Effect of Deployment of Jack-up on Piles and Structure of Existing Offshore Platform – A Case Study

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Abstract. Jack-up rigs are mobile offshore platforms deployed mostly to carry out drilling and work-over activities related to exploration and production of oil and gas. For activities related to production of hydrocarbon, jack-ups are deployed near existing fixed jacket platforms frequently. Most of the Jack-up rigs are, 3-legged units supported by foundations known as 'spudcans' fixed at the bottom of their legs. Fixed offshore platforms are supported by open-ended steel tubular piles. Spudcans of a jack-up penetrate below the seafloor during its deployment in offshore. Diameter of spudcan is much larger compared to diameter of piles supporting a fixed platform. Due to penetration of spudcans into seafloor, capacity, loads and load-displacement behavior of nearby piles of the fixed platform may be affected since displacement and remoulding of a large volume of soil occurs near the piles. Analysis was carried out for a case in western Indian offshore to examine the effect of spudcan penetration on the safety of piles and structure of a fixed platform. Also, the minimum distance to be maintained between pile and spudcan to avoid over-stressing of piles and structure was worked out. The analysis and results are discussed in the paper.

Keywords: Offshore, Pile, Jack-up.

1 Introduction

Jacket type fixed offshore platforms are supported by open-ended, steel tubular piles. In general, the diameter of piles for these platforms in Indian offshore is within the range of 1.2 to 2.4 m. The vertical penetration below the seafloor may be typically, 60 to 150 m. The load-deformation behaviour and the capacity of a pile depend on the soil condition surrounding the pile. Also, the stress and displacement of structural components are influenced by the stiffness of the soil-foundation system. Therefore, an interactive analysis of soil, pile and the structure is carried out to analyze structural integrity and to predict performance of the piles. In-place analysis of structure must account for any changes in soil properties near the piles especially, due to deployment of jack-up rig as it may significantly influence the performance of the foundation and the jacket structure.

Jack-ups are deployed in offshore near well-head platforms to carry out drilling and work-over jobs in the wells installed on these platforms. They are, generally, three-legged units and supported by individual foundations, termed as spudcans, under the legs. To carry out drilling or work-over jobs in wells, drilling derrick is cantilevered-out from the jack-up over well positions (slots) located on the deck of the jacket platform. Deployment of a jack-up near the fixed platform causes disturbance to the soil around the spudcans. As the large foundations (spudcans) of a jack-up penetrate below seafloor, large volume of soil gets displaced and especially the clays get remoulded around the depth of penetration of the spudcans. Similarly soil disturbance takes place upon withdrawal of a jack-up from an offshore site after completion of their work. The effect of remoulding and movement of soil may have adverse effect on the piles falling in the zone of disturbance. Soil properties, distance between spudcan and pile, and spudcan's depth of penetration below seafloor are important factors which influence the magnitude of such effects. Cases where the spudcan of a jack-up is in close proximity of piles of the fixed platform, the effect needs to be incorporated in the analysis so that the structure and the foundation remain safe due to jack-up deployment. This paper presents a case study on effect of spudcan penetration on nearby piles and structure due to deployment of a jack-up at specified position near an existing fixed jacket platform.

2 Background of Study

There is limitation on the movement and length of extension of the drilling derrick mounted on the jack-up rig. Therefore, jack-ups are often required to be deployed close to the platforms so that all the wells in the platform are accessible. Position of the jack-up vis a vis the well-head platform is planned accordingly. Most of the piles for fixed offshore platforms in western Indian offshore are designed to be inclined with respect to the vertical. Figure 1 shows a sketch of typical foundation plan with four piles where two of the piles are inclined in both X and Y directions with respect to vertical and the other two (piles near which the jack-up is installed) are inclined with respect to vertical in Y direction only.

