

Application of RPD on Spudcan Sliding during Jack-up Installation near the Footprints

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ABSTRACT

Before well repairing operation, it is often necessary to install the jack-up very close to the existing spudcan pits, which called footprints. The spudcan is prone to slide towards the footprint in this process, which can lead to damage of legs, jacking system and the hull structure. RPD (Rack Phase Difference) system can monitor the rack vertical phase difference of adjacent chord of truss type leg. In this paper, the RPD calculation principle is studied and an available analysis method of critical RPD applicable to spudcan sliding condition is obtained. The method can provide useful guidance to the designers and operators.

KEY WORDS: jack-up platform; installation near the footprints; spudcan sliding; critical RPD.

1. INTRODUCTION

Jack-up drilling unit is the platform whose main hull can be elevated along the leg to the certain height above the sea for drilling operation. The Jack-up has been widely used in offshore oil and gas exploration. With the development of deep-sea oil and gas exploration, the working depth of the jack-up unit is constantly increasing and the structural safety has been paid more attention (Chen Hong, 2008). Before well repairing operation, the jack-up is usually installed near the fixed structure or wellhead. The seabed depressions which remain when a jack-up is removed from a location are referred to as 'footprints'. The difference in resistance between the original soil and the disturbed soil in the footprint area or the slope at the footprint perimeter, may cause the spudcans to slide towards the footprint. The resulting leg displacements could cause severe damage to the structure and, at worst, could lead to catastrophic failure (SNAME, 2007). The schematic drawing is shown in Fig.1. In May 2012, "Shengli 3" Jack-up skidded during the preloading operation in Yellow Sea and the platform structure was seriously damaged. Then the platform capsized, so as to cause serious operational accidents. In May 2009, in the course of preloading operation for "HYSY941" in the South China Sea, the bow leg sliding leads bow inclination of 6.2 degrees and large deformation of 4 diagonal braces and two internal horizontal braces. Therefore, before the jack-up preloads near the footprints, more detailed analysis must be executed and response measures should be prepared to avoid

the structural injury by spudcan sliding.

The traditional RPD monitoring system monitors the deformation of each chord of the legs. Once the deformation of the legs approach the critical value, the RPD system will alarm and the jacking operation of the hull must be stopped. Then the jacking system should be adjusted according to the operating rules to restore the hull to the horizontal position. At present, the advanced jack-ups are equipped with the RPD monitoring systems. For example, an overall basic design report for jack-up (Gusto MSC, 2007) shows that, the ultimate RPD of CJ46 jack-up designed by Gusto MSC is 58mm; the ultimate RPD of the JU-2000E jack-up designed by F&G Company is 203mm (Chen and Li, 2007); the BMC375 jack-up is also installed similar monitoring system. However, the traditional design method is only for the leg strength RPD analysis and does not involve the strength of the jacking system and the leg-well, which is not suitable for the special working condition of the side-sliding. So for the spudcan sliding condition, the comprehensively influencing factors should be considered.

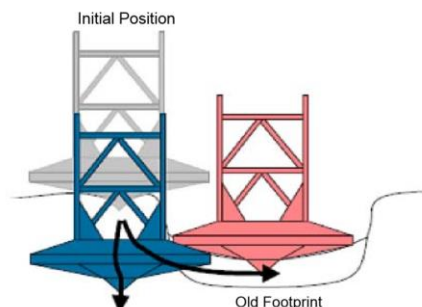


Fig.1 Installation Near the Footprint for Jack-up Unit (Qin and Wang ,2010)

In this paper, the RPD calculation principle is studied for the penetration on existing footprints and an available analysis method of critical RPD applicable to spudcan sliding is determined. The finite element method is used to simulate the sliding of the leg in different directions and at different distances to calculate the structural strength of the legs, jacking device and leg-well. Then the ultimate capacity of the platform is determined. Finally, using the iterative searching

vertical stiffness coefficient of the spring on single chord can be expressed as follows,

$$K_{Vjack} = \frac{1}{1/(n_p K_{Vpinion}) + 1/K_{Vjackhouse}} \quad (5)$$

Where,

n_p is the number of lifting pinions on each chord;

$K_{Vpinion}$ is vertical stiffness coefficient for single pinion, which can be given in the jacking system product manual;

$K_{Vjackhouse}$ is vertical stiffness coefficient for single jacking box, which can be calculated by the specific structure construction.

d) The Connection of Leg and Upper /Lower Guide

Usually, there is a certain assembly gap between chord rack and upper /lower guide. For the accurate simulation of the free RPD due to the gap between the chord and the upper /lower guide, non-linear spring element is used to simulate the connection in the finite element analysis. The element shown in Fig.3 has an initial gap δ_0 and only can withstand axial pressure after the contact.

