The Motion Response Analysis of Floating Jack-Up Rigs in the Operating Condition

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Keywords: *floating jack-up, motion, wave, six degree of freedom*

Abstract: Natural gas reservoirs near the seabed (shallow gas) make drilling activities prone to blowout. Using a modified jack-up in a floating state will facilitate evacuation to avoid gas explosion. The floating jack-up is a misuse of the concept of jack-up structure design which must be operated in a fixed structural condition. This issue requires further investigation regarding the feasibility of the drilling operation process. Motion response of the floating structure is revealed in order to explore the feasibility of the operation of the jack-up. In this study, the motion response of the floating bodies will be compared by varying the jack-up leg length immersed in the water. The site reviewed in this analysis is in the Madura Strait, Indonesia. The floating jack-up was modeled and analysed in the MOSES offshore platform design and simulation software. Results show that the response amplitude operator of pitch motion has the most significant response in each variation. From motion validation with rules it can be concluded that the heave motion of this structure exceeded criteria limits for BOP and riser operations but is allowed for drilling activities. The obtained results show that a drilling process in the Madura Strait site using a floating jack-up could possibly be operated by lowering the legs until it reaches five meters above the seabed without running BOP and risers.

1 INTRODUCTION

Jack-up rigs are offshore drilling platforms with legs that can be raised and lowered in the installation process. The concept of designing a jack-up structure is that it combines the advantages of fixed structure buildings such as platform jacket legs and floating platforms such as floating barges. The jack-up is a self-elevating unit. The transportation and installation phases are done during floating conditions, while the spud cans will be jacked onto the seabed during the operating or drilling phase (DNV, 1996).

Seabed sub-surface soil conditions containing shallow gas where the trap of natural gas reservoirs located near the seabed floor will cause the area to be prone to blowout. The presence of shallow gas may possibly cause blowout that will damage the jack-up structure. The penetration of jack-up legs will make it difficult to structure evacuation, because the jacking process of the jack-up legs will take a long time. This problem raises an idea: what if this offshore building structure is operated under conditions where the legs are not fixed on the sea floor or operated in floating condition. Jack-up legs do not touch the sea floor, meaning jack-ups will always be floating in the ocean so evacuation procedures can run smoothly and prevent damage to the structure. A jack-up structure with hanging legs may prove to be the solution. In accordance to the concept of jack-up design, the floating structure of the jack-up clearly does not fulfil the design rule. It may be questioned whether the jack-up can remain stable in a state of operation (drilling activities), how the structure moves, if it can still withstand environmental loads such as wind, currents and waves. With this analysis, we will find out whether the floating jack-up can be operated in drilling or operating conditions.

This research focuses on jack-up rigs of the three independent leg type with K-braced truss legs. It discusses how the motion response of the floating jack-up was subjected to the environmental load. The location of study of this simulation is in the Madura Strait in Indonesia, which has a water depth of 57m. This paper describes and compares the structural motion analysis of six variations of immersed jack-up legs which were subjected to environmental loads. The behavior of motion response of each variation was recorded.

Sawiji, A.
The Motion Response Analysis of Floating Jack-Up Rigs in the Operating Condition.
DOI: 10.5220/0008908100002481
In *Proceedings of the Built Environment, Science and Technology International Conference (BEST ICON 2018)*, pages 191-196
ISBN: 978-989-758-414-5