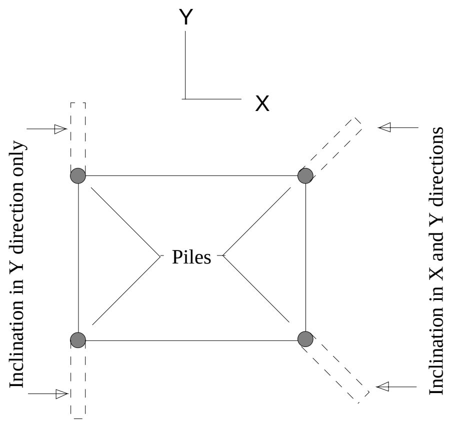

Fig. 1. Conventional plan of piles for a 4-piled well-head jacket platform

This is done to provide safe distance between spudcan and piles when jack-ups are deployed on that side of the platform. However, in the platform (supported by 8 piles – two at each corner) considered in this case-study, all piles were designed with inclination on both X and Y directions since originally deployment of jack-ups near this platform was not planned. Later on, due to some operational exigency, an option was to be examined if a particular jack-up could be deployed near the platform without compromising safety of the structure and foundation. Researchers [1,2,3] have demonstrated that deployment of jack-up rig near an existing platform may have significant effect on the stress and displacement of nearby piles and jacket's structural components depending on the proximity of the spudcan, type of soil, depth of penetration of spudcan etc.

In order to access all the wells of the fixed platform by the jack-up rig, due to the limitation on extension of the cantilevered part of the jack-up and piles being inclined on both X and Y directions, in this case, only available option was to deploy the rig at a position where two spudcans would be quite near to four of the eight piles of the platform. The relative positions of spudcans and the platform piles for carrying out the analysis are shown in Fig. 2.

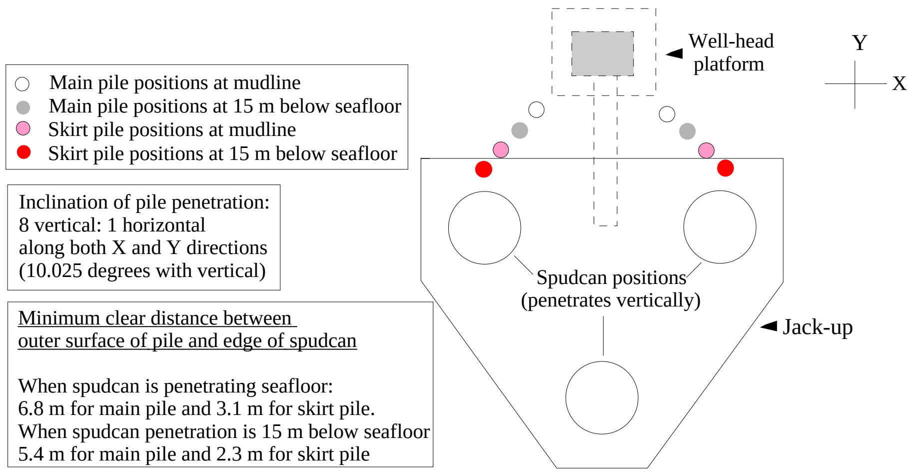

Fig.2. Schematic showing the proposed deployment of jack-up near the fixed platform and relative positions of piles with respect to spudcans (Figure is not to scale).

Generally, for normal deployment of jack-ups near well-head platforms, a minimum clear gap of not less than 0.5 times diameter of spudcan is maintained between edge of spudcan and nearest surface of pile.

A study was carried out to examine whether the piles and structure of the platform would be safe with the design loads for the plan of deployment as shown in Fig. 2.

3 Soil, Pile and Spudcan Data

The soil profile at the location comprises of both sand and clay layers. However, the zone of soil near the seafloor where the spudcan penetration can take place is predominantly clayey. Relevant soil data have been presented in Table 1. The soil properties were derived on the basis of an in-situ test, i.e. CPTU (Cone Penetration test with pore pressure measurement) and laboratory test on samples recovered by an offshore geotechnical vessel.

Table 1. Soil parameters in top layers for the location.

