia are situated under a safe condition when subjected to low seismic activity based on the study.

1. Introduction

Earthquake are one of the greatest natural hazards to life and property. Reid's theory of elastic rebound claims that earthquakes are the result of sudden release of stresses that slowly accumulate in the rocks on the opposite sides of a fault when these opposite sides tend to move relative to each other, but the motion is being resisted by frictional forces. When the accumulated stresses are greater than the frictional resistance between two sides, the fault starts to slip at its weakest point and leads to the occurrence of ruptures along its entire surface immediately. Then, the rebounds of rock occur on both sides of the fault to an unstrained position afterward, releasing the stored elastic energy in the form of heat and emitting seismic waves. For example, an earthquake with a magnitude of Mw= 9.1 which occurred on the western coast of Banda Aceh, North Sumatera had generated a massive Indian Ocean tsunami on December 26th, 2004. The tsunami had struck the coast of several countries in Southeast Asia and East Africa which included Indonesia, Sri Lanka, Thailand, Maldives, Somalia, Myanmar, Malaysia and Seychelles [1]. Around 220,000 people were killed in the incident, making it the one of the deadliest natural disaster in modern history [2]. When the structure experiences earthquake, it will caused structural damage. Which the normal buildings only can resist inelastic energy and the loading caused by dead load and live load will dissipate in structural systems [3].



2. Problem Statement

In Malaysia, most of the Malaysian citizens are not aware of earthquake hazards because the active seismic fault zone is located about 350km away from Malaysia. This is the reason why earthquake engineering in Malaysia is relatively behind compared to other engineering fields due to our less profound earthquake history. Although Malaysia is located on the stable Sunda Shelf with low to medium seismic activity level, Malaysia is surrounded by high seismicity regions at the east, west, and south parts as shown in Figure 1. The two most seismically active plate boundaries are situated close to Malaysia which is the subduction zones between the Eurasian and Philippines plates at the east region. However, several tremors due to the active seismic area from Sumatra has been reported along the west coast of Peninsular Malaysia. For instance, Malaysian Meteorological Department (METMalaysia) reported that the earthquake near Sumatra on November 2nd, 2002 had cause tremors to several cities in Peninsular Malaysia which included Penang and Kuala Lumpur.

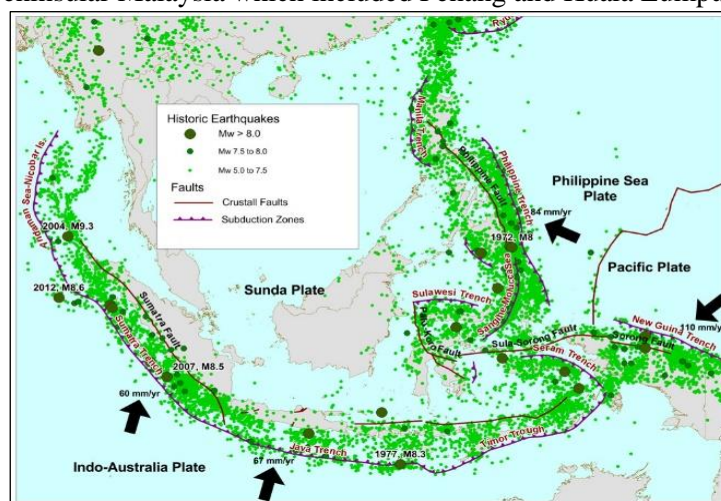


Figure 1. Active faults and historical seismicity in the Southeast Asia region (Bingming Shen-Tu, 2016).

Apart from that, Bukit Tinggi and Sabah also experienced earthquake of local origin. According to the Malaysian Meteorological Department (METMalaysia), a magnitude of 5.9 Scale Richter moderate earthquake had struck Ranau, Sabah on June 5th, 2015 has taken eighteen unfortunate lives and caused significant damage to properties (Shah, 2016). Recently, another 5.2 magnitude earthquake has struck Ranau, Sabah again on March 8th, 2018 less than three years since the fatal 2015 Ranau earthquake according to the record of United State Geological Survey (USGS). Likewise, oil and gas industry plays a vital role in Malaysian economy due to the signification contribution of nearly 20% of the country's total gross domestic product in recent years [4]. Malay basin, Sabah basin, and Sarawak basin are the three main oil-producing basins in Malaysia which are located mainly in offshore regions as shown in Figure 2. Thus, the oil and gas exploration and production activities are fully utilized by a large number of offshore platforms throughout Malaysian territories.



