Looking back at successful jack-up preloading operations
Managing and applying key data

R.J. Hunt
Gorevega Ltd

Abstract

This paper looks back at a number of jack-up preloading operations in different parts of the world to understand both the planned operation and the challenges faced in executing that plan. Rig-move logs and daily operations reports have been reviewed to understand how the preloading operations were managed to ensure the required amount of preload was applied for the specified duration. Key data requirements are identified and used to profile a number of actual preloading operations with particular attention to locations where rapid leg penetration was either expected or occurred. Several recommendations are made on how to identify, prepare for and manage difficult locations.

KEY WORDS: Jack-up, preload, rapid leg penetration

Summary

The challenges associated with jack-up preloading operations are not new, and place considerable demands on the expertise of all parties involved. Recent rig incident data demonstrate that these demands are not always being met and, hopefully, the reasons for this will become clearer once the investigations into those incidents have been concluded.

In the interim, a review of nine jack-up rig moves has revealed a worrying variability in the methods used to manage the hazards associated with a preloading operation. This review also highlighted the variability of data logging and management, which seems illogical given the complexity of the operations.

A summary of the key data that needs to be managed is provided in the hope that this will provide both the basis for planning a preloading operation at a particular location, and an understanding of whether the operation is proceeding as expected.

Introduction

The operations involved in moving a jack-up rig are deceptively complex. This is because the rig changes from being a bottom-supported offshore structure to a floating vessel and then back to being a bottom-supported structure. The activities associated with rig departure from a location may be considered the "easier" operation in that the management of the hazards of that phase of the rig move may be focussed on the performance of the jacking and jetting systems, the weather conditions and, if the rig is not self-propelled, the capabilities of the vessels used to tow it once the hull is fully afloat. In contrast, the activities associated with rig arrival need to manage not only the need for the smooth functioning of the jacking system, the availability of suitable weather conditions, tug management and an anchoring plan but also the hazards associated with a short-term testing of the rig's foundation at the new location.

For a three-leg jack-up, the introduction of sea-water ballast, to provide the necessary preload, places considerable demands on the elevating and holding capacities of the jacking system. Jacking systems are designed assuming minimal friction at the leg guides, which in practice means that the hull must be kept level during preload operations so that the legs can pass smoothly through the guides. In theory simultaneous preload of all three legs may seem to facilitate this, but experience has shown that, once the hull is lifted clear of the water, simultaneous leg penetration under identical leg load is a rare occurrence. Leg-specific load versus penetration predictions are made, but it is important to consider if it is real variability of the site soil conditions, inadequacies in the site investigation or preload operations themselves that is the cause of this.

Of all the onshore engineering activities associated with every jack-up rig move, the development of accurate and realistic leg load versus leg penetration prediction curves is probably the most vital. Done correctly, these predictions should enable the rig move team to assess the challenge of the pre-loading operation and plan accordingly.

Current rig incident data /1/ is dominated by foundation failures for rigs moving onto location; especially punch-throughs or sliding into footprints. Without reviewing the individual Rig Move Procedures and subsequent rig move logs it is unclear if the rig move teams were “ambushed” by the location specifics - such as seabed bathymetry or soil strength variation or, if “challenges” were expected, did the rig move team find that the planned mitigation measures were insufficient or impractical? Planned mitigation measures could have included reduced threshold metocean conditions, limiting airgap or requiring hull draft, and individual leg-by-leg preload. Unfortunately, the introduction of some of these mitigation measures may not be straightforward. For example, the use of a minimum airgap is often proposed as a key “defence” against rapid leg penetration, but may be difficult to achieve (and unpopular!) when there is a lot of swell at the location and single leg preloading introduces delays that can induce soil property changes on the other two legs.

