

Linear Static Analysis of Jack Up Structure at Different Modes of Operations

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ABSTRACT

A Jack up is an offshore structure with tubular members consisting of a buoyant hull which is self-elevating with number of movable legs, capable of raising its hull over the surface of sea. The Jack up is also called a mobile platform. The buoyant hull enables transportation of the unit and all attached machinery to a desired location. Once on location the hull is raised to the required elevation above the sea surface on its legs supported by the sea bed. The legs of such units may be designed to penetrate the sea bed, may be fitted with enlarged sections or footings, or may be attached to a bottom mat.

It experiences various type of loading such as wind, wave and current forces. There are specific formulae for finding these loads in the structure. Different classification societies like API, ABS, and DNV etc. have certain rules for the construction of the Jack up.

Some studies are done on these rules given by classification societies and a certain rule is selected for the present study. Loads will be calculated and the structure will be modeled using FEA package ANSYS 10.0. Finally results will be tabulated for different water depths.

Keywords – Hull, Jack-Up, Offshore, Self-elevating, Wave.

I. Introduction

The jack-up barges are typically three-legged structures having a deck supported on their legs. The legs are made of tubular truss members whereas the deck is typically buoyant. The jack ups are used for the drilling operation and, therefore, frequent transit is required. Sometimes it may be self propelled or they are transported on top of barges. They are called jack ups because once at the drilling site, the legs are set on the ocean bottom and the deck is jacked up on these legs above the waterline. The jack-up structures/barges behave like the stationary platform during the drilling operation. The major loads acting on the structure at operation are wind, wave and current forces. In this paper the attention is focused mainly on wave loading i.e. a dynamic load.

Present study is focused on jack up structures analysis. M.J. Cassidy [1] studied about the dynamic assessment of jack up due to random ocean waves and for increasing sea-state severity there was an increasing variation in the extreme horizontal deck displacements. A. Dier [2] concludes that jack-up effectively reacts statically to the vertical loading. Bernt J. Leira [3] studied about the site-dependent response characteristics of a jack-up platform operating at two different locations in the North Sea with different water depth and wave environment. D. Karunakaran [7] studied about the jack up platforms under extreme wave loading condition which exhibit

significant nonlinear behaviour and concluded that the major sources of non linear behaviour are the wave loading, the damping mechanisms and the soil structure interaction.

In our present study a linear static analysis of jack up structures at different modes of operations (ie. Operation, Survival and Transit mode) are considered for its structural response. A suitable structural dimension of the model is identified and the wave forces acting on the structure is calculated at different sites. The loads will be calculated using linear wave theory for different site location. Global analysis of the Jack up structure was carried out by applying wave loads, a particular joint where maximum stress was found is analysed and the same joint is taken for local analysis. For local analysis the joint selected is analysed to find its stress range and to predict its life. The linear static analysis will be carried out using FEA package ANSYS 10.0.

II. Structural Model

There are typically 3-legged and 4-legged jack-up structures. The jack-up barges are towed while supported by the buoyancy of their own hull. Sometimes, they are transported on top of transport barges. However the majority of the jack-ups that are produced are 3 legged. Fig.1 shows a typical 3-legged jack up structure.

