INSTALLING A JACKUP IN SWELL CONDITIONS WITH RESPONSES ALMOST DOUBLE THE MOM LIMITS – A CASE STUDY

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ABSTRACT
This article presents a case study demonstrating the benefits of using onboard IMUs and enhanced GoL limits derived through advanced analysis to minimize a jackup's waiting on weather in swell-dominated locations.

In August of 2018, the ENSCO 107 (Now the VALARIS 107) was mobilized for a multi-site campaign off the coast of Northwestern Australia. As the rig approached the East Spar 3 site, the onboard Inertia Measurement Unit (IMU) recorded extreme pitch / roll motions of approximately +/-4 degrees. Those motions are more than double the allowable wave period-based rotation angles in the Rig's Marine Operating Manual for Going on Location. Given the extreme rig motions, the decision was made to modify the campaign and move to another site to commence work while waiting for favorable conditions at the East Spar 3 site.

Weather forecast for the East Spar 3 indicated similar metocean conditions for at least the next 10 days. Rather than risk waiting on weather for an extended period of time, the decision was made to perform an advanced GoL analysis. The GoL analysis would provide enhanced GoL limits, accounting for the site-specific water depth and soil conditions. In addition to producing enhanced hull rotation vs period curves, the site-specific GoL work produced a rig installation tool to calculate structural utilization ratios based on local metocean forecast for various combinations of swells and wind-driven waves.

Using the weather forecast information for the rig move window, the installation tool indicated that the risk for structural damage to the Rig would be minimal and the GoL operation could commence given the large motions. As a result, the rig was moved to the site and installed successfully, despite the relatively large rotation angles.

Less than a month later, the rig was safely installed at near-by East Spar 6 in similar metocean conditions. During the 36 days the rig was on the East Spar sites, there was no acceptable weather window as defined by the MoM limits for installing the Rig. The use of an onboard IMU and enhanced GoL limits enabled safe installations of the Rig, whilst eliminating over a month of WoW time.

Since then, the VALARIS 107 has been equipped with Valaris' patented SafeMOVE system, which uses real-time motion data to calculate GoL utilization ratios not just for a given site, but for any site within a range of water depths and soil conditions. The system is also installed on ten other of Valaris' jackups.

KEY WORDS: Jackups, Going on Location, Onboard IMU.

INTRODUCTION AND BACKGROUND

The below quote from a 2017 paper by Carre, McArthur, Simpson, Zhang and Vazquez, is still generally applicable today:

> Jackups have class-approved Marine Operating Manuals (MOMs) which provide guidelines for their operations and list their design limits. The MOMs are usually prepared by the jackup designer and submitted to review by a Class Society. Each Class Society has its own set of requirements for classing a jackup and as of the writing of this paper, they do not include any specific criteria for Going on Location or Coming off Location. Therefore, if any specific guidance is included in the MOM, it has been solely to the discretion of the designer [Ref 1].

Until recently, many jackups have only had simple wave height and/or hull rotation limits for going on location (GoL) operations. Typically, this is a single wave height limit with no clear distinction as to whether the wave height limits are significant wave height values or maximum wave height values. A few designers have included permissible rotation angle vs oscillation period curves for different water depths in soft and/or stiff soil conditions in the Class-approved Marine Operating Manual (MoM) as is the case with the VALARIS 107. A small number of jackups have been outfitted with inertia measurement units (IMU) to remove the subjectivity in establishing hull rotations (both amplitude and period) from the decision-making process.

This paper presents the particulars from a multi-site campaign off the coast of Northwest Australia (NW AUS). Using a combination of onboard IMU data and enhanced site-specific GoL limits derived through advanced analysis, multiple installations were completed safely, with zero time spent waiting-on-weather (WoW). During this time, installation would not have been possible within the bounds of the MoM-approved limits.

The VALARIS 107 is a Keppel FELS MOD V design, built in 2006. The particulars for the Rig are shown in Table 1 [Ref 2].

Table 1 - Jackup Particulars [Ref 2]

Parameter		VALARIS 107
Length	ft	234
Breadth	ft	208
Hull Depth	ft	25
Transverse Leg Spacing	ft	142
Longitudinal Leg Spacing	ft	129
Leg Length	ft	517
Load Line Draft	ft	16

On August 19, 2018 the ENSCO 107 (Now the VALARIS 107) was mobilized from the Dorado to East Spar 3 site. The Rig was equipped with an onboard IMU and as it approached the installation site, it recorded pitch/roll motions of approximately +/-4 degrees. Those motions are more than double the wave period based rotation limits stated in the Rig's MoM [Ref 5] and as such, the decision was made to forgo the planned GoL operations and move to a nearby (sheltered) site and continue operations.

The weather forecast indicated similar metocean conditions for at least the next 10 days. Knowing that the designer-provided limits are conservative, a decision was made to perform an advanced GoL analysis, accounting for the site-specific water depth and soil conditions.

The GoL analytical model was calibrated using the recorded roll/pitch data and known wave conditions from the East Spar 3 installation attempt. Additionally, an installation tool was developed to calculate critical structural utilization ratios for the legs and jacking system during GoL, assisting the Rig crew's decision to lower the spudcans to seabed. This tool accepted inputs from a detailed local metocean forecast, which consisted of both wind-driven waves and swells. The tool also had a feature to calculate critical utilization ratios based on the Rig's onboard IMU recorded data, though this was not a real-time feature.