There are several other possible causes for this recent increase in rig incidents, for example:

- Many of the newer jack-up designs are being stretched to operate in greater water depths and, therefore, have a smaller leg-strength reserve. These legs work well under normal operating conditions (with fixation systems engaged) but have reduced capacity to resist the greater loads experienced during a punch-through.
- The need for some designs to use their fixation system (rack chocks) to briefly protect the climbing pinion capacity during preload places an additional burden on the rig move team.
- There is also at least one new rig design where the Marine Operation Manual includes a section on punch through which states: “The Unit is not classed to be installed in Punch Through Site.”(sic) This has several implications, not least the quality demanded from the leg penetration assessment and the techniques and the data used to develop it.

These newer rigs may also have elevating systems that are more complex to operate, requiring more experienced personnel trained in the measurement and control of leg chord loading and leg brace loading. Leg brace loading is monitored by the measurement of Rack Phase Difference (RPD).

There also seems to be a developing shortage of skilled rig movers, and many offshore rig move personnel do not have the skills to accurately monitor leg penetration and leg loading as the rig loses draft and then goes into preload operations. The combination of inadequate tools (e.g. stability programs, pinion load and RPD monitoring systems) and inadequate knowledge and experience tend to result in protracted conversations between the rig and shore base that can be confusing and non-productive.

Leg load versus leg penetration prediction curves

Figures 1 to 4 show typical leg load versus penetration prediction curves, the first three deal with issues presented by the site soil conditions the fourth deals with an issue created by human factors. Figure 1 represents a site with low foundation risk due to an increasing strength with depth profile. The reduction in hull draft (between leg self-weight and rig self-weight) is achieved against an increasing spudcan penetration so that jacking the rig two metres may only change the draft by one metre. In this example very little additional leg penetration is achieved during pre-load operations, so a relatively straight forward pre-load operation is expected.

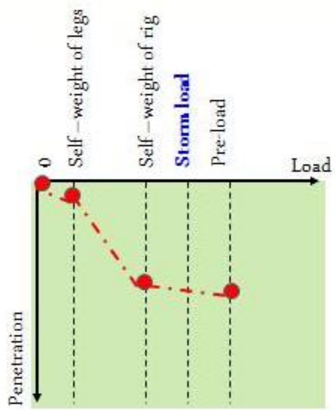

Figure 1 Example Prediction # 1

The curve in Figure 2 predicts rapid leg penetration prior to the hull coming out of the water - this is relatively straightforward because with the hull in the water the sudden increase in spudcan penetration occurs without losing trim/heel. In this example a large amount of additional leg penetration is predicted during preload operations, which may require a sequence of loading and dumping operations to ensure minimum airgap is maintained. With a deep target leg penetration, there is always the temptation of minimizing the number of load-dump-elevate cycles by using a bigger air gap. This temptation must be resisted.

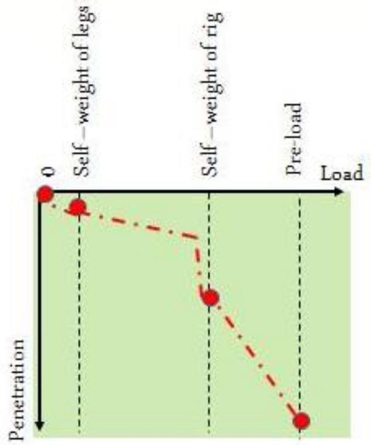

Figure 2 Example Prediction # 2

The curve in Figure 3 predicts rapid leg penetration close to full preload - this is the most challenging way of experiencing rapid leg penetration and, if it exceeds the jacking capacity or speed of the elevating system, or the hull is too far from the water, it may result in a substantial loss of trim/heel – with subsequent damage to the rig a very real possibility. Note that for a 3-leg unit, loss of trim/heel will result in the “punching leg” attracting more load as the centre of gravity shifts to exacerbate the situation. For a rapid leg penetration of either of the stern legs, the sudden shift of the centre of gravity may result in the rig striking any adjacent platform.

