The Effect of Possible Spud-Can Punch Through on the Reliability Index of Neka Drilling Type Jack-up Platform

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***Abstract*- In the present study, the effect of spud-can punch-through has been studied on the reliability of the Neka Jack-up platform. Elasto-plastic, hyper-elastic and also continuum mechanics models of spud-can-soil interaction have been used. The reliability index of Neka jack-up platform was studied in three different soil profiles at the sea-bed in CaspianSea. The study showed that the reliability index of jack-up system varies quite significantly for the studied jack-up system with the type of soil profile at the sea-bed and also with the pre-load factor (PLF). The sensitivity studies of the jack-up system for punch-through effect revealed that the reliability index of the jack-up system can be affected by the choice of the spud-can-soil interaction model and the soil parameters. Study of importance factors also showed that spud can-soil interaction model and soil parameters have significant contribution to the overall reliability of the jack-up system.**

Keywords*- *Jack-Up Platform; Reliability Index; Punch Through

I. INTRODUCTION

In the past decades, mobile Jack-Up systems have been widely used as drilling rigs in the water depths of around 100m in most offshore regions such as North-Sea, Gulf of Mexico and Caspian Sea. Jack-up systems are usually built of lattice structures (legs members) which support the hull and the drilling facilities over it. The whole structure is supported on spud-can type shallow footings which usually have a conical shape at its base. The Jack-up system resistance under action of waves and current would entirely depend on the degree of fixity and the support reactions at its base. Hence, according to the guidelines during the pre-load phase of spud-cans, the hull is jacked up over a safe distance and then ballasted with water to a vertical load level of near PLF 2.0. During the preloading, particularly in soft clay or loose sand, the spud-can footing may penetrate rapidly the sea-bed into a greater depth to achieve the stability required. In this pre-loading phase the ultimate bearing capacity of soft clay or loose sandy soil may be exceeded, which would result in a rapid penetration of the sea-bed layer and hence might result in damage into the main leg or even in severe cases into loss of overall stability of the jack-up platform (see Fig. 1).

In the past years, several studies on the topic of jack-up-spud-can-soil interaction modeling have been performed for e.g. [1], [3], [4, 5], [22], [23], [25], [7], [27], [29], [24], [16,17]. Some of these studies either consider very simple spud-can-soil interaction models or completely neglect it. In other studies, such as work in [4, 5], although more refined plasticity models are applied for modeling the spud-can-soil interaction, these models have been more rigorous and quite tedious for practical use in offshore industry. In another recent work in [26], a more refined model considering both near field and far field spud-can-soil interaction effects has been also used. A more efficient and also refined model was initially developed in [30] and [34], and has been implemented and tested into usfos computer program [19, 28] which is used in the most recent works [13, 14] by the author. The model is based on a 2D-plasticity formulation of spud-can-soil interaction in both sand and clayey soils [1]. It takes into account the spud-can slippage, suction at the sea-bed, and penetration depth effect of the spud-can [14].

More recent studies of spud-can punch through mechanisms in layered soft clay and sand have been also performed for e.g. [8], [32], [31], [36] and [37] etc. These studies mostly considered the spud-can failure mechanisms such as back flow etc. But in most cases, there is a lack of complete study of the effects of spud-can parameters and PLF on the reliability index of the global response of the Jack-up type platform. In this study, we shall also consider the effects of various soil types such as soft clay, stiff clay and also loose to dense sand layers at the sea-bed on the reliability of jack-up system. The reliability index (β) of the jack-up system is studied under the pre-load and the combined load condition due to wave and current.

Fig. 1 a view of a drilling jack up failure due to spud can punch through (maersk drilling rig) after t.aust

II. JACK-UP STRUCTURAL MODELLING

The Jack-Up system modeling consists of 3-main leg structural model, hull model and spud-can foundation model. The main legs are modelled by using pipe elements while the hull structure itself can be represented as equivalent general beam sections [13]. In a more refined model the hull structure is represented here using shell elements (see Figs.

2, 3). The upper deck drilling facilities are not modelled here. While, the hull-to-leg connections can also be modelled using the non-linear spring elements in usfos computer program [19] (see also Appendix). A more refined FE model of hull-to-leg has been used in [26] for Neka Jack-up platform.

The yield surface function F(X) for the jack-up system under the action of waves and current is considered in a compact form as follows: [19, 28]:

$$F(X) = F(\frac{N}{N_P}, \frac{Q}{Q_P}, \frac{M}{M_P}) = 0 \qquad (1)$$

Where, N, Q and M represent the axial force, the shear force and the bending moment components at each cross section, respectively. N_P, Q_P and M_p indicate the plastic axial, shear and bending moment resistance of the cross-section of the structural member. The consistency criterion [19, 28] is also satisfied as follows:

$$\Delta F = \frac{\partial F}{\partial S}\Delta S + \frac{\partial F}{\partial P}\Delta P + \frac{\partial F}{\partial N}\Delta N \qquad (2)$$

Where S, P and N denote the tangential force, the external load and the axial force in the jack-up member, respectively. Other parameters are as defined above. The consistency of the yield surface then implies that:

$$\Delta F = 0 \qquad (3)$$

The normality rule implies that during any plastic strain, the vector of plastic strain increment should be normal to the yield surface at that point.

III. SPUD-CAN FOUNDATION MODELING

In this section, we describe a plastic interaction model for the spud-can foundation of jack-up platform (see Figs. 2 and 3). The spud-can foundation is modelled as a coupled elasto-plastic spring using a plasticity flow rule. It is assumed that there is a strong capacity interaction between various force components, namely, H, V, M.

The computations in [34] showed that the shape of the yield surface is slightly changed in this case with the internal friction angle of the sand at the sea-bed, on the pre-load level of jack-up and the apex angle of the spud-can foundation. Nevertheless, the penetration in the sand layer at the sea-bed together with the pre-load effect will give rise to a base moment capacity (i.e. M≠0). This will certainly have a considerable impact on the overall jack-up rig behavior.