Figure 2. Malaysian sedimentary basins [5].

In fact, Malaysia's government authorities have not specified any seismic provision but has only taken considerations of wind load, wave load, and current load in designing the fixed offshore platforms [6]. The satisfaction of existing structures in Malaysia in terms of earthquake tolerance are being questioned by Malaysians following the recent events of tremors arising from neighbouring countries. In light of the facts, seismic hazard assessment has become a prerequisite in order to keep in check the detrimental effects of potential future large earthquakes to ensure that the offshore structures exhibit sufficient resistant against earthquake loading.

3. Methodology

This offshore wellhead platform used in this case study is an existing structure which is located off the coast of Terengganu, Malaysia. SAP2000 software is used for the process of modeling the offshore wellhead platform. The dead loads, live loads, environmental loads include wind, wave, current as well as earthquake loads has been defined in the load cases of the offshore structure. Basically, all the environmental loads are determined from the specific location of the offshore wellhead platform located and also calculated by following the American Petroleum Institute criteria standard [7]. In addition, some analysis such as free vibration analysis, time history analysis, and response spectrum analysis will be performed using the SAP2000 software. For the free vibration analysis, the natural period and the mode shape of the structure will be obtained from this analysis. The time history analysis will be performed by referring to the time history earthquake data from 2004 Aceh earthquake which obtained from Malaysian Meteorological Department [8,9,10]. Likewise, the curve of response spectra in Eurocode 8 will be used to perform the response spectrum analysis. Several combinations of load cases that will be applied in this analysis using interface of load input in SAP2000 software. The combinations are as follows:

1. Dead Load (DL) + Live Load (LL)
2. Environmental Load (EL)
3. Dead Load (DL) + Live Load (LL) + Environmental Load (EL) + Time History Load (TH)
4. Response Spectrum Load (RS)

On the other hand, the manual calculation has been carried out to compare the results in order to ensure the accuracy of the results obtained from SAP2000 software. From the software results, the particular beam, column, and truss with the highest P-M interaction ratios are chosen to carry out the manual calculation.

4. Results and Discussions

4.1. Free Vibration Analysis

The twelve (12) mode shapes of offshore wellhead platform along with the natural period and natural frequency have been obtained throughout this analysis. Table 1 shows the summary of the analysis results. Figure 3 and Figure 4 show the first and second mode of vibrations which are considered the critical mode to the structure because the first mode normally has the longest natural period and followed by the second mode. The grey colour shape represented the undeformed shape of the structure, while the blue colour shape represented the deformed shape of the structure.

Table 1: Results from the free vibration analysis.

Mode	Natural Period, T (sec)	Natural Frequency, f (Hz)
1	0.1062	9.4173
2	0.0888	11.2646
3	0.0832	12.0188
4	0.0820	12.1914
5	0.0790	12.6652
6	0.0783	12.7728
7	0.0783	12.7738
8	0.0709	14.0950
9	0.0699	14.3136
10	0.0671	14.9016
11	0.0661	15.1371
12	0.0650	15.3822

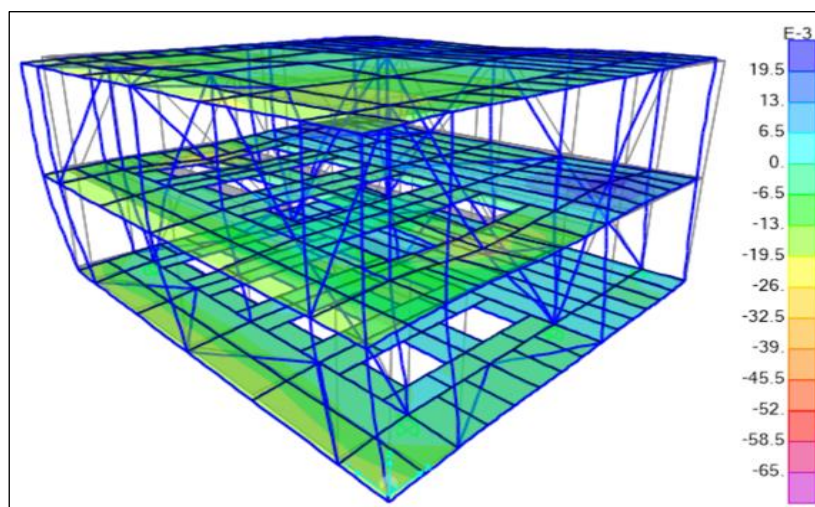


Figure 3. Mode shape 1 of the offshore wellhead platform.