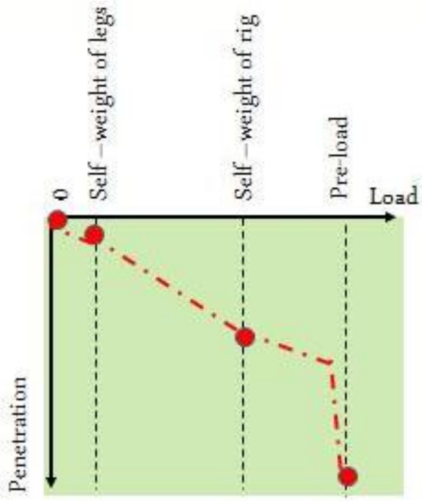

Figure 3 Example Prediction # 3

The prediction made in Figure 4 reflects either an inadequate site investigation or an overly pessimistic interpretation of the soil data (or both). The result is a wide range of possible leg penetrations. This is very difficult for the offshore rig move team to use with any confidence – and needs to be resolved prior to the rig deployment. It requires enhanced geotechnical analysis methods or using offset leg penetration data and/or additional geotechnical or geophysical data to narrow the prediction range.

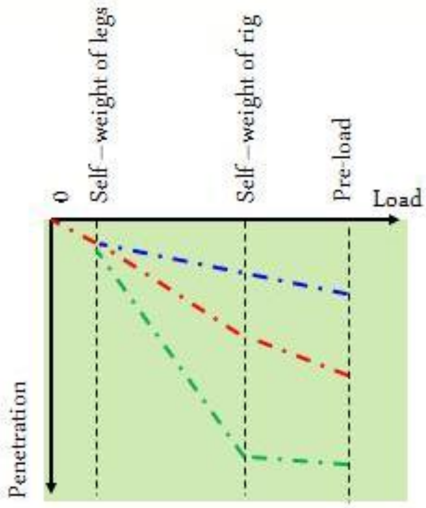

Figure 4 Example Predictions

The current state-of-the-art leg penetration prediction methods are based on a wished-in-place spudcan – that is, they do not model the physical process of leg penetration. This often results in wildly inaccurate predictions and has the very serious knock-on consequence that they are not consulted by the rig move team and removes a potentially very valuable safety check. Trapped-plug prediction methods are much to be preferred at sites with challenging soil conditions. These methods are described in /2/ and /3/.

Armed with an accurate leg load versus leg penetration prediction curve the most vital part of the offshore preload monitoring activities is the comparison of “predicted” versus “actual penetration”. Significant deviations away from the prediction curve should be recognised immediately and managed. This was the background to the Matthews-Daniel “program PRELOAD” developed after the Huthnance jack-up; Vanguard II, suffered a punch-through and damage to all three legs offshore Indonesia in 1992.

If the leg penetration prediction includes a rapid leg penetration event, the following items would normally be considered to manage the situation:

- Leg by leg pre-loading, with the leg furthest from a fixed asset loaded first.
- Additional manning of specialist rig move personnel
- Daylight only operations
- Monitoring of tidal fluctuations – especially if operational delays occur.
- Reduced weather criteria
- Hull in water at minimum draft
- All personnel on deck to wear personal flotation devices
- All rig transit sea-fastenings to remain in place until after pre-load operations completed.
- Watertight integrity management maintained
- Minimize or eliminate crane movement until after pre-load operations completed.
- Maximize clearance with existing assets (Platforms)
- Use of intentional loss of trim away from asset (bow down) during stern legs pre-load
- Punch-through response training, with particular focus on recovery without leg damage
- Punch-through structural capacity engineering calculations
- “Move the rig on paper” exercise prior to rig mobilisation

If a rig move team are unprepared for rapid leg penetration it is clear that they may find it difficult to determine their best course of action in real time during the event. There should be a shared understanding of when “Plan A” is no longer valid and a “Plan B” is required ASAP.