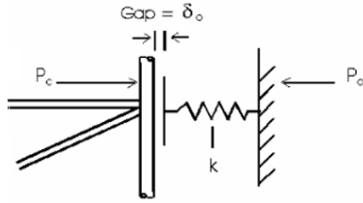


Fig.3 The Schematic Drawing of Non-linear Spring Element (SNAME, 2007)

e) Boundary Condition

On account of the soil is compacted continually by Spudcan during preloading condition, it is difficult to determine the accurate soil stiffness. If considering horizontal soil stiffness, it can make the allowable sliding distance increases. Instead, if considering rotational soil stiffness, it can make the allowable sliding distance decreases. So by the sensitivity analysis, there is little difference between pinned constraint and spring constraint considering horizontal stiffness and rotational stiffness at the same time. So the pinned constraint can be used on the motionless Spudcan, and the enforced displacement at the centroid of the side-slip Spudcan is applied as the sliding load.

3.2. Loads

The loads during jack-up installation near the footprints include weight load, environment load and sliding load.

a) The weight loads include dead load, variable load and ballast water weight.

b) Environment loads during preloading operation include the loads induced by wind, wave, current and P-Delta effect. The specific methods of environment loads are detailed in rules for classification of mobile offshore units (CCS, 2016).

c) The sliding load is the unfavorable load caused by large deformation of legs and platform. An enforced displacement at the centroid of the side-slip Spudcan can be simulated as sliding load.

About the loading direction, it is important to emphasize that the influence of different sliding direction for the structure need to be considered. According to the principle of the structural damage to be aggravating, the environment load is applied on the opposite direction of Spudcan sliding. So the calculation results are conservative. The relationship between Spudcan sliding direction and environment load

direction is shown in Fig.4

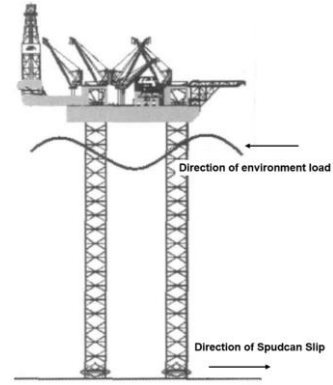


Fig.4 The relationship between Spudcan sliding direction and environment load direction

3.3. Critical Sliding Capacity

The critical sliding capacity for jack-up unit is the maximum distance to keep the leg structure, the jacking system and lower guide structure away from damage. It can be determined in accordance with the formula below,

$$UC_{max} = \max(UC_L, UC_H, UC_J) \approx 1 \quad (6)$$

UC_L and UC_J can be calculated according to the simple model; UC_H can be obtained by the detailed local model analysis. Relevant classification standards can be used for the strength check, such as rules of CCS (CCS, 2016), ABS (ABS, 2014) and so on. To increase the sliding distance constantly, until the UC_{max} approach 1.0. At this point, the sliding distance is the ultimate sliding distance of the platform.

4. CASE STUDY

4.1. Calculation Model

A traditional jack-up platform with cantilever, triangular box-shaped hull and three truss legs is selected for calculation example. The operation water depth is 400ft. Each leg has three split tube chords. Jacking systems are used for elevating and lowering the hull and each chord is equipped with four jacking pinions. Each leg equips a circular Spudcan at the bottom of the leg. According to the requirements in the last section, a simplified model of example unit and a detailed local model of the hull structure are established, which are shown in Fig. 5 and Fig. 6.

