Offshore Triceratops – A Review on Dynamic Analysis

Harija K S[1], Induekha P[2], Dr. Jayalekshmi R[3]

[1,2]PG Student, Department of Civil Engineering, NSS College of Engineering, Palakkad
[3]Professor, Department of Civil Engineering, NSS College of Engineering, Palakkad

---

Abstract - *Among the existing offshore platforms, offshore triceratops is somewhat an emerging new concept with respect to its structural form. This offshore platform can be employed in ultradeep water as well. It consists of a deck, a positively buoyant, buoyant leg structures (BLS), ball joint which connects deck to the BLS unit and the platform is position-restrained by tethers. The ball joint present keeps the deck horizontal. A stiffened triceratops is the one in which each buoyant leg unit is stiffened using a set of stiffeners joining the three columns and central moon-pool. Stiffeners make the BLS units monolithic and thereby reducing the effect of the encountered wave loads. This paper provides a review of studies conducted on offshore triceratops.*

***Key Words*: Triceratops, Buoyant Leg Structure, Central Moon Pool System.**

1. INTRODUCTION

More novel geometric forms of offshore platforms are evolved in the recent past to advance the motion characteristics of these platforms under deep and ultradeep waters. Triceratops, Non-ship shaped FPSOs are few of them. Compliant structures namely tension leg platforms (TLPs) and spar showed considerable tether tension variations under vertical seismic excitations caused at seabed. Combined with the wave loads, their dynamic responses become dangerous. Investigating the responses of the offshore platforms under severe loading cases is gaining attention these days. Changes have been done to the existing structural forms in deep-water platforms to improve their response characteristics. Robert and Cuneyt (1995) introduced the concept of buoyant leg structures (BLS) units. Numerous features of TLP and spar were merged in the new structural form of BLS unit. A positively buoyant structure is the one in which buoyancy exceeds the downward load acting on the structure which includes weight, payload, ballast weight and pre-tension in the restraining system. Triceratop is a positively buoyant structure. It bears a resemblance to spar because of its positive buoyancy and deep draft. On the other hand it resembles a TLP due to their restraining system. Systematic numerical studies on BLS are recommended since there exist limitations in modeling for experimental investigations.

2. OFFSHORE TRICERATOPS

Charles N White (2005) configured a new-generation offshore platform, triceratops. This is done by making use of the structural advantages of the BLS. The most important unit in a triceratops is the ball joint which connects the BLS unit to the deck. The ball joint offers significant operational and structural advantages like no rotation is transmitted to the deck from the BLS and vice-versa. Preliminary studies show that triceratops is suitable for deep and ultradeep waters. Detailed experimental studies further validates the concept and it also made sure that there is reduction in the deck displacements. Installation of the platform is done by free-floating method which makes the process easier. In order to extend it to deep waters only the desirable pretension is required. The most important advantages of triceratops are better motion characteristics and simple restraining system.

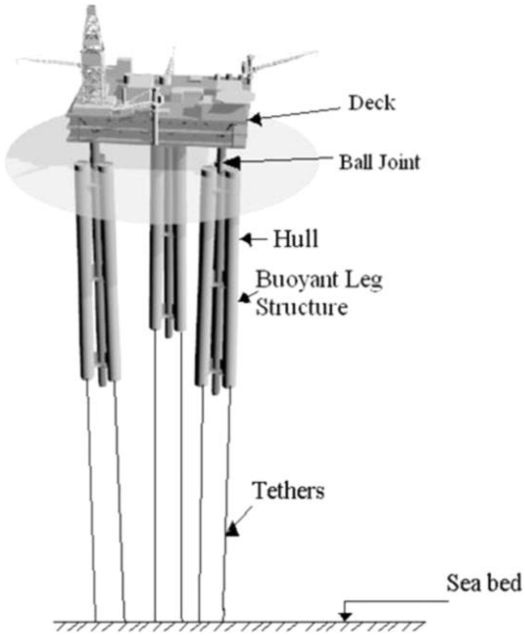

Fig -1: Conceptual view of a Triceratop

Triceratops consists of three BLS units, deck, and three ball joints between the BLS units and the deck. The restoring system is either with restraining legs or with the tether. When water depth is less than 1500 m restraining legs will be employed if not tethers will be employed.

