Reviews on mitigation techniques of offshore jack up hazard by FEM analysis

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Abstract: It is very well observed that offshore sites mostly contains soft/loose soils may be of sand or clay or may be multiple layer of soil mixture under saturated condition. This particular soil undergoes large deformation on the installation of any offshore structure like jack up. It is also observed that jack up may tilt or sink under its own weight without any lateral load or hydrodynamic pressure or any natural hazard like liquefactionor hurricane. It may undergo punching shear failure due presence of soft soil. It may suffer failure due to jack up leg and foundation element connection failure. It gets affected by rotational stiffness, foundation fixity parameters.To overcome this situation, several techniques had been proposed by various researchers. Spud can, Anchors, Mud mat, Bucket foundation, Suction Caisson foundation etc are used to overcome such difficulties. These techniques of mitigation subsequently affect bearing capacity failure zones of soil. Sinking and tilting effects are due to overlapping of bearing capacity failure zones. Hence by advancing changing in shape and spacing of jack up legs, sinking and tilting effects can be considerably reduced. In particular research paper an attempt has been made to investigate the effects of various mitigation techniques by previous researchers. All field and laboratory studies along with soft computing with FEM based software had been discussed. Considerable researchers had shown that provision of mud mat in jack up bottom increases stability of jack up structure. To visualize the various effects FEM based PLAXIS 3D program had also been used.

Keywords: Jack Up Foundation, PLAXIS 3D for Jack Up Leg Analysis, Bearing Capacity Failure

1.0 Introduction

Jack up Foundation Elements subjected to Vertical axial loads, Moments and Lateral wave loads in the offshore regions creates vital stability issues. The particular offshore structures are mainly subjected to following kinds of failures. A.) Subjected to Overturning Moment and leads to overturn. B.) Punch through failures i.e. immediate bearing capacity failure or overlapping of failure zones. C.) Jack up foundation element Sinking & Tilting. How one can overcome these issues. The particular research paper reviews various techniques and methodologies for mitigating this kind of offshore geohazard. The research paper also highlights the recent trends and current practices, the old age techniques and their likely improvement with the time and lastly also discusses what the future holds in innovation in this area. Research paper highlights the improvement in resisting penetration of offshore jack up structure by suitable input parameters in FEM analysis.

2.0 Problem statement using plaxis 3D

Here to get the clear idea of the problem faced by Oil & Gas Industries, Author had modeled Jack up Foundation (Jack up deck and 4 Nos. of Jack up Legs connected on periphery of deck plate) using conventional assumptions of Finite Element Method which is embedded in Offshore Cohesive soil using FEM based software PLAXIS 3D. Results of the same are represented in the Figure. 2.