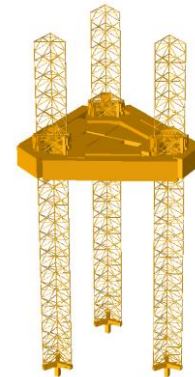


Fig.5 The Simplified Model of Example Platform

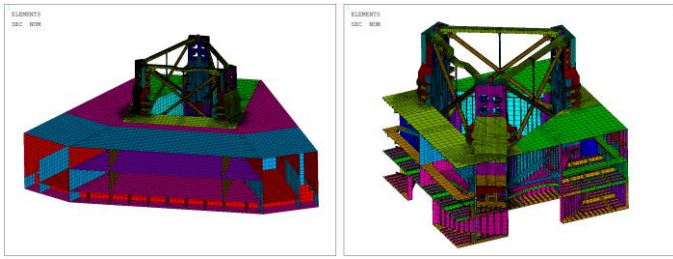


Fig.6 The Detailed Model of the Hull Structure

4.2. Main Parameters

The environment conditions and main parameters of the example platform are shown in Table 1.

Table 1. Main parameters of Jack-up Platform

Preloading Condition	Value
Water Depth (m)	90
Maximum Wave Height (m)	1.83
Wave Period (s)	3
Maximum Wind Velocity (m/s)	10.8
Current(m/s) Surface	1.02
Current(m/s) Bottom	0
Preload Reaction (t)	10770
Holding capacity for single pinion (t)	970
Holding capacity for single chord (t)	3880
Weight of per Leg (t)	1659
Gap(mm)	20

4.3. Analysis for Spudcan Sliding

Firstly, we search the critical sliding capacity UC_{max} of the platform. On different directions, we increase the sliding distance constantly, until the UC_{max} approach 1.0. The UC_{max} value and sliding distance of bow and starboard Spudcan are shown in Fig.7 and Fig.8.

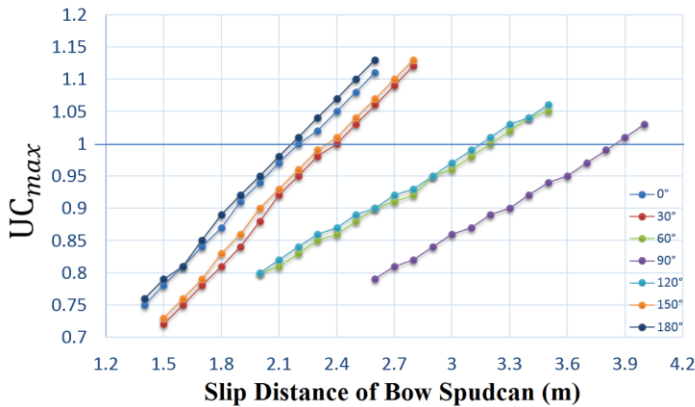


Fig.7 UC_{max} and sliding distance of bow Spudcan

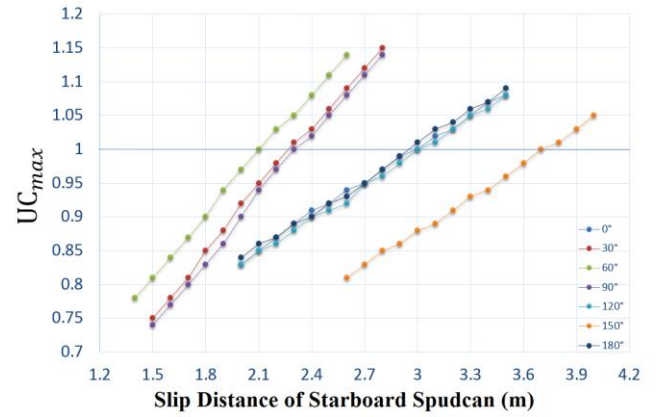


Fig.8 UC_{max} and sliding distance of starboard Spudcan

The results show, on single leg preloading condition, if the pressed spudcan slide towards the footprint, the general trend is that the lifting pinions overload firstly, then the brace of leg structure overload and finally the lower guide structure overload. It is related to the platform design concept. The UC_L , UC_H and UC_J of bow leg sliding condition are shown in Table 2 for instance.