Rectangular or triangular deck is chosen. This is helpful in providing more workspace and the payload is equally distributed between the three BLS units.

BLS is a positively buoyant, floating, deep-draft structure intended for use in ultra-deep waters. Each BLS unit resembles a spar because of its deep draft. The buoyant leg configuration has a central cylindrical shell and three buoyant tanks. Each buoyant tank is divided into eight compartments, among which the bottom three are ballasted. Ring stiffeners are provided in each compartment at different spacing. Stringer stiffeners with equal spacing are provided as well. The whole BLS unit is a simple cylindrical structure which provides required buoyancy to support deck structure, buoyant leg, and tethering system.

Ball joints transfer all translations but no rotations about any axis, making sure that the deck has got only reduced responses when compared to the BLS unit. This makes the platform different from other types of offshore structures. Ball joints conform to horizontal position of the deck even under rough weather conditions.

For ultra-deep waters flexible behavior is economical. To ensure that foundation system is chosen as tethered system since. If the water depth is less than 1500 m restraining legs may be employed, else tethers will be provided.

There are possibilities of corrosion. This is due to the deep draft of the BLS. Some techniques like frequent inspection using corrosion testing probes; use of sacrificial anodes; anti-corrosive coatings; use of cathodic protection helps prevent corrosion to some extent.

2.1 Stiffened Triceratop

In a triceratop, finite number of stiffeners is used to connect three columns and central moon-pool. This makes the triceratop a stiffened one. This stiffeners helps in making the BLS units monolithic and hence reduce the effect of the wave loads on the structure.

2.2 Advantages

The structural form of offshore triceratop is less complex in comparison to those of TLPs and spar. It requires only simpler station keeping systems. Installation and decommissioning of the platform contributes to major reduction of expenditure making it more affordable. Risers are positioned within a protected surrounding makes them laterally supported moreover safe.

Common types of deep-water offshore structures have rigid connections. This leads to production of more stresses on members, when subjected to environmental loads. Offshore triceratops reduces the severity of the encountered environmental loads by virtue of its new structural form and design.

The prominent advantages of triceratops are specifically

(i) Simplicity of structure

(ii) Easiness of install and decommission;

(iii) Reusability and re-locatable;

(iv)Much simpler restraining system compared to TLPs requiring less pretension

(v) Better stability of structure;

(vi) Relatively low cost.

(vii) Forces exerted on the platform seems to be reduced due to the decrease in the exposed fraction of the structure near the free surface

(viii) Risers are located inside the moon pool of the BLS, hence protects the risers from lateral forces.

3. LITERATURE REVIEW

Capanoglu et al [2002] studied the effectiveness of BLS unit to counteract the lateral loads in deep and ultra-deep waters through experimental and computational studies. The buoyant leg is designed to provide adequate buoyancy to support the combined weight of the deck payload, deck structure, deck and hull outfitting, buoyant leg, restraining leg, hull appurtenances and ballast and to provide pretension for the restraining system. They stated that articulated joints are one of the most suitable structural form of offshore structures in deep waters.

Charles and Robert (2005) introduced a new concept-offshore platform, triceratops, which combine desirable characteristics of both spar and tension leg platforms, whose inherent characteristics enables its cost effective construction, installation and lessen possible problems during its service life. TLP and SPAR are very expensive to build due to a various reasons such as their large hulls, complex joints and massive station-keeping systems and costly as well to inspect, maintain and repair due to problems related with the characteristic responses of each platform to excitation forces such as large dynamic surges, vortex induced motions, ringing and springing of the tethers and the adverse effect of stress cycles on riser and tether fatigue lives, triceratops are simple effective platforms for deep and ultra deep waters. The structural form of the platform enables to counteract the encountered environmental loads efficiently. As the joints provide rotational compliancy to hull units, the deck of the Triceratops does not pitch and roll with the limited surge, sway, pitch and roll motions of the BLS hulls.

By comparing with the past construction data and the characteristics of various Spars and TLPs, it has been estimated that the Triceratops can be designed, constructed and installed in 20 to 22 months. Each BLS is taken to the site by towing or by using barge and floated in the site. Free flooding of the restraining legs will complete the upending of each BLS unit. Each upended BLS unit is then further ballasted in preparation for float-over deck installation. Once the barge is in place, each BLS unit is de-ballasted to allow lifting of the deck from the barge. This helps the unit to attain the pretension which makes it a positively buoyant structure. It also helps to attain suitable draft for operation. Restraining legs would extend about 1 m when subjected to full pretension.

