NEW LESSONS LEARNED FROM NORTH SEA JACK-UP DRILLING OPERATIONS

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ABSTRACT

This paper describes how site-specific assessments (SSA) were used to evaluate candidate jack-up rig designs for HP/HT development drilling at the Culzean wellhead platform in the UK Central North Sea. The paper also presents the lessons learned during this evaluation process and reports on the measurements made since the selected rig arrived on location in Q3 2016.

The SSA of each candidate jack-up was performed using the latest version of the relevant international standard. These assessments focus on the strength of the rig and the characteristics of the supporting foundation and the interaction between these two issues is explored. The importance of the consistent application of key input data, such as metocean conditions, cantilever position and rig working airgap, is illustrated.

The rig evaluation process for Culzean showed how the application of the existing international standard by different practitioners can produce diverse results. This is especially true for the part of the standard that addresses the subject of spudcan fixity. The treatment of this parameter is shown to have a considerable impact on the assessment of rig suitability. This paper confirms that the standard method of calculating spudcan fixity is noticeably conservative. Measurements of hull motion, recorded by the successful candidate on location, substantiate this finding, and it is hoped that these measurements will contribute to the improvement of the industry practice. Since the rig arrived on location, the rig has experienced extreme event weather conditions which are expected to make the motion monitoring data particularly valuable.

KEYWORDS: Jack-up, pre-load, spudcan fixity, motion prediction, motion measurement

SUMMARY

The identification and selection of a candidate jack-up rig to perform drilling operations at the Culzean WHP in the UK CNS took place in a robust rig market. Candidates were therefore identified by their suitability to the location (e.g. 90m; 300ft water depth), with only limited consideration of rigs that had surplus capacity (e.g. 120m; 400ft water depth).

For each candidate, a standard SSA was performed to confirm that both the rig structural capacity, and the location foundation capacity, were sufficient. The combined effects of: airgap, rig centre of gravity offset during extreme environmental conditions, and minimal spudcan penetration were shown to be quite demanding. The robustness of the seabed soils at Culzean, and the resultant minimal spudcan penetration, placed considerable demands on the standard methods of modelling the spudcan/seabed interaction, to the extent that two assessments of the same rig produced widely differing results.

Spudcan penetrations measured as the rig went on location in September 2016 showed some variability between the stand-off and the alongside positions. Motion measurements have since confirmed that the key parameter of spudcan rotational fixity is considerably greater that would have been predicted for the limited amount of spudcan penetration achieved during pre-load.

No degradation of rotational fixity has been measured, despite extreme event loading conditions such as those caused by storm Conor on December 26th 2016.

INTRODUCTION

Maersk Oil and its co-venturers, JX Nippon and BP (Britoil) are investing approximately USD 4.5bn in the development of the Culzean high pressure, high temperature (HP/HT) field in Block 22/25 in the UK Central North Sea [CNS]. The water depth is approximately 90m (300ft). Discovered in 2008 (Figure 1), the gas condensate field has resources estimated at 250-300 million barrels of oil equivalent. Initially three bridge-linked platforms will form the offshore platform complex: a wellhead platform [WHP], a Central Processing Facility [CPF] and a Utilities and Living Quarters [ULQ].

The WHP substructure was installed in 2016. In September that year the Maersk Highlander jack-up began drilling one of the first of six production wells. The substructures for the CPF and ULQ platforms were installed earlier this year. When the three topsides are installed in 2018 and hooked up in 2019, three of the six production wells will be ready for first gas.

JACK-UP RIG CANDIDATES FOR UK CNS

For many years, Offshore Magazine has been publishing a useful summary of jack-up rigs with a rated water depth [RWD] equal to or greater than 350ft (107m). The 2015 version of this poster (Ref. 1) lists one hundred and fifty-nine individual units from seven different designers, and these are presented in Figure 2. So, in terms of RWD alone, the 90m water depth at Culzean should result in many suitable candidate rigs being identified. Rig availability would then diminish this number, which would then be further reduced by consideration of rig strength and foundation strength. An example of insufficient rig strength would be the Baker Marine Pacific class design which is not well suited to the combined demands of the all-year weather criteria and water depths of the UK CNS.

It is also important to note that many rigs are designed with the assumption that the cantilever is retracted to balance the leg load during extreme event weather (Figure 3). This load case is consistent with a rig evacuated prior to the arrival of a hurricane. However, when a rig is assessed for manned non-evacuated operations in the North Sea with the cantilever extended (Figure 4), this increases the demands being made on the rig structure and its foundation.

For 90m water depth in the UK CNS, the following rig designs may initially be considered as suitable:

- Friede & Goldman [F&G] Mod V, JU-2000, JU-2000E & JU-3000N
- Keppel-FELS [KFELS] Mod VA, Mod VB & Super A
- Gusto-MSC CJ50-100
- LeTourneau [LeT] Gorilla (also known as 150-88)

This suitability is then verified by SSA using location-specific foundation and metocean data.

As the water depth increases from 90m to 120m, the target hook loads range from 1.5 to 2 million lbs and the cantilever position or pre-load requirements become onerous, suitable rig designs may be limited to the much smaller population of "bigger" harsh environment rigs given below:

- KFELS N class
- Gusto-MSC CJ62-120 & CJ70-120
- LeT Super Gorilla
- F&G Mod VI

CANTILEVER REQUIREMENTS

Rig interface considerations include the ability of the jack-up to be brought alongside the wellhead platform without damage to the platform topsides, its substructure, foundation piles, and any adjacent pipelines, flowlines & risers. Selecting just one of these issues as an example, empirical industry guidelines on "pile-proximity" recommend a one jack-up spudcan diameter (100%) clearance between the edge of the spudcan and the platform's piles. This places extra demands on the jack-up cantilever reach.

The Culzean project team reviewed the option of a "standard" wellhead substructure versus a "twisted base" design. Fixed offshore platform design should result in the platform having fundamental (primary) natural periods of oscillation (e.g. surge & sway) of less than three seconds. This is to minimize the interaction with wave energy, and the associated accumulation of fatigue damage to the platform structure. In shallow water (e.g. less than 30m) in the Southern North Sea [SNS], the requirement for both strength capacity and fatigue endurance may be achieved by a platform substructure with vertical faces. An example design of a vertical face jacket with a double wellbay for a SNS location in 22m water depth is presented in Figure 5.

It is noticeable that the example platform does not have a dual-access well bay but instead has two separate 15-slot wellbays at either end of the platform (separation exceeds 20 m) so that the external perimeters of the two jack-up cantilevered drilling derricks may be accommodated.