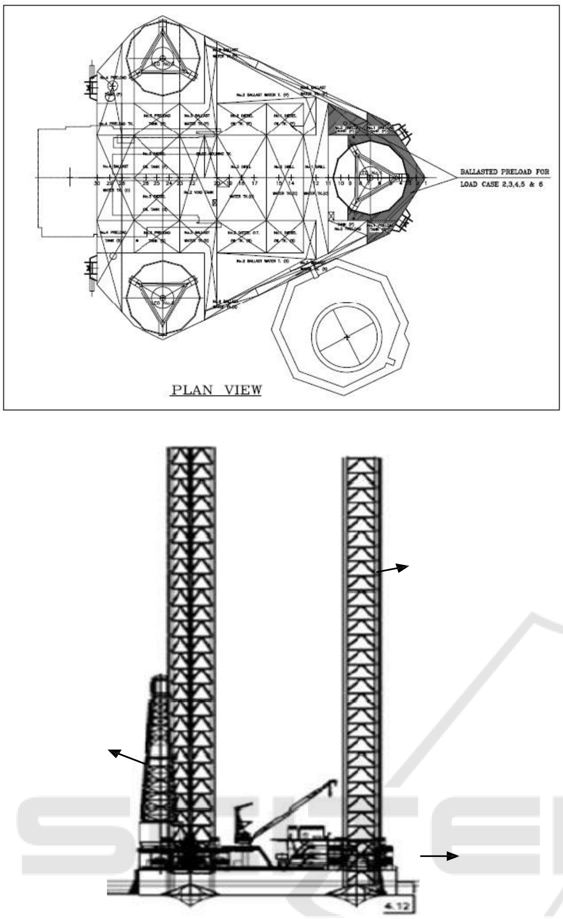

Figure 1: Outboard Profile and Plan Views

The principle particulars of the vessel are as indicated below:

Length Moulded	64.643 m
Width of Hull	64.008 m
Depth of Hull	7.925 m
Leg length	140.208 m
Overall Length of Spud Legs	140.208 m
Longitudinal Leg Centres	40.915 m
Transverse Leg Centres	47.244 m
LCG Bow (Forward)Leg	10.622 m
Diameter of Spud Cans	7.315 m
Displacement at Load Line	23033.5 kips

The jack-up platform was normally designed to function in several different operational modes, i.e. the transit, installation, retrieval and operational condition. Response of the jack-up in the floating mode of operation is obviously far different from that of the jack-up in the installed, elevated condition. Both of these modes are critical to the safe operating of a jack-up unit as each mode of operation may impose its own limiting design criteria on certain parts of the structure (DNV, 1996). In the transportation phase, the jack-up is towed towards the drilling point location with the leg lifted above the hull. Arriving at the drilling point, the jack-up legs are lowered down onto the seabed then jacked until the bearing capacity is sufficient to hold the sea current. The installation phase is the phase where the jack-up leg is self-elevating upward and downward in the sea water, which is commonly called the jacking process. The operation phase is the phase where the jack-up performs its function.

This paper considered the operation phase as the focus of analysis. Six cases were chosen to analyse the motion response of the jack-up platform to explore the possibilities of this structure when operated in a floating condition. The cases are described in the table below.

Table 1: Motion response analyses of case studies.

Case	Immersed Leg Length (m)	Remarks
1	0	Towing
2	14.25	¼ of Water Depth
3	28.5	½ of Water Depth
4	42.75	¾ of Water Depth
5	52	5 meters above seabed
6	57	Jacked

2 METHOD

The jack-up rig of this model was simulated on the MOSES 7.0 software with the aim of discovering the motion response of the structure. The jack up was designed in three dimensions and was only considered on the operating condition. The WSD method was generally used in this analysis. The hull and leg structure was modelled as subjected to horizontal load (wind, wave, current load) for all cases. The structural load implied on this model is the self-weight of the jack-up, distributed load on the hull and the derrick load. The Metocean data used in this analysis was one year of the return period. Based on environmental data, the heading direction was dominantly from the west. The wind speed used in this analysis was 3 seconds gusting condition or 50.268 knots, the significant wave height was 3.24 meters, with a wave period of 9.01 seconds. The current speed was 0.62 m/s on the mean sea level and 0.49 m/s on the seabed.

The floating jack-up is identified as a mobile offshore drilling unit (MODU). The designing of a

MODU needs to consider the variation of environmental load, minimize riser vibration and interference between risers and structure in order to anticipate the structural failure and blow out. To understand which cases can be applied on the drilling operation condition based on the analysis of criteria such as motion response, drilling and tripping, running and setting casing, running and landing BOP/Riser, transferring equipment, they were verified based on the book Floating Drilling: Equipment and Its Use by Riley Sheffield, 1980.

The motion of floating was considered in order to find out the behaviour of the structure. The behaviour of the floating structure is the freedom of movement or oscillation. This oscillation consists of six movements, which consist of three lateral movements and three rotational movements in three direction axes, as shown on Figure 2.