Layer	Soil Type	Depth (m)	s_u (kPa)	ϕ' (deg.)	γ' (kN/m^3)	ε_{50}	q_{lim}	K
1	Sand	0-1.0	-	35	8	-	7	34.6
2	Sand	1.0-2.3	-	15	8	-	2	5.5
3	Clay	2.3-6.4	60-30	-	8	1.5	-	-
4	Clay	6.4-10.0	20-35	-	8	1.5	-	-
5	Clay	10.0-13.6	30	-	8	1.5	-	-
6	Sand	13.6-15.0	-	25	8.5	-	3	5.5
7	Sand	15.0-17.2	-	35	10	-	8	34.6
8	Clay	17.2-22.0	35-55	-	8	1.5	-	-
9	Sand	22.0-23.0	-	25	9	-	2	5.5
10	Clay	23.0-24.0	70	-	9	1.0	-	-
11	Sand	24.0-25.8	-	25	9	-	2	5.5
12	Clay	25.8-27.0	65	-	8.5	1.0	-	-
13	Sand	27.0-32.5	-	30	9	-	4	16.6
14	Clay	32.5-40	100	-	8.5	1.0	-	-

Note: s_u = undrained shear strength; ¤′= effective angle of internal friction; ¥′= effective unit weight; £$_{50}$ = strain at 50% failure stress; k = rate of increase with depth of initial modulus of subgrade reaction for lateral soil resistance; q_{lim} = Limit unit end bearing pressure.

The platform was supported by eight piles where four of the piles were main piles (driven through the main legs of the structure) and the remaining four piles were driven as skirt piles. Outer diameter was 1.829 m for all the piles. Wall thickness for pile sections near seafloor was 63.5 mm. For pile segments at greater depth below seafloor, wall thickness was 50 mm and 44 mm. Further details are described subsequently in Table 2. Equivalent diameter of spudcan was 15.2 m.

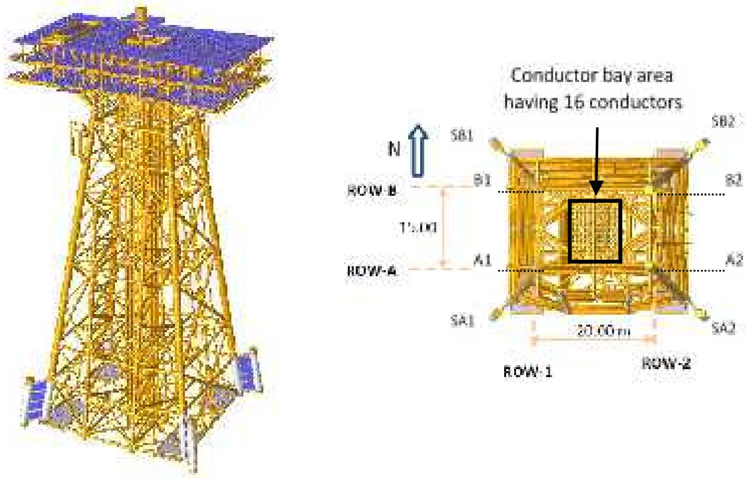

Fig. 3. Structural model of the platform and pile positions.

4 Structure of the Jacket Platform

The structural model, generated by using the software SACS, is shown in Fig. 3.The positions of the conductors, jacket structural members and piles are shown. The well conductors are in the middle of one side of the structure. The feasibility for using a 3-legged, cantilever type, spudcan supported jack-up rig to be deployed near the fixed platform was to be examined under the present study. Some of the salient features of the platform are mentioned below at Table 2.

Table 2. Salient details of the platform and foundation.

Feature	Description
Platform Type	Well-head, fixed platform
Water depth	76 m
No. of wells in the platform	16
Diameter of piles	1.829 m (outer diameter)
Type of pile	Open-ended tubular; steel
Pile wall thickness	63.5 mm near seafloor; 50 and 44 mm downwards
Jacket leg and pile inclination	1(horizontal) : 5.657 (vertical), double battered
Vertical penetration of main Piles	116.2 m for Main Piles
Vertical penetration of skirt piles	102.0 m for Skirt Piles

5 Methodology for Analysis

Offshore piles and structures are designed by carrying out interactive analysis of pile, soil and structure where the load-displacement properties of soil along with stress-strain behaviour of the structural material (steel) are taken into account. The analysis of the present case was carried out using software SACS where, user-defined load-displacement data of soil was input with required modifications as explained subsequently.