A second installation attempt at the East Spar 3 site was planned for late-September. Using the weather forecast information for the rig move window, the installation tool indicated that it would be safe to perform the GoL operations. As a result, the Rig was mobilized and installed successfully, despite the relatively large

motions. Less than a month later, the Rig was safely installed at near-by East Spar 6 in similar metocean conditions.

During the 36 days the Rig was on the East Spar sites, there were no acceptable weather windows as defined by the MoM limits. Valaris's use of the Rig's onboard IMU and enhanced GoL limits enabled multiple safe installations, whilst eliminating over a month of WoW time.

REGION INFORMATION

The VALARIS 107 was slated for a plug & abandon (P&A) campaign off the coast of Northwestern Australia (NW AUS) in 2018. The campaign required the Rig to be installed at 5 different sites for 2 to 3 week's duration at each site. Three of the sites were located on the Eastern side of Barrow Island, while the remaining two sites were located to the West of Barrow Island. The sites to the west of Barrow Island are subject to Antarctic Swells. Figure 1 depicts the 2m H_s Risk Forecast for NW AUS during the time of installation. The red-blue colored areas of Figure 1 are locations in which a vessel would be exposed to significant swells while the area east of the colored portion of the map are considered sheltered from significant swells. Figure 2 shows the 2018 campagin sites with the the leading edge of the Swell Risk overlaid, illustrating the Exposed vs Sheltered areas.

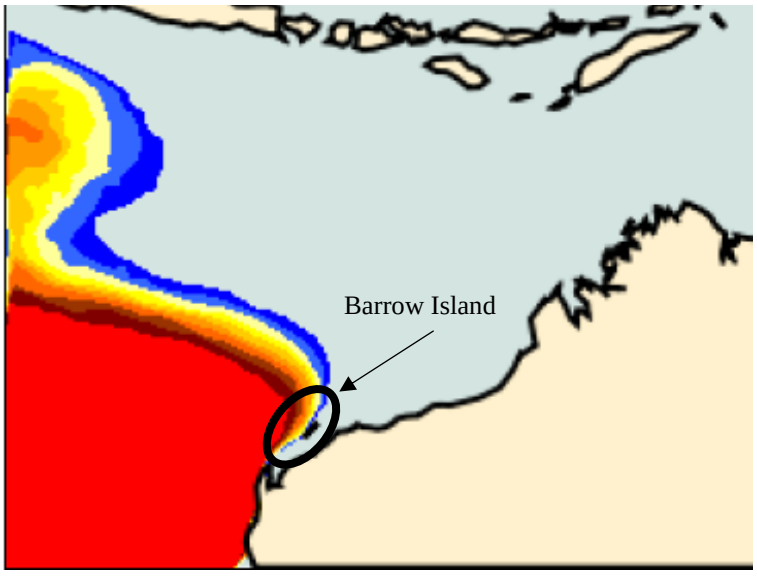


Figure 1 – Barrow Island Region: 2m H_s Risk Forecast (TYP) [Ref 3]

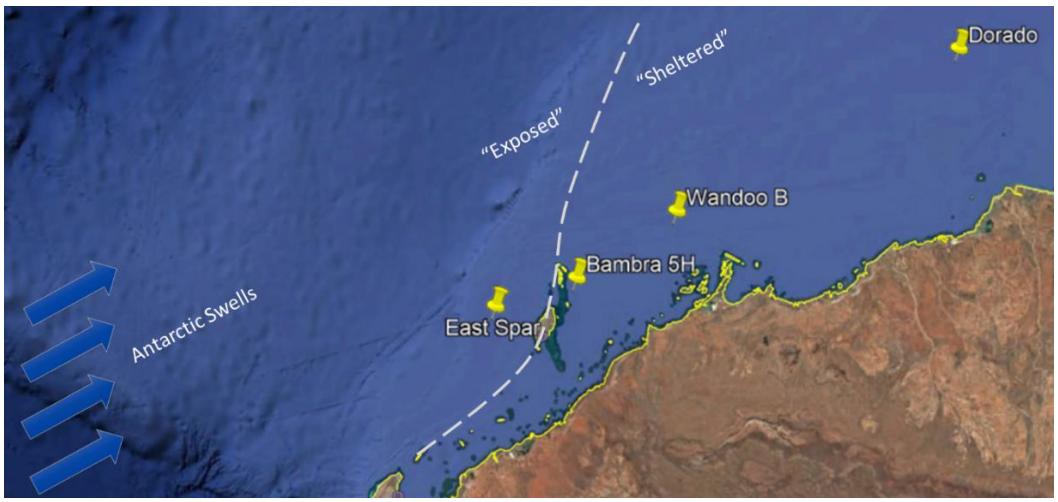


Figure 2 – NW AUS 2018 P&A Campaign Sites [Ref 3]

SITE INFORMATION

The water depths at the East Spar site range from 95m to 99m. The soil conditions at East Spar 3 and East Spar 6 are presented in Table 2, with the corresponding leg penetration curves for the VALARIS 107 shown in Figure 3 [Ref 4]. These sites are classified as having "medium soft" soils (i.e., soils where the spudcan penetrates to a minimum of the full bearing area but less than 10m).