As the water depth increases from the SNS to the CNS, so does the temptation to design a substructure with non-vertical faces so that the plan area of the jacket at mudline is larger than the plan area at sea level. Combining this with the desire to install vertical well conductors within the plan area of the substructure, increases the reach requirements for cantilevered jack-up drilling operations. For CNS wellhead platforms in 90 to 120 m water depth, the offshore industry has developed two design solutions, presented as Figures 6 & 7.

The twisted-base jacket presented in Figure 6 is a useful solution, but does have cost implications for the jacket fabrication, transportation and installation. The more standard extrapolation of the SNS design, using leg batter (e.g. 10 degrees) between sea level and mudline to increase the dimension of the jacket foundation, is presented in Figure 7. In this example in 120m water depth, one face of the jacket remains vertical to minimize the jack-up cantilever reach requirements.

For the Culzean wellhead platform in 90m water depth, plan view schematics of example jack-up interfaces are presented in Figure 8. The rig in this example has a cantilever envelope that extends 75ft aft of the stern transom and has a 15ft reach to both port and starboard. In both the example layouts, a 60% spudcan diameter clearance has been achieved. This illustrates the advantages of the twisted base design with its access to all 14 slots compared to only 8 slots being easily accessible to the example rig from the vertical face of the 16-slot substructure.

Also presented in Figure 8 are outlines of the cantilever structure, typically 5 to 10 metres beyond the cantilever envelope. This illustrates that if a two-rig dual-access drilling activity were required, the wellhead platform would need to include a 10 to 20 metre "dead space" between the two sets of drilling slots, with each set of drilling slots only being accessible from one side.

To ensure that the 60% spudcan diameter clearance is acceptable, in terms of proximity to the substructure piles, an assessment of spudcan bearing pressures was required. Using the centre of the stern transom as a fixed reference point, and considering a range of candidate rigs for Culzean, it was possible to develop the following screening criteria from Figure 9:

- 50 t/m^2 at 60% spudcan diameter separation
- 60 t/m^2 at 80% spudcan diameter separation

Note 1 tonne per square metre [t/m^2] is approximately 10 kiloPascals [kPa]

The assessment showed that for the particular case of the Culzean WHP piles and the Culzean soils, the reduction from 100% clearance to 60% clearance was acceptable

JACK-UP RIG CANDIDATE REVIEW

Prior to the Culzean project team issuing an Invitation to Tender [ITT], and before any location specific geotechnical data was available, several rig designs were screened for their suitability. In addition to the 90m water depth capacity, a spudcan penetration of 5m was assumed along with a hull airgap of 28m. This initial study was conducted against a background of high rig rates, especially for the "bigger" rigs. With the vulnerability of the "standard" 90m water depth rigs to the influence of foundation effects the study was only able to conclude with confidence that the bigger rigs would be suitable, with the smaller rigs being "unlikely to be suitable". Offset data for other jack-up rig deployments in adjacent fields (in Figure 1) such as Shearwater, Elgin, Franklin and Lomond was useful in terms of confirming that a particular rig design could work in similar water depths and similar metocean conditions. However, until the target location geotechnical data was available, it was not possible to address the suitability of the smaller (and less costly!) rig designs.

A jack-up interfacing with a wellhead platform requires that:

- the rig has sufficient capacity to elevate the hull bottom clear of the predicted extreme water level [EWL]
- the rig has sufficient capacity to present its cantilever above the platform weather deck.

where rig capacity includes both leg length and rig strength.

The 10,000 year EWL at Culzean is defined as being 22m above lowest astronomical tide [LAT]. At an open field location this would set the required minimum air gap of the hull. Note that for jack-up rig deployments "airgap" is the distance between LAT and the underside of the hull. However, with the weather deck of the Culzean WHP at 40 m above LAT, it is the ability of the cantilever to get above the weather deck that is the key parameter in setting the hull elevation. Assuming a "typical" hull depth of 10m, the minimum air gap is, therefore, 30m. This air gap requirement makes no allowance for cantilever deflection or any particular requirements associated with the drilling interface.

Once the location-specific geotechnical data was available, the jack-up drilling ITT's were issued. Unfortunately, the resultant submissions from individual rig owners included a number of technical variations in the site-specific assessments that made comparisons difficult, including:

- Hull air gap set between 23m and 40m
- Only one rig owner had the cantilever deployed
- Some assessments had used generic (not Culzean) metocean data

Of these three, the variability introduced by a misunderstanding of the required air gap is the easiest to “fix” as described below:

Hull Air Gap Taking as an example a Friede & Goldman JU 2000E design jack-up in 89m of water depth in the Central North Sea. The total axial leg load is a combination of the rig still-water load, the effect of spudcan rotational fixity and four components of storm load: wind load, wave & current load, inertia (dynamic) load and a “P-delta” load due to the horizontal offset of the rig. This is illustrated in Figure 10.

The first three components are horizontal loads and are applied at different elevations, with lever arms above the point of fixity that govern their contribution to the total overturning moment [OTM]. This OTM is resisted by the foundation (spudcan) support. To simplify this example, the load is assumed to be “bow-on”, so that any load reduction (uplift) on the bow leg is equally shared by additional bearing (downward) load on the two stern legs.

An increase of airgap from 22 to 28 metres has no effect on the wave & current loading, increases the wind OTM by 4%, the inertia OTM by 5% and P-delta OTM by 18%. But given their relative contribution to the total OTM, the overall increase is only 6%, with the total axial load (which includes the rig still-water leg load) only increasing by 2%, (approximately 220 tonnes). While this is a minor increase in the load on the stern leg spudcans, the total combined axial leg load of 11,000 tonnes may be moving close to both the pre-load capacity of the rig and the associated spudcan capacity.

Cantilever Deployment A similarly small but possibly “not easy to accommodate” increase in leg load will be introduced by the offset of hull centre of gravity caused by the cantilever deployment. A key assumption for any SSA is the configuration of the rig; topsides weight & centre of gravity, during the storm. If the intent is to be able to perform drilling operations and/or provide support to the drilling configuration during extreme weather, then the load condition needs to reflect this, especially the longitudinal centre of gravity [LCG] and transverse centre of gravity [TCG]. For this example rig design, a 1m stern offset of the LCG from the geometric leg centre results in the axial load in the stern legs increasing by 160 tonnes.