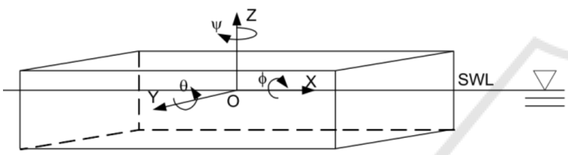

Figure 2: Six degrees of freedom

These types of movements are:

a. Surging: Movement of lateral oscillations on the x-axis.

b. Swaying: Movement of lateral oscillations on the -y axis.

c. Heaving: Movement of lateral oscillations on the -z axis.

d. Rolling: Movement of rotational oscillations on the x-axis.

e. Pitching: Rotational oscillation movement against the -y axis.

f. Yawing: Rotational oscillation movement against the -z axis.

However, the scope of work of this paper only considered the heave, roll and pitch motions. These three motion responses were analysed on the MOSES software with the output of Response Amplitude Operator. The Response Amplitude Operator was used to assess the frequency-domain linear wave body response of the floating platform during the design process. RAO is defined as the response amplitude per unit wave height (Chakrabarti, 1987).

$$Response\ (\omega) = RAO\,\eta\,(\omega) \qquad (1)$$

Where: η = Wave amplitude (m, ft)

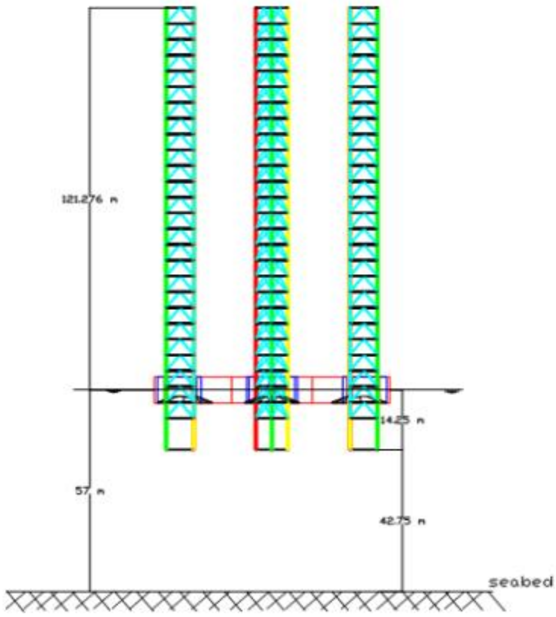

Figure 3: Jack-up modelling on MOSES 7.0 (case 2)

3. RESULT AND DISCUSSION

Sawiji (2015) stated that the stability of a floating jack-up with the leg length of 140.208m and water depth 57m is classified as a stable structure with an area ratio above 1.4 and a tilted angle more than 28°(American Bureau of Shipping, 2005). In structure response analysis, cases are exposed to waves, winds and currents in five different directions, i.e. in the heading direction of 0°, 45°, 90°, 135°, 180°. In the MOSES software, the angle direction is read in a clockwise direction. The five heading directions were the approaching wave and wind direction.

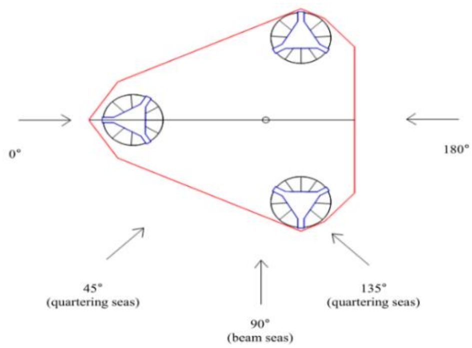

Figure 4: Heading Direction

The following figure displays some of the results of the structural response from several cases. The chart shows that the heave motion at heading 90° was relatively higher than the other heading directions in all cases. The maximum heave motion in these cases was 1.491m on 90° direction on case 1. Based on (Sheffield, 1980), the heave RAO should be under 10 ft or 3.048 m. It shows that the vertical oscillation for the six cases has fulfilled the criteria.

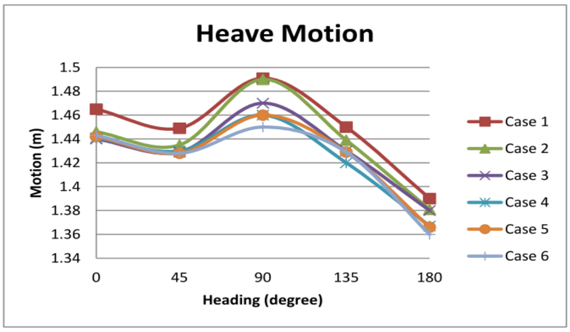

Figure 5: Heave motion of six cases

Table 2: The results of heave motion by considering the floating jack-up as a vessel with/without pipe handling equipment.

