VIBRATION CONTROL OF TENSION LEG PLATFORMS USING MASS DAMPERS UNDER RANDOM WAVES

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Abstract— An offshore structure may be defined as one, which has no fixed access to dry land and which is required to stay in position in all weather conditions. A tension leg platform is a compliant offshore structure which allows lateral movements of surge, sway and yaw but restrains heave, pitch and roll. Due to the cost effectiveness of TLP in deep sea, they are favoured by the offshore industry. These offshore structures should be able to withstand the dynamic effects of environmental loads during their lifetime. TLP drift motions (surge–sway–yaw motion), due to the action of wave forces, can be significant during extreme weather conditions. These motions could affect the performance during operation and maintenance. Damping devices integrated into the TLP structure could improve the response characteristics, as they have been proved to be beneficial in reducing the vibrations in civil engineering structures. This paper deals with the detailed numerical investigations of the dynamic behaviour of a TLP using mass dampers under random waves. The numerical study has been carried out using finite element software ANSYS AQWA using diffraction theory.

Index Terms— Tension Leg Platforms, Mass dampers, Random Waves, Dynamic Analysis, ANSYS AQWA.

1 Introduction

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Tension Leg Platforms (TLPs) are floating structures of semi-submersible type, moored by vertical tendons under initial pretension imposed by excess buoyancy. Several TLPs have been used for oil drilling and production operations in deep water. They can be modelled as a rigid body having six degrees of freedom, including three translations (surge, x, sway, y, and heave, z) and three rotations (roll, pitch, & yaw). The natural period in surge, sway and yaw are in the range 80-120 s and well above the range of dominant waves, which typically have periods 6-18 s. On the other hand, the heave, pitch and roll periods are typically in the range 2-4 s and below the period of storm waves. Thus, forces at the dominant wave frequencies do not excite the TLP at its natural frequencies. Deep-water TLPs have longer periods for the heave, pitch and roll motions (up to 6 s) which are close to the dominant periods of fatigue sea states and thus may be excited at resonance by direct wave energy.

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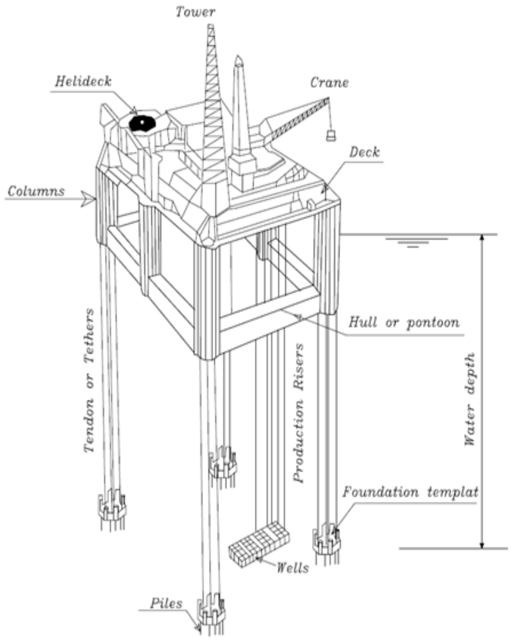

Fig.. Tension Leg Platform

In the present work, the dynamic analysis of a TLP using mass dampers under random waves has been carried out using the finite element software ANSYS AQWA.

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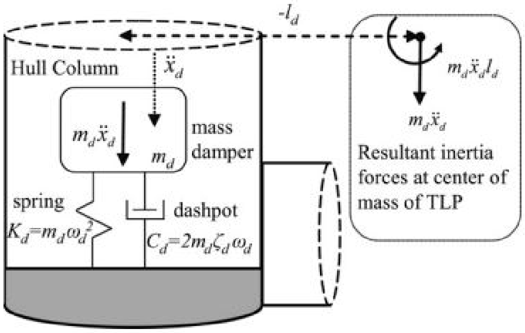
2 Random Wave Kinematics

For a known random wave elevation, the wave kinematics and the pressure intensity need to be calculated. For this purpose, the random wave surface elevation η at x from origin and at time t can be considered as a superposition of N different monochromatic Airy's wave heights H_i, i = 1 to N and frequencies ω_i, i = 1 to N combined with the random phase angle Φ_i. Thus,



Where Φ_i can take values in the range $0<\Phi_i<2\pi$ with uniform probability density and N is related to the cut off frequency. The corresponding fluid velocity, acceleration and pressure intensity at depth z can be written in terms of the regular wave heights H_i and frequency ω_i which are obtained by using Fast Fourier Transform. Thus for a random wave

2.1 Dynamics of Tlp

The forces acting on the system are generally a function of both time and vessel position. In order to try to separate the forces into separate terms to allow simple solution, a number of assumptions and linearization are usually made. The expression generally used to describe the motion is given by:

$$M(t) + C(t) + K(t)x=F(x,t)$$

Where

M(t) = inertial mass matrix,

C(t) = damping matrix,

K(t) = stiffness matrix,

= system displacement vector,

= system velocity vector,

= system acceleration vector.

A common assumption is to limit the system model to a rigid platform and exclude riser and tendon displacements. The system has 6 degrees of freedom. The fixed coordinates are coincident with the principal directions of the platform when the platform is at rest. The assumption of no interaction between tendon and riser dynamic response and the platform dynamic response leads to the label of “uncoupled analysis” for this simple case. The motions of the platform are coupled with the dynamics of the mooring system. The coupling of motions between the platform, risers and mooring systems becomes increasingly more important as water depth increases. Here coupled time domain analysis is performed to understand the behaviour of TLP under the dynamic load.

