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DYNAMIC RESPONSE OF OFFSHORE TRICERATOPS UNDER ENVIRONMENTAL LOADS

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ABSTRACT

Offshore Triceratops is relatively new concept in deep water oil explorations in recent times. They exhibit structural advantages in comparison to other platforms suitable for deep water applications. Structural integration of deck system, ball joint, Buoyant Leg Structures (BLS) and foundation system make them attractive for the encountered environmental loads. BLS is a positively buoyant system that serves as a buoyant chamber and storage chamber as well. Ball joints provided between deck and BLS do not transfer rotation; but transfers lateral displacements, making them more effective to encounter undesirable yaw motion caused due to aerodynamic loading. Detailed dynamic analysis of offshore triceratops under wind, wave and current are presented. Based on the analytical studies carried out using ANSYS AQWA, it is seen that the deck response is relatively less in comparison to the buoyant legs, making advantageous for operation in moderate sea states.

Key words: Ball Joint, Buoyant Leg Structure, Non-linear Dynamic Analysis, Triceratops.

1. INTRODUCTION

Recent advancements in oil and gas exploration demands more innovative platform designs to alleviate wave loads in ultra-deep waters. Considering the fact that oil reserve found in shallow waters are almost been exploited, future exploration is expected to be towards ultra-deepwater (1000 to 3000m and deeper). This necessitates innovative platform geometries that are capable of alleviating encountered environmental loads at these greater depths. Tension leg platforms (TLP), sub-sea systems, semi submersibles, FPS, FPSOs and Spars are suitable for greater depths of about 1000m to 3000m. However, they are expensive due to factors namely: i) large deck payloads; ii) large hull size, iii) complex station keeping systems etc. TLP, a most commonly preferred platform for deep water, is a hybrid design; it is stiff in vertical direction and compliant in horizontal direction, making it advantageous to alleviate the encountered environmental loads. On the other hand, offshore triceratops has a structural integration of deck structure, ball joint, BLS and tethering system, making it more suitable for ultra-deep waters. Ball joints are special components that transfer displacements from BLS to deck and vice-versa; pitch, roll and yaw motions are not transferred.

Experimental investigations and simplified analyses employed to study the dynamic response of TLPs show that the analytical methods are valid and practical [27]. Experimental investigations made to estimate tether force of deep water TLP model closely agree with the analytical methods, validating the employed analytical methods [25]. Researchers also emphasized the necessity of estimating the wave forces on TLPs at displaced position to account for non-linear effects in their dynamic response behavior [21].

Yoshida et al. [28] discussed linear response analysis of TLP under regular waves by considering the flexibility of superstructure in the equations of motion; response motions, tension variations of tendons and structural member forces were solved simultaneously. The applicability of this method was confirmed by comparison with the test results on two kinds of small-scale TLP models. A new spectral description of the longitudinal wind velocity fluctuations over the ocean for estimating the wind induced response to TLP was used [1]. Haritos [12] modeled the response of TLP under wind and wave loading; the study highlighted the aerodynamic influence on surge response, in particular. Analytical studies conducted on TLP model by estimating wave forces using three-dimensional singularity method proved to closely agree with that of the results of experimental investigations carried out. The study also showed a close agreement of the simulated time history with respect to the experimental ones [17].

Nordgren [20] analyzed high frequency vibration of TLP using spectral analysis. Results used to estimate the fatigue life of the platform was found to be adequate. However, few researchers conducted linear analysis in frequency domain to estimate the surge response under random waves. The nonlinear time domain and frequency domain approaches used in the study show that the varying damping ratio does not influence the mean surge response of TLP [10-11]. Kareem and Zhao [16] analyzed the response of TLP for random wind loading using Gaussian distribution and equivalent quadratization method. The higher order response cumulants were developed based on Volterra series. A direct integration and Kac-Siegert technique was used to evaluate the response cumulants. The results showed a good comparison with simulation. Jain [14] examined nonlinear coupled response of offshore TLP to regular wave forces considering coupling between surge, sway, heave, roll, pith and yaw DOF's. The nonlinearities arising from hydro-dynamic drag, change in tether tension, variable submergence effect was highlighted in the study. Higher order nonlinear transfer functions were also alternatively employed by researchers to estimate the TLP response; the results showed linear and nonlinear components of the response, explicitly [13, 2].