Table 2 - Stratigraphy Interpreted from Sub-bottom Profile Data [Ref 4]

	East Spar-3					East Spar-6				
Unit Description	**Bottom Marker**	**Start Depth (m)**		**Thickness (m)**		**Bottom Marker**	**Start Depth (m)**		**Thickness (m)**	
		LE	**HE**	**LE**	**HE**		**LE**	**HE**	**LE**	**HE**
Sandy Silt over Silt	Pink	0	0	6.4	7.2	Green	0	0	3.2	3.7
Silty Sand	n/a	n/a	n/a	n/a	n/a	Pink	3.2	3.7	7.6	9.6
Calcarenite	Red	6.4	7.2	5.9	8	Red	10.8	13.2	4.1	5.5

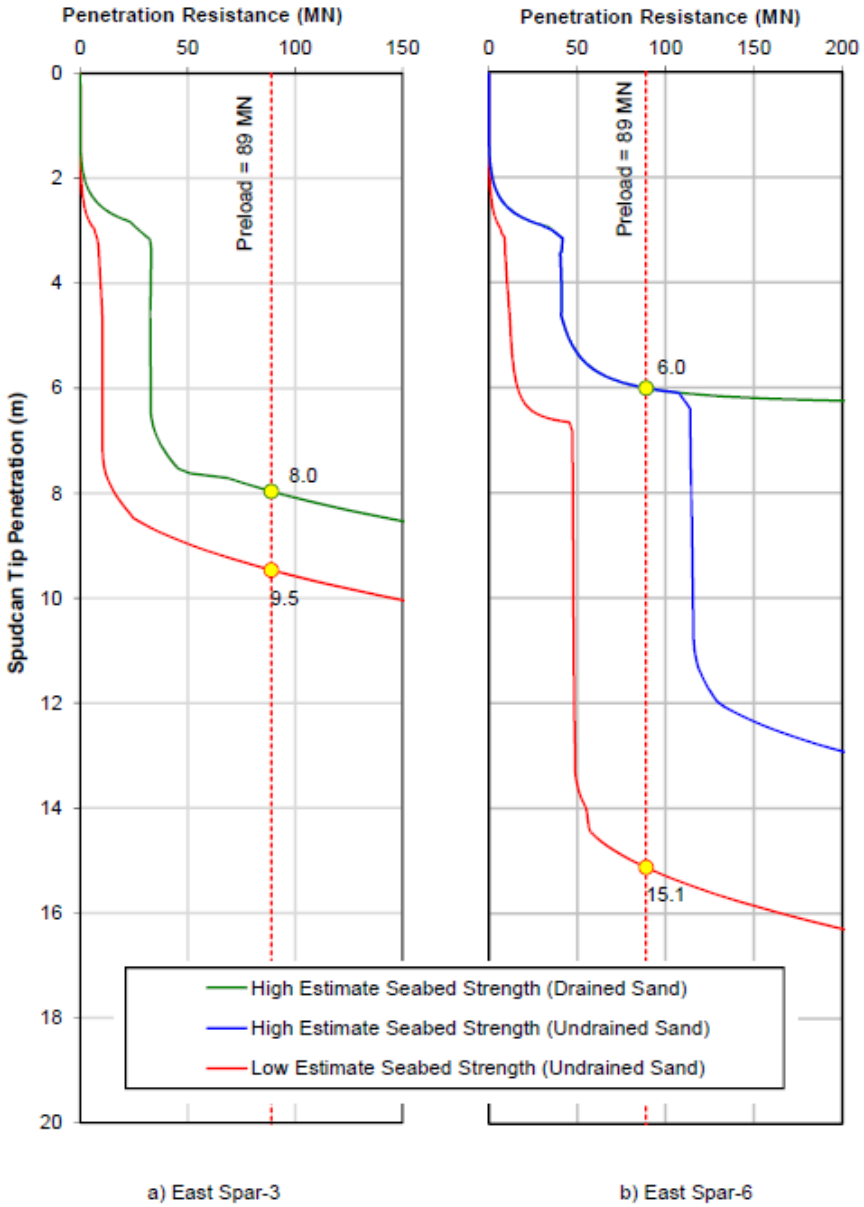


Figure 3 – VALARIS 107 Spudcan Penetration Resistance for East Spar Sites [Ref 4]

EXISTING LIMITS AND OBSERVATIONS FROM FIRST MOVE

On August 19 2018, the VALARIS 107 transited from El Dorado to East Spar 3. At the time of arrival, the forecast called for significant wave heights between 1.28m and 1.42m, with maximum wave heights between 2.0m and 2.6m and with periods between 12sec and 16sec (see Figure 4).

Days 1 and 2

Date	Sun 19/08								Mon 20/08							
Time (WST)	00	03	06	09	12	15	18	21	00	03	06	09	12	15	18	21
Wind																
Direction				140	120	080	060	060	080	190	140	100	080	080	070	070
Speed (kn) Range Est ± (kn)				9 ±3	10 ±3	11 ±3	9 ±3	5 ±3	4 ±3	4 ±3	9 ±3	13 ±3	10 ±3	9 ±3	8 ±3	6 ±3
Gust (kn)				14	15	17	14	8	6	6	14	20	15	14	12	9
Sea/Swell																
Sig Ht (m) Range Est ± (m)				1.3 ±0.2	1.4 ±0.2	1.3 ±0.2	1.4 ±0.2	1.3 ±0.2	1.2 ±0.2	1.1 ±0.2	1.1 ±0.2	1.2 ±0.2	1.2 ±0.2	1.2 ±0.2	1.2 ±0.2	1.3 ±0.2
Max Ht (m)				2.4	2.6	2.4	2.6	2.4	2.2	2.0	2.0	2.2	2.2	2.2	2.2	2.4
Period (s)				14/17	14/17	13/16	13/16	13/16	12/15	12/15	12/15	12/15	12/15	12/15	12/15	12/15
Direction				230	230	230	230	230	230	230	230	230	230	230	230	230