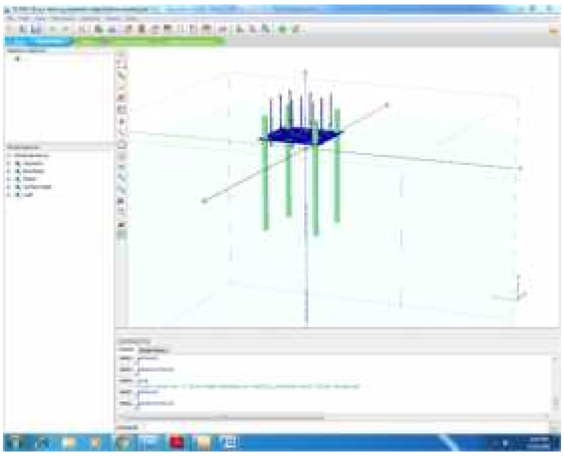

Fig.1 Jack up and 4 nos. of legs Embedded in KaolinClay modelled in Plaxis 3D

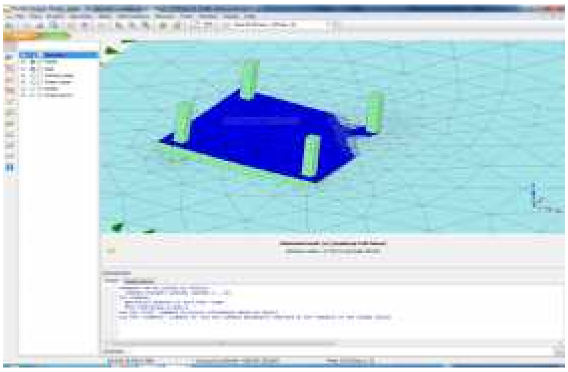

Fig.2 Sinking and Tilting Behavior as Observed inPlaxis 3Dfor jack up leg

3.0 Various Mitigation Practices

3.1.) Mat-Supported Jack-Up Foundation

Ralph Scales (1976)had worked in similar concepts. The findings of the scales have been reproduced here in terms of advantage of mat foundation to jack up.

A mat supported rig with bottom bearings founds to be very well suited for all types of environmental conditions. These types of Rigs had performed very well under the event of hurricane also on extremely weak soils like Mississippi river delta area.
One more interesting advantage of jack up supported mat is it works as active damper in the entire system. Lowering of the mat at the particular site location allows the jack up deck to be jacked up out of the water very quickly. The lowered mat which is leveled to the sea bed top acts as damper which gradually eliminates wave induced rig heave and therefore impacting or pounding on the bottom. This characteristic permits the jack up to move to more severe and harsh wave condition in comparison with other types of Jack up.

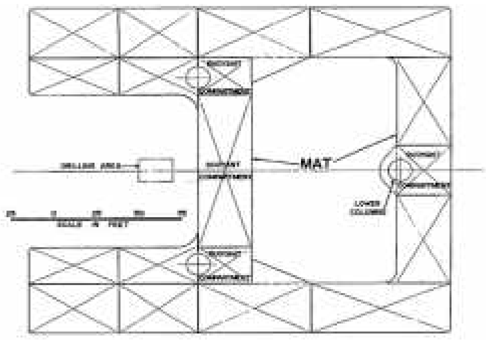

Fig. 3 Mat Foundation for Jack up in plan for Ralph Scales. (1976)

3.2) Mat-Supported Jack-Up Foundation with Skirt

W.P.Stewart(2007) has done extensive work in bearing capacity analysis and percentage increase in resisting overturning moment of jack up rig maleo producer which is supported by large cut out mats as shown in the figure.3 and figure.4. Here Study has been carried out in soft clays on level sea bed. Mud mat rigs will penetrate into the sea bed until a depth where the soil bearing capacity is just sufficient to support the weight of the structureless itsbuoyancy weight. Particular Mat penetratesin clay slowly. Jack up structure not penetrating evenly. Jack up uneven penetration causes the structure to tilt back and forth and the bearing pressures to increase and decrease from one side of the mat to the other which are difficult to assess.

W. P. Stewart has made Comparison of bearing capacity by taking initial bearing capacity of soil calculated by local soil investigation. Particular bearing capacity is considered as basic bearing pressure before placement and lowering the mat support to seabed. And then after lowering the mat supported jack up at the site the bearing pressure indicates rise of 50% to 66% compared to basic value. This is tabulated as follows. Here one can also visualize the effect of skirt – Confinement of soil beneath skirt plate gives rise in bearing capacity by around 16%.