Heading	Heave Motion	Vessel with/without pipe handling equipment			
		drilling dan tripping	fishing and logging	Running casing	Running BOP/Riser
(degree)	(meter)	Max. 7 ft	Max. 5 ft	Max. 5 ft	Max. 2.7 ft
Case 1		2.1336 m	1.524 m	1.524 m	0.822 m
0	1.465	OK	OK	OK	FAILURE
45	1.449	OK	OK	OK	FAILURE
90	1.491	OK	OK	OK	FAILURE
135	1.45	OK	OK	OK	FAILURE
180	1.39	OK	OK	OK	FAILURE
Case 2					
0	1.446	OK	OK	OK	FAILURE
45	1.435	OK	OK	OK	FAILURE
90	1.49	OK	OK	OK	FAILURE
135	1.439	OK	OK	OK	FAILURE
180	1.381	OK	OK	OK	FAILURE
Case 3					
0	1.44	OK	OK	OK	FAILURE
45	1.429	OK	OK	OK	FAILURE
90	1.47	OK	OK	OK	FAILURE
135	1.43	OK	OK	OK	FAILURE
180	1.38	OK	OK	OK	FAILURE
Case 4					
0	1.441	OK	OK	OK	FAILURE
45	1.43	OK	OK	OK	FAILURE
90	1.46	OK	OK	OK	FAILURE
135	1.42	OK	OK	OK	FAILURE
180	1.367	OK	OK	OK	FAILURE
Case 5					
0	1.442	OK	OK	OK	FAILURE
45	1.428	OK	OK	OK	FAILURE
90	1.46	OK	OK	OK	FAILURE
135	1.429	OK	OK	OK	FAILURE
180	1.366	OK	OK	OK	FAILURE
Case 6					
0	1.443	OK	OK	OK	FAILURE
45	1.428	OK	OK	OK	FAILURE
90	1.45	OK	OK	OK	FAILURE
135	1.429	OK	OK	OK	FAILURE
180	1.36	OK	OK	OK	FAILURE

After considering the response amplitude operator as a criteria of mobile offshore drilling unit operation, it should also be reviewed and simulated when all activities are running. To determine whether it fulfils the drilling criteria, as mentioned in the book Floating Drilling: equipment and its use, Sheffield 1980, where the heaving movement limit criteria for drilling and tripping activity must be below 7 ft, in this study it can be concluded that all activities can still run, except the activity of running BOP and installation of risers. The running of the blow out preventer requires the maximum allowable heaving motion of 0.822m, whereas the result measured out of the criteria.

Different to the heave motion, the roll motion graphs show that the structural movements tend to be high in the direction of loading 45° and 135°, and tend to be low in headings 0°, 90 ° and 180 °. The highest motion roll was 1.65°, heading 45°, on case variation one.

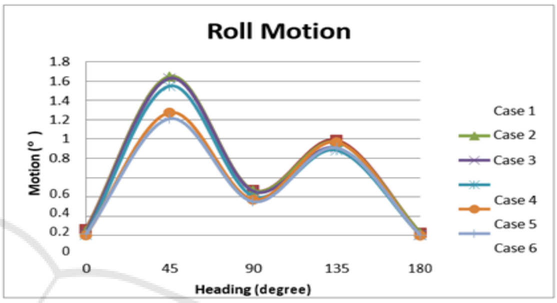

Figure 6: Roll motion of six cases

Table 3: The results of roll motion by considering the floating jack-up as a vessel with pipe handling equipment

Heading	Roll Motion	Vessel **with** pipe handling equipment			
		Drilling dan tripping	Fishing and logging	Running casing	Running BOP/Riser
(degree)	(degree)	max 7 deg	max 5 deg	max 5 deg	max 2.7 deg
Variation 1					
0	0.066	OK	OK	OK	OK
45	1.65	OK	OK	OK	OK
90	0.471	OK	OK	OK	OK
135	0.99	OK	OK	OK	OK
180	0.03	OK	OK	OK	OK
Variation 2					
0	0.05	OK	OK	OK	OK
45	1.65	OK	OK	OK	OK
90	0.47	OK	OK	OK	OK
135	0.97	OK	OK	OK	OK
180	0.03	OK	OK	OK	OK
Variation 3					
0	0.033	OK	OK	OK	OK
45	1.63	OK	OK	OK	OK
90	0.46	OK	OK	OK	OK
135	0.91	OK	OK	OK	OK
180	0.008	OK	OK	OK	OK
Variation 4					
0	0.007	OK	OK	OK	OK
45	1.551	OK	OK	OK	OK
90	0.407	OK	OK	OK	OK
135	0.884	OK	OK	OK	OK
180	0.004	OK	OK	OK	OK
Variation 5					
0	0.003	OK	OK	OK	OK
45	1.275	OK	OK	OK	OK
90	0.372	OK	OK	OK	OK
135	0.968	OK	OK	OK	OK
180	0.001	OK	OK	OK	OK
Variation 6					
0	0.014	OK	OK	OK	OK
45	1.212	OK	OK	OK	OK
90	0.351	OK	OK	OK	OK
135	0.909	OK	OK	OK	OK
180	0.005	OK	OK	OK	OK