Metocean Conditions Comparing rig assessments that have used different metocean conditions (e.g. wind velocity, wave height/period & current velocity) is not straightforward and usually requires the assessments to be repeated using the project data set; i.e. the Culzean metocean data.

FOUNDATION MODELLING – THE PREDICTION OF SPUDCAN PENETRATION

The soil conditions at the Culzean WHP consist of very competent and laterally uniform layers of sand, silt and clay that prevented the jack-up spudcans penetrating sufficiently to establish soil contact over their full areas and this became important when assessing foundation behaviour.

While the load <u>increase</u> on the stern legs due to air gap and cantilever position was a concern in terms of pre-load capacity and spudcan strength, the associated load <u>decrease</u> on the bow leg also proved to be important because its effect on sliding resistance. Thus, the SSA’s that accompanied the tender submissions revealed some stark contrasts in the calculation of spudcan sliding utilization ratios. An optimistic spudcan penetration prediction for a rig that had both LCG and TCG at the geometric leg centre resulted in sliding utilization ratios that were substantially lower than those generated more conservatively.

Another issue that emerged was the treatment of spudcan rotational fixity. A spudcan that is not fully embedded (penetrated beyond its widest section) may develop considerably less rotational fixity than is desirable due to its cubic relationship with diameter. The importance of spudcan rotational fixity for jack-ups has been extensively studied over the years. Of particular note is the 1999 City conference presentation by Nelson, Stonor & Versavel (Ref. 2). This presentation provides the "often-referenced" schematics of Figure 11, where both the static and dynamic effects of fixity are shown.

Since 1990, the results from several rig motion monitoring programs in the North Sea have been reported; a bibliography of published data is given at the end of this paper. The monitoring reports for the GSF Monitor and GSF Magellan, reported in Ref's 2, 3 & 4; are particularly useful as this F&G Mod V rig design is a good representative of the 90m water depth rigs of section 3. A collation of the measured natural periods of vibration in surge and sway is presented in Table 1 and shows that for different locations, and associated leg penetrations, the surge/sway periods are less than seven seconds.

Having identified the preferred candidate (a F&G JU2000E design) with the SSA provided by the original rig owner, a third party verification analysis was commissioned to review the importance of the assumptions being made with respect to:

- ✓ LCG & TCG
- ✓ Spudcan penetration
- ✓ Rotational fixity (initial & during extreme event loading)

A comparison of these two SSAs revealed some stark contrasts, especially in the treatment of spudcan rotational fixity and its effect on surge & sway periods. For the same rig the analysis by Company 1 had the period at 7.6 seconds, while Company 2 were predicting 8.5 seconds. The effect of this on total axial leg load is shown in Figure 12.

In summary, Company 1 was predicting a maximum total axial leg load of 11,700 tonnes. This was achieved with a spudcan penetration of 1.1m and P-Δ contribution to rig overturning of Δ = 1.8m. In contrast, Company 2 was predicting a maximum total axial leg load of 13,700 tonnes. This was achieved with a spudcan penetration of 0.6m and a Δ of 3.3m.

While the 2,000 tonnes difference in maximum axial leg load was interesting from an engineering perspective, the ramifications were quite blunt: One SSA had the rig meeting all the key utilisation ratios, the other SSA did not.

MANAGEMENT OF STILL-WATER LEG LOAD

The Maersk Highlander (F&G JU2000E) jack-up was delivered in May 2016. Prior to delivery, the rig inclining test confirmed the hull lightship weight and its centre of gravity, LCG & TCG. This then allowed the rig stability "booklet" to be configured and a series of load scenarios to be investigated.

A key feature of the original "Company 1" SSA was the assumption that even with the cantilever extended, a certain amount of VDL could be used to balance the rig so the LCG and TCG offset were zero. This could now be confirmed with the rig stability program as individual tank positions and contents could be assigned. Indeed, rather than using a theoretical value of total hull weight LCG & TCG in the SSA, the actual numbers could be used.

As the demands made on the rig increase in terms of cantilever position and VDL requirements, it is possible to use the measured response data to benchmark the rig model used in the SSA.

FOUNDATION MODELLING – THE PREDICTION OF SPUDCAN STIFFNESS

It is clear from Figure 12 that the modelling by the two companies of both the "fair weather" initial rotational stiffness (for inertia loading) and the "extreme event" degraded spring stiffness (for P-Δ) calculation are very different. In an attempt to reconcile the modelling of the "fair weather" initial stiffnesses, Halliard Consulting Limited [HCL] performed an independent analysis:

Vertical, horizontal and rotational stiffnesses of the foundation were calculated using the elastic solutions for a rigid disc on elastic half-space and the formulae given in ISO:19905-1 (Ref. 5) for zero embedment:

Vertical stiffness $Kv = 2G_{max}B/(1-\upsilon)$

Horizontal stiffness $Kh = 16G_{max}B(1-\upsilon)/(7-8\upsilon)$.

Rotational stiffness $K\theta = G_{max}B^3/[3(1-\upsilon)]$.

Where: - G_{max} is the initial soil shear modulus

- B is the diameter of the spudcan/soil contact area and

- υ is Poisson ratio, taken to be 0.5 in clay and 0.3 in sand

In the assessment G_{max} was modified as follows:

- Kv is affected by the Culzean layered soil profile so a relationship suggested by Poulos and Davis (Ref. 6) has been used to give an equivalent $Gv_{max} = 0.8G_{max}$ (clay)
- Kh is unaffected by soil layering and $Gh_{max} = G_{max}$ (sand)
- $K\theta$ is controlled by the confining stress across the rotational surface on which movement occurs under the footing. Typical contours of this stress were based on a Boussinesq analysis and the surface with a radius equal to that of the spudcan's contact area was used. So $G\theta_{max} = 0.65\ G_{max}$ (sand)

Spring stiffnesses for the Maersk Highlander rig at Culzean are compared in Table 2. The HCL calculations were based on an assumed Bow leg still-water load of 63MN. Stiffnesses for the Port and Starboard legs were predicted to be larger due to their greater bearing stresses.

The HCL predicted penetration at full pre-load was between 0.9 and 1.1m where the 1.1m represents a fully embedded spudcan. The spring stiffnesses associated with the fully embedded spudcan were greater than those calculated by Company 1. For a reduced 0.6m of penetration, the spring stiffnesses calculated by Company 2 and HCL were similar, especially the rotational stiffness. With the spudcan rotational stiffness being a key differentiator in the calculation of rig response, the importance of measuring the achieved spudcan penetration, and the subsequent rig natural periods of vibration in surge & sway, became clear.