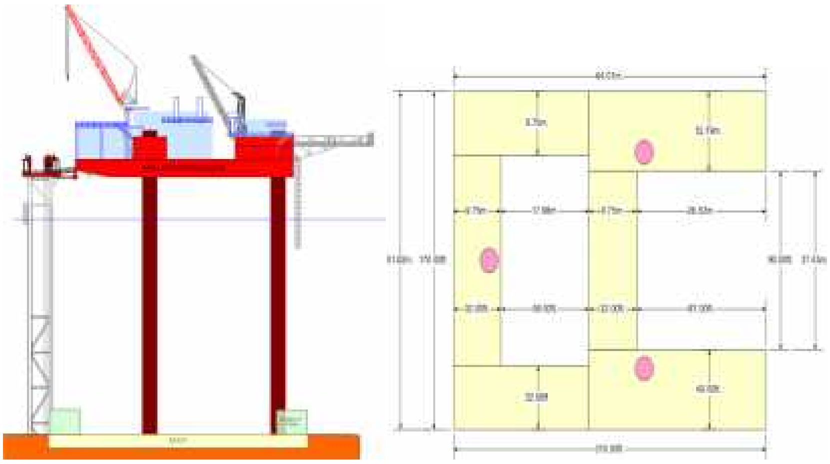

Fig. 4 Jack up Rig with Mat foundation with skirt.

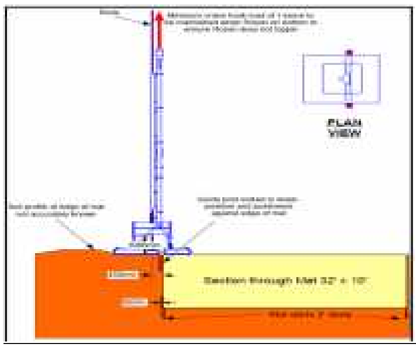

Fig. 5 Mat Foundation in side elevation with clear view of skirts penetration (2'Deep) in surrounding soil.

Table.1Comparison of Bearing Capacity Results

Condition	q_{ult} kpa	q_{ult} Ratio
Avg. Max. Bearing Pressure at Pre load	29	Basic
Bearing Pressure at mat bottom using avg. Cu	34	18 %
As Above with Overburden Pressure	43	50 %
As Above with O.B. + Full Skirt Effect	48	66 %

W.P. Stewart had also attempted calculation of Mat overturning resistance. The Mat supported rig mostly prone to overturn by mechanism of deep seated slip circle failure or bearing capacity failure as local failure to be started at the edges of the mat.

Mat overturning resistance has been calculated by assuming strip foundation method for the mat cut outs. The Strip foundation method proves to be better in comparison of the slip circle of method of soil. In this method simple single force acting vertically in the center of each cut out strips. The overturning resistance is taken as the sum of each force multiplied by its horizontal distance or lever arm, from assumed horizontal axis of rotation. The moment calculated from the axis of rotation may add or subtract to the overturning moment caused by environmental loading. This is generally combination of wind, wave and current forces and their vertical distances above the assumed horizontal axis of rotation. Factor of safety against overturning or OTSF is defined as

OTSF = (SRmoment-Wmoment)/OTmoment , Where,
SR moment= soil ultimate capacity resisting moment
W moment= (Weight –Buoyancy) Moment
OT moment= over turning moment from environmental forces

Results are tabulated in Table.2 regarding benefit of providing mat foundation to jack up structure.

Table.2 Comparison of OTSF Results

Condition	q_{ult}kpa	OTSF	OTSF Ratio
Avg. Max. Bearing Pressure at Pre load	29	1.70	Basic
Bearing Pressure at mat bottom using avg. Cu	34	2.24	32 %
As Above with Overburden Pressure	43	3.23	90 %
As Above with O.B. + Full Skirt	48	3.72	119%

3.3) Spud Cans to the legs as Foundation Element

Eric J. Parker, Francesco Mirabelli& Lorenzo Paoletti from Italy had studied the concept of predicting jack up leg penetration from the conventional mathematical expressions. They compared predicted and observed Jack up spud can leg penetrations in their research for 15 offshore sites. Although soft formulation for the same approach had not been mentioned in the research paper. They had attempted to give bearing capacity formulas for spud can by making changes into conventional bearing capacity equations for various soil layers as well as in multiple soil layers.