Example Rig Moves

In this section, the highlights from nine rig moves are presented. The majority of these rig moves were identified as part of the offset data collected in anticipation of an upcoming rig deployment in the same vicinity. The contrast between these rig moves is considerable, with some operations being performed expertly, whilst others seem to rely on (or need) a degree of good fortune so that they did not become another jack-up accident statistic; such as those presented in /1/.

Example Rig Move #1

An example of a successful preloading operation at a difficult site is provided by a preloading operation in 2006. There were three leg penetration assessments for this KFELS Super B Class rig at a location offshore Sarawak. With an expected and challenging 25m penetration, the Marine Warranty providers instruction was to “go carefully” due to the possibility of a rapid leg penetration during preload. A specialist consultant’s view was that there was a severe risk of punch-through and as such the site was unsuitable. The leg penetration prediction from a second specialist consultant was similar to that developed by the Marine Warranty provider, but no advice was offered.

The operation went ahead and was performed in 6-stages with leg-by-leg preloading. For the first four stages the operation was performed with the hull in the water. All three legs achieved 25m penetration after multiple punch-throughs and rapid leg penetrations. No leg damage occurred. The after action review highlighted these points:

The rig move team were provided with proper information and tools:

- Leg Penetration vs Leg Load prediction
- Stability program to provide leg load
- The capability to measure leg penetration progress

The rig was set up on location without endangering personnel or equipment. This was attributed to provision of a thorough geotechnical investigation, useful operational tools & proactive RPD countermeasures. These topics are explored further in /4/.

Example Rig Moves #2, 3, 4 & 5

Prior to rig move operations in 2016 in the UK CNS, (#5) offset data was reviewed for three adjacent locations, with particular emphasis of the experiences of the rig move teams:

The first location (#2) was within a mapped infilled channel where considerable variations in soil strength could occur. It is not clear if the challenges associated with this were understood by the rig move team as simultaneous (all leg) preload was performed. The very limited geotechnical investigations adjacent to the rig’s legs showed that each soil profile in the top 7m was different. This raised the question of how representative the revealed profiles were for each of the 18m-diameter spudcans. The different soil profiles also meant that there were soil boundaries of considerable slope under the rig’s legs. This introduces a risk of leg sliding or the sort of uneven spudcan loading that causes leg distortion. It was therefore not a surprise to find that RPD management had been an issue.

The second location (#3) had no such problem of soil profile variability and all three spudcans achieved penetrations of approximately 1m. The problem that emerged in the weeks that followed the preload operation was that of loss of trim and heel during drilling operations, this required normal operations to be suspended while the rig was re-levelled. The re-levelling was performed at the full working airgap with the cantilever extended and no further preloading operations were performed. It is not clear how the decisions to perform these operations (or not!) were reached.

Subsequent investigation of the second location showed the loss of trim & heel could be due to dilation and the development of negative pore pressure in a silt during preload giving a temporary strength that decayed as drainage occurred and the silt consolidated. These lessons were carried through to a third offset location where leg-by-leg preloading was performed over a period of 3.5 days. The rig move report says that the preload was performed at a 12ft air gap. If true, this seems to have been a hazardous decision.

The rig move report for this third location (#4) also contains some interesting statements;

- " .. on two occasions the load had to be dumped to level the barge because the inclination was at the maximum allowable limit of 0.3°.
- " On occasion the leg would settle after the pre-load had been dumped, not while under full pre-load".
- "Some legs required 6 cycles of pre-load."

The review of these three offset locations allowed the local soil characteristics to be understood and managed to the extent that the subsequent rig move (#5) was performed without incident.

Example Rig Move #6

This rig move was faced with a dilemma. At the previous site the rig had suffered a rapid leg penetration and sustained leg damage that had just been repaired. The leg penetration prediction for the new location, in 90m water depth, included a warning about a possible 5m punch-through during a 12m leg penetration. This was later assessed by others to be a 1m rapid leg penetration during a 5m leg penetration..

