JACK-UP FOUNDATION ANALYSIS AND MONITORING

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ABSTRACT

An initial assessment of the suitability of a jack-up drilling rig for any offshore location relies on a consideration of the required leg length based on estimates of air gap, water depth and leg penetration. A detailed assessment of rig compatibility may then be performed as site specific metocean and seabed data become available. This site specific assessment provides a location specific evaluation of the strength of the rig and the characteristics of the supporting foundation, and the interaction between the two.

The challenges presented by all-year operations in the harsh environment of the UK Central North Sea are such that the results of these detailed rig evaluations can vary considerably, with spudcan rotational fixity being identified as a key variable. As the amount of anticipated rotational fixity decreases, the rig's calculated response to storm loads may increase to a point that the rig is shown to be "overwhelmed"; either in terms of extreme leg load or in terms of excessive rig motion. Reductions in the metocean criteria associated with limiting the operations to "summer only" may not be cost effective. The introduction of constraints on variable deck load may adversely impact the drilling operation and the logistics of supplying the rig.

The site specific assessment is completed before the rig is deployed. Once the jack-up is on location, motion monitoring may be used to confirm the adequacy of the foundation model. The measurement of rig natural frequencies in surge and sway provides immediate feedback on the adequacy of the modelling of spudcan rotational fixity. Hull displacement data may subsequently be used to assist in managing the interface with the drilling operation, particularly when the jack-up is drilling over a fixed structure such as a wellhead platform.

Motion data acquired during a one-year storm event will be presented. The recorded hull displacements and natural frequencies will be compared to predicted responses from pre-deployment modelling and how these were able to demonstrate on-going spud can fixity. It is envisaged that this work will inform operators of industry best-practice, improve safety and optimise operational limits for jack-ups.

Keywords: Jack-Up, Spud Can Fixity, Motion Measurement.

INTRODUCTION

Operation of jack-ups provides a flexible platform for drilling operations. However, by being mobile, careful consideration must be made as to the suitability of a jack-up for each deployed location. This is particularly the case for regions like the North Sea which are subject to severe weather conditions. It is absolutely essential that the jack-up can safety endure the expected wave and wind loading.

The Maersk Highlander was deployed at the Culzean field (Block 22/25a) 145 miles east of Aberdeen. At this location the water depth is 90 m. Discovered in 2008, development of the Culzean field started in 2016. At Culzean, the seabed was found to be highly consolidated. This makes it difficult to embed the spudcans fully. Depending on the approach adopted, the predicted response of the jack-up in various sea states was a concern, including the operating window for drilling. Large hull motions could limit drilling operations due to bending forces developed in the well surface equipment. To address these concerns, a monitoring system was installed on the jack-up to record hull motions so that an informed assessment could be undertaken.

On 7 December 2017 the Maersk Highlander experienced a one-year return period intensity storm. Throughout the storm, the platform motions were recorded by a motion monitoring system comprising two sets of biaxial accelerometers installed at the hull main deck level. The accelerometer signals from all four accelerometers were processed to produce displacements and torsion (i.e. rotation about the vertical axis) of the jack-up. The natural frequencies of the platform modes, sway and torsion, were identified and tracked throughout the event. The natural frequencies provide an indication of the foundation stiffness (i.e. spud can fixity) and track how this changes as platform motions increase and then subside during passage of the storm.

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1. WAVE LOADING

The Maersk Highlander jack-up is fitted with a wave sensor that measures the distance from the sensor (installed at deck level) to the water surface. Thus, a succession of wave crests and troughs are recorded, and these can be used to compute the sea statistics. Figure 1 shows the observed significant wave height during and after the peak of the storm – a period of four days. It is seen the maximum intensity of the storm occurred late on the 7 December when the significant wave height reached 8.7 m.

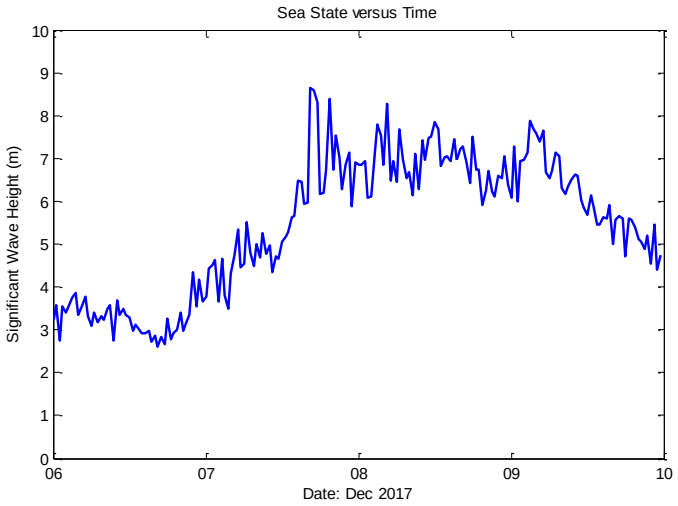

FIGURE 1: SIGNIFICANT WAVE HEIGHT DURING STORM

During the storm the wave spectral peak period lengthened from around 8 s during 6 December to 12 s on 8 December. At the height of the storm the wave period was 10.8 s.