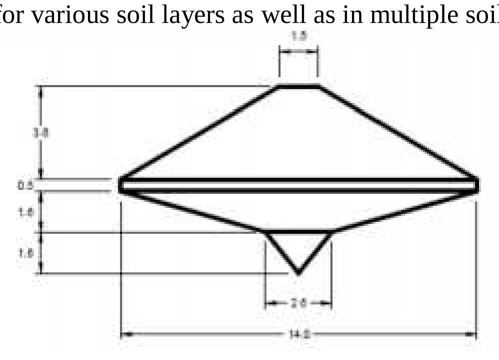

Fig.6 Spud Can geometry in Vertical Section.

Some of the major Conclusions of Eric & team can be mentioned here as follows.

In general jack-up leg penetration can be well predicted by simple bearing capacity equations. Practical Spud can penetration in sands usually stops when the maximum section comes to bear on the sand layer.

Leg penetrations can be large in normally consolidated clays. Penetration stops either at the base of Holocene Wedge or on silty / sandy interbedds. Predictions are most difficult in interbedded profiles, with the most critical cases being the presence of thin silty layers in soft layers For purposes, the greatest risk of punch throughis found in the Holocene wedge area.

Eric Parker and Team have given various bearing capacity formula for different soil layer condition. This is not mentioned here. To visualize the advantage of the spud can, one can use normal bearing capacity equation and modified bearing capacity equation given in the particular research paper.

3.4) Spud Cans with buoyancy modules to the legs as Foundation Element

An earlier solution by various researchers has been carried out to increase bearing capacity and increasing stability. Spud can with buoyancy modules are suggested byZhao TianfengaandSunChengmeng by considering problems associated with the retrieval operations of Jack up spud can legs. Most of the cases in spud can embedded legs it is found that retrieving requires very heavy uplift pressure to remove spud cans which are embedded in intermediate layers of soil. Hence to overcome these problem spud cans with buoyancy modules has been suggested.
It is proposed to remove the soil resting on the upper surface of the spudcan and thus reduce the pull-out resistance during the extraction process after drilling. The new spudcan has three pontoons, eachcomposed of three prismatic ballast cabins equipped withmud-filtering devices, jetting nozzles, jetting lines and gas injection lines. By injecting compressed air, the cabins can discharge ballast water through the mud-filtering devices on the pontoons, which act as drainage channels. Several mud fenders are positioned on the outside surfaces of the pontoon to protect the jetting nozzles, which are the outlets of the jetting lines inside the pontoon. Periodic jettingcan be carried out to avoid soil consolidation near the leg. In comparison with existing spudcans, the buoyancy spudcans occupy the cavity space and reduce the amount of soil above the spudcan to gain a significant reduction in pull-out resistance. After the ballast water is discharged, buoyancy forces can also be acquired from empty pontoons to help leg extraction.

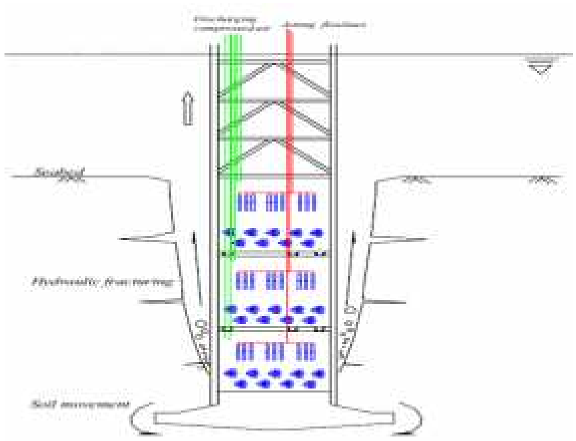

Fig 7 Spud Can geometry in Vertical Section with buoyancy module

3.5) Skirted spud Cans

L. Kellezi, O. Koreta and S. S. Sundararajan has performed research on various geometry of skirted spud cans and found that skirted spud can is helpful in providing resistance to penetration and also helps in developing resistance against rotation for the combined VMH loading. It helps in resisting punching shear by providing confinement beneath the geometry inside seabed.