By using a corrected version of the DNV-GL Noble Denton rapid leg penetration (RLP) assessment method /5/, it was possible to assess the options of performing simultaneous (all-leg) or single (leg-by-leg) preload. This simplified method calculates the increase in leg load as the centre of gravity shifts due to a RLP. This increase in leg load is mitigated by hull buoyancy as the hull is immersed. The loss of trim, required before this buoyancy is "generated", is dependent on the airgap adopted at the start of the operation and the water depth.

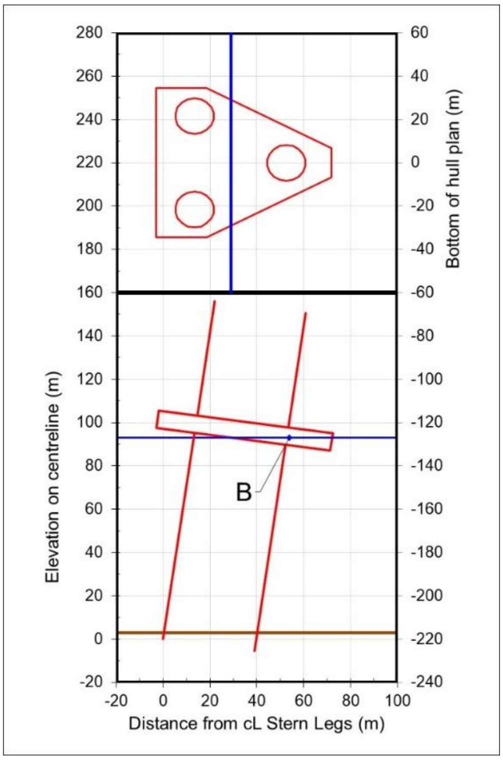

Figure 5 Location of centre of buoyancy due to a bow leg RLP with an 8° loss of trim
The location of the hull centre of gravity is dependent on amount & location of preload

The implications of choosing a particular air gap was evaluated and the result for an all-leg preload is shown in Figure 6. At this particular location a preload of 9,200tonne at the spudcan requires 8,000tonnes of load at the elevation of the pinions. To enable the elevating and holding system capacities to be included in the same plot as the spudcan loads this difference of 1,200tonnes has been added to the rated values in Figure 6 to give the “effective” system capacities that are plotted. Note that the real elevating system capacities will reduce as the amount of guide friction increases due to loss of trim/heel, so the jacking capacity lines will not be vertical. Note also that these 18-pinion leg capacities assume an equal distribution of individual pinion load, with no local overloading. In reality, some jacking systems will have individual pinions carrying considerably more than the average which is why the management of pinion overload alarms can demand the attention of the rig move team.