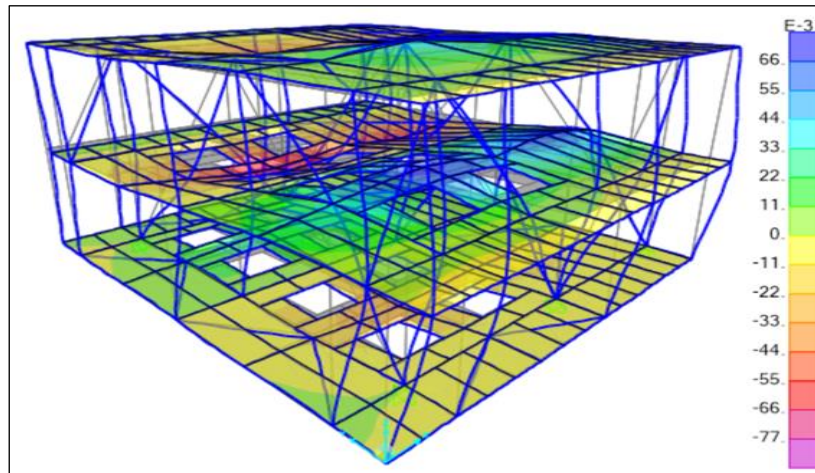


Figure 4. Mode shape 2 of the offshore wellhead platform.

4.2 Maximum Unity Check

The most critical frame element in this structure has been determined from the results obtained in SAP2000 software which is frame member 87 and 88 with 0.58 ratio as shown in Figure 5. This is because these beam elements are symmetric to each other in the offshore wellhead platform.

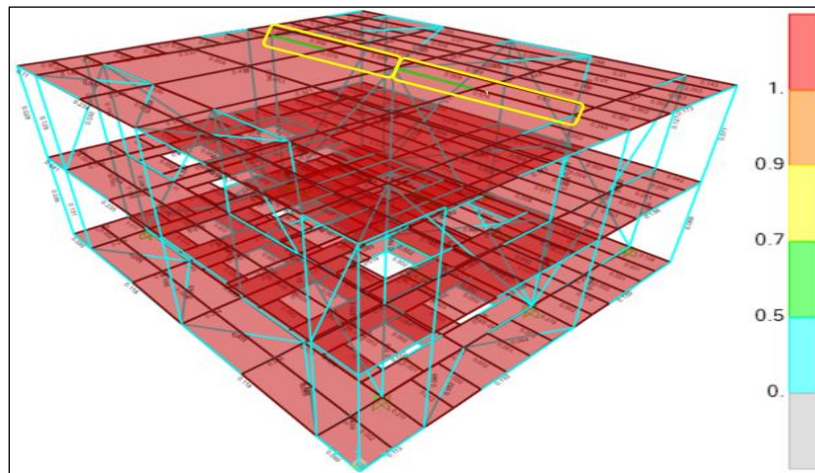


Figure 5. Offshore wellhead platform with the P-M interaction ratio.

Furthermore, the output of the results from various load combination cases for this particular frame element have been determined and illustrated in Figure 6 and Figure 7 which consist of the graph of shear stress versus load combinations and bending stress versus load combinations respectively. From Figure 6, the load combination of dead load and live load has the highest shear stress, 13,671.15 kN/m² among others, while the allowable shear stress is 130,481.13 kN/m². Therefore, the offshore structure is able to resist the loading based on the results shown in the graph where the actual shear stress is less than the allowable shear stress. Moreover, the highest bending stress can be observed from Figure 7 which occurs at the load combination of dead load and live load with the value of 231,032.44 kN/m², while the allowable bending stress is 480,739.77 kN/m². Based on Figure 7, all the bending stress from different load combinations do not exceed the allowable bending stress. Therefore, the offshore structure is situated under a safe condition when subjected to dead load, live load, environmental load, and earthquake load.