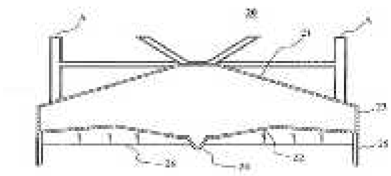

Fig 8 Skirted Spudcan Geometry

4.0 Analytical Methodology

For the purpose of working out most practical and efficient foundation element following procedure is adopted. Author had studied the load penetration studies by taking jack up structure as intake and varying different foundation element with same pinned connection and rotational stiffness. Here FEM analysis had been carried out using jack up weight including foundation element. Here spudcan, skirt plate, mat foundation and oversize mat foundation has been checked with same jack up structure. All foundation elements are taken are of the same geometrical variance. Quantity of material consumption in different foundation element is maintained as constant to the extent possible to achieve economical option. Plaxis 3D FEM tool is used in analysis. Most of FEM elements are considered as planar 6 node plate elements for steel components and 10 node volume elements for soil volume.

Table.3 Offshore Cohesive Soil Properties used in Current FEM Analysis

Soil Properties	Value
Modulus of Elasticity of Soil, E	5000 kN/m^2
Undrained Shear Strength of Soil, Su	10 kN/m^2

4.0 Analytical Results

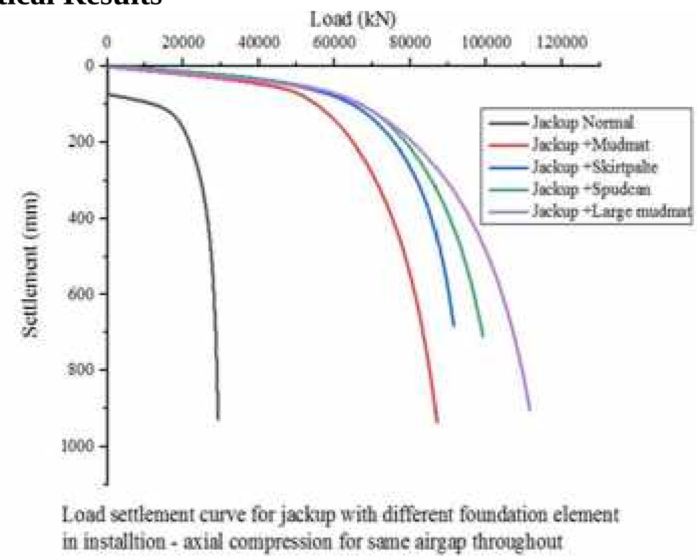

Fig. 9 Load settlement curves for jack up with foundation element in compression

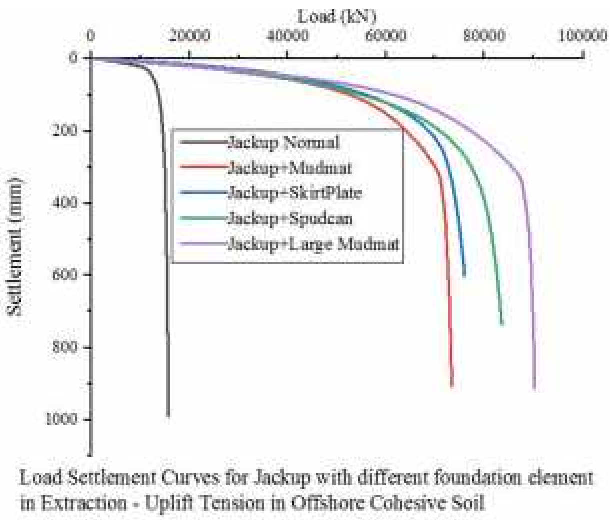

Fig 10Load settlement curves for jack up with foundation element in tension

5.0 Plaxis 3D Result for different foundation element showing penetration under static condition of loading in offshore cohesive soil