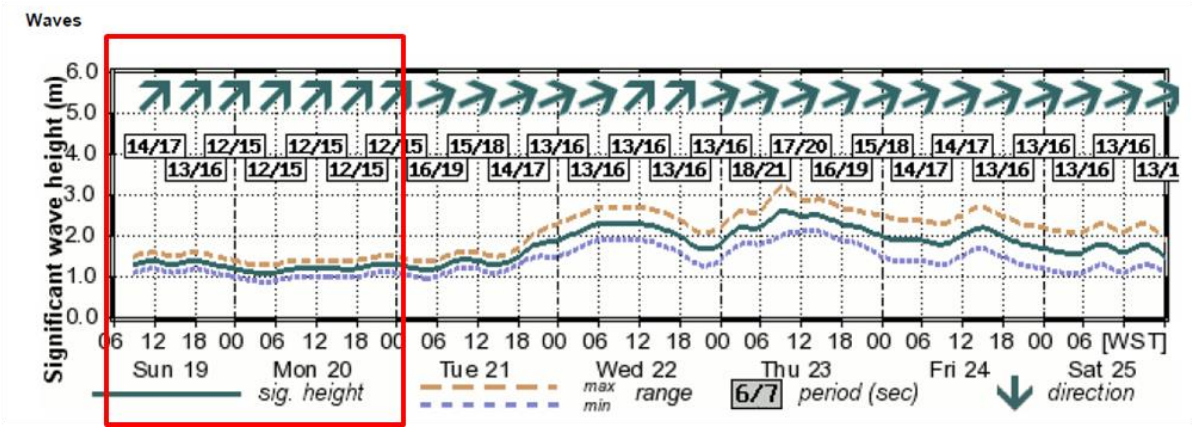


Figure 4 – Aug 19-20, 2018 Wave Forecast at East Spar Site [Ref 5]

The onboard IMU recorded extreme pitch and roll motions for the Rig of approximately 4 degrees (See Figure 5). These motions were more than double the limit stated in the Rig's MoM [Ref 5] (see Figure 6). Figure 7 shows a photo of the rig while on transit Aug 19, 2018. At that time, the legs were deployed to 253ft below the hull baseline (HBL).

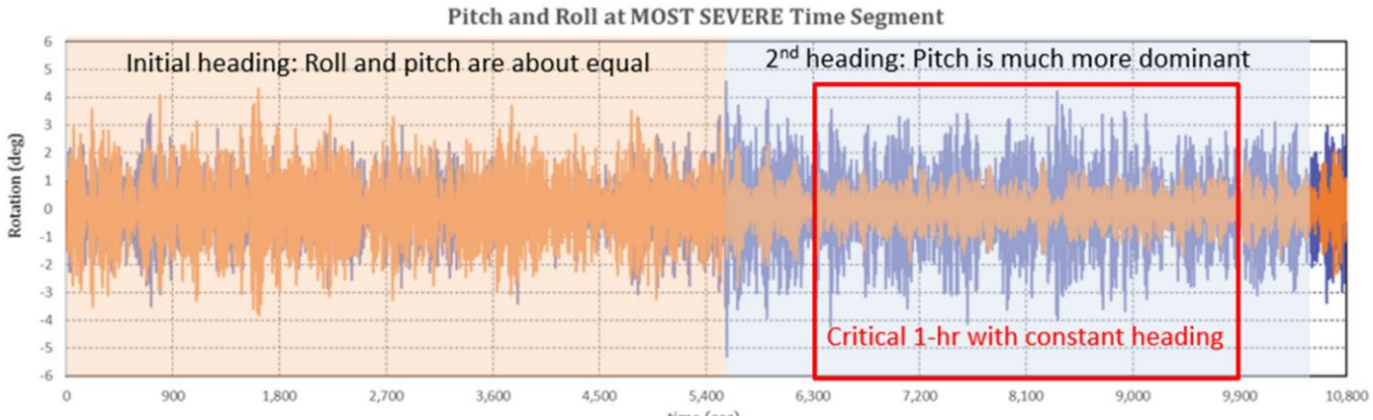


Figure 5 – Aug 19, 2018 Recorded Roll/Pitch Motions near East Spar Site [Ref 5]