The interaction formula for the spud-can footing of the jack-up platform is given as follows [1, 19]:

$$\left(\frac{M}{M_0}\right)^{1.2} + \left(\frac{H}{H_0}\right)^{1.2} = 1.0 \qquad (4)$$

Where M, H, M_O and H_o denote the overturning moment, the horizontal force (base shear), the overturning moment at (H=0) [20] and the horizontal force at (M=0), respectively.

A unified yield function f (V, H, M) ≤0 has been used in usfos program[19] based on the above equations as[19, 30]:

$$f(H,V,M) = \sqrt{\left(\frac{M}{2R_E V_P}\right)^2 + \left(\frac{H}{V_P}\right)^2} - 0.5(\frac{V}{V_P})(1-\frac{V}{V_P}) \le 0 \qquad (5)$$

Where V and V_P represent the current vertical force at the spud-can footing and the vertical pre-load, respectively. In addition to these parameters, the effective radius of the spud-can base R_E also affects the overturning moment capacity [1, 30].

A similar yield function for spud-can-soil interaction was proposed by Van Langen et al. [34]. This failure fuction has been also used for jack-up analysis in usfos program [19]. Another function for the bounding surface taking a kinematic hardening rule has been applied as [1, 19]:

$$f = f_y + (f_u - f_y)R_G \qquad (6)$$

Where f, f_y and f_u denote the current failure surface, the initial yield surface and the ultimate failure (bounding) surface, respectively. R_G parameter is a function of plastic hinge rotation θ_p in the spud-can footing [2, 19]. It has to be noted that both the initial yield and the final bounding surfaces are given by Eq. 6 applying the moment capacity factors of 0.3 and 0.625 for these two surfaces, respectively.

A non-associated type plasticity rule has been used in the current pushover analyses in usfos program. This decision was taken, since previous research work [1] has shown that the associated form of plasticity flow rule has lead to some unrealistic uplift and hence a permanent reduction in the capacity. This flow rule would result in a smooth transition in the yield surface and less plastic uplift too. It is therefore decided to use the plastic potential formulation given in [34] for usfos jack-up analyses [1, 10, 19].

IV. RELIABILITY THEORY

The annual probability of failure of the jack-up system can be defined in a simple form as [14]:

$$P_f = P[g(X) = \chi_R R(X) - \chi_L L(X) \le 0] \qquad (7)$$

Where, the annual probability of jack-up system failure is defined here as probability of having less ultimate strength of the jack-up-spud-can-soil system than the annual load. Then the annual jack-up-spud-can-soil resistance function can be computed in a linearized form as [14]:

$$R(X) = R(\bar{X}_{SS}, \bar{X}_{SC}, \bar{X}_S, \bar{X}_{SSM}) + \sum_{i=1}^{n} \frac{\partial R(X)}{\partial X_i}.\delta X + 0^+{}_i \qquad (8)$$

where the first term in Eq. 8 represents the reference value of the random resistance parameter $R(X)$ computed for instance at the mean values of the each random array's parameters, however, the second term in Eq. 8 includes the first derivate of the jack-up system resistance with respect to each of the random variables in the arrays $X_{SS}, X_{SC}, X_S, X_{SSM}$. The simplification above is based on the assumption that the variation of each random parameter δX_i is relatively small (that is to say 10-20% at max. of that particular random variable X_i). Then the last term which represents the error in the linearization of the jack-up strength function will be minimized [14, 33]. The above procedure of FORM was implemented in RELJSS computer program [12] which has been used during this work for reliability analyses. A more refined method based on a series of jack-up simulations using usfos program has been also adopted to avoid any large error involved in evaluation of *R(x)* [14]. A second order reliability analysis method (SORM) was also used based on a second order expansion of *R(X)* (see for e.g. [14]) for the sake of comparison of the FORM analysis results.

V. UNCERTAINTY MODELLING

The uncertainty due to the system resistance or load modeling may be described as follows. The uncertainty in the structural system resistance evaluation may be due to the fabrication errors as well as calculation model and numerical errors. The uncertainty in the spud-can foundation and the supporting sea-bed soil might be due to the usfos spud-can-soil interaction model used as well as the inherent randomness in soil medium and also the geotechnical lab methods for estimation of the soil (shear strength, density, poisson's ratio, etc) parameters. The uncertainty in the load modeling may be due to the random sea-state, the wave-load modeling, the wave theory, wave load Morrison's equation, the distribution (pattern) of wave load on the jack-up platform.

To perform parametric (sensitivity) studies and more efficient reliability analyses, the mean and COV values of resistance (*R*) and load (*L)* parameters are considered in a single limit state function (*LSF1*). The distribution of the resistance parameter (*R*) of the jack-up platform is assumed to be normal with a mean value of its ultimate static or dynamic strength (form static and dynamic pushover analyses) and COV of about 0.15. The distribution of the load parameter (*L*) is considered to be normal with a mean value of the static or dynamic base shear for an annual wave height (H_1) and COV of about 0.25 [9,11]. For the bias parameter of resistance (χ_R) a mean value of 1.0 and COV of 0.1 and for the bias parameter of load (χ_L) a mean value of 0.95 and a COV of 0.15 were used in the second limit state function. For more detailed information about other uncertainty measures of structure, soil parameters, wave load model, wave height and sea-state, please refer to. [9, 10], [15]. Algorithms of the above procedures in RELJSS program is given in [12, 14].

VI. BASE SHEAR AND ANNUAL WAVE MODELLING

The wave and current induced load on the jack-up platform may be taken as the overall static or dynamic base shear which can also be related to the wave height via a power form relationship, in general as follows[9,14]:

$$L(X) = BS_W = a_1.H^{b_1} + a_2(H - H_D)^{b_2} \tag{9}$$

Where, BS_w represents the total base-shear at leg-spud-can footing interface, and H and H_D denote the scaled wave height and the wave height corresponding to the deck level. a_1, a_2, b_1 and b_2 are regression or curve fitting coefficients and might be determined by a series of single (regular) wave analyses of the jack-up platform. For the Neka drilling jack-up platform, simple power relationships for both static and dynamic base-shear functions were obtained which are described in the summary of results. In this study, the current load is superimposed on wave load and wind effect is not considered. Hence, the correlation between wind and current speeds is not considered here and the corresponding response surface excludes the wind or current speed effects as correlated random variables.