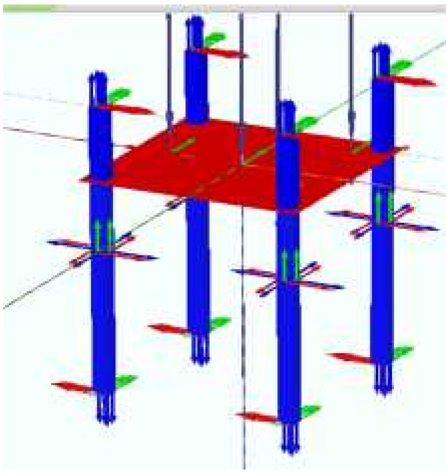

Fig 11 Normal Jackup in operation

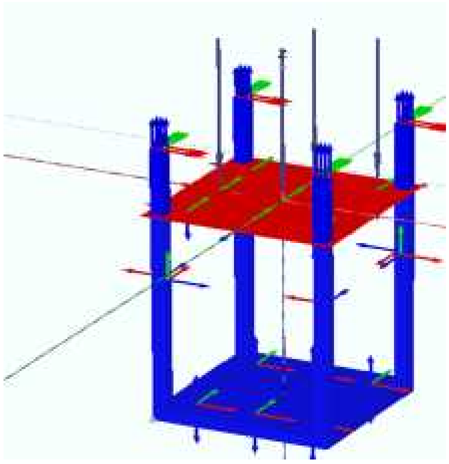

Fig 12 Jackup with Mat

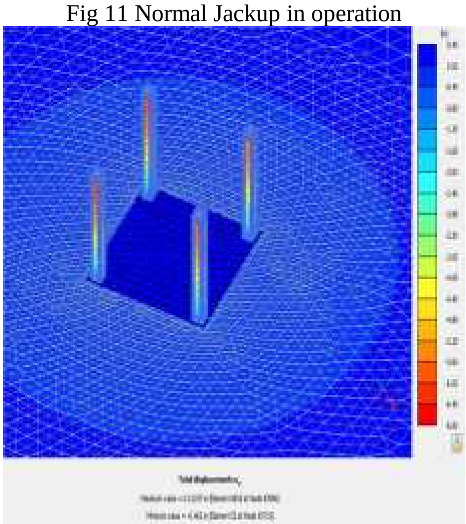

Fig 13 Jackup penetration of 6.8 m

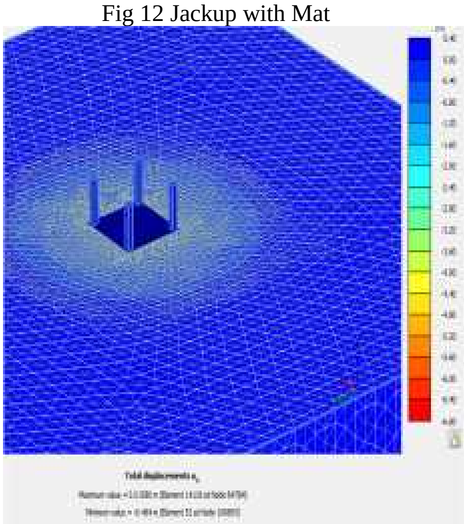

Fig 14 Jackupskirtplate penetration of 6.7m

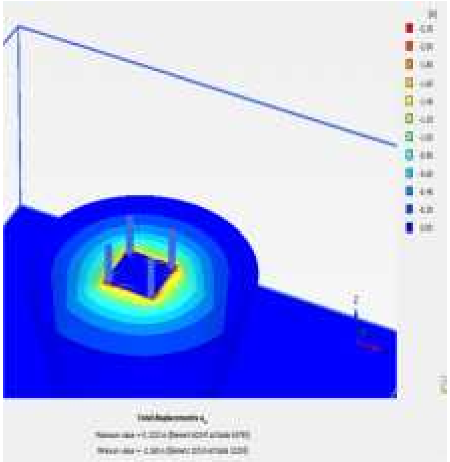

Fig 15 Jackupspudcan penetration of 6.4 m

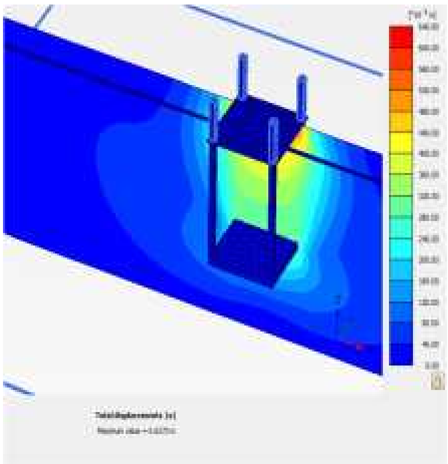

Fig 16 Jackupmudmat penetration of 6.5 m

6. Conclusion and Future Prospects

A. Figure 9 Shows load penetration curves with different foundation element in axial compression i.e. during installation. It indicates under normal condition jack up penetrates will be faster due lesser initial shear strength of soil. Once it is associated with foundation element it resists penetration subsequently depending on the geometry of foundation element and confinement provided beneath foundation element in seabed. The sequence of effectiveness of different foundation element is described in representative figure. Axial compression helps in estimation of pre load capacity during installation. Once pre load capacity is known then punching shear should be easily avoided. Similarly Fig 10 shows jack up with different foundation element in uplift tension which helps in estimation of extraction forces. Fig 9 and Fig10 is important in developing monogram for specific jack up structure with different foundation element of equivalent dimensions. It helps in its lifecycle operations to avoid offshore hazard by correct estimation of installation and extraction forces. Fig 13, 14, 15, 16 subsequently shows penetration records as derived from plaxis 3D for specific nodesin axial compression for different foundation elements as described in representative notations for the figure.Figure.9 and 10 are most important for identical jack up structure in use for its hazard free life cycle operation and also in increasing its durability.

B. Here in particular research papers submitted by various researchers about Mat Supported Jack up, eventually researchers has found that Mat acts as damper to the system but no analytical work/ soft computing work has been done to visualize the same effect. Dynamic analysis of mat supported jack up legs embedded in soil will fetch interesting results.