The relative positions of spudcan of the jack-up and piles of the jacket structure was shown in Figure 2.

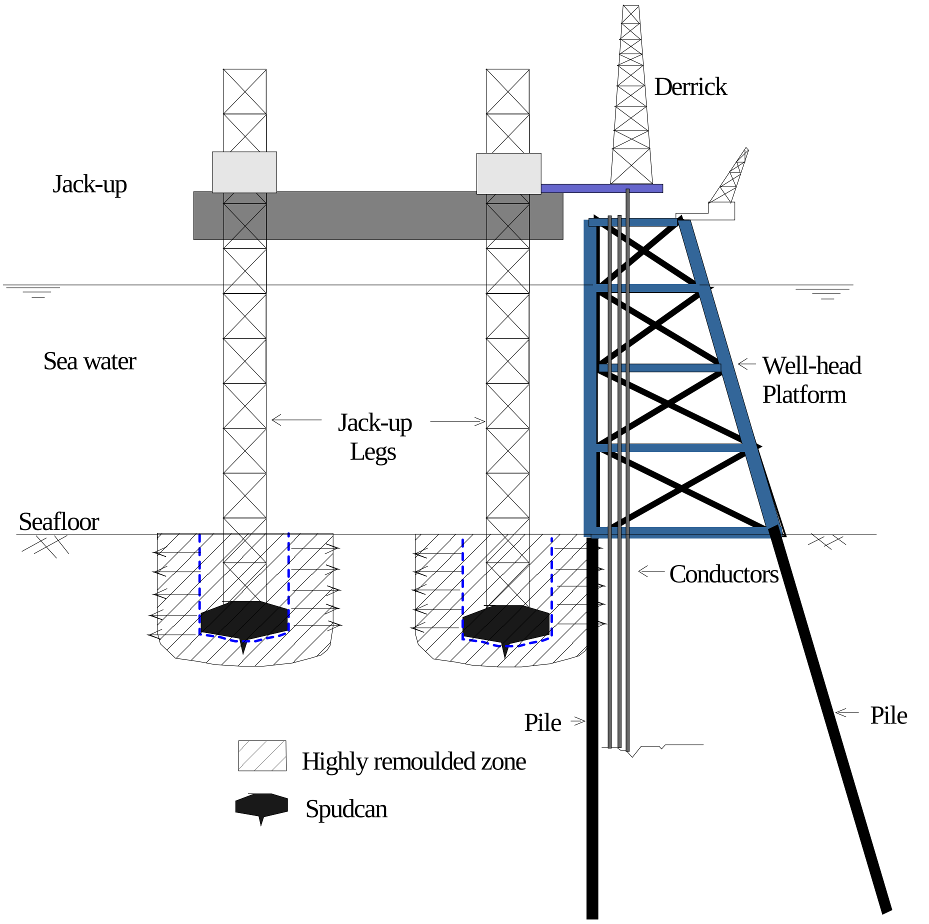

Fig. 4. Soil remoulding and lateral displacement of soil due to penetration of spudcan.

During spudcan penetration, remoulding of soil occurs and due to movement of soil, significant soil forces could be transmitted to nearby piles. Figure 4 indicates, through a simplified sketch, pile of a fixed platform getting affected by the lateral movement and remoulding of soil due to spudcan penetration below seafloor.

Therefore, interactive analysis of soil-pile-structure was carried out where the effect of penetration of the jack-up spudcan into the seafloor was also considered. Conventional interactive analysis was carried out using the pile load-transfer curves viz. t-z, q-z and p-y; where, t-z is axial shaft resistance versus displacement, q-z is end bearing resistance versus displacement and p-y is lateral resistance versus displacement of soil. All the three types of curves represent non-linear stress-strain response of soil. Cyclic p-y data were used in view of offshore environmental loading. Load transfer data (t-z, q-z and p-y) were generated as per the code of practice [4].