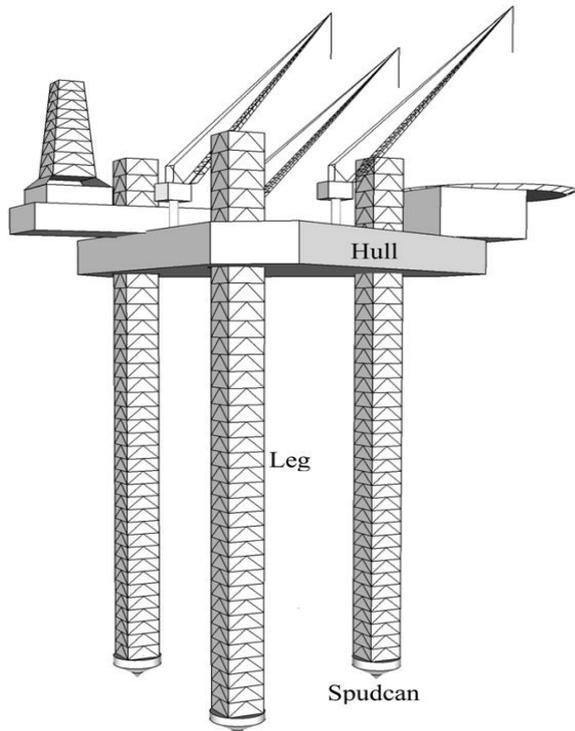


Fig.1 Typical three legged jack up unit [12]

III. Operation Mode

In Operation Mode, the main loads acting on the structure are wave, current, wind and some other live loads and operational loads. The wave data in North Sea at two different locations are considered for the analysis.

The jack up structure having a spud can of diameter approximately equal to 14.4 m is considered for the study. The wave loads are calculated using the Airy's theory and the following equations (ie. Eqn.1 & 2) are mainly used for the calculation of loads and the wave data for two locations are show in Table 1.

Drag Force, F_D , and Inertia Force, F_I , are quantified by;

$$F_D = \frac{\rho C_D D}{32k} \omega H^2 \left[\frac{\sinh 2ky}{\sinh^2 kh} + \frac{2ky}{\sinh^2 kh} \right] |\cos \omega t| \cos \omega t \quad (1)$$

$$F_I = \frac{-\rho C_I}{2k} \frac{\pi D^2}{4} \omega^2 H \left[\frac{\sinh ky}{\sinh kh} \right] \sin \omega t \quad (2)$$

Where, ρ = density of sea water; D =diameter of tubular member; ω =value of dispersion; ωt =angle in radians; k =wave number; h = water depth; H =wave height; C_D = drag coefficient and C_I = inertia coefficient.

For considering soil structure interaction effects FEA carried out using a set of spring elements which is equivalent to soil stiffness. The jack up structure having a spud can of diameter approximately equal to

14.4 m is considered for the study. For soil structure interaction effects depth equal to 2.5 times the diameter of spud can is considered (i.e. = 36 m).

The following equation gives the spring stiffness in different directions;

$$K_x = \frac{16 G_x B (1-\nu)}{(7-8\nu)} \quad (3)$$

$$K_y = \frac{2 G_y B}{(7-\nu)} \quad (4)$$

$$K_z = \frac{16 G_z B (1-\nu)}{(7-8\nu)} \quad (5)$$

Where, G_x and G_z = shear modulus for horizontal loadings in x- diction and z-direction; G_y = shear modulus for vertical loading in y-direction; B = effective spudcan diameter at the uppermost part of the bearing area; ν = Poisson's ratio of the soil.

For the dynamic analysis, the foundation spring stiffnesses are evaluated in accordance with Chan Ghee Koh [12] and the values are given below.

$$K_x = 3.24 \times 10^8 \text{ N/m}$$

$$K_y = 6.97 \times 10^8 \text{ N/m}$$

$$K_z = 3.24 \times 10^8 \text{ N/m}$$

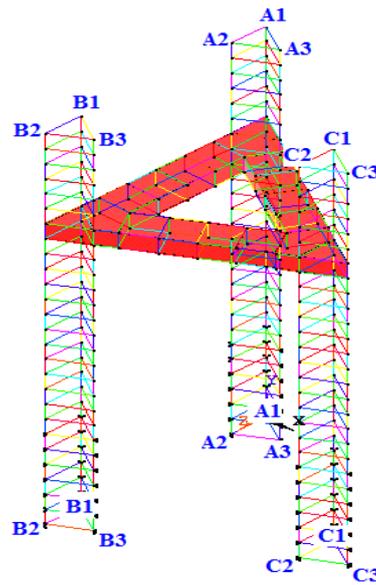


Fig.2 Simplified model of a jack up structure

Table 1 Wave data in North Sea at two different locations

DATA	Site 1	Site 2
Water Depth (h)	70 m	100 m
Wave Height (H)	15.5 m	11.0 m
Time Period (T)	10.82 sec	13.90 sec

3.1 Finite Element Analysis

In ANSYS 10.0 the following elements Beam188 and Shell63 is used for our analysis. The Fig.2 shows the simplified model of the jack up structure at site 1. The plan view of jack up as shown in Fig.3.