C. More Geometrical variations of Jack up leg foundation element shapes & geometry can be studied which confines the soil during penetration or installation of jack up will also help in mitigating offshore geohazard.

D. More Variations in spacing of Jack up legs in interaction with soil and geometrical changes in shape of Jack up leg also give fruitful results.

E. As Jack up Structures is bottom based floating structure, the maintenance of air gap the clear height between the bottom of the deck plate of the jack up and top of the seabed should also not in transition zone of the waves to avoid any Geohazard. Placement of the hull is important aspect in avoiding hazard. Impacts of air gap during various operations of jack up structures should also be studied.

F. Generally offshore installations alike jack up study should be carried out in station mode in shallow to deeper water where stability becomes a time dependent phenomenon. A lapse of time in maintaining the jack up pressure on all legs (as applicable) may govern the conditions of stability studies.

7.Acknowledgements

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8. References

1. Guidance Notes on Geotechnical Performance of Spud Can Foundations January 2019 American Bureau of Shipping (ABS).
2. Abdalla, B., Wang, F.S. and Hossain, M.K., 2013, June. “FEA-Based Stability Analysis of Mud mats: Coupled Soil-Structure-Flow line Interaction Model”. In *ASME 2013 32nd International Conference on Ocean, Offshore and Arctic Engineering* (pp. V006T10A032-V006T10A032). American Society of Mechanical Engineers.
3. Abyaneh, S., Kennedy, A. andJ., Maconochie Oliphant, J., 2018, July. “Capacity of Strip Foundations on Sand Overlying Clay Soils under Planar Combined Loading.” In *The 28th International Ocean and Polar Engineering Conference*. International Society of Offshore and Polar Engineers.
4. American Petroleum Institute (API) Codes –RP2 Geo , RP 2A - Latest Edition
5. Amin Rismanchian and Nick Ramsay “Fugro Presentation – Drained or Undrained” with collaboration of Prof. David White & Dr. Fraser Bransby.
6. Azadi, M.R.E., 2012. “The effect of possible spud-can punches through on the reliability index of Neka drilling type jack-up platform”. *Journal of Civil Engineering Science*, *1*, pp.80-89.
7. Ballard, J.C. and Charue, N., 2013. “Influences of jack-up footprints on mud