The distribution function of the maximum annual wave height is computed according to the long term exponential distribution of individual wave heights as follows [9, 14]:

$$H_1 = H_{100}(1 - \frac{\log N_1}{\log N_{100}}) \approx 0.77 H_{100} \tag{10}$$

where H_1 and H_{100} denote the most probable maximum annual and 100-year wave heights, respectively. Alternatively, the statistics of the maximum annual wave heights can be used to determine H_1 based on the long-term statistical data which offers the significant wave height (*Hs*) for the given sea-state. The most probable maximum wave height H_{MAX} might be obtained as $1.86H_S$. A truncated Weibull type long-term distribution of maximum wave height might also be used for modeling the maximum annual wave height [15, 22].

VII. NUMERICAL SOLUTION METHOD

The nonlinear dynamic equation of motion of the jack-up platform is integrated in the time domain by means of HHT-α algorithms [18]. This algorithm is actually based on the Newmark's-β family of schemes, however, it introduces some numerical damping by means of time averaging. The dynamic incremental equilibrium equation then reads [19]:

$$\begin{aligned}&(M + M_a)\ddot{r}_{n+1} + (1+\alpha)C(r)\dot{r}_{n+1} - \alpha C(r)\dot{r}_n + \\ &(1+\alpha)K(r)r_{n+1} - \alpha K(r)r_n = (1+\alpha)F_{e,n+1} - \alpha F_{e,n}\end{aligned} \tag{11}$$

Where, n and n+1 denote two consecutive time states. The effect of α parameter is to damp out higher order frequency contributions into the global platform response. *M*, M_a, *C(r)* and *K(r)* represent the structural mass matrix, the hydrodynamic added mass matrix, the damping matrix and the restoring force matrix, respectively. The numerical integration of Eq. 11 can be performed by means of a conventional predictor-corrector scheme. This method allows for time-step scaling in the predictor phase in order to bring the force back to the yield surface once a yield has occurred.

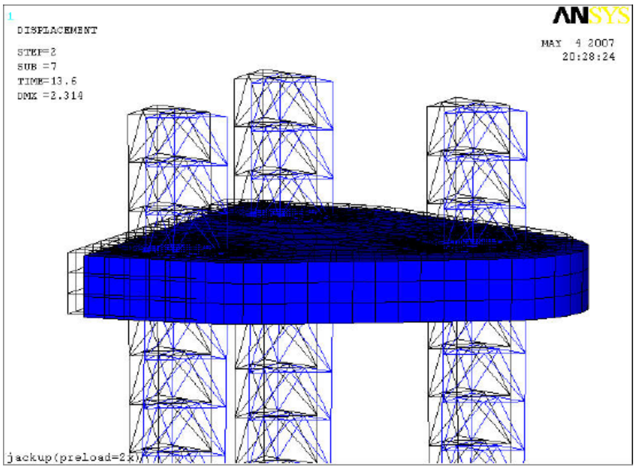

Fig. 2 FEM model of 3-leg North-Sea jack-up with deck (after Nobari)

VIII. CASE STUDY

Several dynamic pushover analyses were carried out for various soil type and spud-can penetration depth into sea-bed soil. The structural and foundation descriptions for the Jack-up platform are given in details in [7] and [26].

IX. STRUCTURAL SYSTEM

The finite element model of the jack-up system has been shown in Fig. 2. As shown, the jack-up consists of three main legs and a hull which supports the drilling facilities on its top. The main legs are supported on three spud-can foundations. Each main leg has a lattice structure consisting of 3 chords and the bracing system. The bracing system includes horizontal and vertical braces as well as the diagonal-braces. The hull is located 95.2m above the sea bed while the top of main legs are located 125.5.m above the base. The designed hull depth was 7.62m and the hull draft was 4.57m. The hull structure was initially modelled using the equivalent tubular and general beam members in a triangular form horizontally braced frame [13]. In this study, a more refined FE model of hull structure using shell elements was also used [14]. Detail description of the Neka Jack-up is given by for e.g. [7] and [26].

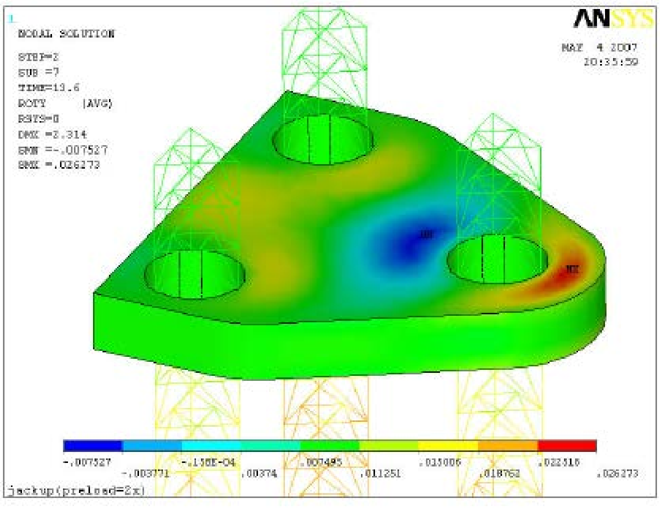

Fig. 3 FE model of a north sea jack up(hull legs)

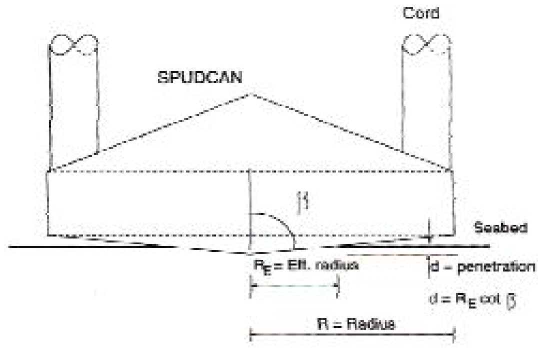

Fig. 4 Spud can footing of jack up (after Amdahl et al)

