Ocean Engineering 109 (2015) 401–409

Contents lists available at ScienceDirect

Ocean Engineering

journal homepage: www.elsevier.com/locate/oceaneng

Dynamic response of offshore triceratops: Numerical and experimental investigations

Srinivasan Chandrasekaran [a,*], S. Madhuri [a,b]

[a] Department of Ocean Engineering, Indian Institute of Technology Madras, 600036 India
[b] Department of Civil Engineering, University College of Engineering, JNTU Kakinada, Andhra Pradesh 533003, India

ARTICLE INFO

Article history:
Received 28 May 2013
Accepted 20 September 2015
Available online 8 October 2015

Keywords:
Hinged/ball joint
Buoyant leg structure
Offshore triceratops
Rotational stiffness
Experimental studies

ABSTRACT

Offshore triceratops is a new generation offshore platforms that alleviates wave loads by virtue of 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. Main objective of the present research is to study the dynamic response characteristics of offshore triceratops through experimental and numerical investigations. Natural periods in different degrees-of-freedom are estimated experimentally for different boundary conditions and are verified with that of the numerical and empirical relationships. Experimental studies are performed to study the dynamic response of triceratops in coupled degrees of freedoms under regular waves for uni-directional wave on the scaled model. Numerical studies are also carried to verify the experimental results and dynamic responses of the triceratops under different wave headings for regular and random waves. Based on the detailed investigations carried out, it is seen that the coupled responses of the deck in rotational degrees-of-freedom are lesser than that of the buoyant legs. Presented study is a prime-facie to show that the chosen structural configuration is advantageous and deserves attention of the research community.

1. Introduction

Complexities that arise in deep water oil exploration demands a more adaptable structural form to alleviate the encountered loads without compromising on the complaint characteristics that are advantageous and cost-effective. One of the recent developments is offshore triceratops (Charles and Robert 2005). Its main components are namely: (i) deck structure that is equipped with all necessary topside facilities; (ii) three buoyant legs (BLS); (iii) ball joints that connect buoyant legs with the deck; and (iv) restoring system with taut-moored tethers. Fig. 1 shows the structural components of offshore triceratops. Ball joints are capable of transferring only translations but no rotations; this improves operability of the platform as the deck will remain horizontal under lateral loads. BLS units are cylindrical, water-piercing columns with the deep-draft, which are similar to that of a spar and positive buoyant like a TLP (Robert et al., 1995; Perryman et al. 1995, Shaver et al., 2001; Capanoglu et al., 2002). By virtue of the excess buoyancy, weight of topside, ballast and pretension in the restoring system are counteracted. Several researchers have examined the response behavior of innovative structural forms of offshore platforms to assess their adaptability to deep waters (Logan et al., 1996; Muren et al., 1996). Halkyard et al., (1991) highlighted the salient advantages of tensioned buoyant tower through coupled analysis and highlighted that response reduction can be achieved by virtue of the chosen structural form. Chandrasekaran and Jain (2002a, 2002b) compared the dynamic response behavior of four legged with that of a triangular configuration TLP under regular and random waves. They highlighted reduction in responses in surge and heave degrees-of-freedom that arise mainly from the triangular configuration. Shaver et al. (2001) and Capanoglu et al. (2002) showed the effectiveness of buoyant BLS unit to counteract the lateral loads through experimental and computational studies. They stated that presence of articulated joints could be one of the most suitable structural forms of offshore platforms for deep waters. However, advantages of the presence of hinged joints in the structural forms of semi-submersibles, articulated loading platforms and multi-leg articulated towers are already well established (Alexander and Copson 1985; Witz et al., 1986; Han and Jack, 1991; Nagamani and Ganapathy 2000). Derived from the advantages of the above mentioned studies, a new structural form is formulated by the researchers in the recent past (Chandrasekaran et al., 2010). Studies carried out on the new form of offshore platforms showed their suitability for

Abbreviations: BLS, Buoyant Leg Structure; VCG, Vertical Center of Gravity; PSD, Power Spectral Density

* Corresponding author. Fax: +91 4422574802.
E-mail addresses: drsekaran@iitm.ac.in (S. Chandrasekaran), madhuri.seeram@gmail.com (S. Madhuri).

http://dx.doi.org/10.1016/j.oceaneng.2015.09.042
0029-8018/

Nomenclature

A_c	area of cross-section of the member
$[C]$	damping matrix
C_a	added mass coefficient (C_m-1)
C_d	drag coefficient
C_m	inertia coefficient
D	diameter of the cylinder
df	force per unit length
$\{f(t)\}$	force vector
F_c	restoring force
F_D	damping force
F_I	inertia force
$[K]$	stiffness matrix of the platform
l	wave length
$[M]$	mass matrix
$[M_a]$	added mass matrix
u_f	fluid velocity in the transverse direction of the member
u_s	structure velocity in the transverse direction of the member
$\dot{u}_f$	fluid acceleration in the transverse direction of the member
$\dot{u}_s$	structure acceleration in the transverse direction of the member
$\{X, \dot{X}, \ddot{X}\}$	displacement, velocity and acceleration of the structure
ρ_w	fluid density
I	moment of inertia of the element