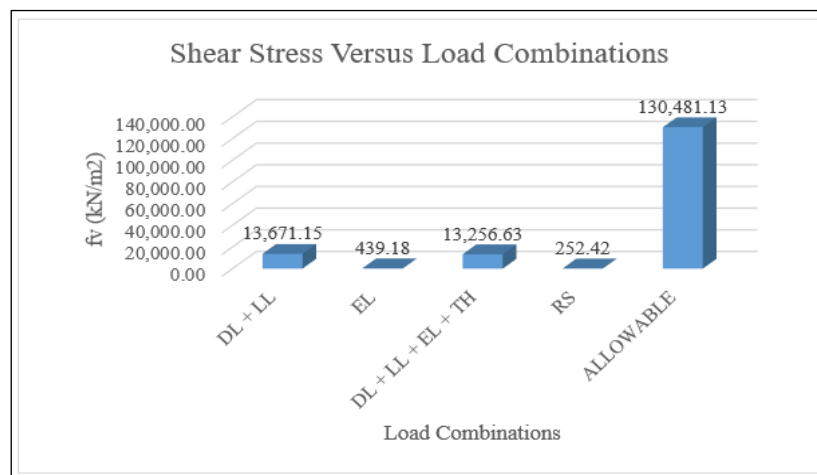


Figure 6. Graph of shear stress versus load combinations.

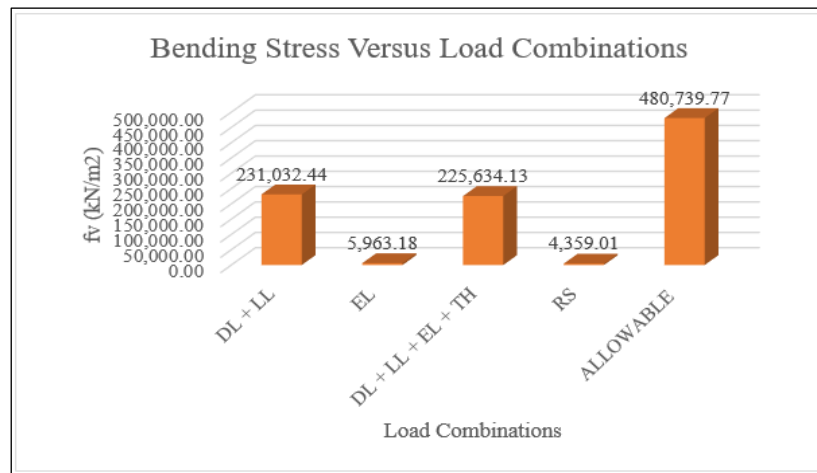


Figure 7. Graph of bending stress versus load combinations.

4.3 Comparison of Results between Manual Calculation and SAP2000

Table 2 shows the comparison of P-M interaction ratios results obtained from manual calculation as well as SAP2000 software. Both of the results from manual design and software design are passed under unity check since all the ratios obtained are less than 1 as shown in table below. Frame member 87 and 88 are the most critical beam elements with the P-M interaction ratio of 0.58 obtained from SAP2000. For manual calculations, the P-M interaction ratio for frame member 87 and 88 is 0.73. Moreover, frame member 105 and 129 are the most critical column elements which have the P-M interaction ratio of 0.28 in SAP2000 and P-M interaction ratio of 0.47 in manual calculation. Likewise, frame member 166 is the most critical truss element in tension which has 0.03 P-M interaction ratio from SAP2000 and 0.04 P-M interaction ratio from manual calculation. While for the truss element in compression, frame member 175 is considered as the most critical element with P-M interaction ratio of 0.40 in SAP2000 and P-M interaction ratio of 0.56 in manual calculation. Therefore, the offshore structure is considered in a safe condition when subjected to earthquake loading based on the results obtained from software design as well as manual design.

Table 2. Comparison of P-M interaction ratios results between manual calculation and SAP2000.

Element	Frame	P-M Interaction
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Design	Member	Ratios	
		Manual	SAP2000
Beam	87, 88	0.73	0.58
Column	105, 129	0.47	0.28
Truss (Tension)	166	0.04	0.03
Truss (Compression)	175	0.56	0.40

5. Conclusions

Based on the results obtained throughout this case study, the offshore wellhead platforms in Malaysia region are capable of resisting low seismic activity. This can be proven by the maximum shear stress and bending stress which were below the allowable capacity checks after several load combination cases were applied into the analysis. The unity check for every element of the offshore structure such as beams, column, and trusses have been performed. As a result, all the steel structure of the offshore platform are passed under the unity check as all the P-M interaction ratios were less than 1 based on the results obtained from the analysis. The most critical frame element in the offshore structure is frame member 87 and 88 with the P-M interaction ratio of 0.58. In free vibration analysis, the highest value of natural period is 0.1062 second of mode shape 1 with the natural frequency value of 9.4173 Hz. In addition, the highest shear stress and bending stress for frame member 87 and 88 are 13,671.15 kN/m² and 231,032.44 kN/m² respectively which has occurred at the load combination of dead load and live load.

6. References

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