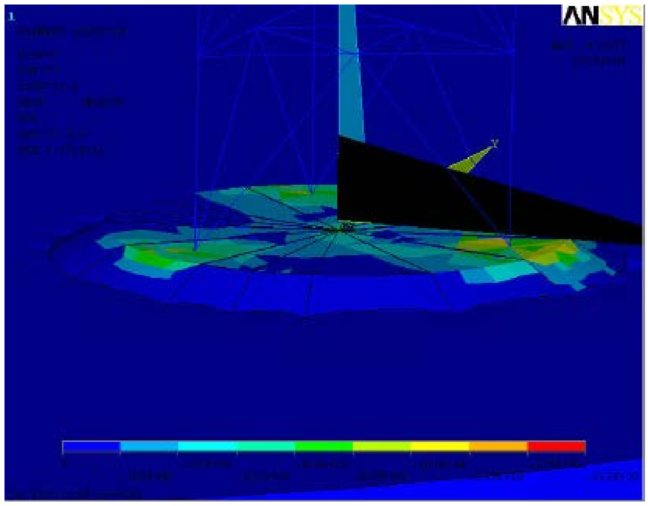

Fig. 5 A spud can deformed model of jack up (after Nobari)

X. FOUNDATION SYSTEM

The foundation of the jack-up system consists of three shallow spud-can footings. Each spud-can footing has a conical shape at its base while it has a diameter of 18.7m and a total height of 9.6m (see Appendix). This configuration was then modified (e.g. [26]) for FE modeling of spud-can footing of Neka Platform (see Appendix). Fig. 4 shows a typical configuration of the spud-cans. Apex angle of spud-can is also varied from 60 to 85deg. The embedment of spud-can is varied between 8.5m and 14.5m. Fig. 5 shows a more refined finite element model of spud-can footing of Neka Jack-up platform [26]. Figs 5 and 6 show the visualization of our finite element model for the spud-can footing and its deformed shape with an indicator of plastic usage factor for spud-can-soil interaction in usfos program [19].

In usfos spud-can element since only parameters such as R_E, Apex Angle of spud-can, V_P etc are considered, the height of spud-can is not directly used as input. This means that the actual configuration or height of spud-can is modelled with a rather simple non-linear elasto-plastic hardening type (SPUD) element. While in a more refined FE modeling [26], the total height can be modified to allow for sitting of the leg chords. This technique would enable modeling the stiffeners and also the leg-spud-can connection parts (see also Figs. 5 and 6).

XI. LOAD DESCRIPTION

The gravity, functional and environmental loading are applied on the Jack-up platform. The gravity load consists of self-weight of jack-up main legs and spud-cans, hull structure weight. The self-weight of platform is applied on each element as distributed load and also the other parts are considered as equivalent nodal loads. Functional loads due to the drilling and other top facilities are also considered as nodal and also equivalent distributed loads on the hull structure. To generate sea waves, a 5^{th} order stokes wave theory is used. A modified design significant wave height of 15.5m with a mean period of 13.6 sec is used for the initial dynamic pushover analysis. Also we use in most pushover dynamic analyses, a more appropriate significant wave height for the Neka region as Hs=12.5m. The generated wave height using the Stokes's 5^{th} order wave theory is then increased in an incremental manner until the ultimate jack-up collapse. The sea wave forces are computed according to Modified Morison's equation (see for e.g. [6] using a drag coefficient of C_D as 0.7 and inertia coefficient C_m as 2.0. Computation of any possible wave-in- deck load could also be computed according to [2] and [21]. A current profile with a maximum speed of 1.2m/sec at the sea surface is used. The wave and current induced loads are superimposed and applied on the wet part of jack-up platform. Current wheeler stretching technique is used to compute the current induced forces at the instantaneous sea surface. Detail description is given by [7] (see also Appendix).

XII. SUMMARY OF RESULTS

Figs. 3 and 6 show the deformed models of the jack-up system (hull and legs) under the action of extreme wave and current. The deck area shell elements used for modeling the deck hull horizontal and vertical plates with equivalent thickness ranging from 0.08 to 0.12m had a maximum von Mises stress level well below the yield stress of the plate. No global or local elasto-plastic buckling of deck plate has occurred during the simulation time for the waves approaching the deck area. This was because the initial design and re-modeling of deck were so that the deck hull seems to be more rigid and behave completely elastically.

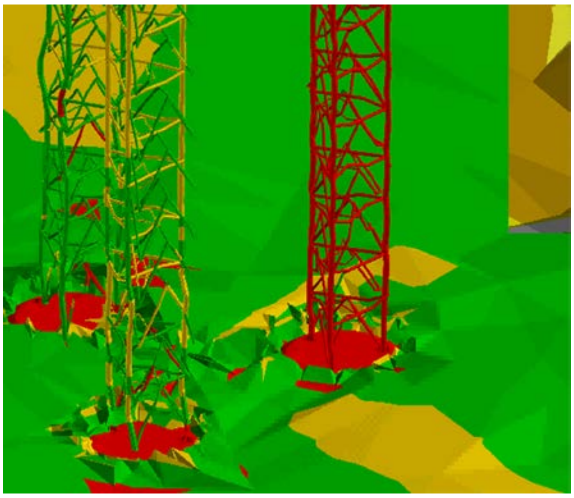

Fig. 6 Deformed model of a three-leg north sea jack up platform under action of sea waves and current (Emami Azadi, 2010)

Fig. 7 represents a typical spud-can model of USFOS [19] during punch-through type failure in a soft clay soil layer at sea-bed. Fig. 8 also shows a typical global loss of stability of jack-up platform under action of wave and current due to spud-can footing failure in soft clayey soil at sea-bed. Figs. 9 through 11 show the displacement at spud-can level and at hull level vs. global vertical load for different soil types such as soft clay, stiff clay and loose to dense sand profiles at sea-bed, respectively. Locations of ref. nodes 1001, 1020 and 3020 are shown on Fig. 8. As shown in Fig. 9, the vertical displacement initially increases rapidly with increase of vertical load and then it reaches a peak value. It can be seen that the vertical displacement of spud-can increases further with a slight decrease of vertical load. This would indicate a punch through failure at the spud-can footing in very soft clay. Since this soft clay layer is quite thick compared to the diameter of spud-can which is in the range of 17.0-21.0m, with average Su=5KPa, no further resistance of soil can be mobilized after the soil yield underneath the spud-can base. This is different from a multi-layered soil failure mechanism of non-uniform type such as sand over soft clay etc which have been extensively studied previously by many researchers [31, 32, 36,37]. A similar behavior of the jack-up supported on soft clay soil (SU=15KPa) is shown in Fig. 11. However, the vertical force reaction is comparatively higher than the case of very soft-clay bed.