As well as the initial soil stiffness, a simple method for predicting the degradation of rotational fixity as spudcan load increases is also presented in ISO-19905-1. This simple method employs a stiffness reduction factor [f_r] (Section A.9.3.4.2.3) as the leg load vectors move towards the yield envelope. However, this stiffness reduction is quite onerous (conservative). A more sophisticated alternative is identified in Section A.9.3.4.2.4. which requires dedicated software.

Motion measurements that capture an extreme event (storm) load condition are an alternative to this more sophisticated method, but their applicability will always be limited to the severity of the conditions "encountered". One immediate application of measured response data may be the demonstration that any non-linearity of the response, has not yet occurred, and if it does occur it will be limited to sea-states greater than those already experienced.

SPUDCAN PENETRATION ACHIEVED AND RIG RESPONSE MEASUREMENTS

The rig arrived at the stand-off location at the Culzean WHP in September 2016. At the stand-off location, the reported spudcan penetrations due to self-weight (no pre-load) ranged from 0.8 to 1.1m. After pre-load had been applied at the alongside position, the spudcan penetration was found to be 0.6m. This was re-confirmed in a subsequent survey.

While the spudcan penetration was less than anticipated, two independent motion monitoring systems that were activated on arrival (MM1 & MM2 in Figure 13) showed the rig surge/sway periods to be 6.7 seconds (0.15Hz) and a considerable improvement on the 7.6 & 8.5 seconds estimated by Company 1 & Company 2. This measured surge/sway response of 6.7 seconds is very much in line with the other North Sea rig deployments of Table 1. The measured hull lateral motions were also very small, and nothing like the sort of magnitude that would be expected for a rig that is predicted to generate Δ's of between 1.8m and 3.3m in a 50-year storm condition. Small hull motion amplitudes allow the drilling operation to continue without generating noticeable bending loads on the drilling configuration.

The measured response indicated that the methods used to calculate the initial (fair weather) rotational stiffness were conservative, and represented an opportunity to re-calibrate the engineering assumptions.

The 3-hour Hs (significant wave height) of 10.5m recorded during storm Conor on Dec 26th 2016 represented a 5-year return period storm. The natural period of sway/surge remained at 6.7 seconds (0.15Hz) throughout the storm. These measurements represent another opportunity to re-calibrate the engineering methods on this location.

CONCLUSIONS

1. The Maersk Highlander has been on location at the Culzean WHP for more than one year. Despite the limited spudcan penetration, the fundamental response periods of surge and sway are considerably lower than those predicted by any of the rig evaluation analyses. The associated hull motions are also considerably smaller.

2. The results of the SSAs performed for this rig deployment were found to be sensitive to both the input data and the application of the assessment method. In the candidate rig evaluation process, rig designs such as the F&G JU-2000E selected for Culzean, and alternative designs that are similar, are vulnerable to results that include this amount of variability. Because of this, rig evaluation parameters should be explicitly defined and the subsequent analyses submitted should be screened for full compliance.

3. For those rigs that are working close to their rated water depths, rig evaluations without site specific data are of limited use.

4. For North Sea rig deployments, the evaluations must represent manned non-evacuated operations.

5. For a new-build platform, early engagement with the designers of the wellhead platform is essential to ensure that the key interface issues are harmonized.

6. Once a candidate rig has been selected, early access to the rig stability "booklet" allows a much better definition of how cantilever position and variable load may be managed to minimize the offsets to the rig LCG & TCG. This then minimizes the range of the LCG & TCG offsets that need to be incorporated in the SSA.

7. Opportunities have been identified to improve the standard methods of site specific assessment.

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Year	Location	Block	Water depth	Air gap	Leg pen.	Tn (surge/sway)
1993	Halley North*	30/12b	83.5	19.8	0.9	5.8
1994	North Everest	22/10	88.5	19.0	3.0	5.6
1995	Joanne	30/7a	77.0	21.0	0.9	5.4
1998	Franklin	29/5b	91.8	23.5	2.4	6.4
1999						6.4 to 6.8
2000						6.6 to 6.8
2001	Elgin	22/30c			4.6	6.3 to 6.6
2002	Franklin	29/5b	91.8	23.5	2.4	6.7 to 6.8

Table 1 Measurements of natural periods of surge & sway in CNS

(note * denotes jack-up rig is GSF Monitor, all other results are for GSF Magellan)

parameter	units	Company 1	Company 2	HCL	
Spudcan pen.	m	1.1	0.6	1.1	0.6
Vertical Kv	kN/m $*10^6$	2.1	2.0	5.2	4.0
Horizontal Kh	kN/m $*10^6$	1.8	1.7	3.8	3.4
Rotational Kθ	kNm/rad $*10^6$	102	61	142	58

