Response Mitigation of Offshore Triceratops

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Abstract - *Offshore triceratops is relatively a new concept with respect to the structural form that is attempted for ultra-deep waters. It consists of a deck and buoyant leg structures (BLS) that are positively buoyant and the platform is position-restrained by tethers. Ball joints, which connect the deck and the BLS units, restrain the transfer of rotations between them. Introduction of ball joints between the deck and buoyant leg structure (BLS) which transfers the translations from BLS but restrains the transfer of rotations to the deck makes triceratops different from other new-generation offshore platforms. This paper deals with the detailed numerical investigations of the dynamic behaviour of deep water triceratops under extreme regular waves excitations using the finite element software ANSYS AQWA. This paper aims to address the control of vibrations by passive method of control. A Tuned Mass Damper (TMD) is used to achieve the response control in surge and heave degrees of freedom. Three models of TMD are attempted- one with mass ratio of 2% and one with mass ratio of 3%. Comparison of RAO of triceratops with and without TMD from the numerical analysis showed that with the increase in mass ratio of TMD, more control over surge, heave and pitch degrees of freedom can be attained.*

Key Words*: *Triceratops, Buoyant Leg Structure, Tuned Mass Dampers, ANSYS AQWA

1. INTRODUCTION

Offshore triceratops is a new generation offshore platform that controls wave loads by its innovative structural form and design. It consists of a deck structure, buoyant legs (BLS) and ball joints that are placed between the deck and the buoyant legs. Platform is position-restrained by taut-moored tethers. Complexities that arise in deep water oil exploration demands a more adaptable structural form to alleviate the encountered loads without compromising on the compliant characteristics that are advantageous and cost-effective.

Each BLS hull supports the deck structure through a large ball joint, thus making the triceratops stable. The deck of the triceratops does not pitch and roll with the limited surge, sway, pitch and roll motions of the BLS hulls as these joints provide the hull units with rotational compliancy. Triceratops requires pretension, typically one-third to one-half of the TLP pretension requirements. Another very important characteristic of the BLS units supporting the triceratops deck structure is their configuration consisting of multiple cylindrical shells. These ring- and stringer-stiffened cylindrical shells are easy to construct, thereby minimizing fabrication defects, facilitating parallel construction, reducing construction cost and shortening the overall schedule.

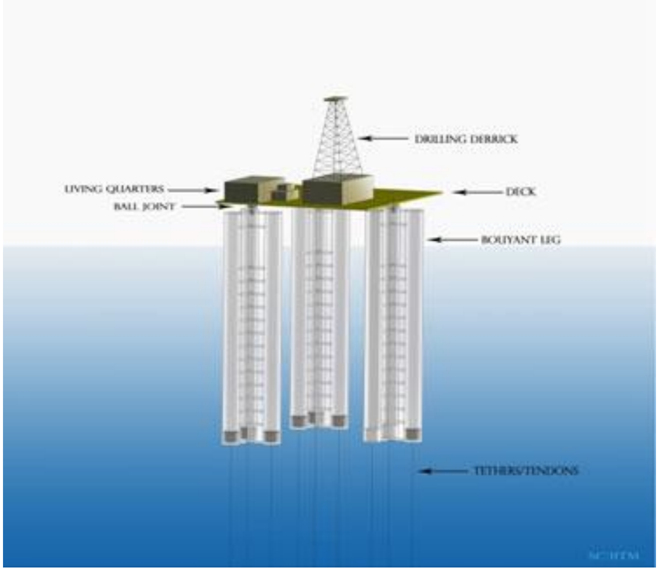

Fig -1: Conceptual view of an offshore triceratops

In this study focus is laid on heave, pitch and surge response of BLS units and deck. Close examination of heave response becomes necessary since it is affected by tether tension variations and may result in tether pull-out, which can cause serious operational problems to the taut moored systems like offshore triceratops. Pitch response of the BLS units and deck are examined to highlight the reduction in response of the deck in the presence of ball joints and this ensures that the platform shall remain horizontal even under critical loading conditions. Triceratops' motion characteristics are better than those of other floating production platforms without the disadvantages associated with larger environmental loads, complex structural details and higher costs. Fig 1 shows the conceptual view of an offshore triceratops.