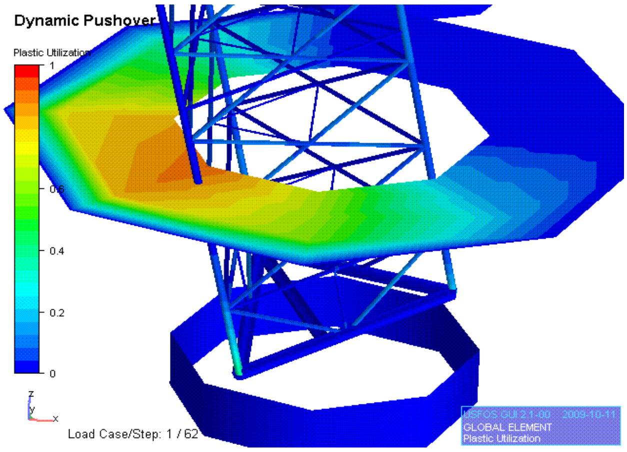

Fig. 7 USFOS model of spud can punch through failure

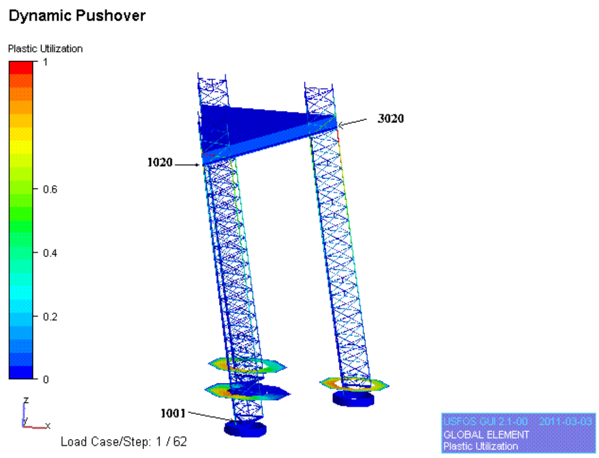

Fig. 8 USFOS deformed model of spud can footing with punch through type failure (Emami Azadi, 2010)

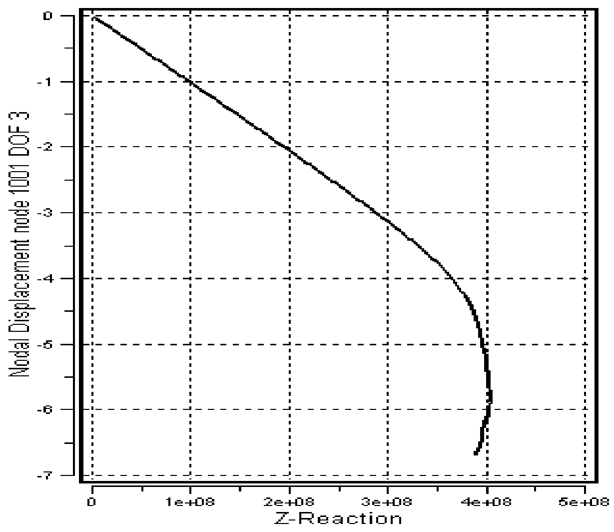

Fig. 9 Nodal displacement at spud can level vs. global vertical load in soft lay(SU-5kpa)

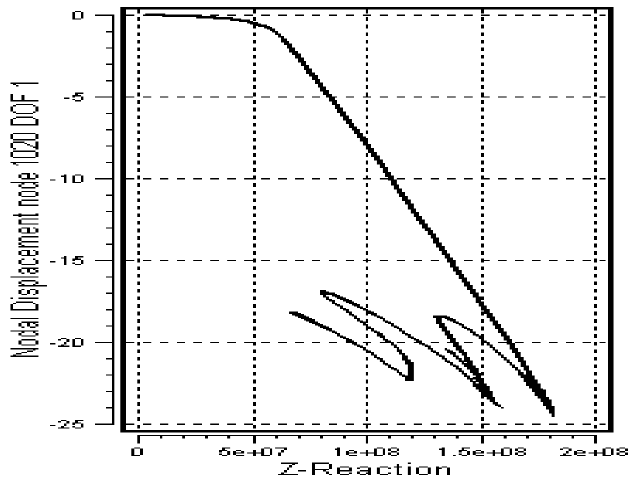

Fig. 10 Nodal displacement at hull level above spud can vs. global vertical load in very loose sand

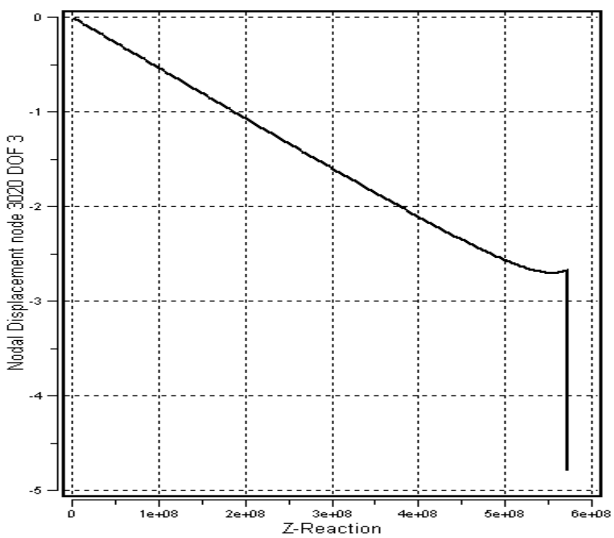

Fig. 11 Nodal displacement at hull level above spud can vs. global vertical load in soft clay (SU=15kpa)