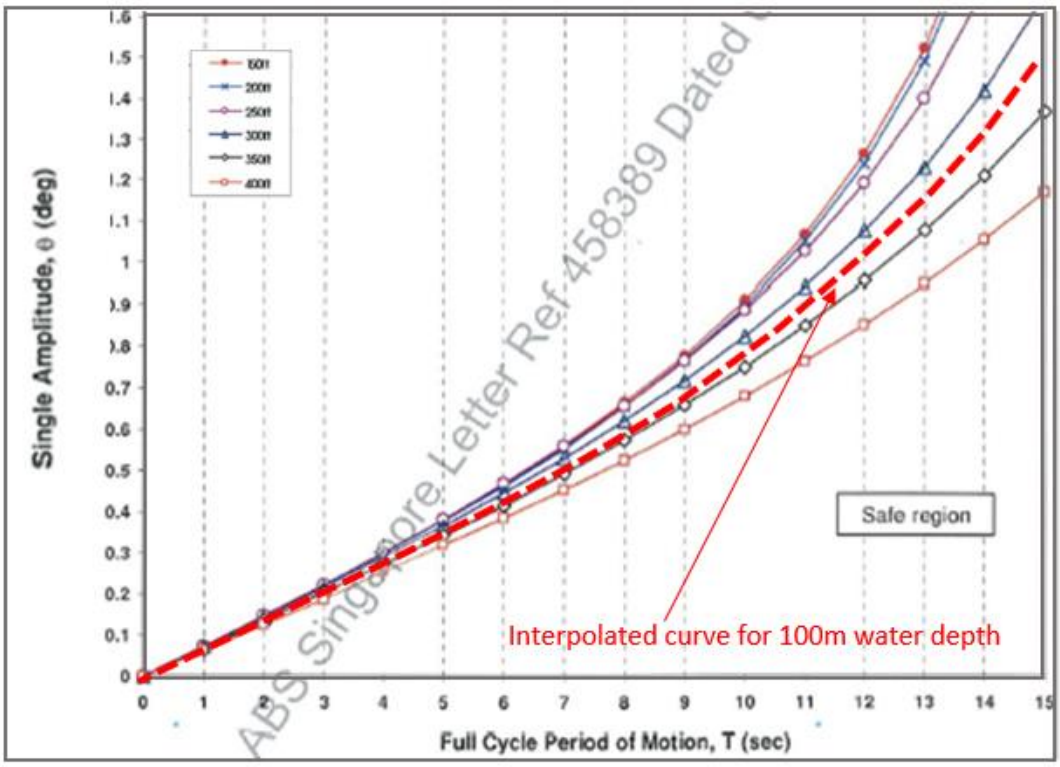


Figure 6 – Going on Location Limits for VALARIS 107 (modified to focus on 100m Depth) [Ref 5]

Figure 7 – VALARIS 107 in Transit Aug 19, 2018 [Ref 5]

With no forecasted improvement in metocean conditions, the decision was made to forgo the planned GoL operation and move to Bambra 5H, which is located on the eastern side of Barrow Island and sheltered from swells. The prompt decision to move the Rig to Bambra 5H minimized the exposure to WOW time. However, operations at Bambra 5H were expected to take no more than 14 days and the rig would then need to be moved back to East Spar 3, with East Spar 6 to follow.

Given the soil characteristics at the East Spar 3 and 6 sites (classified as "Medium Soft"), the MoM limits for GoL were likely overly conservative. For locations with prevailing swells, even relatively small changes in the permissible limits can result in drastic reductions of time waiting on weather, as documented in 2017 by Carre et al [Ref 1]. To maximize the likelihood of a successful installation, the decision was made to develop new, site-specific limits using advanced GoL analysis techniques. These enhanced limits would need to be completed quickly, such as not to delay the rig move.

ANALYSIS APPROACH

While there are currently no class approved analysis methodologies for establishing the limiting wave heights/motions for GoL, an advanced analysis would need to account for all of the below key factors:

1. Water depth
2. Tip of Can position (in close proximity of the seabed)
3. Structural Capacity of the Legs and Jacking System
4. Wave Direction w.r.t. Rig heading
5. Wave Periods
6. Soil conditions

A variation of the analysis methodology described in the 2017 paper by Vazquez, Gamino, Grasso and Templeton [Ref 6] was used for the VALARIS 107 at the East Spar sites. The results of these analyses are a series of site-specific Permissible Wave Height Curves (PWHCs) and Permissible Rotation Angle Curves (PRACs) based on wave period. The PWHC results were linearized and expanded to account for wave direction, producing Utilization Ratio RAOs for each of the legs and thus allowing for obtaining results in seas with different directions.

The Rig had recorded roll/pitch motions from an onboard IMU and a set of corresponding wave forecasts for the planned initial East Spar installation. The start of the analysis involved calibration of the model, as the analytical results for large periods are particularly sensitive to the amount of assumed damping.

Figure 8 shows the roll and pitch motion statistics for the selected 1-hour data set, which was analyzed using the standard zero-upcrossing methodology. As can be seen, the ratio of significant roll to pitch is 2.23°/5.21° = 0.43. This suggests an apparent axis of rotation that is 67° from the jackup's longitudinal axis, but the waves are not necessarily from a direction that is +/-90° off (since the rig is not axisymetric, and experiences pitch even in beam seas). However, when doing the calibration, the 0.43 ratio is important.

Results for 1-hr constant heading segment - Roll						Results for 1-hr constant heading segment - Pitch					
Number of cycles in record	268					Number of cycles in record	279				
θ_s	2.23	deg	T_s	13.99	sec	θ_s	5.21	deg	T_s	13.02	sec
θ_{max}	3.40	deg	T_{ass}	13.49	sec	θ_{max}	8.20	deg	T_{ass}	13.18	sec
			T_z	13.4	sec				T_z	12.8	sec

Figure 8 – Roll and Pitch (double-amplitude) Motion Statistics for Critical 1-hour Segment [Ref 5]

Figure 9 shows the particulars of the wave forecast for the time of interest and how it relates to the known Rig heading at that time. Figure 9 also depicts the Rig orientation during the attempted installation as well as the Rig in Model Space. From the Rig heading and the dominant wave directions, the model was analyzied with waves traveling in the 166° direction to calibrate the model. The calculated 166° relative wave direction is 9° off from the apparent axis of rotation (67°+90°=157°). This apparent 9° variation is deemed appropriate, given the shape of the hull and the expected amount of variation in waave direction from the forecast's information.

It is critical to the analysis to determine an appropriate amount of external damping. Assuming a free-floating condition and using trial and error with different amounts of external damping (with and without wave spreading), the model was calibrated to have similar motions to those experienced by the Rig.