Table 1 shows the design sea states at the drilling location. The storm on 7 December equates to a 1-year return storm. During the course of drilling operations at Culzean, larger storms are to be expected due to the multi-year duration of the drilling campaign. A standard industry requirement for manned, non-evacuated operations in the North Sea is for the rig to be assessed against a 50-year storm loading condition [2]. To demonstrate additional safety margin, the storm loads are factored up and the rig and foundation capacities are factored down.

Direction (°N)	Hs: 1-year Storm (m)	Hs: 10-year Storm (m)	Hs: 50-year Storm (m)
000	8.7	10.8	12.3
045	5.9	7.3	8.3
090	8.2	10.3	11.6
135	8.6	10.7	12.2
180	7.6	9.5	10.8
225	8.5	10.6	12.1
270	8.8	10.9	12.4
315	8.9	11.1	12.6

TABLE 1: DESIGN SEA STATES FOR 1-YEAR, 10-YEAR AND 50-YEAR CONDITIONS (Culzean Field UK Central North Sea)

2. DECK DISPLACEMENTS

The motion measurement system installed on the jack-up uses accelerometers to record the motion of jack-up hull. The displacement amplitudes are determined by double integration of the accelerometer signal. As such it is only sensitive to dynamic motion. The quasi-static response is present in the recorded signals only in diminishing amplitudes as lower frequencies are considered. Figure 2 shows the deck motion at the sensor location near the forward leg. For each hour, the direction of dominant motion is determined using a least-squares best-fit and the standard deviation statistic calculated on the displacement resolved along this axis.

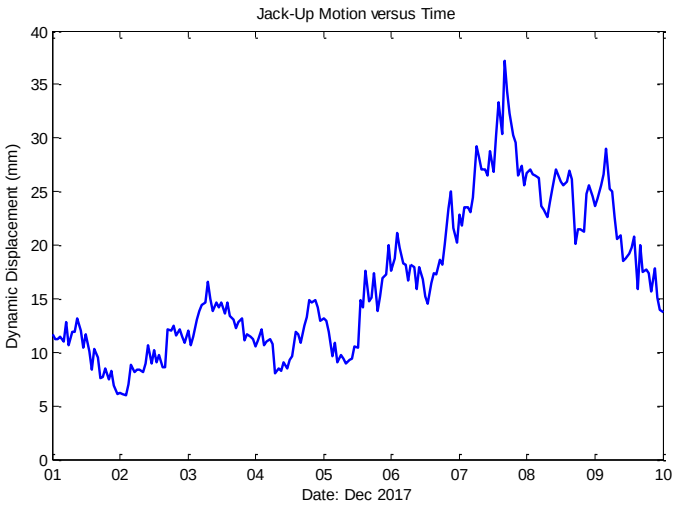

FIGURE 2: HULL DISPLACEMENT VERSUS TIME

In a similar manner to the integrated displacement described above, the rotational motion is also calculated. This uses the orthogonal separation of two accelerometers to calculate the difference signal that is produced by deck rotation. Figure 3 shows deck rotation (about the vertical axis) throughout the storm period.

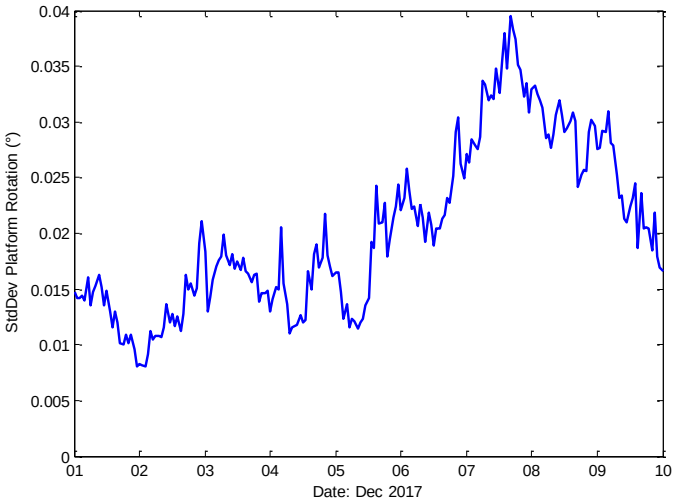

FIGURE 3: HULL ROTATION VERSUS TIME

3. RIG NATURAL FREQUENCIES

Accelerometers installed on the jack-up record motion of the platform deck. The hull motion is primarily in response to wave loading, which has a wide range of spectral components centered on a peak typically around 0.1 Hz (i.e. corresponding to a wave period of between 8 s and 12 s). When the spectral content of the accelerometer signals is examined, the natural frequencies of the structure give rise to peaks in response – one for each mode. There are three fundamental modes: sway and surge along orthogonal axes and torsion about the vertical axis.