Table 2 Initial Spring Stiffnesses for the Maersk Highlander at Culzean WHP

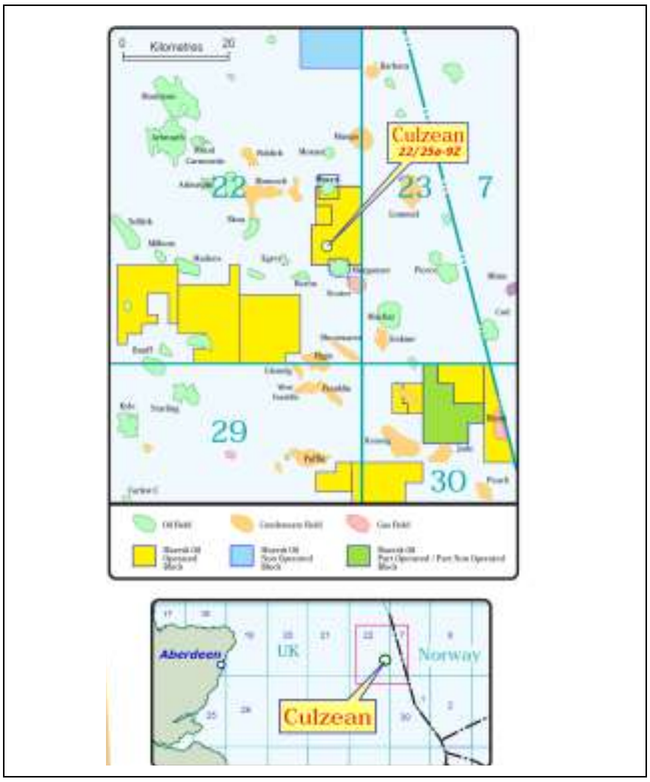


Figure 1 Culzean Discovery well 22/25a-9z

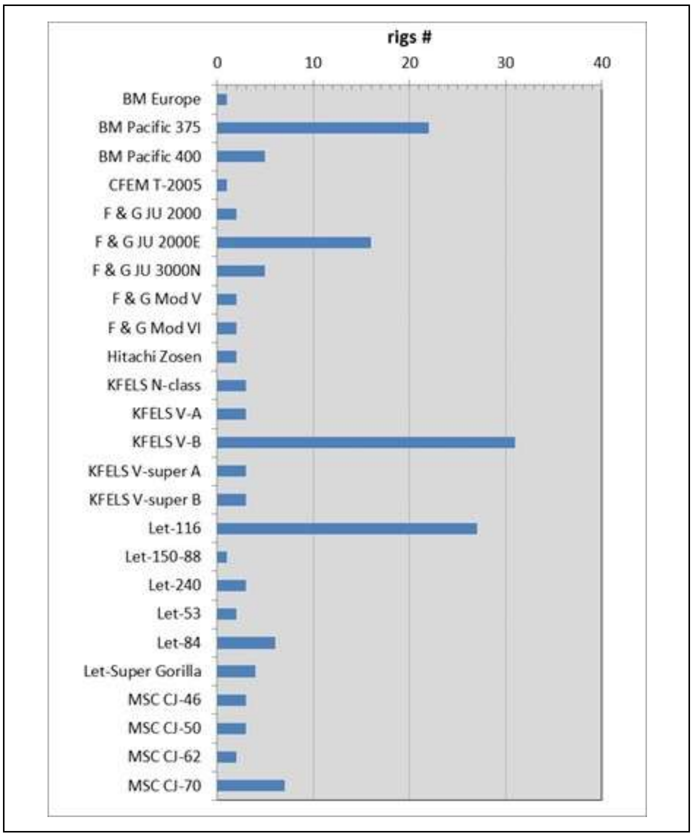


Figure 2 Worldwide jack-up rig fleet with RWD of 350ft [107m]

Data from Offshore Magazine "Worldwide Survey of Deepwater Jack-Up Rigs 2015"