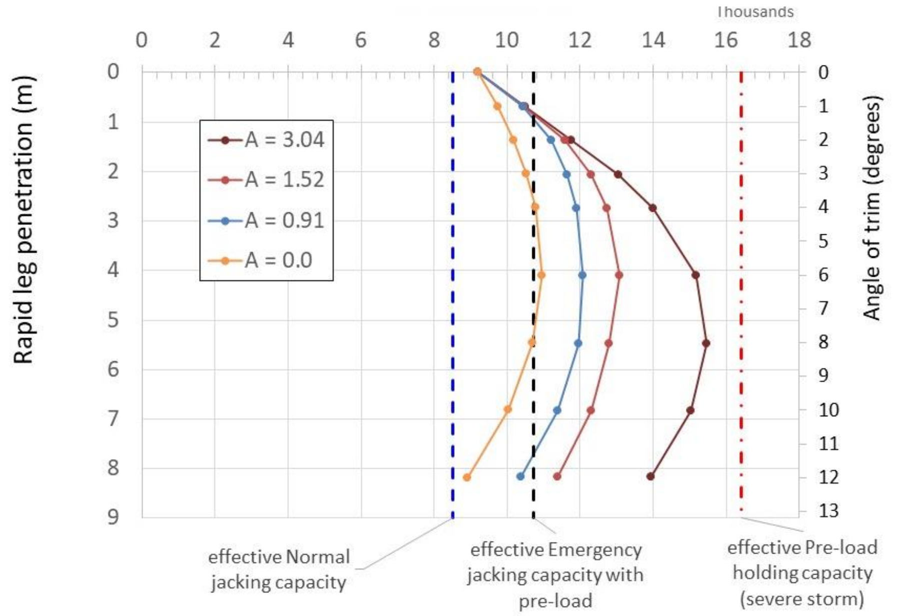

Figure 6 Maximum Leg Reaction during All-leg Preload (tonnes)
ILP = 3.05m, water depth = 90m

The simplified RPL method assumes a bow leg penetration with the rig rotating about the stern legs and that the stern leg spudcans have no moment capacity. For these simplified calculations, an initial leg penetration (ILP) of 3m was assumed. The airgap (A) was varied from 0m to 3m. The results for the all-leg preload assumption are presented in Figure 6.

Several issues emerge:

- The increase in leg load above the initial preload of 9,200tonnes is significant, even for small changes to the hull trim due to a rapid leg penetration of 1m or so.
- Small changes to the starting airgap (from 0m to 3m) have a major impact on the results.
- At full preload and assuming zero loss of trim, the Normal jacking capacity is exceeded. For airgaps of greater than 0.9m, any adjustments to correct for loss of trim of less than 1.5 degrees will need to be made using the Emergency jacking capacity. Beyond these angles of trim, the jacking system overload protection system should ignore any commands made at the jacking panel. Hence the need to dump preload before recovery operations can even be considered.
- If for any reason an airgap of 3m was adopted, the predicted 5m punch-through would bring the leg loads up to the sort of load levels that could overwhelm the holding capacity, with potentially disastrous consequences.

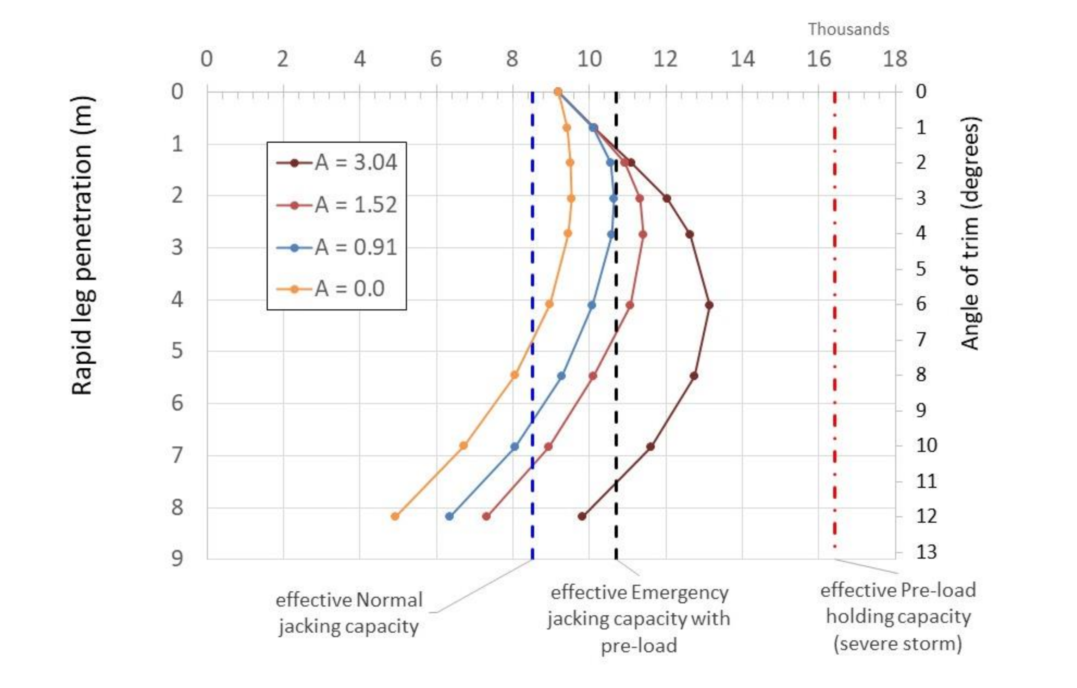

Figure 7 Maximum Leg Reaction during Single-leg Preload (tonnes)
ILP = 3.05m, water depth = 90m