Table 2. The UC values of bow leg sliding condition

Sliding Direction	0°	30°	60°	90°
Sliding Distance (m)	2.1	2.3	3.1	3.8
UC_J	0.97	0.98	0.97	0.99
UC_L	0.91	0.92	0.95	0.97
UC_H	0.89	0.92	0.93	0.96

The critical slip distance of bow leg is minimum for 0° direction case and maximum for 90° direction case. And the critical slip distance of starboard leg is minimum for 60° direction case and maximum for 150° direction case. The deformation drawing of platform in bow leg 0°, 90° direction case and starboard leg 60° direction case are shown in Fig.9, Fig.10 and Fig.11.

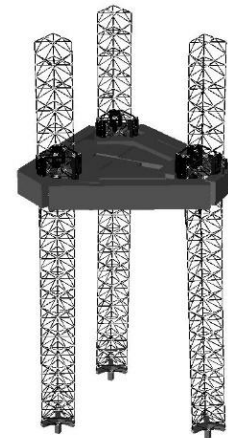


Fig.9 The Platform Deformation Drawing in Bow Leg 0° Direction Case

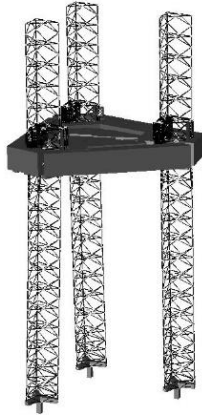


Fig.10 The Platform Deformation Drawing in Bow Leg 90° Direction Case

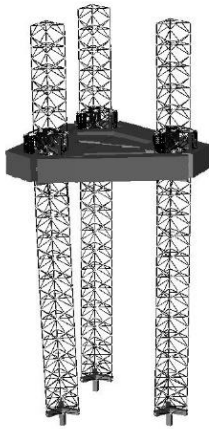


Fig.11 The Platform Deformation Drawing in Starboard Leg 60° Direction Case

Take the bow leg for example, the maximum sliding distance is 3.8m in 90° direction case. In this case, the maximum UC_H is 0.96, which appears on lower guide structure. The vomis stress of lower guide in this case is shown in Fig.12.

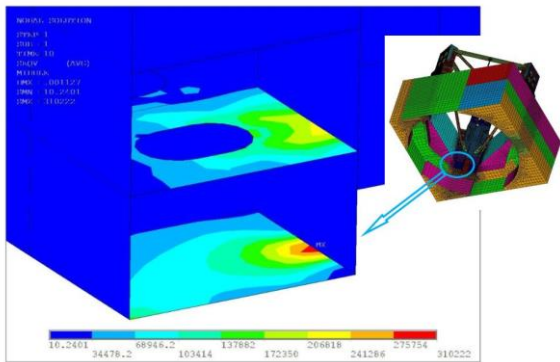


Fig.12 The vomis stress of lower guide in 90° direction case of bow leg

The research shows that the allowable sliding distances for different legs in different directions are all different. The envelope curve chart of critical sliding distance for bow and starboard leg are shown in Fig.13,

Fig.14, which can provide theoretical guidance for jack-up installation near the footprints.