Date	Sun 19/08	
Time (WST)	09	12
Wind		
Direction	140	120
Speed (kn) Range Est ± (kn)	9 ±3	10 ±3
Gust (kn)	14	15
Sea/Swell		
Sig Ht (m) Range Est ± (m)	1.3 ±0.2	1.4 ±0.2
Max Ht (m)	2.4	2.6
Period (s)	14/17	14/17
Direction	230	230

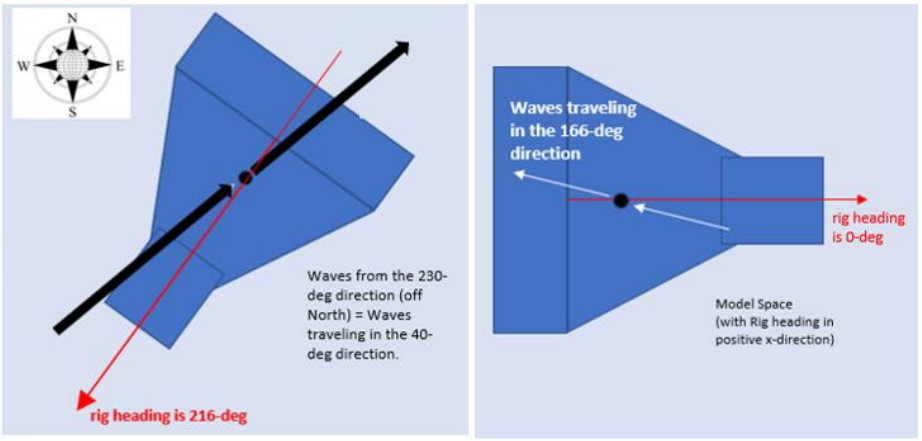
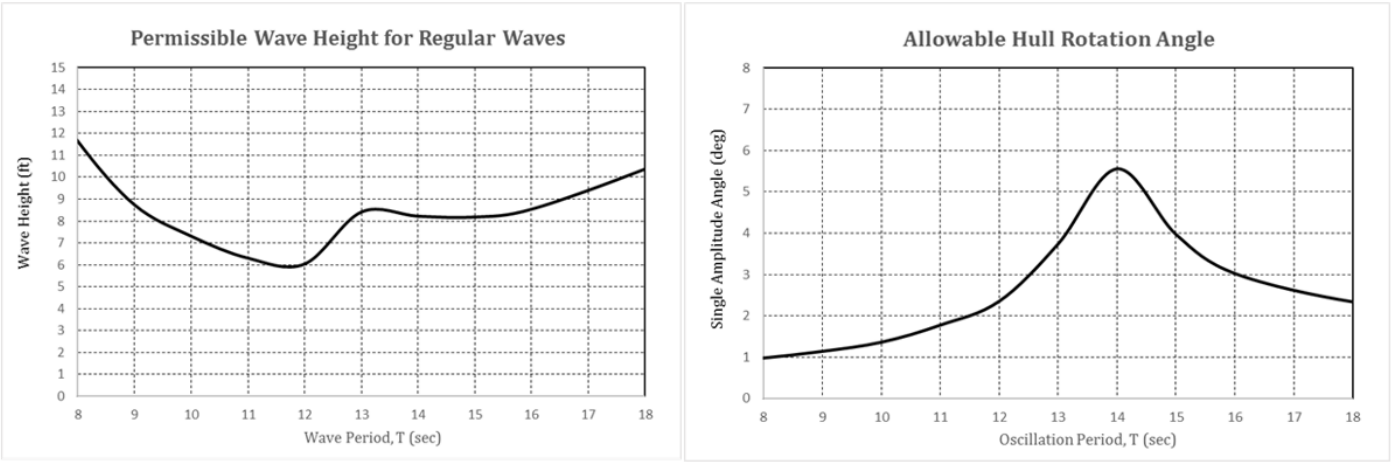


Figure 9 – Particulars for Calibration Model [Ref 5]

After calibrating the model for the free floating condition with 253ft of deployed leg, a new model with the ToC in close proximity to the seabed was created and simulations in regular waves were carried out. Due to the extra amount of deployed leg for the GoL analyses, external roll/pitch damping ratios were increased by 1%. It is noted that the effect of deployed leg length on damping ratios has now been quantified [Ref. 7] and the assumption for the East Spar analyses has proven conservative.

The initial end-product of these analyses is a set of permissible wave height and associated hull rotation angle curves. An initial set of analyses were carried out for what is expected to be the most onerous relative wave direction (head seas). Figure 10 shows the results for the most onerous wave direction [Ref 8].



Above curves are for the most onerous wave direction

Figure 10 – Site-Specific Permissible Wave Height and Rotation Curves for VALARIS 107 [Ref 8]

NEED FOR A TOOL

Encouraged by the results for the most-onerous wave direction, additional analyses to cover a full range of wave directions were performed.

Two key factors were considered when deciding whether to simply create more graphs or create a tool.

1. Available Technology to Crew: While the Rig was equipped with an onboard IMU, the Rig did not have onboard processing capabilities to see much more than peak values for roll and pitch. Reliable use of permissible rotation data requires more than just peak values and significant or mean rotation periods, and this cannot be done manually.
2. Wave Forecast Complexity: The wave forecast provided wave height, period, and direction for wind driven waves, plus four swell components. In order to avoid being overly conservative, it would be essential that the final evaluation accounted for multiple sets of waves. So, even if the crew were given separate direction-dependent permissible wave height curves for regular waves and for random seas they would not be able to combine them without necessarily being conservative.

Therefore, the standard GoL analyses were modified to track leg utilization ratios on all legs, not only on the critical leg, and to carry out the evaluations with up to four swells, each possibly having different direction. A simplified user interface was designed to facilitate efficent use of the tool by Rig and shorebased support personnel.