In the present case, axial capacity of pile was found to be adequate even if soil disturbance due to jack-up deployment was considered since contribution of soil zone for the length of piles affected by jack-up deployment to the axial pile resistance is not significant. As such, effect of jack-up deployment on axial load-movement of pile in the present case was not further investigated.

Due to the proximity of spudcan to some of the piles, the possibility of spudcans fouling any piles while penetrating the seafloor was first examined. Spudcan penetration below seafloor was estimated considering the designated maximum axial load (preload) to be applied per leg of the unit. The leg-penetration analysis was carried out as per [5] and [6] and penetration of the spudcan was estimated to be 15 m for the subsequent analyses. Based on the estimated penetration, the soil lateral movement applicable for the piles near spudcan positions was calculated based on references [1 and 2] using the concept of 'shifted p-y'. Remoulding of clayey soil within the estimated disturbed soil zone was also considered through modification of p-y data for the piles close to spudcans. Pile group effect with respect to lateral loading for the 2-pile groups was also considered by modifying p-y data with applicable P and Y multiplying factors as 0.8 and 4.5 respectively which were derived as per method recommended by API [4].

Global static in-place analysis was carried out based on working stress method using SACS software for 100 year extreme storm and 1 year operating storm condition. Additional analysis was carried out for 100 year fair weather condition to explore the feasibility for deployment of jack up rig for periods with less harsh weather conditions. In this paper, the structural analysis results for 100 year extreme storm condition have been presented. The $1/3^{rd}$ (33%) increase in allowable stresses have been considered as per the provisions in design codes [7 and 8]. Structural members were checked for yield, stability and nominal joint strength considering gravity and all lateral loads, i.e. wave, current and wind for 8 (eight) directions. Marine growth of 100 mm thickness from elevation level (+) 6.0 m to (-) 30 m and 50 mm thickness from (-) 30 m to seafloor was considered. These elevations are with respect to chart datum for the offshore location. The piles have been checked for load carrying capacity and stress 'unity-check' (UC) ratio. The connection between main & skirt piles in the platform have been modeled using the advanced feature of meshing of plates for ensuring proper load-transfer mechanism.

6 Lateral Soil Movement and 'shifted p-y'

As mentioned already, when the spudcan position is close to an existing offshore structure, its penetration may cause significant deformation to the soil surrounding the nearby piles. Forces are transferred to nearby piles due to the soil displacement and also forces are induced in the jacket structural components.

Soil displacement due to jack-up deployment has been considered in the analysis by modifying lateral load-displacement data (p-y characteristics) of soil for the piles located on the side facing the jack-up. Remoulded strength of clayey soils (with sensitivity of clay as 2.0) was considered for piles facing the jack-up for the estimated depth of penetration of the spudcan. In the p-y data, 'y' values were shifted based on estimation of soil displacements following guidelines in references [1].Two critical depths of spudcan penetration have been considered in the analysis. They are, when spudcan of jack-up rig penetrates the seafloor, i.e. at the beginning of penetration and when it penetrates 15 m below seafloor. Shifted values of 'y' in relevant 'p-y' data for the conditions are shown in Fig. 5.