As for roll motion, the maximum allowable roll motion was 7 degrees. The rolling movements that occurred in the structure were feasible for drilling activities for all cases. Moreover, from the Pitch Motion graphs we can see that the pitching motion of the structure is very high in headings 0° and 180°, with the maximum value of 4.117 degrees in the first variation in heading 0°.

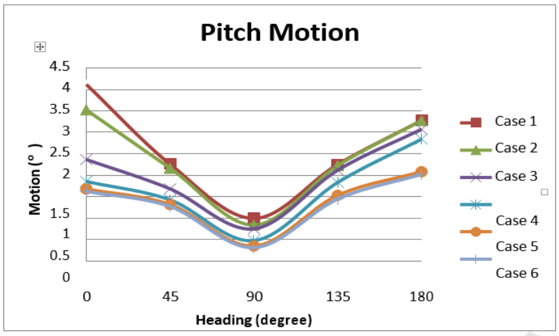

Figure 7: Pitch motion of six cases

Regarding pitch motion, the maximum allowable pitch movement for drilling and tripping activities is 7 degrees. In the case of pitch motion, the running BOP and riser installation activities in cases 5 and 6 were accepted.

Table 4. The results of pitch motion considering the floating jack-up as a vessel with pipe handling equipment

Heading	Pitch Motion	Vessel **with** pipe handling equipment			
		Drilling dan tripping	Fishing and logging	Running casing	Running BOP/Riser
(degree)	(deg)	max 7 deg	max 5 deg	max 5 deg	max 2.7 deg
Variation 1		7 deg	5 deg	5 deg	2.7 deg
0	4.117	OK	OK	OK	FAILURE
45	2.259	OK	OK	OK	OK
90	0.997	OK	OK	OK	OK
135	2.257	OK	OK	OK	OK
180	3.277	OK	OK	OK	FAILURE
Variation 2					
0	3.525	OK	OK	OK	FAILURE
45	2.167	OK	OK	OK	OK
90	0.842	OK	OK	OK	OK
135	2.229	OK	OK	OK	OK
180	3.275	OK	OK	OK	FAILURE
Variation 3					
0	2.367	OK	OK	OK	OK
45	1.683	OK	OK	OK	OK
90	0.754	OK	OK	OK	OK
135	2.118	OK	OK	OK	OK
180	3.071	OK	OK	OK	FAILURE
Variation 4					
0	1.857	OK	OK	OK	OK
45	1.428	OK	OK	OK	OK
90	0.481	OK	OK	OK	OK
135	1.835	OK	OK	OK	OK
180	2.843	OK	OK	OK	FAILURE
Variation 5					
0	1.68	OK	OK	OK	OK
45	1.318	OK	OK	OK	OK
90	0.354	OK	OK	OK	OK
135	1.532	OK	OK	OK	OK
180	2.083	OK	OK	OK	OK
Variation 6					
0	1.627	OK	OK	OK	OK
45	1.273	OK	OK	OK	OK
90	0.313	OK	OK	OK	OK
135	1.447	OK	OK	OK	OK
180	2.023	OK	OK	OK	OK

4 CONCLUSION

The results show that the response amplitude operator of pitch motion had the most significant response in each variation. From the motion validation with rules, it can be concluded that the heave motion of this structure exceeded criteria limits for BOP and riser operations, but is still allowed for drilling activities. The obtained results show that drilling processes in the Madura Strait site using the floating jack-up could possibly be operated by at least lowering the legs until it is 5 meters above the seabed without running BOP and risers.

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