2. DYNAMICS OF TRICERATOPS

The equation of equilibrium between the buoyancy, dead weight and the tether tension is given by:

$$F_b = 3T_0 + W$$

Where

F_b is the buoyant force,

T_0 is the initial pre-tension in each tether, and

W is the weight of the platform

The equation for motion of the platform is

$$[M]\{\ddot{x}\} + [C]\{\dot{x}\} + [K]\{x\} = \{F(t)\}$$

The mass matrix $[M]$ as given by (see Chandrasekharan et.al 2012)

$$\begin{bmatrix} M_{11}+M_{a11} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & M_{22} & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & M_{33}+M_{a33} & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & M_{44} & 0 & 0 & 0 & 0 & 0 \\ M_{a51} & 0 & M_{a53} & 0 & M_{55} & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & M_{66} & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & M_{77} & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & M_{88} & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & M_{99} \end{bmatrix}$$

$$M_{11} = M_{22} = M_{33} = M_{deck} + M_{BLS} + Payload$$

M_{44}, M_{55}, M_{66} are the total mass moment of inertia of BLS about the x,y,z axis and M_{77}, M_{88}, M_{99} are the total mass moment of inertia of deck about the x,y,z axis. M_{a11}, $M_{a33}, M_{a51}, M_{a53}$ are the added mass terms.

$[C]$ is the damping matrix.

The global stiffness matrix $[K]$ is given by (see Chandrasekharan et.al 2012)

$$\begin{bmatrix} k_{11} & 0 & 0 & 0 & k_{15} & 0 & 0 & k_{18} & 0 \\ 0 & k_{22} & 0 & k_{24} & 0 & 0 & k_{27} & 0 & 0 \\ k_{31} & k_{32} & k_{33} & k_{34} & k_{35} & k_{36} & k_{37} & k_{38} & k_{39} \\ 0 & k_{42} & 0 & k_{44} & 0 & 0 & k_{47} & 0 & 0 \\ k_{51} & 0 & 0 & 0 & k_{55} & 0 & 0 & k_{58} & 0 \\ 0 & 0 & 0 & 0 & 0 & k_{66} & 0 & 0 & k_{69} \\ 0 & k_{72} & 0 & k_{74} & 0 & 0 & k_{77} & 0 & 0 \\ k_{81} & 0 & 0 & 0 & k_{85} & 0 & 0 & k_{88} & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & k_{99} \end{bmatrix}$$

The coefficients, *Kij*, of the stiffness matrix of the triceratops are derived as the reaction in the degree of freedom *i* due to unit displacement in the degree of freedom *j*, keeping all other degrees of freedom restrained. The degrees of freedom surge (1), sway (2), heave (3), roll (4), pitch (5) and yaw (6) are associated with the BLS units; and degrees-of-freedom 7, 8 and 9are associated with roll, pitch and yaw of the deck, respectively.

The force vector at any time instant is

$$\{F(t)\} = [F_1 \quad F_2 \quad F_3 \quad F_4 \quad F_5 \quad F_6 \quad F_7 \quad F_8 \quad F_9]^T$$

Where F_i is the force in i^{th} degree-of-freedom.

Force vector is calculated for extreme waves without considering the effect of wind and current.

According to Morison's equation, the intensity of wave force per unit length on the structure is given as:

$$df = 0.5\rho_w D C_d(\dot{u_f} - \dot{x}_s)|\dot{u_f} - \dot{x}_s| + \rho_w A C_m \ddot{u_f} - \rho_w A(C_m - 1)\ddot{x}_s$$

where C_d is the drag coefficient, C_m is the inertia coefficient, D=Characteristic drag diameter, $\dot{u_f}$ is the fluid velocity in the transverse direction, $\dot{x}_s, \ddot{x}_s$ are the structural velocity and acceleration in the transverse direction of BLS respectively, A is the cross-sectional area, ρ_w is the mass density of the fluid
$(\dot{u_f} - \dot{x}_s)$ is the instantaneous relative velocity in the considered direction.

3. NUMERICAL ANALYSIS

Green canyon, GOM (27.05N, 90.45W) is chosen as the location for the proposed platform. The selected area has a water depth of 1296m. The mass and geometric properties of deck of the proposed platform is derived from the existing tension leg platform, Marco Polo located in the same region.

Table-1: Mass Properties of platform

Details	Tethered (kg)
Payload	21550000
Ball joint	1,013,000
Leg weight	10829953.45
Ballast	12723450.25
Tether mass	21289041.89
Pretension	5575853.079
Total load	67405445.59
Total Buoyancy force	84133004.83

The surface profile of the triceratops is simulated in 3D modelling software called "Design Modular" which is available in ANSYS AQWA. BLS units are modelled as tube elements in ANSYS AQWA and the deck is modelled as surface elements. Since dampers cannot be modelled physically in AQWA, values of damping force are inserted.