The results for the single leg preload assumption are presented in Figure 7. The rig move team can now focus their attention on one leg at a time, and there are some key advantages:

- With a rig self-weight leg load of less than 6,000tonnes, corrective jacking (down) to recover the heel angle on the unloaded legs may be achieved within the Normal jacking capacity.
- The increase in leg load above the initial preload of 9,200tonnes is still significant, but considerably improved and stays well short of the holding capacity, even for a punch-through of 5m or more.
- For airgaps less than 0.9m, corrective jacking (up) to recover the heel angle is possible without exceeding the Emergency jacking capacity
- For airgaps greater than 0.9m, there is still the need to acknowledge the trim angle beyond which no further corrective jacking will be attempted, which for this simple model is approximately 1°.

Leg-by-leg preloading was adopted for this location. It was performed with the hull at approximately 4ft draft which meant that additional preload was taken onboard to counter the effects of hull buoyancy. Continuous hull draft and preload ballast tank status monitoring was used to ensure that the correct amount of preload was applied for the required duration. After some discussion, the target preload was reduced slightly to a level that was in harmony with the normal jacking capacity. It is important to realise that the decision to preload with the hull in the water, requires considerable care to ensure that the hull draft is maintained, so that the seawater ballast taken onboard to counter hull buoyancy does not cause the target pinion loads or the target preload levels to be exceeded. The preloading operation for this rig was completed without incident with all spudcans achieving approximately 5m penetration.

Example Rig Moves #7, 8 & 9

In preparation for a future operation in the UK CNS, offset data was reviewed for three adjacent locations:

A seabed bathymetry survey at the first location showed that spudcan penetrations made many years earlier were still visible as footprints. which suggested that sediment transport due to the combination of tidal currents and granular seabed soils was not an issue in this region of the UK Central North Sea.

For the second location the onshore rig move team relied on shallow (5m maximum depth) cone penetrometer tests (CPTs) from the site investigation to derive a predicted leg penetration range from 3.2 to 8.4m. The scope of this site investigation is inadequate for this leg penetration. These spudcan penetration analyses included rapid leg penetration events of between 2m and 7m. In addition to the punch-through risk during preload being identified, the potential for scour-induced storm load punch-through was also identified. The option of removing the sand layer by dredging prior to the rig arrival was discussed, but this was not done.

Given the predicted punch-through risk, using an airgap of 3ft to 5ft for all three legs would have been the cautious thing to do. However, it seems that once the rig had recorded a bow leg penetration of 4.6m without any leg run, the 10ft airgap being used was increased to 15ft for both the stern legs. Unfortunately, a rapid leg penetration, that exceeded the jacking capacity of the elevating system, was experienced on the port leg. This required the preload seawater ballast to be dumped so the rig could be elevated back to the preload airgap. For the starboard leg, some settlement did occur which was within the capacity of the jacking system. It is also noteworthy that the Towmaster for this rig move departed the rig before the preload operations were completed. This is a reminder that some Towmasters regard jacking operations as outside their remit so a job title of Rig Mover (for all phases of the rig move) is recommended as a basic requirement. The rig was on location over the winter months.