The accelerometer signals are processed in hourly segments and the power spectral calculated. The response peak associated with each mode is identified and the center frequency is tracked for each time segment (e.g. using methods outlined in [3]). This gives a track of natural frequency over time updated every hour. This is shown in Figure 4.

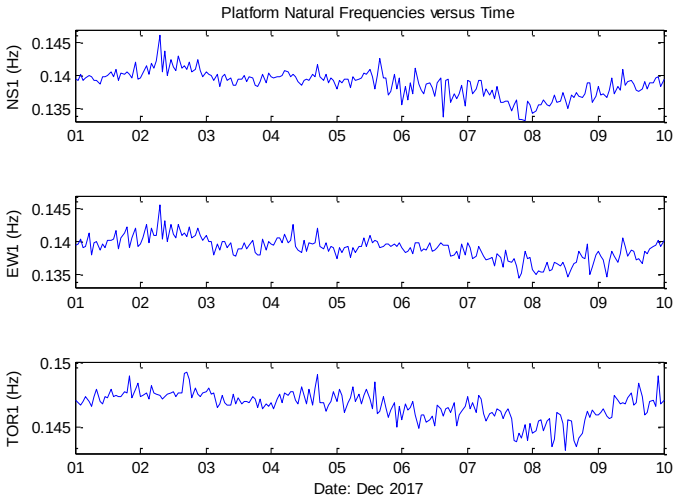

FIGURE 4: RIG NATURAL FREQUENCIES VERSUS TIME

To explore softening of the seabed foundation in greater detail, the natural frequencies are plotted against the deck displacement in Figure 5 (a, b and c). A best-fit line has been superimposed on the plots. This shows a clear correspondence between increasing platform motion and reduced natural frequencies. For the 1-year storm condition, the sway mode natural frequencies are reduced by 5%. For torsion, the effect is smaller at 2.7%. Note that the deck displacements at the sensor installation have been used as these are good estimates of the leg motion as the sensors were near the top of the forward leg.

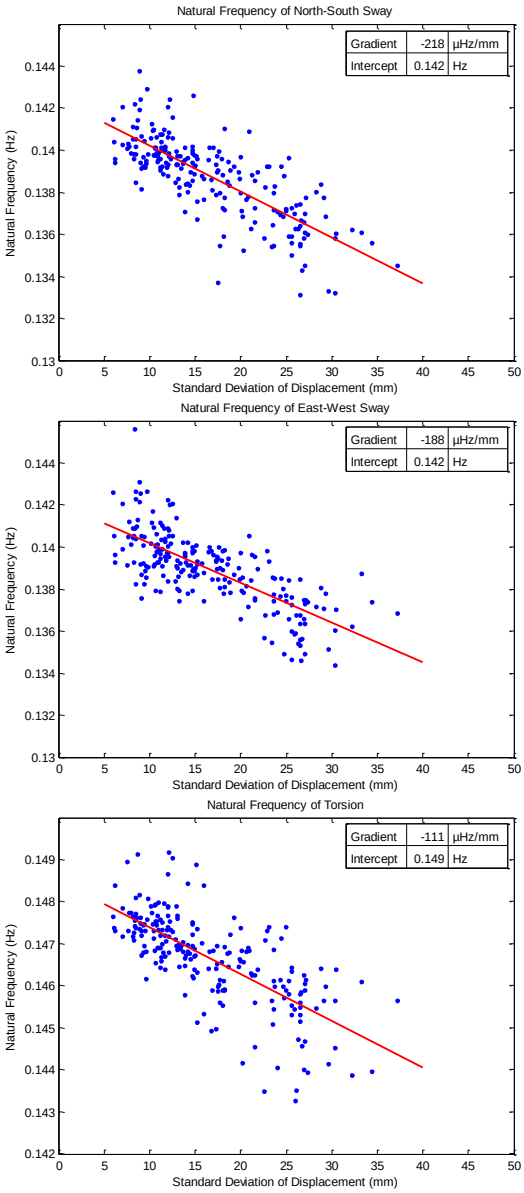

FIGURE 5: RIG NATURAL FREQUENCIES VERSUS PLATFORM DISPLACEMENT

4. DESIGN COMPARISON

The site-specific assessment requires modelling of the jack-up during the limiting storm criteria. Thus, time domain analyses are performed for the 50-year storm arriving from each octant. (Results from other analyses with more frequent storms is also available.) The predicted deck displacements comprise a quasi-static deflection as well as a dynamic response to wave loading. The dynamic component is due to direct response at the spectral peak period of the waves, but also from excitation of the resonant modes (i.e. sway and torsion) of the jack-up. Initial site specific assessments predicted rig natural periods of surge and sway at 0.12Hz (8.5s)