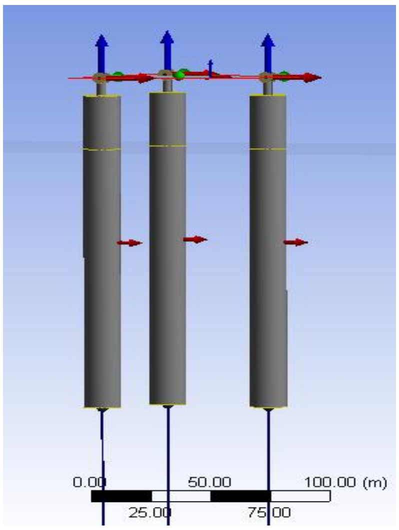

Fig -2: Triceratops modelled in ANSYS AQWA

3. RESULTS AND DISCUSSIONS

Dynamic analysis is carried out triceratops model with three configurations- one without TMD, triceratops with TMD of mass ratio 2% and triceratops with TMD 3% (with damping ratio of 1%) placed within the three BLS units. A single mass damper per BLS unit, that is total three mass dampers are provided.

Table-2: Structural Properties of platform

Details	Tethered
Water depth (m)	1296
Draft (m)	145
Density of water(kg/m^3)	1,025
Density of steel (kg/m^3)	7850
BLS	
Outer diameter(m)	15.5
c/c distance (m)	70
Cylinder height(m)	175
VCG from MSL(m)	−46.30793
VCB from MSL(m)	-72.5
r_x, r_y	47.78724374
r_z	5.45356105
Deck	
Shape of the deck	Triangular deck
Length of the deck	95m
r_{Dx}, r_{Dy}	17.5944
r_{Dz}	17.45143
VCG	40.25
Length of the tether	1151 m
Modulus of elasticity	2×10^8kN/m^2

The natural periods of vibration of the structure is summarised in Table 3

Table-3: Natural Periods of vibration

Degree of freedom	Natural Period(s)
Surge	143.6782
Sway	143.6782
Heave	2.094767

Fig 3 to 5 shows time history of triceratops without damper for a wave height of 19.6m and wave period of 12s. The response of the deck of the platform is very less compared to that of BLS units indicating the effectiveness of ball joint.

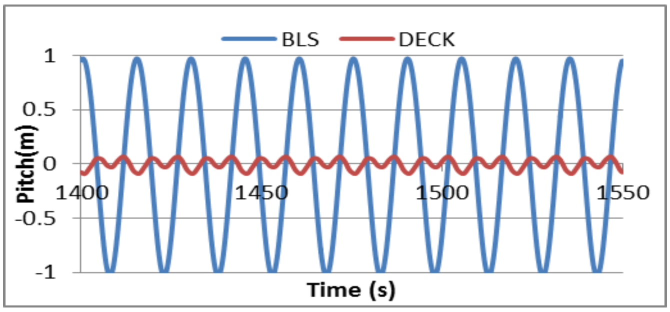

Fig-3: Pitch response of triceratops without TMD (H_{max}=19.2m, T=15s)

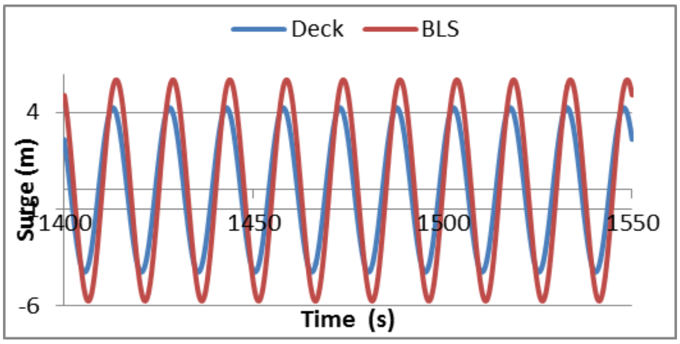

Fig-4: Surge response of triceratops without TMD (H_{max}=19.2m, T=15s)

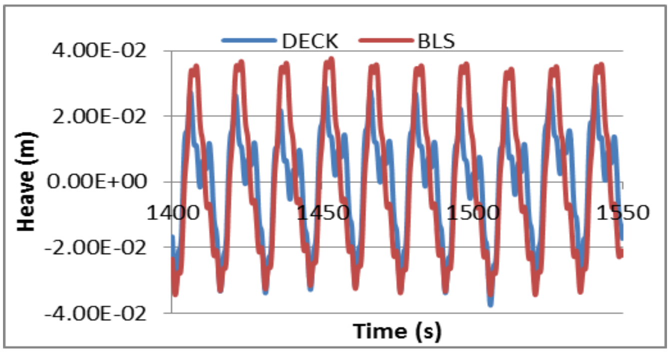

Fig-5: Heave response of triceratops without TMD (H_{max}=19.2m, T=15s)