Mekha et al. [19] studied the implication of the tendon modeling on the global response of TLP in general and on the limits of the tendon forces in particular. Thiagarajan and Troesch [23] conducted model tests to examine the heave effects of uniform current in the presence of disk at TLP columns. The hydrodynamic interactions among TLP members are generally included in the motion and structural response analysis; elastic mode is applied to solve the radiation problem [9]. Tabeshpour et al. [22] studied the nonlinear dynamic response of TLP in both time and frequency domains under random sea wave loading. The time history of random wave is generated based on Pierson-Moskowitz spectrum while hydrodynamic forces are calculated using modified Morison equation. The power spectral densities (PSDs) of displacements, velocities and accelerations are calculated from nonlinear responses. Statistical linearization techniques were employed to model the tendon forces more effectively [18]. Yan et al. [26] presented stress response of a tension leg platform in extreme environments.

Chandrasekaran & Jain [3-4] compared the dynamic behaviour of square and triangular TLP under regular and random waves loading. The results show that the triangular TLP exhibits a lower response in the surge and heave degrees of freedom than that of the four-legged (square) TLP. The triangular TLP attracts more forces in the pitch degree of freedom and the response in this degree of freedom is more than that of the four-legged (square) TLP. Chandrasekaran & Jain [5] studied the aerodynamic behavior of triangular TLP due to low frequency wind force and random waves. The effect of the offset of aerodynamic center (AC) and center of gravity (CG) of the platform on the coupled response of triangular TLP is discussed. Results shows that the low-frequency wind alter the response of TLP to a considerable extent. Studies report that the influence of hydrodynamic coefficients in TLP response is nonlinear; they also influence the plan dimension of TLP and its site location. Chandrasekaran et al. [7] presented response behavior of triangular TLP under impact loading and investigated to be safe for the considered Mathieu stability analyses. Zeng et.al [29] developed theoretical model for analyzing the nonlinear behavior of a TLP with finite displacement in which multi-fold nonlinearities are taken into account, i.e., finite displacement, coupling of the six degrees of freedom, instantaneous position, instantaneous wet surface, free surface effects and viscous drag force. Chandrasekaran et al. [6] presented the response behavior of triangular TLP under regular waves using Stokes nonlinear wave theory. Results show that the coupled response in surge and pitch degree of freedom obtained using Stokes' theory is lesser than that obtained using the Airy's theory. Chandrasekaran et al. [8] studied the response behavior of triangular TLPs using Dynamic Morison equation considering nonlinearities associated with vorter shedding effects.

White and Copple [24] introduced an innovative effective platform named "triceratops" in ultra deep water application. They highlighted the inherent characteristics that facilitate its cost effective construction and installation while minimizing potential problems during its service life.

It is seen from the literature that dynamic response analyse on offshore triceratops are scarce despite the platform design being innovative. The present study is focused on the analytical estimate of response of triceratops under different sea states.

2. ANALYSIS OF TRICERATOPS

2.1 Structural Modeling

Triangular TLP and triceratops at 600m water depth are modeled; for the basis of comparison, buoyancy and water depth are kept same for both the models. Details of the models considered in the analysis are given in Table 1. Triceratops is modeled in ANSYS AQWA software by using cylinders for BLS structure and plate for the deck. Meshing of the model is done using quadrilateral plate elements. Total No. of nodes and elements are 3006 and 2940 respectively. Total No. of diffracting nodes and elements are 1635 and

1608 respectively. The Plan and elevation of the model are shown in Figs. 1- 2.

The behavior of Triceratops is studied for different environmental loads such as waves, wind and current. The waves are generated using Pierson-Moskowitz spectra. The waves, wind and current data is given in Table 2.

Table 1. Details of Triangular TLP and Triceratops.

Description	Notation	Units	TLP	Triceratops
Water depth	D	m	600	600
Material			Steel	Steel
Unit Weight of the material	ρ	kg/m^3	7850	7850
Centre to Centre distance of the legs	Pb	m	70	70
Diameter/equivalent dia. of each leg	d	m	17	17
Freeboard		m	22	22
Draft		m	32	74.7
Length of each leg	L	m	54	96.7
Tether Length	l	m	568	525.3
Unit weight of surrounding fluid		kN/m^3	10.25	10.25
Buoyancy of TLP including pontoons	F_B	kN	521600	521600
Area of deck	A	m^2	1732.41	1732.41
Self weight of TLP+Payload	W	kN	351600	351600
Total Tether force	T_t	kN	170000	170000
Radius of gyration about x axis	r_x	m	35.1	35.1
Radius of gyration about y axis	r_y	m	35.1	35.1
Radius of gyration about z axis	r_z	m	35.1	35.1
AE/l of the tether		kN/m	84000	84000
Area of the tether	A	m^2	0.24	0.22
Diameter of tether	d	m	0.55	0.53