S. Chandrasekaran et al. (2011) carried out experimental and numerical studies on 1:150 scaled model of triceratops, in free-floating and tethered conditions under unidirectional regular waves; natural periods in heave and pitch/roll degrees of freedom are discussed for installation and decommissioning purposes.

The analytical studies are done in ANSYS AQWA software. The free-floating model is studied at 4 m water depth, while the tethered model of prototype is analyzed at 600 m water depth. Since BLS units are Morison elements, the line elements are used to model the tubular members with segments, and the deck is modeled as quadratic plate elements, inbuilt ball joint is used in the analysis and the tethers are modeled as steel wire ropes. Free-decay test is carried out analytically by subjecting the structure to zero wave amplitude and necessary initial conditions in the respective degree of freedom. Based on the studies carried out, it is seen that the free-floating natural periods of both single BLS and tethered triceratops are away from the bandwidth of encountered wave periods, making the proposed platform safe and suitable for the chosen sea state and ultra-deep waters. It was also seen that deck response of Triceratops is relatively lower than BLS; this is attributed because of the presence of ball joints.

Madhuri Seeram and S. Chandrasekaran (2012) has conducted experimental investigations on two different BLS units of triceratops. The scaled models of Structure 1 (1:150) have 100mm diameter cylindrical structure as BLS and the structure 2 (1:72.41) has 4 no. of cylindrical structures as one BLS. Ballasting is done to maintain the positive metacentric height of the structure for the stability. Analytical study is also conducted using Morison tube elements in ANSYS AQWA. The results showed that the free floating roll and pitch natural periods are away from the wave periods and the heave natural periods are in wave periods zone (5 to 20s). Therefore installation or decommissioning of the platform has to be planned according the sea state in the site.

S. Chandrasekaran (2013) studied the aerodynamics of the platform offshore triceratops. For this study a mathematical formulation was developed to find out the response under regular waves accompanied by wind. Heave responses are found to be lesser in comparison with surge responses; which implies that the platform is stiff in heave degree-of-freedom, which is required for deep-water offshore platforms. Even when the pitch response is significant in the BLS units, the pitch response in the deck is lesser indicating that the deck remains horizontal; this is one of the salient advantages of ball joints in triceratops. None of the rotational responses are transferred from BLS to deck or vice-versa. Neither the yaw response caused by the wind force nor the pitch response caused by hydrodynamic forces gets transferred from the BLS to the deck.

Madhuri Nannaware and S. Chandrasekaran (2014) examined the triceratops to find out its response under seismic activity. The dynamic tether tension variations is also studied to find out the effect of seismic activity which is indirectly imposed. The tether tension variations that are triggered by the seismic actions are important. In heave degree of freedom the deck response seems to have increased under the seismic activity. The triceratops operates safe under deep waters where chances of seismic activity is too high.

S. Chandrasekaran et al. (2015) investigated the response of triceratops in coupled degrees of freedoms under regular and random waves. The structural configuration and mass distribution for the study were arrived based on the concept suggested by Charles and Robert (2005) and experimental and numerical studies were conducted on 1:72 scaled model. Numerical studies are carried out to support the experimental results. Numerical studies have been conducted for various wave heading angles. Due to reduction in pretension in tethers compared to TLPs, triceratops has higher degree of compliancy in surge, sway and heave degrees-of-freedom, which is indicated by higher natural periods in those DOFs. The response of the structure for different wave headings varied due to the change in orientation of the platform geometry. It is seen that the response of the platform in all active degrees-of-freedom at 120° is lesser than those observed at 0 and 180°. This property can be made use in the installation of the platform by adjusting its orientation with respect to predominant wave direction to reduce the response of the structure. The ball joints between the deck and the BLS unit restrain the transfer of rotational responses from BLS to the deck, thus reducing the response of the deck, in comparison to that of the BLS unit. Rotational response of the deck seems to be reduced when compared with that of the BLS units, which clearly shows the operational benefits of the platform with better safety. The study showed that even for a significant rotation of buoyant legs, the deck remains almost horizontal under the action of the lateral loads.