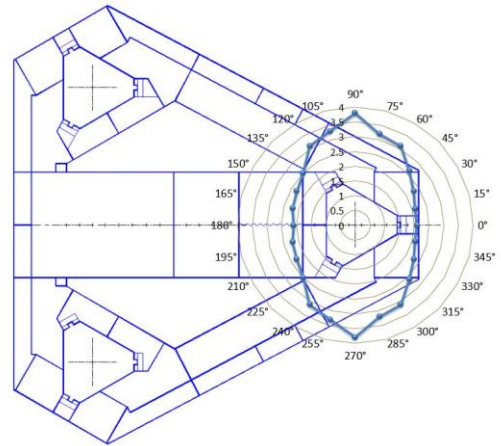


Fig.13 Envelope Curve Chart of Critical Sliding Distance for Bow Leg

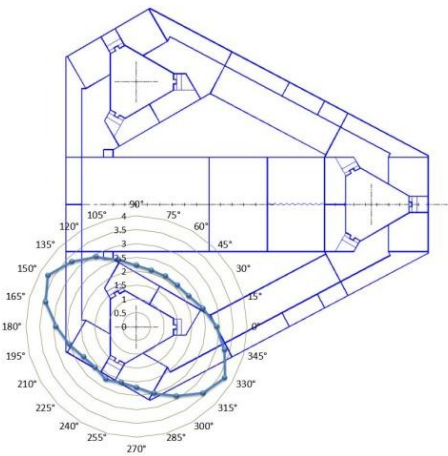


Fig.14 Envelope Curve Chart of Critical Sliding Distance for Starboard Leg

The relationship between sliding distance and RPD is shown in Fig.15. The leg of example platform is triangular truss form. According to the symmetry of the leg and jacking frame, 0° , 30° , 60° direction cases are calculated. The other directions can be obtained according to the asymmetry.

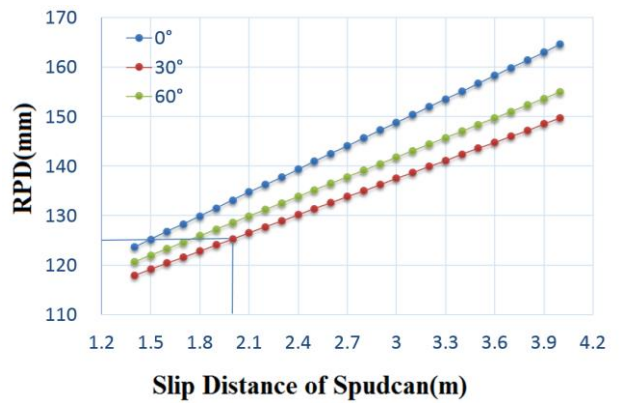


Fig.15 The Relationship Between Sliding Distance and RPD

For conservative consideration, take the minimum sliding distance for all directions as the alarm value of the RPD monitoring system. According to the above calculation results, the critical RPD can be found out, which is 127mm for bow leg, and 125mm for stern leg.

4.4. Discussion and suggestion

a) The maximum lateral sliding distance of the bow leg is slightly larger than the stern leg, which is related to the different construction between bow and stern structures and the different leg spacing distance.

b) For spudcan sliding, the minimum or maximum ultimate sliding distance in different directions inevitably produces the maximum or minimum RPD value. This conforms to the trends that the larger the sliding distance, the greater the adverse effect on the structure and the greater the structural deformation;

c) For bow leg, the maximum ultimate sliding distance and the maximum RPD value appear in the 90 or 270 degree sliding direction with minimum ultimate sliding distance and the minimum RPD value appearing in the 0 or 180 degree sliding direction; For rear legs, the maximum ultimate sliding distance and the maximum RPD value appear in the 150 or 330 degree sliding direction with minimum ultimate sliding distance and the minimum RPD value appearing in the 60 or 240 degree sliding direction.

d) From the UC calculated above for different structures, the general trend is that the lifting pinions firstly overload, then the leg structure overload and finally the lower guide structure and leg-well structure overload, which is related to the platform design concept and basically conforms to the actual side-slip structure damage situation.

e) In the actual preloading operation, it is difficult to determine the specific sliding distance on the platform. Therefore, the safety of the platform structure should be determined by the alarm of the RPD monitoring system. Moreover, it is very difficult to judge the specific sliding direction. So based on conservative consideration, the minimum ultimate RPD value in different directions of the leg sliding is taken as the alarm value of the RPD monitoring system. Therefore, for the example platform, the allowable limit RPD value of the spudcan sliding is 127mm for bow leg, and 125mm for stern leg.

5. CONCLUSION

Spudcan sliding during installing in footprint is an important operational risk encountered under preloading condition for self-elevating unit. To ensure safety, it is generally necessary to analyze the side-slip risk and formulate countermeasures before operation. In this paper, the RPD calculation principle of "step on footprint" of self-elevating platform is studied for the first time, and the RPD calculation method is proposed suited to the spudcan sliding which has some guidance on reducing the structure damage risk for jack-up "step on footprint". However, due to the complexity of the seabed conditions and the uncertainty of the actual operation, the theoretical analysis method still needs further improvement and perfection in the actual engineering verification.

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