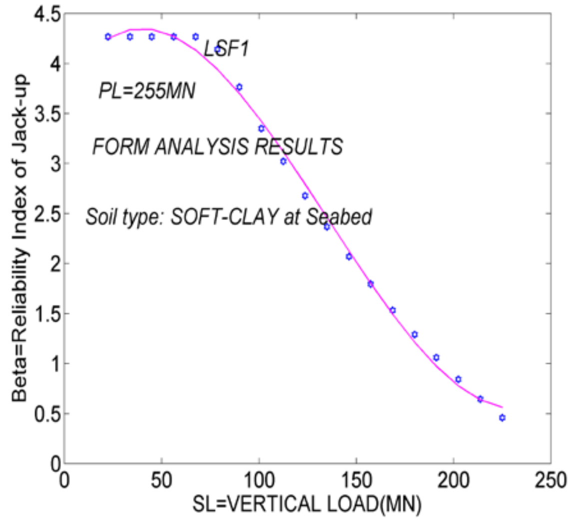

Fig. 12 Variation of the reliability index of jack up system with Vertical Load in soft lay (SU=5kpa)

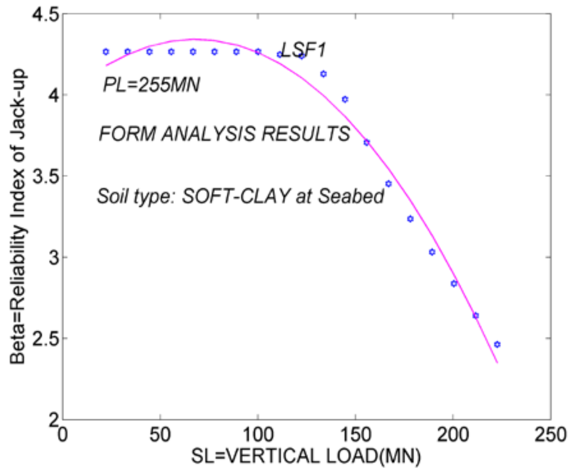

Fig. 13 Variation of the reliability index of jack up system with Vertical Load (SL) in soft clay (SU=50kpa)

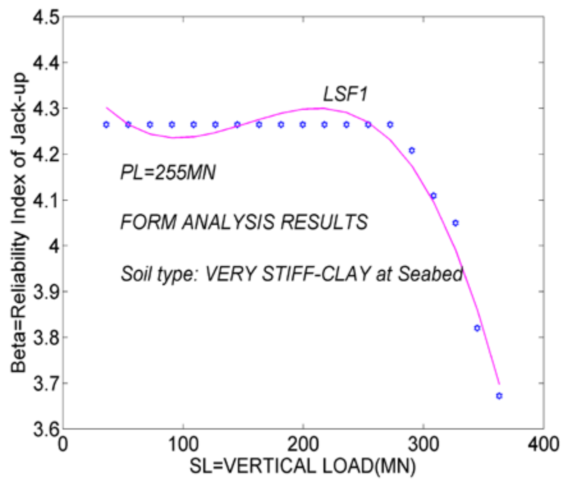

Fig. 14 Variation of the reliability index of jack up system with vertical load (SL) in very stiff clay

In Fig. 10, the spring back behavior has occurred after reaching a peak vertical load value at a large displacement of order of 20m in a spud-can supported in a very loose sand soil layer at the sea-bed. This might also indicate that the soil has failed in this case under a peak vertical load level of 180MN. The ultimate vertical load level which can be resisted by the spud-can footing after this rapid degradation falls below the 70MN which is far less than the designed vertical pre-load. This may indicate a structural failure of elasto-plastic buckling of main leg above the spud-can footing which occurs at this level of vertical displacement. The plastic utilization factor of the model also reveals this fact. Further inspection of the deformed model of the jack-up platform indicates that due to this mode of failure the jack-up structure tilts over the standing front leg and results in loss of global stability of the jack-up platform. This is because the overall dynamic or static equilibrium of the forces can't be achieved at this stage.

Fig. 12 shows the variation of the reliability index (β) of the studied jack-up system in a very soft-clay soil (Su=5KPa) at the sea-bed with vertical load (SL) with a maximum initial design pre-load of 255MN on each leg. As can be seen, the reliability index (β) varies very significantly with vertical load (SL) from near 4.35 at SL<50MN to about 0.5 at SL=225MN< PL=255MN. This might indicate that for this type of soil type the safety may be lost at PL=255MN, while at normal working condition of PLF<1.0, the reliability index (β) would be greater than 2.5.

Fig. 13 shows the variation of the reliability index (β) with the vertical load (SL) for a soft-clay soil (Su=50KPa) at the sea-bed due to gravitational and also wave and current induced loads on the Jack-up platform. As shown, β index varies from near 4.3 at SL<50MN to about 2.4 at SL=225MN<PL=255MN. This would indicate a better level of safety in this soil type during application of the maximum design pre-load.

Fig. 14 represents the variation of the β index with SL for the jack-up system supported in stiff clay soil. The reliability index varies from near 4.25 at SL<50MN to about 3.7 at SL=365MN>PL=255MN. This might indicate a higher level of safety in this case and extremely low probability of a punch through failure at spud-can footing.

Fig. 15 shows the variation of the β index value with SL for the studied jack-up system supported in loose sand. As shown, the reliability index of jack-up system varies in this case from near 4.4 at SL<50MN to about 0.7 at SL=382MN>PL=255MN. This indicates somewhat higher safety level compared to very soft clay type soil. At PL=255MN the reliability index is above 2.25.