For other rig deployments, the design calculations predict that quasi-static and dynamic motions are more or less equal in

amplitude – and this assumption has been made here. As noted above, the measured motions only include the dynamic component. Figure 6 shows the observed maximum hull displacements together with the predictions from modelling. At sea states with significant wave height of around 8 m, the measured motions are substantially smaller than predicted – by a factor of three. There is no indication of a non-linear response within the range of sea states encountered.

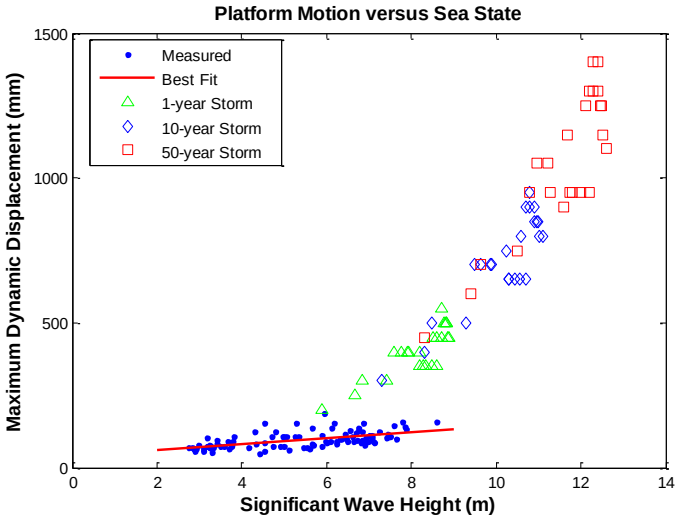

FIGURE 6: PREDICTED HULL DISPLACEMENT VERSUS MEASURED

5. DISCUSSION

The measured response of the jack-up on location during a 1-year return storm demonstrate that the design assumptions used during the preparation of the site specific assessment for the jack-up were conservative in several areas:

- The initial (calm weather) rotational fixity values were better than predicted.
- While the measurements show that there is some degradation of fixity with increase in leg load, (natural period increases slightly) it does not degrade in extreme event weather to the levels assumed.
- The hull motion response appears to be much more linear than predicted. This is in harmony with historical jack-up motion monitoring data presented by others, for example the Maersk Endurer, [4] and [5].

While the original site specific assessment was necessarily conservative, the assumptions associated with modelling spudcan rotational fixity could have introduced a degree of variability in the results that made the rig approval process vulnerable.

The size of the predicted hull deflection amplitudes were such that, if realistic, had the potential to cause substantial disruption to operations. The measured response data has been a key contributor to the management of this aspect of jack-up drilling at Culzean.

6. CONCLUSIONS

The measured displacement response of the jack-up in high seas states is significantly less than predicted. That is, the site-specific analysis is conservative. The highest sea state occurring during the monitoring period has Hs between 8 m to 9 m (roughly the 1-year return storm) and much less than the 50-year return storm Hs = 12.6 (maximum). The results indicate that foundation is stiffer than predicted, and this may point to a more favourable response in extreme sea states, which would increase the operability of the jack-up.

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REFERENCES

[1] Hunt, R. J., Overy, R. F., Vavasseur, D and Stadsgaard, H. *New Lessons Learned from North Sea Jack-Up Drilling Operations* Jack-up Conference, City University, London

[2] ISO19905-1 (2012) *Petroleum and natural gas industries - Site-specific assessment of mobile offshore units - Part 1: Jack-ups*, International Organisation for Standardization, Geneva

[3] Sanderson, D. J., Price, A. G., Nelson, A., Killbourn, S. D. and Dougan, A. (2002) *The Applicability of Online Monitoring for the Assurance of Fixed Jacket Structures' Structural Integrity*, Proceedings of ASME OMAE 2002, OMAE 2002-28614.

[4] Hunt R. J. (1999) Jack-up and Jacket Relative Motions; Prediction and Measurement, Jack-up Conference, City University, London

[5] Hunt R. J., Dier, A. F., Howarth, M. W., Jones, W. (2001) *Further interpretation of North Sea jack-up motion measurements*, Jack-up Conference, City University, London