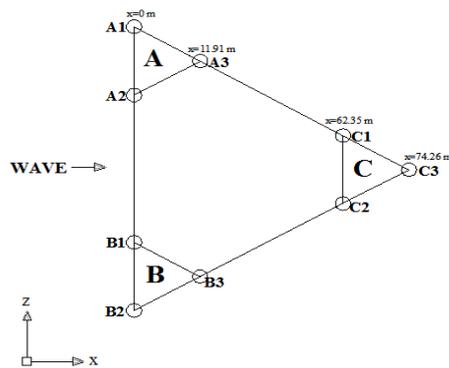


Fig.3 Plan View of a jack up structure

3.2 Jack Up Structure at Site 1

The jack up structure is oriented such that the two standing legs are incident by the wave treating it as a front face loading at site 1. The wave load acting at the peak height of the Jack up structure on each leg is calculated and shown in Table 2. The analysis is carried out in ANSYS10.0 and the stress diagram is found out as shown in Fig. 4.

Table 2 Wave loads at the peak height of the structure

Applied Wave Load at Site 1	Leg A (N)	Leg B (N)	Leg C (N)
Tubular Member 1 in Each Leg	140791	140791	38254
Tubular Member 2 in Each Leg	140791	140791	38254
Tubular Member 3 in Each Leg	100229	100229	52022

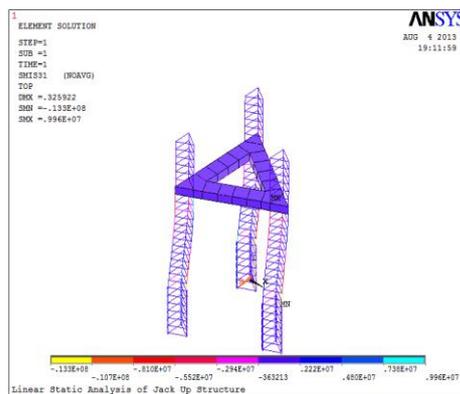


Fig.4 Stress Diagram at Site 1

After the analysis of jack up structure at site 1 got the maximum value of deformation as 0.326 m.

3.3 Jack Up Structure at Site 2

The jack up structure is oriented such that the two standing legs are incident by the wave treating it as a front face loading at site 2. The wave load acting at the peak height of the Jack up structure on each leg is calculated and shown in Table 3. The analysis is carried out in ANSYS10.0 and the stress diagram is found out as shown in Fig. 5.

Table 3 Wave loads at the peak height of the structure

Applied Wave Load at Site 1	Leg A (N)	Leg B (N)	Leg C (N)
Tubular Member 1 in Each Leg	55870	55870	5870
Tubular Member 2 in Each Leg	55870	55870	5870
Tubular Member 3 in Each Leg	50542	50542	23983

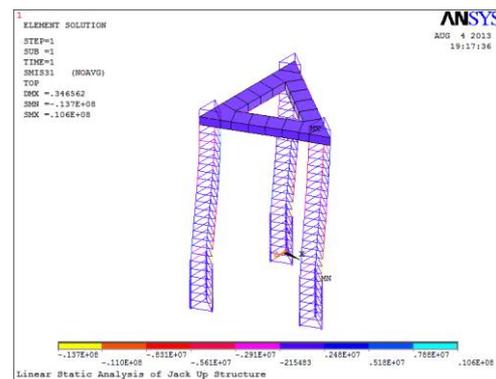


Fig.5 Stress Diagram at Site 2

After the analysis of jack up structure at site 2 got the maximum value of deformation as 0.347 m.

IV. Local Analysis

Global analysis of the Jack up structure was carried out by applying wave loads. A particular joint where maximum stress was found is analysed and the same joint is taken for local analysis. For local analysis the joint selected is analysed to find its stress range and to predict its life.