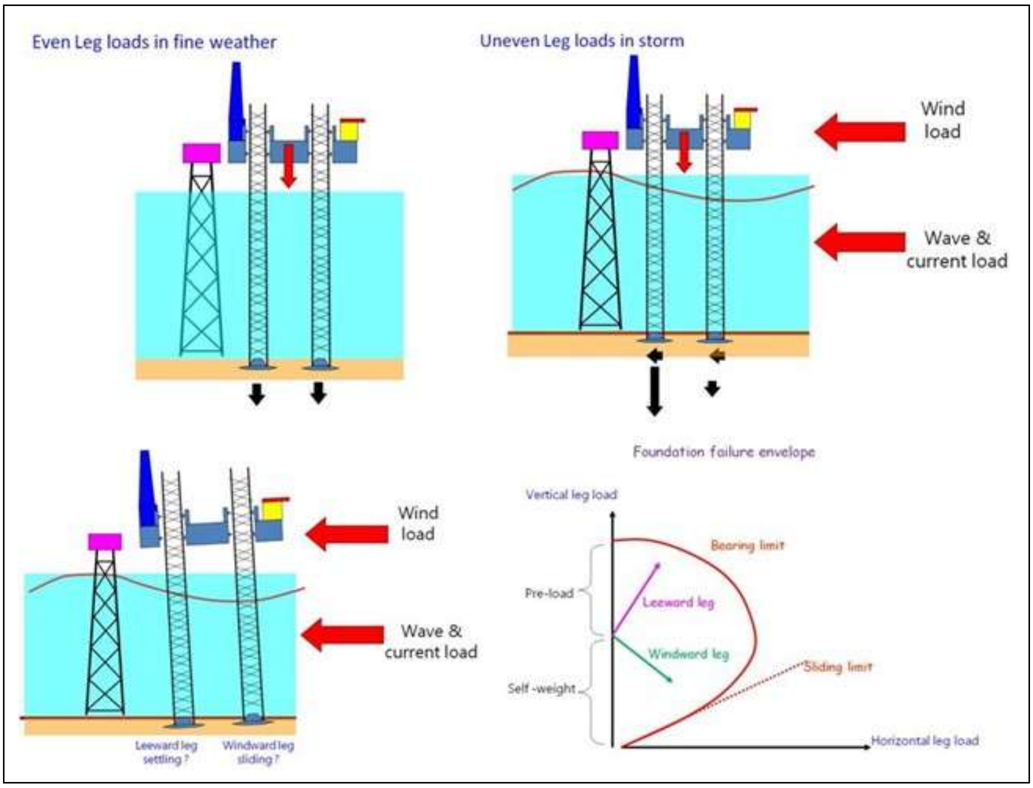


Figure 3 Jack-up foundation capacity checks – leg loads balanced prior to storm

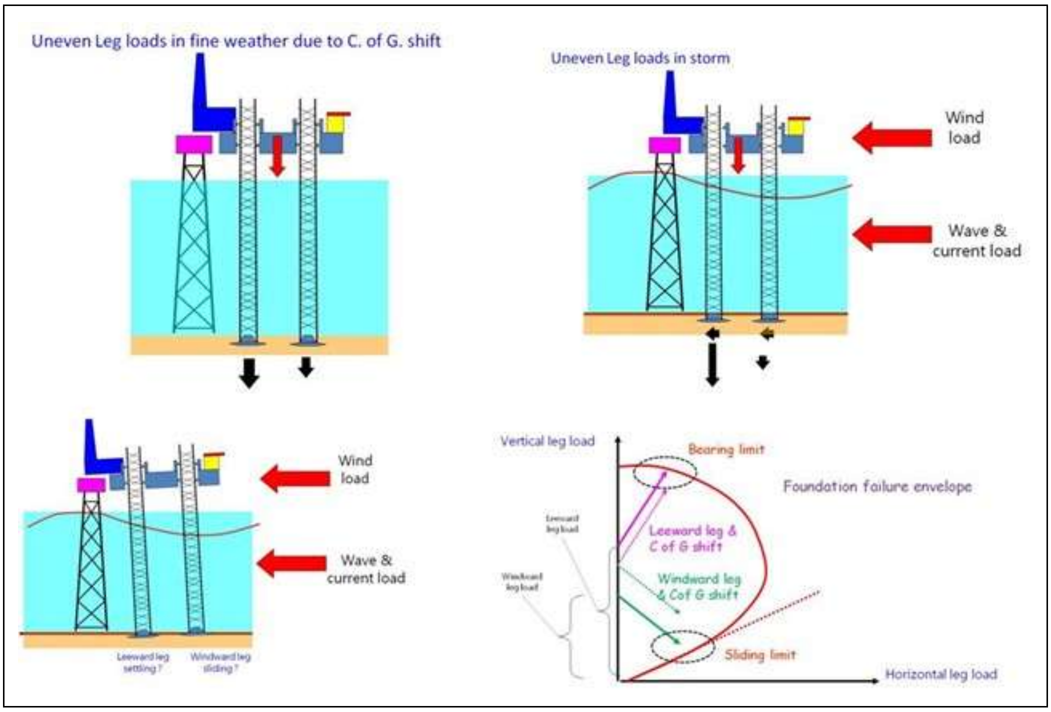
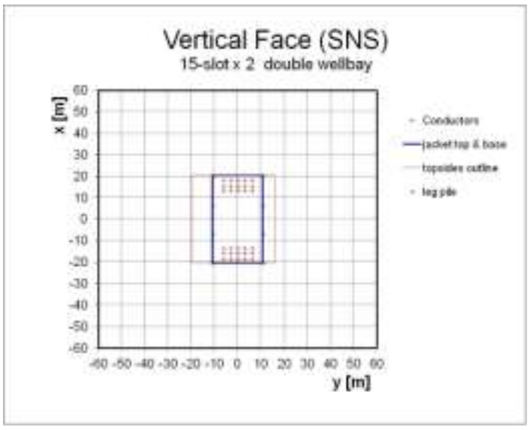


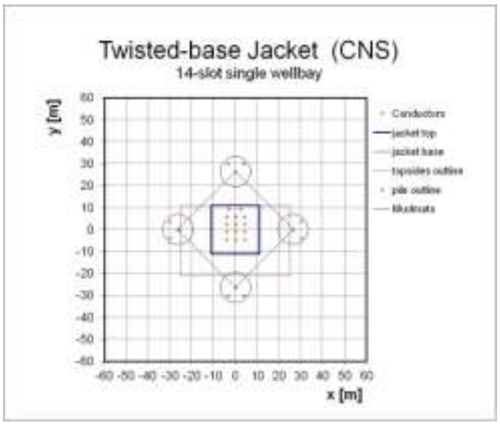
Figure 4 Jack-up foundation capacity checks – leg loads balanced prior to storm



Double-wellbay platform schematic; plan view

Double wellbay platform as-built with simultaneous drilling activity

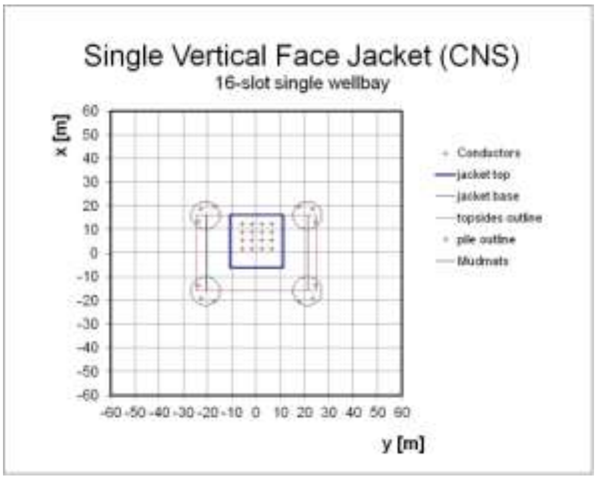
Figure 5 Vertical face wellhead substructure (jacket) design solution for SNS



Single-wellbay platform with twisted base substructure; schematic plan view

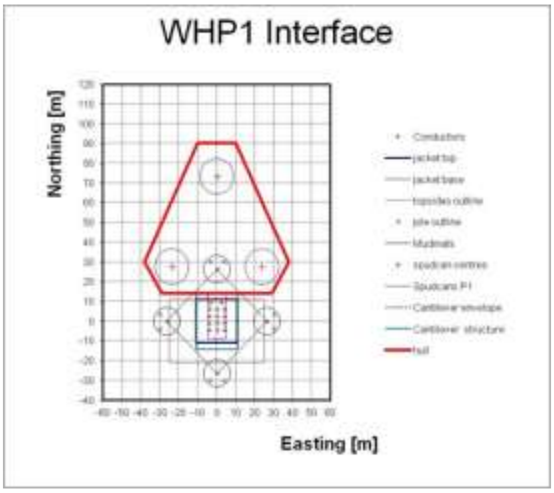
HPHT development including single-wellbay wellhead platform; artist impression

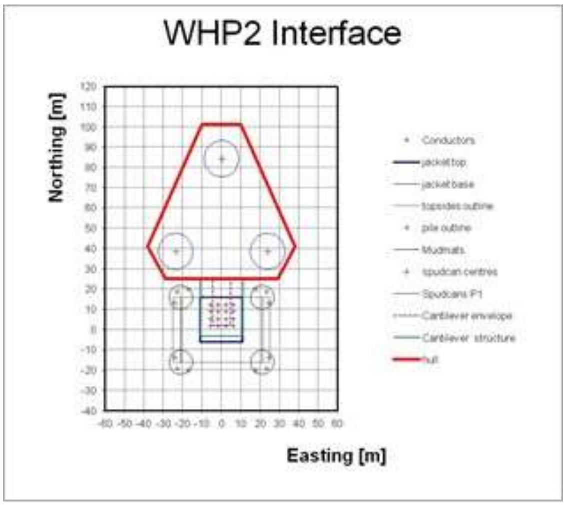
Figure 6 Substructure design solution for CNS - twisted base



Single-wellbay platform with single vertical face substructure; schematic plan view	NPNT development with single-wellbay in single vertical face substructure; artist impression