S. Chandrasekaran and Jamshed Nassery (2015) studied the springing and ringing response of triceratops under irregular wave loading. Springing may cause resonance response in vertical plane which may lead to tether pull-out and is one of the resonance-type responses caused by direct waves when they encounter at the wave sum frequencies. Ringing occurs due to the strong asymmetric waves that are generated in the transient wave mode. Ringing attributes to strong transient response, which is observed under severe loading. This is triggered presumably by the passage of high steep waves. The response buildup resembles that of a church bell being struck. Ringing and springing response, occurring at the natural frequency of one of the stiff degree-of-freedom can endanger the stability of the platform. In addition, ringing can not only cause total breakdown of these platforms even in moderate storms but also can hamper daily operations and lead to fatigue failure.

Dennis Ittyavirah and Vivek Philip (2016) studied the response of an offshore triceratops supporting a wind turbine under hydro-aero dynamic loading. A triceratops platform supporting structure for 5 MW (Mega Watt) offshore wind turbine for deep water is analyzed using NAOS (Nonlinear Analysis of Offshore Structures) and Aerodynamic analysis is done using FAST (Fatigue, Aerodynamics, Structures and Turbulence, developed by National Renewable Energy Limited (NREL), USA).From Eigen value analysis, the natural time period obtained for all modes was found to be well away from the wave time period zone (> 25 s and < 4 s).The RAOs showed gradual change with soft peaks, indicating the stability of the structure against the wave loading. Sway motion at different wind speeds remained unchanged, which means that sway is not affected by the turbines dynamic properties. But yaw response is slightly affected by turbines dynamic properties.

Senger Mayanak and S Chandrasekaran (2016) has investigated on the dynamic analyses of stiffened triceratops under regular waves experimentally. A set of stiffeners join the three columns and central moon-pool. Stiffeners make the BLS units monolithic and in so doing it reduces the effect of the encountered wave loads. Deck response of stiffened triceratops seems to be lesser when compared with that of the BLS units. This reduction in response is due to the presence of ball joints between the deck and the BLS units; and monolithic action of BLS unit due to the presence of stiffeners in between. Though, there is a tolerable increase in the translational response. This may be due to individual compliancy of deck and BLS. The most important benefits of the proposed geometric form is that it guarantees monolithic action. It also safeguards rigid body motion as well.

Ikpe (2016) has made a study on the feasibility of offshore triceratops using FMEA approach. Offshore Triceratops has huge potentials to boom in ultra-deep waters because of its improved motion characteristics and low cost when compared to other conventional offshore structures. It has been recognized as the forthcoming offshore structure. The ball joint is more prone to failure and failure of the ball joint leads to breakdown of the entire structure. Severe sea state, strong tidal wave, corrosion, fatigue etc. likely contributes to the failure. In addition to regular maintenance, checks of the functional elements add to the long life, integrity, and performance of the structure.

Jamshed Nassery and S. Chandrasekharan (2017) simulated impact waves and non-impact waves to study the nonlinear response of stiffened triceratops. High amplitudes steady state (springing) and transient response (ringing) are experienced by the platform. Transient responses in pitch and heave degrees-of-freedom was resulted from impact waves while non-impact waves resulted in steady state response. Impact waves remain a reason for response in higher frequencies and variations in tether tension dynamics. A response alike a beating phenomenon is produced by the non-impact waves. Deck will be more affected by springing response rather than the ringing response.

P A Kiran (2017) studied Mathieu stability of offshore triceratops under postulated failure. Taut-moored buoyant legs experience dynamic tether tension variations under the wave loads which can cause Mathieu-type instability. On increasing payload on the deck the study aims to find out the stability of triceratops through postulated failure case. Stability of the deck is assessed with the help of phase plots, while that of tethers are assessed by means of Mathieu stability. Mathieu stability analysis for tethers under postulated failure cases is crucial since tether tension variation is to be considered for determining the stability of tethers. Unstable response of the deck may or may not be a cause for Mathieu instability in tethers. Some cases under consideration showed that even before tethers showed instability the platform became unstable. Finding out the stability of platform, independent of tether instability under the postulated failure cases becomes critical.