The surge, pitch and heave RAO of the triceratops with and without TMD attached to it is compared as shown in figures

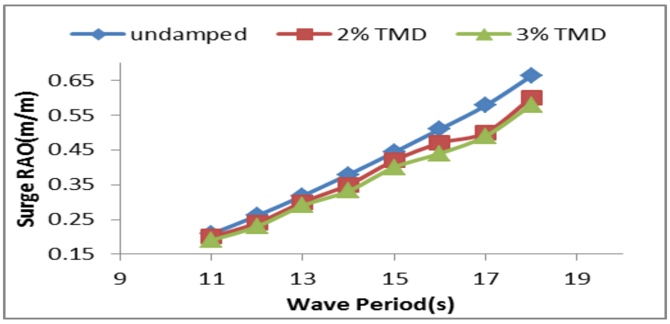

Fig- 6: Comparison of surge RAO for the BLS unit with and without damper, H=19.2m

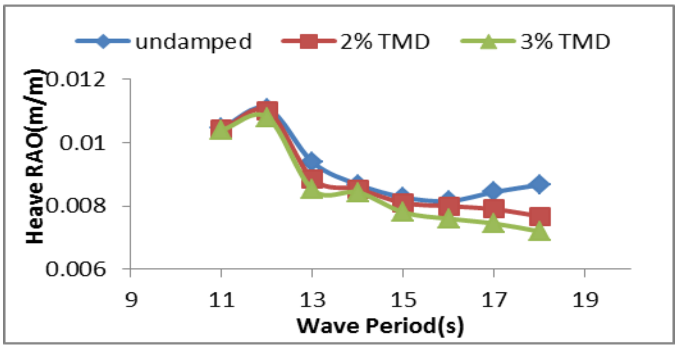

Fig-7: Comparison of heave RAO for the BLS unit with and without damper, H=19.2m

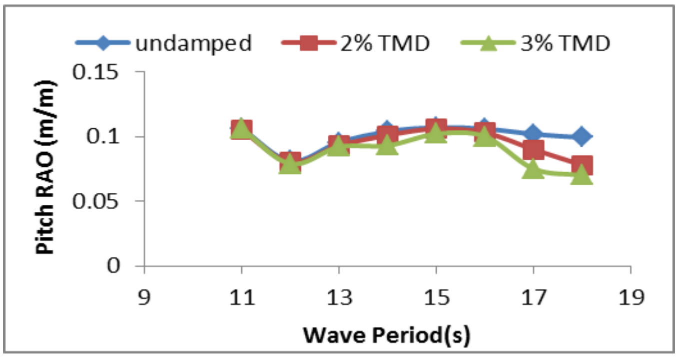

Fig-8: Comparison of pitch RAO for the BLS unit with and without damper, H=19.2m

The maximum percentage reduction in response in different degrees of freedom for wave heights of 12m, 15m and 19.2m are summarized in table4.

Table-4: Maximum percentage reduction in response under regular wave

Response	With TMD (2%)			With TMD (3%)		
H (m)	12	15	19.2	12	15	19.2
Surge	6.31	10.29	12.53	10.73	16.96	17.38
Heave	7.14	5.73	8.13	8.9	12.4	12.6
Pitch	8.42	8.412	8.425	10.27	15.08	15.74

It can be seen that increase in mass ratio of TMD induced better control for the response of triceratops. Increase in mass of the damper inculcates additional damping to the structure and hence response reduction is also increased. The response control in the surge and heave direction indirectly controls the response in pitch degrees of freedom due to coupling. Similar trend of response is obtained for all wave heights considered for the study.

4. CONCLUSIONS

Based on the numerical investigations conducted on triceratops, following conclusions are made:

- The rotations of the deck can be effectively reduced by the use of ball joints. Reduced response in rotational degrees of freedom helps to make the deck remain horizontal thus increasing the operational efficiency.
- A Spring-mass system, with higher mass ratio is effective for response reduction within the range of normal sea wave periods.
- Surge response can be effectively controlled by the use of TMD.
- The maximum percentage reduction in surge response is found to be 6.31% and 10.73% with the mass ratio of 2% and 3% respectively for the wave height of 12m within the period between 7s and 18s.
- The maximum percentage reduction in surge response is found to be 10.297% and 19.66% with the mass ratio of 2% and 3% respectively for the wave height of 15m within the period between 7s and 18s.
- The maximum percentage reduction in surge response is found to be 12.53 % and 17.38% with the mass ratio of 2% and 3% respectively for the wave height of 15m within the period between 7s and 18s.
- By controlling surge response, indirect control is obtained in pitch and heave degree of freedom.
- As the response of BLS is reduced by TMD, a similar control over response of deck is observed.

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