Figure 7 Substructure design solution for CNS – vertical face





Twisted base 14-slot single wellbay	Single vertical face 16-slot single wellbay

Figure 8 Example wellhead platform substructure with example jack-up in CNS

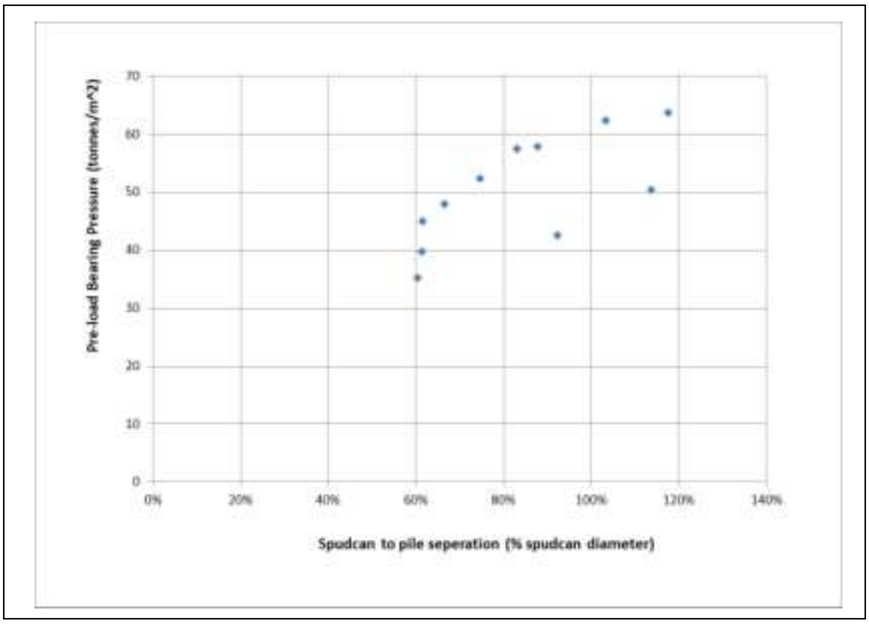


Figure 9 Spudcan proximity & bearing pressure (pre-load)

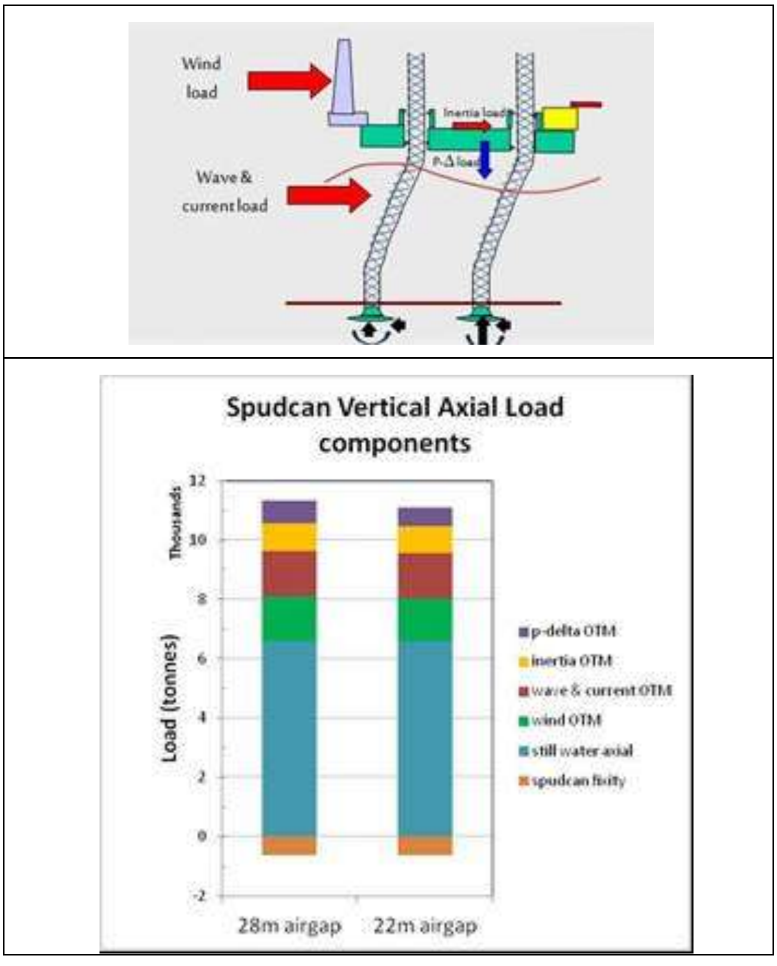


Figure 10 Components of the total axial leg load
[spudcan fixity, still-water & four components of storm induced loading]

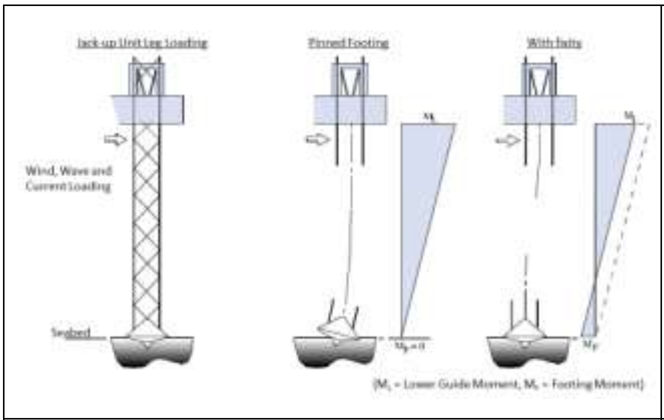
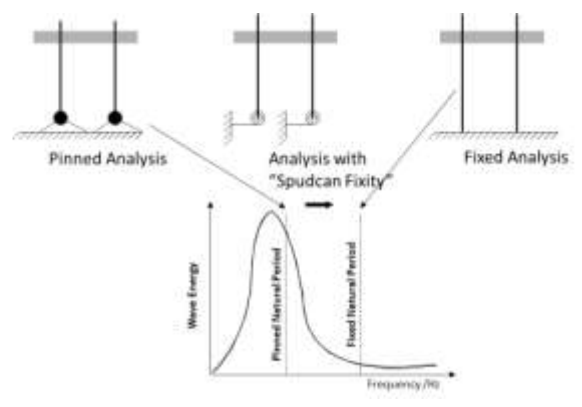
	
Static Effect of Fixity	**Dynamic Effect of Fixity**

Figure 11 Importance of spudcan rotational fixity (from Ref. 2)