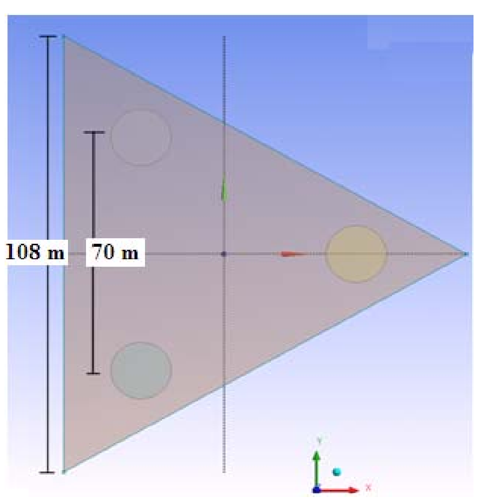

Figure 1. Plan of offshore triceratops model

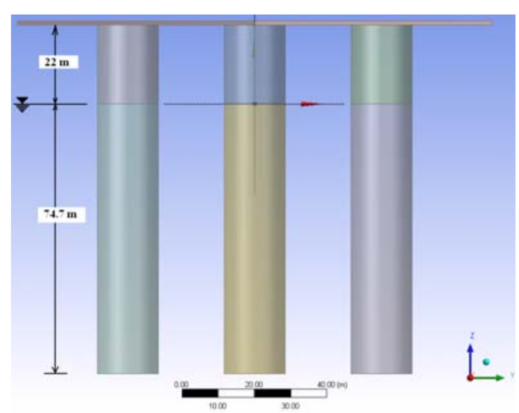

Figure 2. Elevation of the model

Table 2 Wave, current and wind data

Wave Data		Current Data	Wind Data
H_z (m)	T_z sec	V_C (m/s)	V_W (m/s)
(1)* 10	10	0, 0.5	35
(2)* 12	15	0, 1	40
(3) *15	15	0, 1.5	45
* Spectrum Number			

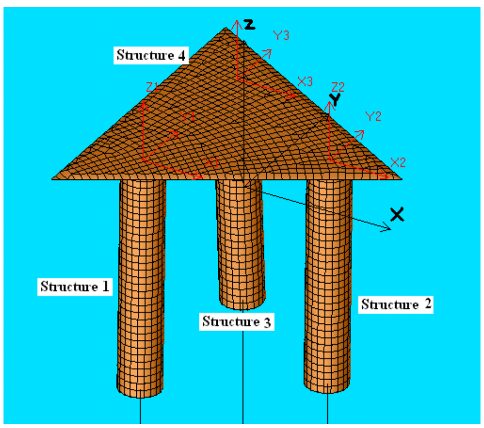

Figure 3. Numbering of structure in the analysis

In the analysis, the response of three BLS structures & the deck are evaluated separately. The structure's numbering is given in Fig. 3. The three BLS structures are connected to the foundation system with the tethers while their connection to the deck is through universal joints (ball joints). The connection of the BLS system to the sea bottom is shown in Fig. 4. The spectra considered for the present study is shown in Fig. 5.

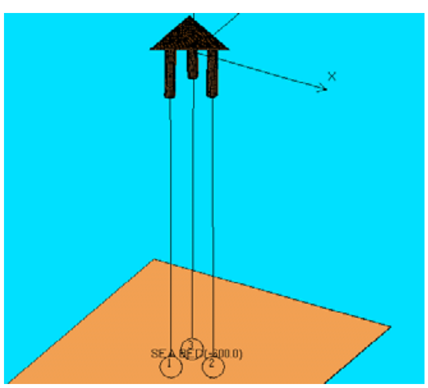

Figure 4. Connection of BLS system to sea floor

The Pierson-Moskowitz spectrums considered for the study is shown in Fig. 5.

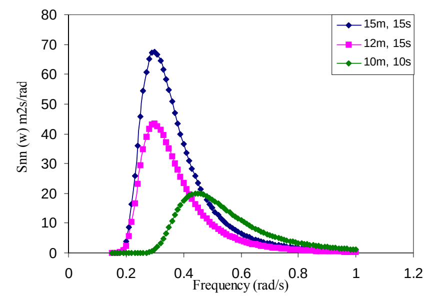

Figure 5. Wave Spectra considered for the present study.