mat stability–How beneficial are 3D effects.” *Proc. 18th ICSMGE*.
8. Bienen, B. and Cassidy, M.J., 2013. “Set up and resulting punch-through risk of jack-up spud cans during installation. *Journal of Geotechnical and Geoenvironmental Engineering”*, *139*(12), pp.2048-2059.
9. Bransby, M.F., Hudacsek, P., Knappett, J.A., Brown, M.J., Morgan, N., Cathie, D.N., Egborge, R., Maconochie, A., Yun, G.J., Brown, N. and Ripley, A., 2010. “The vertical bearing capacity of grillage foundations in sand.” *Proceedings of ISFOG II, Perth*, pp.409-414.
10. Brasted, L.K. and Piter, E.S., Shell offshore Inc. 1988. “Mud mat design (No. US 4720214).”
11. Brinkgreve, R., Burg, M., Lim, L.J. and Andreykiv, A., 2017. “On the practical use of the Material Point Method for offshore geotechnical applications.” *Proceedings of the 19th ICSMGE*.
12. Rohani, M.J., Sha'ari, F.A., Rahman, A.A., Ismail, W.M., Chan, N. and Tho, K.K., 2016, March. Improving Jack-Up Rig Spudcan Penetration Predictions in Malaysian Waters. In *Offshore Technology Conference Asia*. Offshore Technology Conference.
13. Stewart, W.P., 2007. “Mat-supported jack-up foundation on soft clay—overturning storm stability.” *The Jack-Up Platform—September 11th and 12th*.
14. Suroor, H. and Dong, G., 2017, July. “Time-History Seismic Design of Integrated Subsea Pipeline System”. In *The 27th International Ocean and Polar Engineering Conference*. International Society of Offshore and Polar Engineers.
15. Svanø, G. and Tjelta, T.I., 1996. “Skirted spud-cans—extending operational depth and improving performance.” *Marine structures*, *9*(1), pp.129-148.
16. Teh, K.L., Leung, C.F., Chow, Y.K. and Handidjaja, P., 2009, January. “Prediction of punch-through for spudcan penetration in sand overlying clay.” In *Offshore Technology Conference*. Offshore Technology Conference.
17. Tho, K.K., Leung, C.F., Chow, Y.K. and Swaddiwudhipong, S., 2010. “Eulerian finite-element technique for analysis of jack-up spud can penetration.” *International journal of geomechanics*, *12*(1), pp.64-73.
18. Vlahos, G., Cassidy, M.J. and Martin, C.M., 2008. “Experimental investigation of the system behavior of a model three-legged jack-up on clay.” *Applied Ocean Research*, *30*(4), pp.323-337.
19. Zhang, Y., Wang, D., Cassidy, M.J. and Bienen, B., 2014. “Effect of installation on the bearing capacity of a spud can under combined loading in soft clay”. *Journal of Geotechnical and Geoenvironmental Engineering*, *140*(7), p.04014029.
20. Zhao, T. and Sun, C., 2014. “A new spud can with buoyancy modules for mobile jack-up rigs.” *Applied Ocean Research*, *47*, pp.154-162

21. Parker, Eric J., Francesco Mirabella, and Lorenzo Paoletti. "Case Histories Paper: Jack up Rig Spud Can Penetration: A 6,000 Ton Load Test." (2008). Italy
22. Scales RE. A deep water mat-supported jack-up drilling unit with tubular

telescoping columns and intermediate column frame. In Offshore Technology Conference 1976 Jan 1. Offshore Technology Conference. (OTC2504)