The installation tool was created utilizing MS-Excel as its platform. Figure 11 shows the GUI of the program [Ref 9]. It is noted that, given the short time schedule for a possible second attempt, it was decided that some conservatism could be maintained and a single wave direction would be used for all waves.

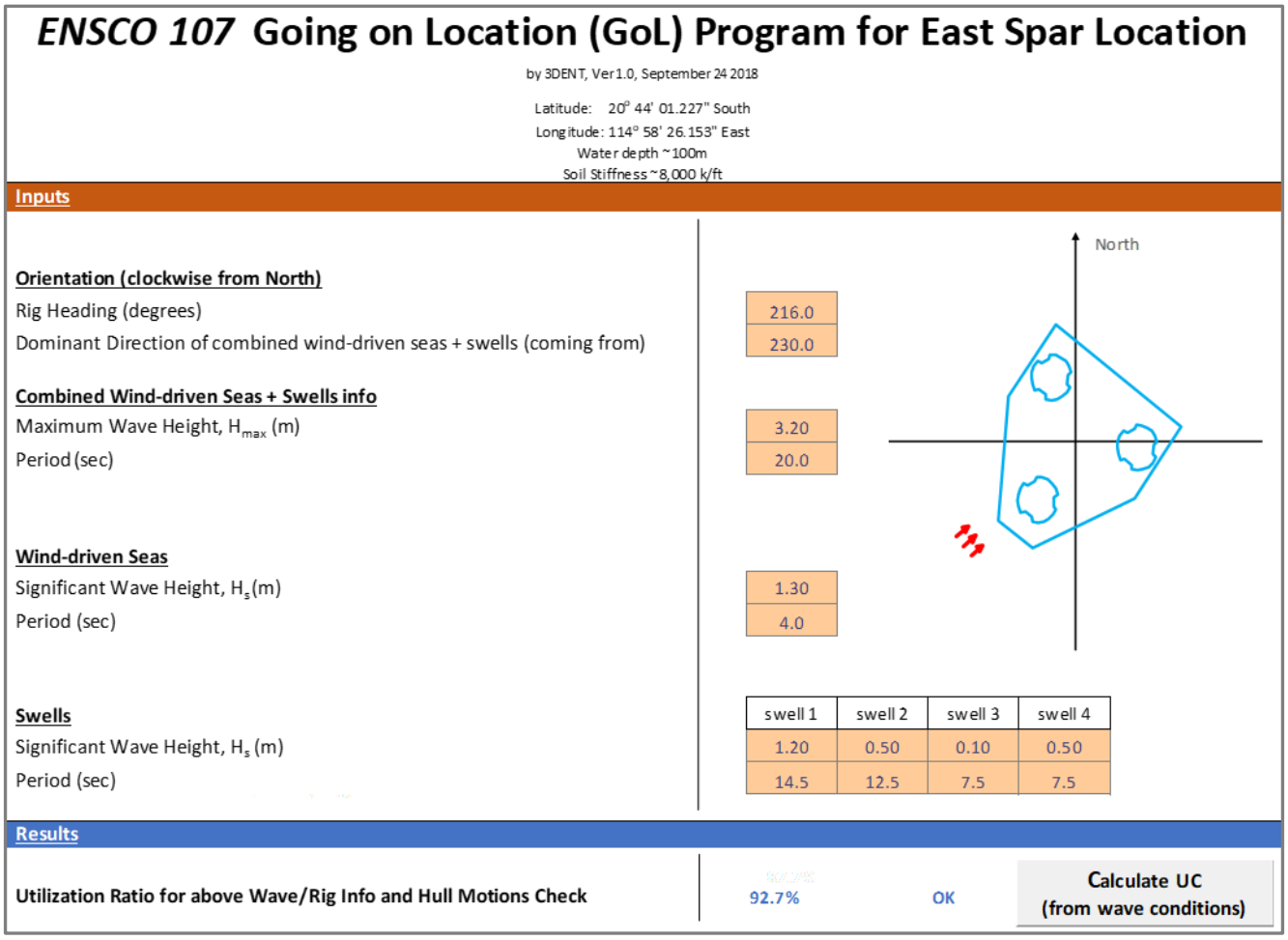


Figure 11 – GUI of GoL Program for the VALARIS 107 at the East Spar Sites [Ref 9]

The primary input for the tool is intended to be wave forecast information only. However, since the Rig has an onboard IMU, the tool was customized to include the capability of reading IMU roll/pitch data for a selected segment of time. The tool reads the raw IMU data, processes the data, and utilizes site specific allowable hull rotation curves to provide a structural utilization based on actual rig motions and East Spar soil parameters. Figure 12 shows a sample set of processed data along with the the allowable rotation curves from the MoM and the advanced analyses.