3. ANALYSIS OF RESULTS

The response amplitude operators (RAO) of each sub-structure of triceratops, in surge and roll degrees-of-freedom are shown in Figures 6-7 respectively; wave height and time period of (H_s,T_z) are taken as (15m-15s; 12m-15s; and 10m- 10s) in the present study. Current velocity of 1.5m/s and wind velocity of 45m/s are considered. For the encountered environmental loads, peak responses in different degrees-of-freedom are given in Table 3.

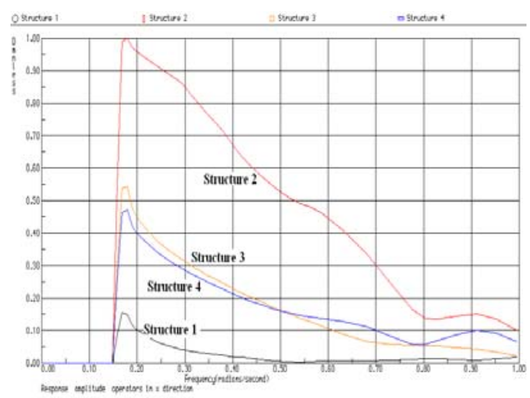

Figure 6. Surge responses of triceratops

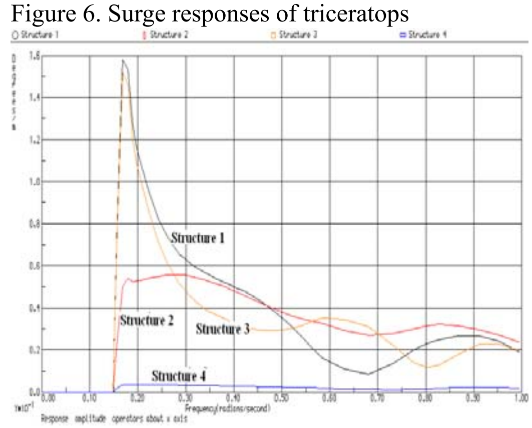

Figure 7. Roll responses of triceratops

Table 3 Peak responses of triceratops for different loads

Description	Surge	Sway	Heave	Roll	Pitch	Yaw
Sp1+Wind	1.15 (2)	0.19 (1)	0.02 (2)	0.158 (1,3)	0.49 (2)	2 (1)
Sp2+Wind	1.15 (2)	0.2 (1)	0.02 (2)	0.165 (1)	0.49 (2)	2.2 (1)
Sp3+Wind	1.0 (2)	0.19 (2)	0.02 (2)	0.16 (1)	0.48 (2)	2.1 (1)
Sp1+Wind +C	1.15 (2)	0.19 (1,3)	0.02 (2)	0.16 (1,3)	0.5 (2)	2.1 (1)
Sp2+Wind +C	1.15 (2)	0.2 (1)	0.022 (2)	0.17 (1)	0.5 (2)	2.2 (1)
Sp3+Wind +C	1.0 (2)	0.17 (2)	0.02 (2)	0.16 (1)	0.48 (2)	2.1 (1)
Sp: Spectrum C : Current (*) : Structure #						

4. DISCUSSION OF RESULTS

Surge and roll RAOs, as seen in Figures 6-7 show that surge response in the deck (marked as structure #4) is comparable with the surge response of individual BLS units. This indicates a collective response of the deck and BLS as an integral unit, ensuring efficient connectivity between BLS and the deck. Excessive surge and roll response in BLS 2 shall be attributed to variation in tether tension caused in leg 2 under the considered sea states. It is seen from the Table 3 that yaw motion is significant manifestation of presence of wind forces under the wave action; however, heave response in the BLS remains under the permissible values. It is also seen that the presence of current does not influence dynamic response of TLP, significantly.

5. CONCLUSIONS

Results show that the deck exhibits less roll response under the chosen sea states, highlighting the advantage of ball joint between the deck and BLS. However, the surge response is considerate, ensuring the effective control of roll motion between the elements namely the deck and BLS, respectively. This type of behavior is advantageous to upkeep more facilities on the deck system and for comfortable operation during moderate sea states.

The paper presented the analytical studies on triceratops under three different critical sea states, which is relatively new in the literature. The focus was to highlight the advantages of the structural configuration, making it suitable for deep waters. However the comparison of its behavior with other deep water platforms is not in the scope of the present study and hence not presented.

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