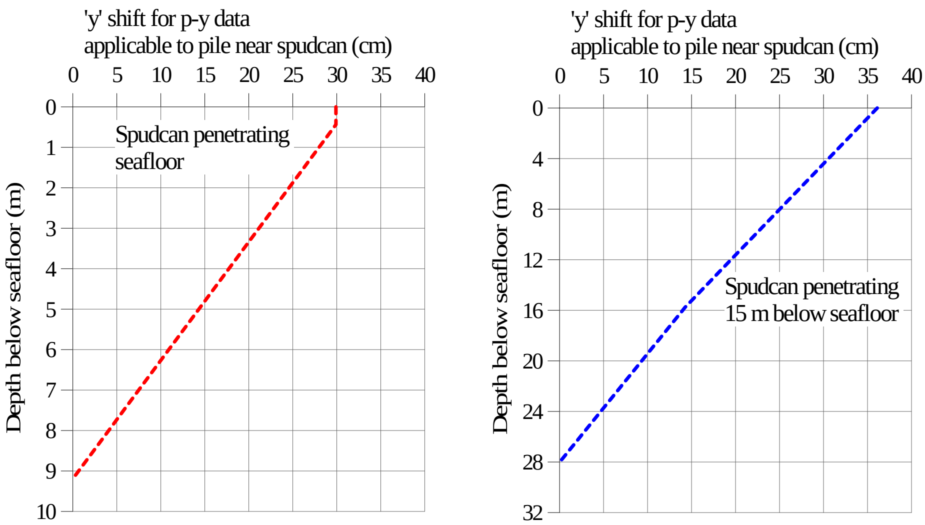

Fig. 5. Shifted 'y' values for spudcan penetration at seafloor and 15 m below seafloor

Undisturbed soil condition without any 'y-shift' in p-y data was considered for the piles on the opposite side of the fixed platform.

7 Results of Analysis and Discussion

The result for bending moment for the most critical pile is presented at Fig. 6. It is corresponding to condition of spudcan penetrations of 15 m below seafloor. The maximum increase of bending moment was observed to be about 215%. The maximum lateral displacement in pile was observed to be 13.6 cm which was not significantly high. It has been oberved that significant re-distribution of loads occurs among the piles when spudcan penetration effect is considered due to different soil conditions considered on two opposite sides (near jack-up and far from jack-up) of the platform while analysing for jack-up deployment.

Analysis shows that due to jack-up deployment, significant increase in stress occurs in pile material. Maximum increase in pile stress was found to be 360%. However, stress utility ratios for all piles are within allowable limit i.e. less than 1.0.

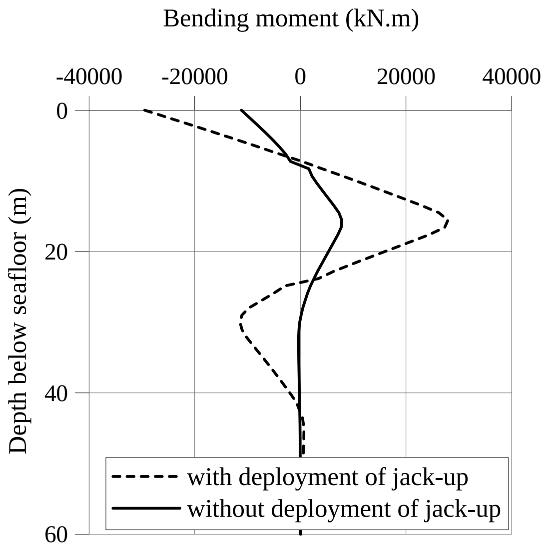

Fig. 6. Bending moment in the most critical pile (SA1) with the critical design load conditions.

The results have been summarized at Table 3 showing maximum increase of stress for individual piles. Pile numbers are indicated in Fig. 3.

Table 3. Maximum increase in pile stress utility ratio for individual piles

Pile number	No jack-up deployment	With jack-up deployment	% increase
A1	0.42	0.74	076.2
SA1	0.25	0.85	240.0
A2	0.28	0.53	089.3
SA2	0.15	0.69	360.0
B1	0.31	0.57	083.9
SB1	0.20	0.43	115.0
B2	0.32	0.53	065.6
SB2	0.16	0.26	062.5

Results in Table 3 are selected for different directions of environmental loading where such increase has been maximum due to the effect of jack-up deployment.

It may be noted that the comparison shown in Table 3 accounts for the re-distribution of loads in the piles and reduction of certain gravity loads (which were considered in original design) due to removal of some equipments from the structure when analysed for deployment of jack-up, which had influence on the stress utility ratios; further, stress in pile is also related to pile wall thickness (which varies along the length of piles). Thus, inspite of the jack-up deployment, pile stress was found to be within allowable limit for all the piles.