R. Nagavinothini and S Chandrasekaran (2018) done a detailed numeric analysis of triceratops at 2400 m water depth under regular and irregular waves using ANSYS AQWA. Free floating analysis of the BLS units showed greater natural periods in roll and pitch degrees of freedom than dominant wave periods (5–20 s) making the installation process much easier. The reduction in deck motion compared to BLS indicated the effectiveness of ball joints, thus indicating the advantages of structural configuration of triceratops.

4. SUMMARY AND CONCLUSIONS

The newly emerged platform offshore triceratops can be called the future offshore structure. When conventional drill ships and semi-submersibles are compared with triceratops, it has better motion characteristics, low cost and simpler station keeping. This differentiates triceratops from other offshore structures. It has also been identified that it has huge potentials to succeed in ultra-deep waters for a number of reasons. The reduction in risks associated with design or safety, construction and project schedule, operations and the reservoir will be reflected in the lifecycle cost savings. Current technology has been utilized by the components and systems of triceratops and the design end product is anticipated to increase structural consistency, reduce risk, provide for useful operations and lessen lifecycle cost. It can be concluded that the Triceratops basically extends fixed platform performance available to deep and ultradeep water. Triceratops' motion characteristics are better with reduced disadvantages associated with larger environmental loads. The studies done so far on triceratops include response analysis under regular and random waves, seismic and aerodynamic loading both experimentally and numerically. Stiffened triceratops has been analyzed for regular waves experimentally.

More detailed investigations are needed regarding response mitigation methods under various environmental conditions for stiffened and unstiffened triceratops.

REFERENCES

[1] Charles N White (2005), "Triceratops: an effective platform for developing oil and gas fields in deep and ultra-deep water", Fifteenth International Offshore and Polar Engineering Conference ,Seoul,Korea, pp 133-139

[2] Chandrasekaran S (2011), "Dynamic Analysis and Design of Offshore Structures", Ocean Engineering and Oceanography, New York

[3] Chandrasekaran S and S Madhuri (2012), "Stability Studies on Offshore Triceratops", International Journal of Innovative Research and Development, vol 1, pp 398-404

[4] Chandrasekaran S and S Madhuri (2013), "Aerodynamic Response of Offshore Triceratops", Ships and Offshore Structure, Vol. 8, No. 2, pp 123-140.

[5] Chandrasekaran S and Nannaware (2014), "Response Analysis of Offshore Triceratops to Seismic Activity", Ships and Offshore Structure, Vol. 9, No. 6, pp 633-642.

[6] Chandrasekaran S and S Madhuri (2015), "Dynamic Response of Offshore Triceratops: Numerical and Experimental Investigation", Ocean Engineering 109, pp 401-409

[7] S Chandrasekaran and Jamshed N (2015), "Springing and Ringing Response of Offshore Triceratops", Proceedings of the ASME 34th International Conference on Ocean, Offshore and Arctic Engineering OMAE2015, Canada, pp 1-6.

[8] Vivek P and Dennis I (2016), "Dynamic Response of Offshore Triceratops – Supporting 5 MW Wind Turbine", International Journal of Engineering Research and Technology, pp 708 – 714

[9] Chandrasekaran S and S Mayanak (2016), "Dynamic Analyses of Stiffened Triceratops under Regular Waves : Experimental Investigation" , Ships and Offshore Engineering, pp 1-9

[10] Ikpe and E Aniekan (2016), "Feasibility Studies on Offshore Triceratops as Future Offshore Structure Using FMEA Approach", International Journal of Innovative Research and Development, vol 5, pp 104-113

[11] S Chandrasekaran and Jamshed N (2017), "Non Linear Response of Stiffened Triceratops under Impact and Non Impact Waves", Ocean Systems Engineering, Vol. 7, No. 3, pp 179-193

[12] P A Kiran and S Chandrasekaran (2017), "Mathieu Stability of Offshore Triceratop under Postulated Failure", Ships and Offshore Structure, pp 1-6.

[13] Capanoglu, C.C., et al "Comparison of Model Test Results and Analytical Motion Studies for a Buoyant Leg Structure," Proceedings of 12th International Offshore and Polar Engineering Conference, ISOPE 2002, Kita-Kyushu, Japan, 27-30 June 2002.