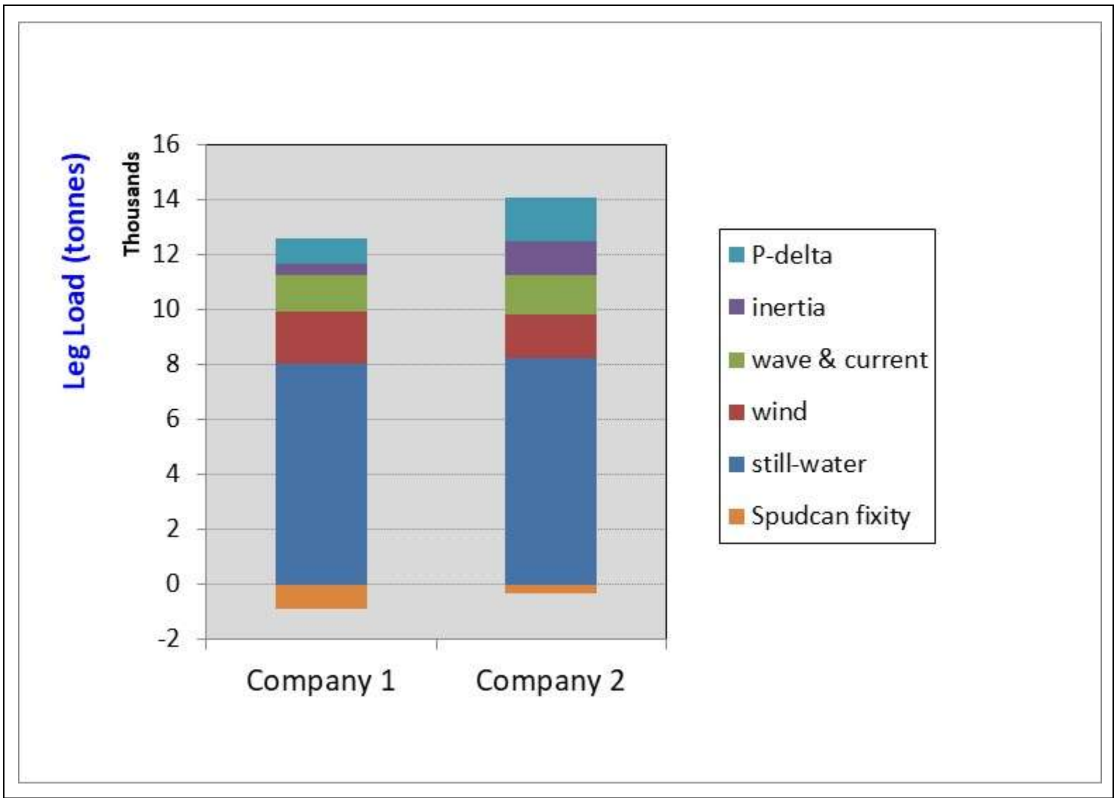


Figure 12 Maximum axial leg load

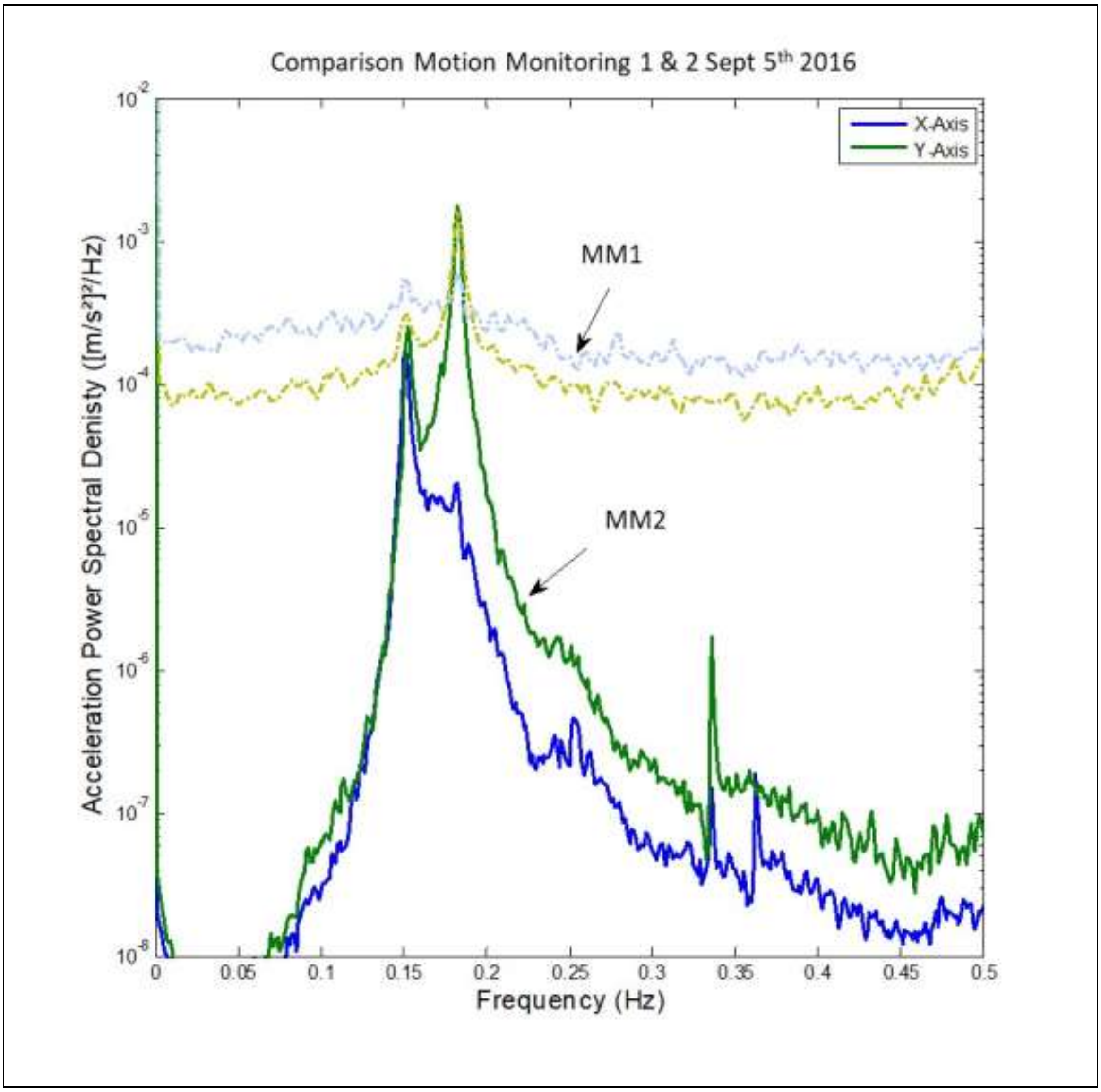


Figure 13 Motion monitoring data Maersk Highlander