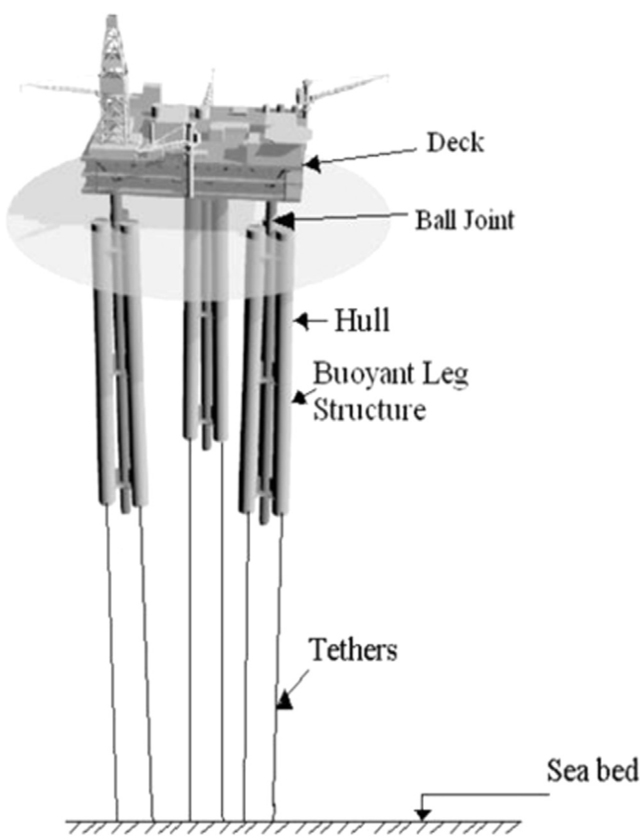

Fig. 1. Conceptual view of triceratops.

drilling and production in deep waters (Chandrasekarn et al., 2011; Chandrasekaran and Madhuri, 2012a). Experimental and numerical studies conducted on the scaled models of offshore triceratops showed response reduction of the deck under the lateral loads (Chandrasekaran et al., 2012; Chandrasekaran and Madhuri, 2012b). Chandrasekaran and Nannaware (2014) studied the response of offshore triceratops under seismic force in the presence of sea waves. They observed a significant reduction in pitch response of the deck in comparison to that of the BLS units under earthquake loads. Based on the critical review of literature as discussed above, it is seen that offshore triceratops is capable of adapting to deep-water conditions with a few advantages. In the absence of detailed dynamic analyses of offshore triceratops, present study is carried out through numerical and experimental investigations.

2. Offshore triceratops

While the structural form attempted in the present study is relatively new, it becomes necessary to assess its pay load capacity for the drilling and production facilities in deep-waters. Mass properties are derived on the basis of the concept suggested by Charles and Robert (2005) to arrive at the member sizing of a scaled model of triceratops. Scale ratio of 1:72 is selected to map the equivalent mass distribution. Tables 1 and 2 list the details of mass properties, structural and hydrodynamic details of both the model and prototype. Triceratops derive high degree of compliancy by virtue of its supported by BLS units. One of the main advantages of BLS is their free-floatation characteristics when not connected to the deck. In order to verify the method of installation it is necessary to study the free floating natural periods with different boundary conditions of BLS units. Hence the meta-centric height of the single buoyant leg is verified with and without pay load, by both experimental and numerical methods. Plan and elevation of a typical BLS unit are shown in Fig. 2. Payload is kept similar to a common drilling, production and operation platform (Frank et al., 1980; Glanville et al., 1991; Chakrabarti, 2005). Rectangular-shaped deck is chosen to accommodate more work space while the payload is equally distributed between the three

Table 1
Mass properties of prototype and model (Scale ratio 1:72.41).

Description	Prototype (ton)	Model (kg)
Topside		
Drilling system	1100	2.9
Other systems	10,355	27.27
Allowance	188	0.5
Steel	3204	8.44
Total mass of topside	14,846	39.10
BLS		
Steel	11,218	29.55
Appurtenances	1310	3.45
Ballast	25,868	68.13
Pretension + tether mass	5974	15.73
Total mass of BLS	44,369	116.87
Displacement	59,216	155.97[a]

[a] Considering flume water density,