In the present study the tubular joint is modelled and the solution is obtained. Usually in FEA the mesh size differ at certain locations i.e. the area where stress gets concentrated is finely meshed. In our analysis the stress gets concentrated at the chord-brace intersection. So the places intersected (joints) in our study is meshed using fine elements. The joint which is considered for the local analysis is shown in Fig.6.

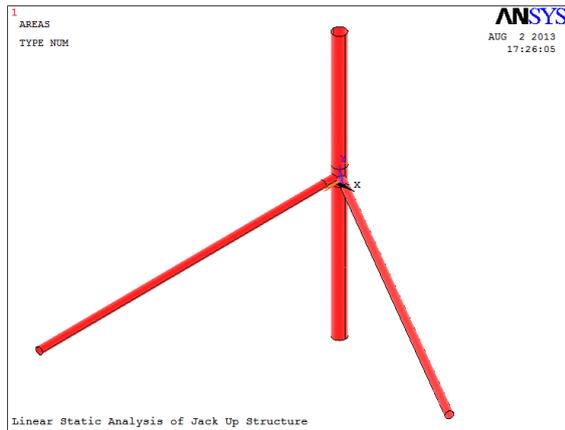


Fig.6 Joint which is considered for Local Analysis

The stresses are calculated for the particular joint (ie. the joint which we are interested) as shown in Fig.7.

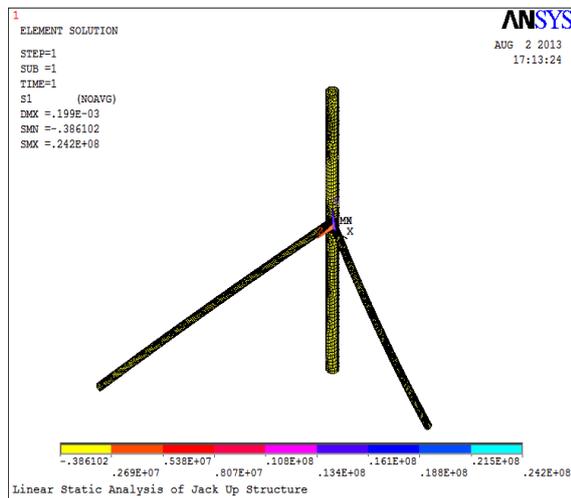


Fig.7 Stress Diagram

4.1 Fatigue Life

Maximum Stress, $\sigma_{max} = 0.242 \times 10^8 \text{ N/m}^2$

Minimum Stress, $\sigma_{min} = 0.3861020 \text{ N/m}^2$

Stress Range, $S = \sigma_{max} - \sigma_{min} = 24.2 \text{ Mpa}$

No. of Cycles Required for Fatigue Failure, $N = A S^{-m}$
As Per ABS Rules for Tubular Joints (Cathodic Protection Condition),

Fatigue Strength Coefficient, $A = 7.30 \times 10^{11} \text{ MPa}$
Exponent Coefficient, $m = 3$

No. of Cycles Required for Fatigue Failure (N),
 $N = 7.3 \times 10^{11} \times 24.2^{-3} = 52 \times 10^6$

No. of Wave Cycles in a Year (n),
 $n = \frac{3600 \times 24 \times 365}{10.815} = 2.9 \times 10^6$

Design Life, $T_d = 15 \text{ years}$
Fatigue Life, $T_f = N/n = 18 \text{ years}$

V. Survival Mode

When the Unit is performing operations, the weather is to be monitored. If non-cyclonic storms which exceed design operating condition environment are predicted, Operations should be stopped and the Unit placed in Storm Survival mode. If cyclonic storms are predicted, the precautions are taken and personnel evacuated from the Unit. 100 year wave condition is used. The 100 year wave data in North Sea is shown in Table 4.

Table 4 100 Year Wave data in North Sea

DATA	DESIGN VALUES
Water Depth (h)	70 m
Wave Height (H)	15.5 m
Time Period (T)	10.82 sec

The wave load acting at the peak height of the Jack up structure on each leg is calculated and shown in Table 5. The analysis is carried out in ANSYS10.0 and the displacement diagram is found out as shown in Fig. 8.