As shown in Fig. 16, the reliability index of the platform would vary from about 4.22 at SL<25MN to near 0.5 at SL=180MN<PL=255MN. This indicates that the annual probability of jack-up rig failure is quite high even for normal working load condition in service.

Fig. 17 shows the variation of the reliability index vs. SL for medium sand layer of soil at sea-bed. B varies from near 4.28 to around 2.8 at SL=380MN>PL.

Fig. 18 also shows the results of FORM reliability analyses of the jack-up system under environmental loads supported in dense sand layer at sea-bed. B varies from above 4.3 at SL<50MN to about 3.7 at SL=385MN>PL. The latter indicates a very low probability of failure of spud-can per annum. It should be noted that in this case the layer of sand thickness is greater than diameter of spud-can 17.0-21.0m but if a thin layer of dense sand to be expected at the sea-bed overlaying a much softer soil layer such as soft clay, the results will be affected. In a subsequent study, this will be addressed.

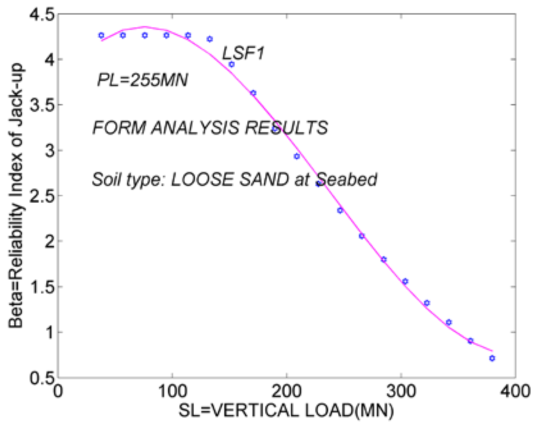

Fig. 15 Variatio of the reliability index of jack up system with vertical load (SL) in loose sand

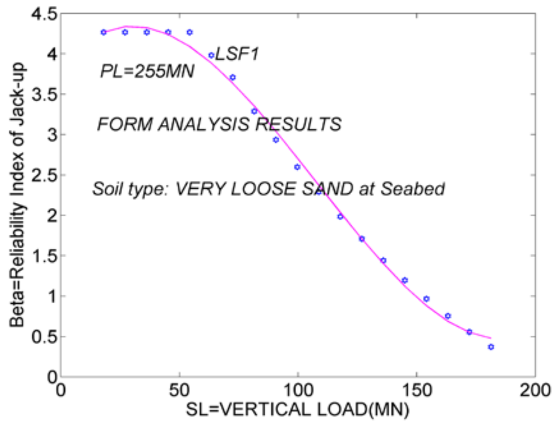

Fig. 16 Variation of the reliability index of jack up system with vertical load (SL) in very loose sand

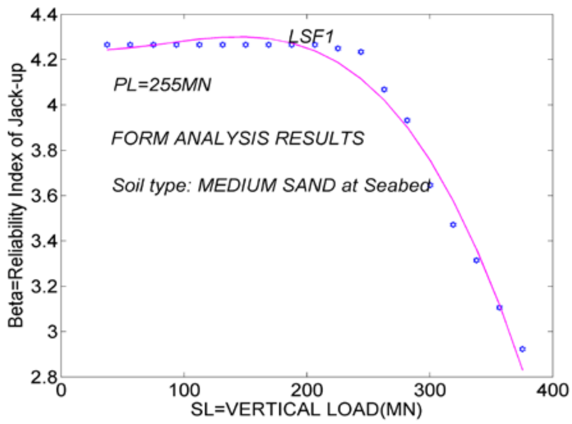

Fig. 17 Variation of the reliability index of jack up system with vertical load (SL) in medium sand

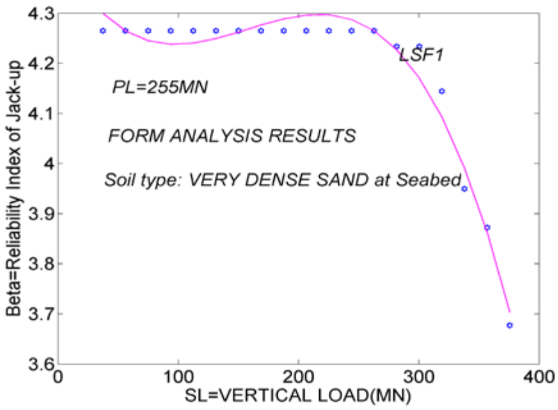

Fig. 18 Variation of the reliability index of jack up system with vertical load (SL) in very dense sand

From FORM and SORM reliability analyses, the importance factors were obtained in the range of 0.41-0.57 for jack-up and spud-can-soil model and also in the range of 0.43-0.59 for sea-state and wave and current load model. The results might also indicate that more refined spud-can-soil interaction modeling as well as wave-in-deck load modeling might improve the calculation models and hence reduce their associated uncertainty in reliability analysis of jack-up type platform.

XIII. CONCLUSION

It is shown that the reliability index (β) of the jack-up platform supported on spud-can footing may vary significantly with the vertical load (SL) due to action of wave and current. It is also concluded that variation of the reliability index of the jack-up rig depends heavily on the soil layer type at the sea-bed supporting the spud-can footing of jack-up.

It is also found that in the case of very soft clay with (SU=5KPa) a rapid penetration of the spud-can might be expected at PL=255MN corresponding to a pre-load factor of PLF=2.0. (Note that the initial design pre-load was about 122.5MN which was increased to 155MN for penetration in medium sand and then to a maximum value of 255MN)

It is also concluded that for a very loose sand layer during a very rapid penetration of spud-can footing occurring at the sea-bed up to order of 20m at a peak value of vertical load SL<PL=255MN, a spring back behavior may be expected due to elasto-plastic buckling occurring at the main-leg of the jack-up platform. This may result in overall loss of stability of the platform.

It is also concluded that the reliability index of the jack-up platform in the case of dense sand and stiff clay may vary less with increase of SL to a level even greater than peak value of PL=255MN, compared to softer clay and looser sand layers.

The Importance factors obtained from FORM and SORM analyses have also indicated that the sea-state and the spud-can-soil random parameters may play very important role in determining the reliability index of the jack-up system.