Regarding increase in stress for structural members, the condition with 15 m penetration of spudcan was found to cause maximum stresses in structural components. Calculated stresses were found to be beyond permissible limits in some of the members. Figure 7 shows the results with maximum effect due to jack-up deployment. Primarily, structural components near the seafloor were found to be over-stressed with stress utility ratio significantly exceeding the allowable limit. Maximum increase in stress for structural member was by more than 570% (stress utility ratio increased from 0.67 to 4.5) compared to original design.

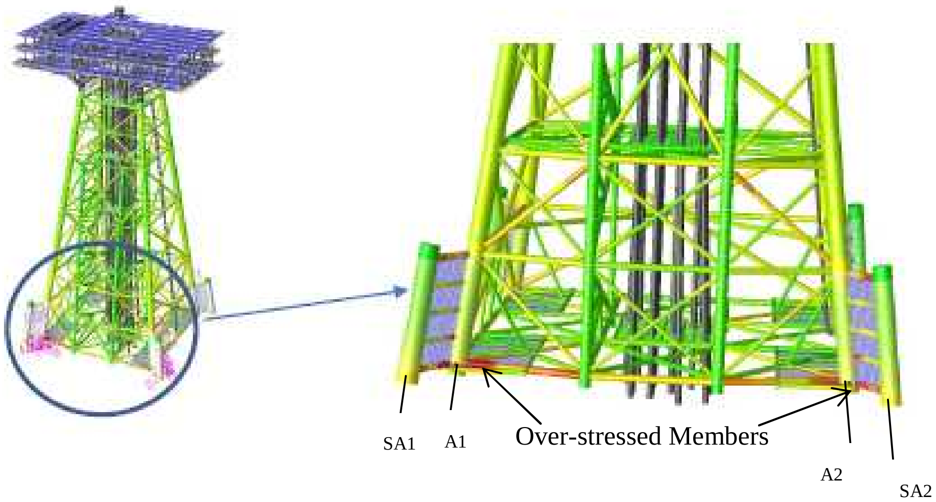

Fig.7. Over-stressed structural components near the jack-up deployment position

Finally, the result of analysis indicated that stresses in many primary structural components would exceed the allowable limit if the jack-up rig was deployed at a position with the specified distance (Fig. 3) with respect to the nearby piles. However, all piles were found to be safe though stress and displacement increases in them due to the deployment of the jack-up. For the structure to be safe with the deployment of the jack-up, minimum spacing of about 8 m needs to be maintained between the edge of spudcan and outer surface of pile.

8 Conclusion

A Case Study on the effect of deployment of jack-up rig on piles and structure of existing offshore platform has been presented.

Given the large size of spudcan, offshore loading environment and spudcans' distance with pile being comparatively very small, the proposed deployment appeared to be practically very risky with possibility of physical contact of pile with spudcan.

The result of analysis shows that all piles meet the required limits of safety even with increase of stress in them arising from close proximity of spudcans. It is thought to be due to having in-built margin on factors of safety in original design of the piles, reduction of some gravity load applicable for the analysis of jack-up deployment and redistribution of loads among piles due to modified soil properties. Regarding the structural integrity, the result of analysis shows that some of the structural components of the jacket structure does not meet the structural integrity assessment criteria for deployment of the jack-up rig near the platform. In view of results of analysis, the proposed deployment was not recommended.

It is also found from analysis that a minimum spacing of about 8 m needs to be maintained between the edge of spudcan and outer surface of pile for the structure to be safe with deployment of the jack-up.

Analysis of such cases involving structure, soil, pile and disturbance of soil due to jack-up leg penetration are complex in nature. The analysis presented in the paper is only an approximate solution based on the methodology that is compatible for interactive analysis of soil, pile and structure although the soil condition is not exactly the same as per procedure [1, 2] used to estimate 'y shifts' in the case. More rigorous analysis specific to such cases preferably with 3-D large deformation finite element analysis and model test may produce more refined outcome to arrive at a generalized formulation to use in practice in such cases. Given the significant cost and the importance of safety aspects in offshore operations, more research on the subject will benefit the offshore industry in terms of comprehensive guidelines and more reliable results of analysis.

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