For the leg penetration analysis at the third location, the rig move team again relied on shallow CPTs. This time, the predicted leg penetration range for all legs was between 1m and 10m i.e. either partial embedment or a sizeable punch-through during preload. Note that again the scope of the site investigation was inadequate for this leg penetration. The actual recorded penetrations were approximately 7m & 1m for the Bow & Stern legs,. The potential for scour induced storm load punch-through of the stern legs was considered to be a real hazard, so tight control of the rig’s centre of gravity was recommended as an immediate mitigation measure. A subsequent scour assessment indicated that the scour hazard was real and recommended the immediate introduction of a perimeter of loose gravel around the two stern spudcans. Anecdotal information was that scour defensive measures were subsequently introduced. The rig was on location over the winter months without incident.

Key Data Requirements

Often, information about the nine rig moves reviewed in the previous section depended entirely on the limited information recorded in the daily operation reports (DORs). These are sometimes referred to as daily drilling reports (DDRs). These reports log a considerable amount of information, from personnel onboard to the status of consumable materials and are not suitable for capturing the range of data needed to track a preloading operation. The authors of some of these DDRs are not familiar with preload operations to the extent that the term 75% preload has two meanings; one of which is correct while the other ignores the fact that the rig’s self-weight has to be subtracted before the percentage of preload is reported.

The key data for a few of the rig moves reviewed in the previous section was contained in rig move reports (RMRs), but these sometimes revealed a lack of understanding of key variables involved in a leg preloading operation, or at least an unwillingness to track and document these variables. For a three-leg unit, several of the key variables are dependent which makes it easier to track the data and ensure data quality. For example, spudcan penetration, water depth, airgap (or hull draft) and leg mark for one leg are all related to the other legs by trim and heel angle. Incomplete or inconsistent data that is only discovered after the rig move can introduce a loss of confidence in the rig move report.

The rig move procedure, developed in advance of the rig move, should clarify what data the rig move team will be using, for example:

- Water depth at location; Lowest Astronomical Tide (LAT)
- Changes in tidal elevation above LAT predicted for duration of rig move
- Hull draft
- Individual leg loads at the elevation of the climbing pinions/rack chocks*
- Pinion alarm settings and alarm activations**
- Hull trim & heel angles
- Guide clearances
- Rack phase values and the subsequent Rack Phase Differences

* Individual leg loads at the elevation of the climbing pinions/rack chocks can be extracted from the rig stability booklet (supplemented by tank soundings), before, during and after preloading. These should be converted to spudcan loads and tabulated against continuously monitored spudcan penetrations.

** Pinion alarm settings and alarm activations will be tracked alongside the pinion loads

Prior to the rig move, it should be clear what hull levelling options are available as the preloading operation matures. For example, at 80% preload, hull elevating to correct a loss of trim may not be possible, so hull lowering may be the only option prior to dumping preload. Similarly the maximum loss of hull trim or heel, past which corrective jacking will not be attempted, should be documented.

The rig move procedure, developed in advance of the rig move, should also allocate the responsibility for recording, managing and sharing the key data. A significant amount of this data should be prepared in advance. If a "move the rig on paper" exercise is held prior to rig mobilisation, several different scenarios should be worked through. For example, what actions would be taken in the event that a high RPD was recorded and how would the data tracking be used to show that the right counter-measures had been taken?

Conclusions and Recommendations

Current rig incident data demonstrates that, for rigs moving onto location, foundation failures are the major causes of incidents. A sample, albeit limited, of a number of rig moves illustrates that sometimes there is insufficient understanding & management of the hazards associated with performing preloading operations.

The complexity of the operations required to move a jack-up should be recognised. Prior to the rig move key data should be identified and proactively managed, especially during preloading operations.

Onshore engineering ahead of the rig move should focus on making the leg load versus leg penetration prediction curves as accurate as possible. This should allow the rig move team to be prepared for the more challenging locations. The rig move team must also have the ability to identify unexpectedly problematic locations, and adjust their operations accordingly. The management and application of key preloading data should make this possible.

Acknowledgments

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Whilst the examples presented in the paper are intentionally unattributed, the Author acknowledges the depth and breadth of the technical discussions held with the rig owners.

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