Table 5 Wave loads at the peak height of the structure

Applied Wave Load in Survival	Leg A (N)	Leg B (N)	Leg C (N)
Tubular Member 1 in Each Leg	587201	587201	15314
Tubular Member 2 in Each Leg	587201	587201	15314
Tubular Member 3 in Each Leg	477676	477676	60057



Fig.8 Displacement Diagram in Survival Mode

After the analysis of jack up structure in survival mode got the maximum value of deformation as 2.34 m and the corresponding value is compared with operation condition. The comparison of result is shown in Table 6.

Table 6 Comparison of Results (Operation and Survival)

RESULT	Operatio n Mode at Site 1(m)	Operatio n Mode at Site 2 (m)	Surviv al Mode (m)
Deformati on	0.326	0.347	2.34

VI. Transit Mode

In Transit Mode wind and wave loads are predominant, but only wave load is considered for the analysis. The Jack Up structure is transported from site A (North Sea location1) to site B (North Sea location 2). Due to lack of availability of data the wave data are averaged from the two site locations and is considered for the analysis.

When the Jack Up structure is transported from site A to site B it experiences wave as well as wind loading and these loadings are applied on the structure to get its response. When the structure is in transit the structure should not fail due to these combined loadings. So a preliminary analysis is to be done to check the structure matches the frequency of wave ie. modal analysis (dynamic) is carried out.

The boundary condition is selected such as the structure is taken at a point and all its bottom deck structure is fixed for the analysis purpose. In Transit Mode, the wave data in North Sea is considered for the analysis. The wave data is shown below in the Table 7.

Table 7 Wave data in North Sea

DATA	DESIGN VALUES
Water Depth (h)	80 m
Wave Height (H)	13.25 m
Time Period (T)	12.36 sec

The model of jack up and the different mode shapes are as shown in Fig.9 to 12.

After the analysis is carried out, the various structure frequencies are obtained and it is compared with the wave frequency. The obtained values of frequencies are does not match with the wave frequency and the comparison of results as shown in Table 8.