ACKNOWLEDGMENT

The author would like to acknowledge the support provided by the Marine Technology Center in Norway and also Usfos Company.

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APPENDIX

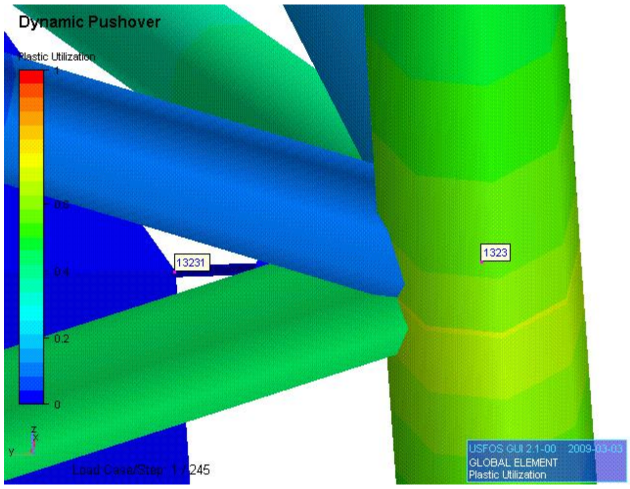

Fig. 1 A shows a typical non-linear spring FE model of usfos (no.13231) used at the connection of the hull-to-leg lattice structure

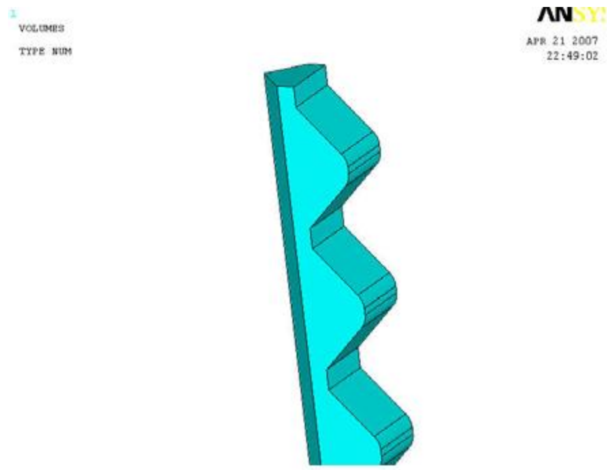

Fig. 2 A shows a more refined modeling of hull- to-leg connection in [26] using a FE model of racks on the leg-face of Neka Jack-up platform

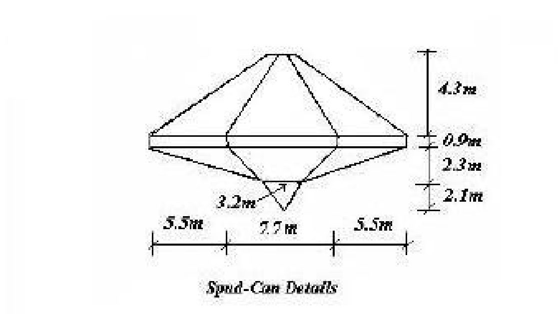

Fig.3 A shows a typical configuration of spud-can used for FE modeling of Neka Jack-up footing [26]:

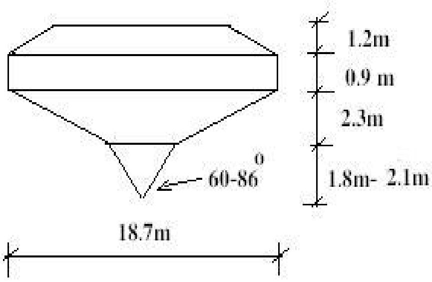

Fig. 4 A shows a modified geometry of the spud-can above as used for FE modeling in [26] and [13, 14]

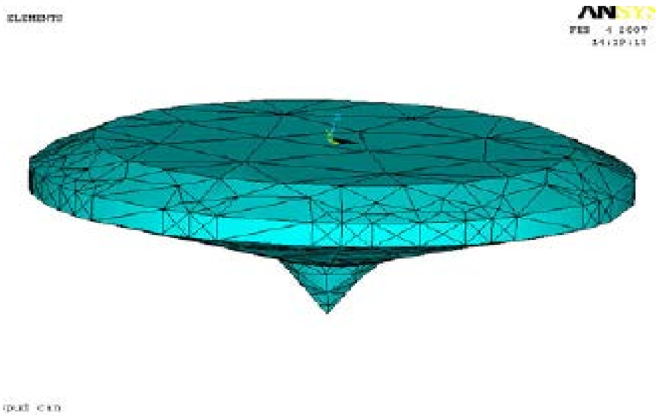

Fig. 5 A shows also a modified and refined FE model of the above spud-can configuration has been used in [26] for modeling of Neka Jack-up footing

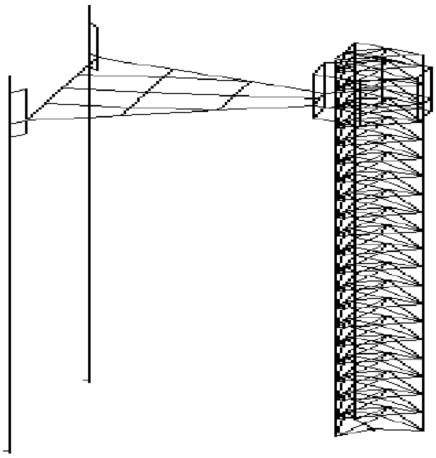

Fig. 6 A shows FE model of Neka Jack-up [7]

• Water depth (including tide and storm surge)	95 *m*
• Significant wave height	H_S=16.1 *m*
• Wave period	T_Z=13.6 *s*
• One minute sustained wind speed (at reference level 10 *m* above mean sea level)	36.5 *m/s*
• Extreme surface current velocity	1.2 *m/s*

Note that the Hs and Tz data were given for Hutton area of North-Sea[7,27] and so two set of different modified Hs and Tz values were used in [13,14] for the Neka Jack-up operating in the Caspian Sea region.

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