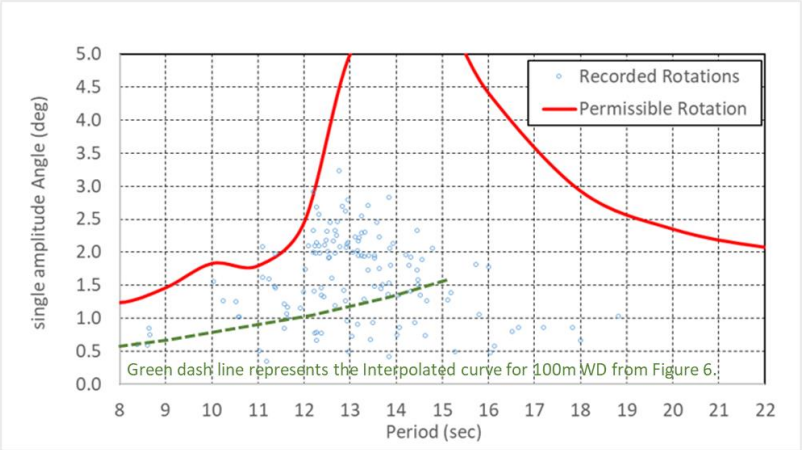


Figure 12 –Permissible Hull Rotation Curve shown with Measured Data [Ref 5]

ATTEMPT 2

After completing work at Bambra 5H, the VALARIS 107 returned to the East Spar 3 site with Enhanced GoL limits. Once on-site, the crew reported larger motions than was experienced in the previous attempt. The decision to install the Rig at East Spar 3 was made based on the Enhanced GoL Limits rather than the MOM-based limits. The MoM GoL utilization for the VALARIS 107 motions at the East Spar 3 site were approximately 200% of the limit, while the Enhanced GoL utiliation was below 100%. The Rig was successfully installed at East Spar 3 without damage.

Furthermore, the Rig was moved off the East Spar 3 site and installed at East Spar 6 under similar metocean conditions. After 36 days on location at East Spar, the Rig was moved to complete the remainder of the 2018 NW AUS P&A campaign, at sites shielded from swells.

Figure 13 shows a plot of both MOM-based and Enhanced GoL based utilizations for the 36 days the Rig was on site at East Spar.

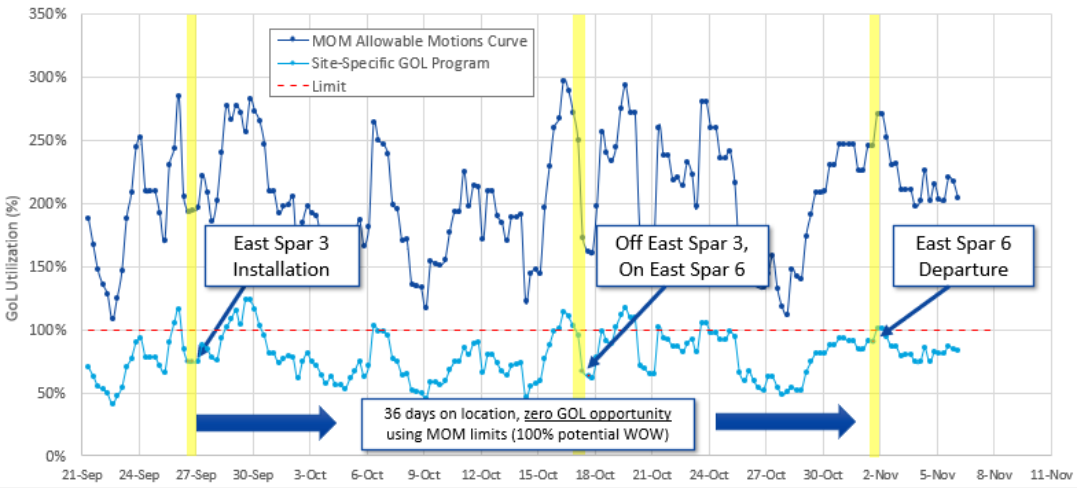


Figure 13 – GoL Utilization for East Spar sites [Ref 3]

SUMMARY AND CONCLUSIONS

The use of Enhanced GoL limits enabled the VALARIS 107 to go on location in conditions that were significantly beyond the limits documented in the Marine Operations Manual, without sustaining damage to the Rig. The Rig saved a minimum of 36 days of waiting on weather time and possibly many more, as the forcast remained the same for quite some time.

This case study illustrates a suscessful pairing of analytical models, real world data, and innovation to balance Safety and Operational Efficiency without increasing the risk to the crew and the VALARIS 107.

REFERENCES

[1] Carre, D., McArthur, L., Simpson, A., Zhang, P. and Vazquez, J.H; "*GSF GALAXY I* Jackup Study for Optimizing Rig Move Performance in North Sea Using an Advanced Simulation Model." Proceedings of the 22nd Offshore Symposium, February 2017, Houston, Texas.

[2] ENSCO 107 - Operating Manual, Rev 0. July 30, 2007.

[3] ENSCO INTERNAL DOCUMENT. "JU 107 – East Spar Installation."

[4] Fugro Document No.: AGTN-2401 Rev A; "Technical Note - East Spar and Bambra: Spudcan Penetration Assessment." Dated November 29, 2017.

[5] 3DENT Presentation 20180803-PRS-4400-02, "ENSCO 107 Motion Data Review and Analyses." Rev 0. Dated September 5, 2018.

[6] Vazquez, J.H., Grasso, B.D., Gamino, M. and Templeton, J. "Seabed Modeling Effects on Jack-up Response while Going on Location." In: Proceedings, The 16th International Conference on the Jack-up Platform Design, Construction & Operation, London, UK, 2017.

[7] Grasso, B.D., Melkowits, M., and Vazquez, J.H. "Pitch Damping Ratios of Jackups with Varying Deployed Leg Lengths." International Conference: The Jack-up Platform (VIRTUAL). November 2021.

[8] 3DENT Report 20180803-RPT-4400-01; "ENSCO 107 Going on Location Study at East Spar." Rev 0, Dated September 6, 2018.

[9] 3DENT Presentation 20180803-PRS-4400-06, "Quantifying the Benefits of the Advanced GoL Analyses for the ENSCO 107 at the EAST SPAR LOCATION." Rev 0. Dated September 29, 2018.