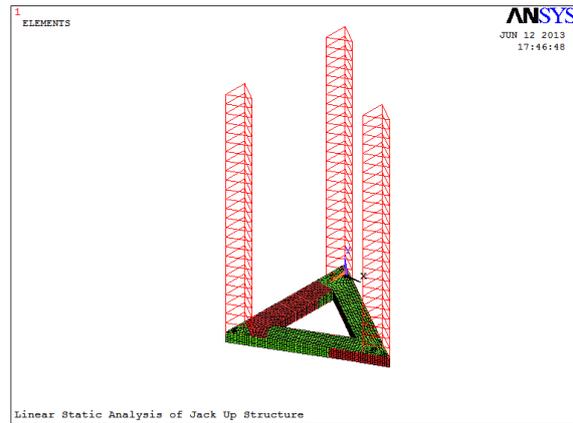


Fig.9 Model of a Jack Up under Transit condition

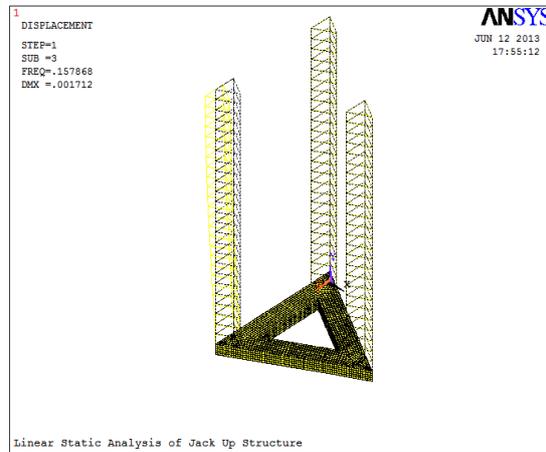


Fig.10 Mode Shape 1 of Jack Up at Transit

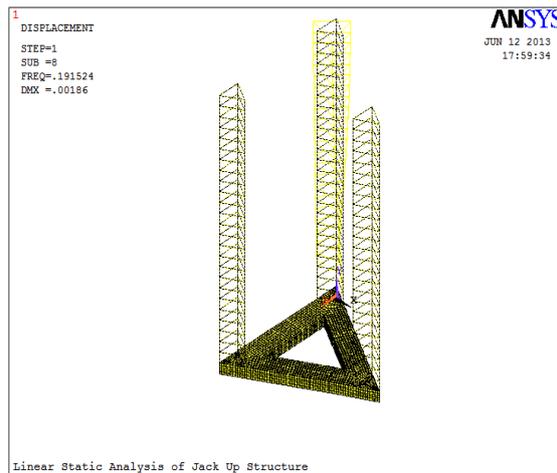


Fig.11 Mode Shape 2 of Jack Up at Transit

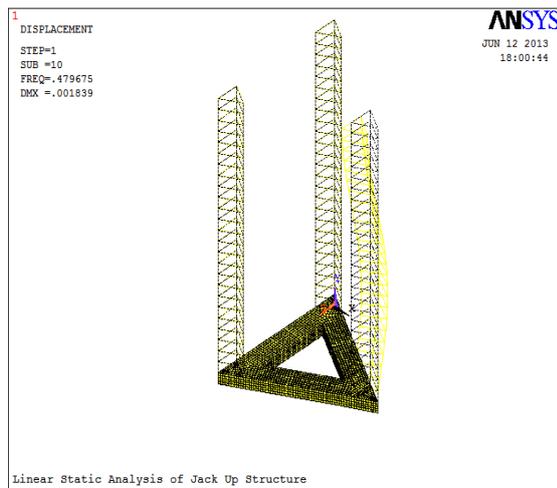


Fig.12 Mode Shape 3 of Jack Up at Transit

Table 8 Comparison of Results (Transit Mode)

MODE SHAPE	Structural Frequency	Wave Frequency
1	0.1579 Hz	0.0809 Hz
2	0.1915 Hz	0.0809 Hz
3	0.4797 Hz	0.0809 Hz

VII. Conclusion

The jack up structure which is a mobile offshore drilling unit experiences various kinds of loads ie while it is in operation and this structure as a whole is transported to the site for drilling and exploratory functions so necessity of carrying its structural response is very important for both survival and operational conditions. This structure differs from other offshore structures because of transit loads i.e other structures is placed in a large floating body, while majority of jack up is self propelled (some are towed). So analysis consideration should be considered for these.

The Jack up structure was identified at two different locations. Among the two, one with the major response was identified and the loadings were calculated using Morison's equation (ie. 25 year wave data for operational and 100 year wave data for survival). The structural response was found using FEA software ANSYS 10.0 for the operational as well as survival condition. The structural response in transit is also done for the same structure which experiences major response.

After the preliminary analysis is done (ie. global analysis), the next study was focussed on a particular tubular joint of interest where maximum stress lies. The same joint was modelled and stresses were carried for the chord-brace intersection.

Next study was focussed on life of the tubular joint which we are interested. This was done using an appropriate S-N curve from the rules (ie. ABS [18])

and by using formulae the life of the tubular joint was found out.

In survival mode the deflection found using preliminary wave load calculation was subsequently higher than the operational modes (ie. 7 times more than the operational mode). From the theoretical part the deflection will be greater for survival condition than in operational mode. The Offshore Industry does calculation for a 50 or 100 year wave data for the survival conditions. The major steps taken by the Offshore Industry is to evacuate personnel from the platform, stop the operation of the structure and necessary precautions will be taken for riser prevention.

Finally the dynamic analysis (ie. modal analysis) was carried out to determine the structural response in transit and its response was found and the results were tabulated. Soil-Structure Interaction (SSI) was also studied to incorporate the behaviour of the structure with the soil.

The analysis model generated can be used for any of the available offshore loading conditions as an initial reference to the design of such structures. The analysis may also be extended to local analysis of legs for more accurate results.

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