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3 Mass Damper Implementation For Tlps

Effective vibration suppression may be established using mass dampers by appropriate tuning of their inertia effect relative to the dynamic characteristics of the primary mass. The term tuning refers to the selection of (i) primarily the natural frequency and (ii) the damping properties of the secondary mass. The mass dampers can be modelled as conventional masses attached to the TLP hull by springs and dashpots as shown in Fig. 2.

The adjustable parameters for TMDs, referred to herein as design variables, consist of the spring and dashpot coefficient or, equivalently, the frequency ωd and the damping ratio ζd of the damper. Larger mass ratios correspond to greater potential impact of the damper to the structure, as long as the damper is appropriately tuned, and thus to better suppression of the structural vibration.

Present analysis is performed using the software ANSYS-AQWA, where the wave forces are estimated using diffraction theory. In this software the damping is introduced as an equivalent damping force which has been estimated by adopting a mass ratio of 4%.

4 Modelling And Analysis

4.1 Analysis Software

For the present study the software ANSYS AQWA is used and the salient features of the same is presented.

Hydrodynamic software Ansys AQWA is used for the hydrodynamic analysis of both fixed and floating structures. It is a diffraction radiation program based on linear potential theory. Second order effects can also be included. Free floating as well as moored floating body RAO can be generated in Ansys AQWA. It works on the principle of panel methods. Ansys AQWA is a set of hydrodynamic software programs and the modules in it are briefly described below.

AQWA-LIBRIUM: Used to find the equilibrium characteristics of a moored or freely floating body or bodies. Steady state environmental loads may also be considered to act on the body.

AQWA-LINE: Used to calculate the wave loading and response of bodies when exposed to a regular harmonic wave environment. The first order wave forces and second order wave drift forces are calculated in the frequency domain.

AQWA-FER: Used to analyse the coupled or uncoupled responses of floating bodies while operating in irregular waves. The analysis is performed in the frequency domain.

AQWA-NAUT: Used to simulate the real time motion of a floating body or bodies while operating in regular or irregular waves.

AQWA-WAVE: Used to transfer wave loads on fixed or floating structure calculated by AQWA-LINE to a finite element structure analysis package.

AQWA GRAPHICAL SUPERVISOR (AGS): It is a pre and post processor for all the modules.

4.2 Environmental Details

For random waves, the wave train is generally specified by a wave spectral density S (f). In the present study a single parameter Pierson-Moskowitz wave spectrum is taken as the representative spectrum. It is given by,

Where f_0 is the peak frequency and is calculated as

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4.3 Platform Configuration of Tlp

As an illustrative example, a typical Tension Leg Platform under random sea environment is discussed in Alexandros A et al [1] is taken for the present study.

TABLE

Platform Data of TLP

Column diameter (D_c)	18 m
Mass (without dampers)	38950 ton
Total pre-tension (T_o)	145 × 10^3 kN
E of tendons	200 kN/cm^2
Water depths d	600 m and 800 m
Significant wave height H_s	12 m and 14 m
C_D	1
Damping coefficient of mass damper (C_d)	1211767 N/(m/s)
Position of center of mass (h_G)	41.8 m above keel
Pontoon diameter (D_p)	9.45 m
Radius of gyration (pitching motion)	43.5 m

Distance between columns (s_o)	62.3 m
Tendon diameter	0.3 m
Draft (D_r)	34.4 m
C_M	2
Column height (h_c)	82 m
Tendons per leg	3

4.4 Modelling Details

The surface profile of the TLP is simulated in 3D modelling software called "Design Modular" which is available in the software package. Then the geometry modelled is imported into the model cell. The model cell selects the geometry object in the tree where the global parameters are given. This platform configuration is given as input.

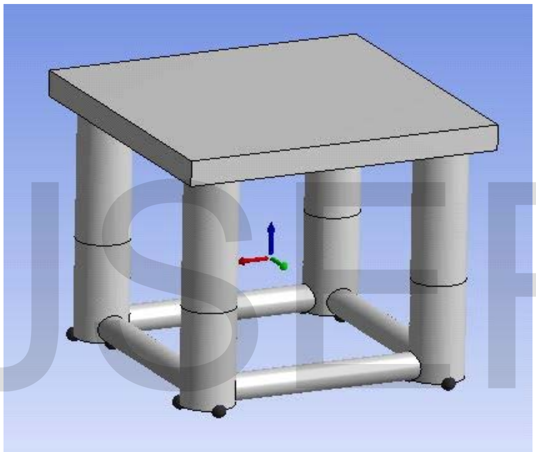

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Fig. . Model created in ANSYS AQWA

5 Results And Discussions

Dynamic analysis is performed with and without considering mass dampers in Tension Leg Platform under random waves. The TLP is analysed for water depths of 600m and 800m. The response of the TLP in the x (surge), z (heave) directions and rotation in y direction (pitch) has been plotted against time for significant wave heights of 12m and 14m corresponding to zero crossing periods 17.31s and 15s.

The variations of responses in surge, heave and pitch values of TLP under random waves for water depths of 600m and 800m for significant wave heights of 12m and 14m without damper and with mass damper are shown in fig. 5 to 10 and fig. 14 to 19 respectively as a graphical representation. These values are summarised in tables 2 and 3. The comparison of maximum responses for 12m and 14m significant wave heights are shown in fig. 11 to 13 and fig. 20 to 22.

By incorporating mass dampers over model without damper, percentage reduction in surge motion increases with significant wave height. The maximum reduction of 66.9% is obtained for surge response when the mass damper was provided at a water depth of 600m and significant wave height 14m.

Marginal effect is observed for heave and pitch motions with respect to water depth.

Fig. . Surge response with time (H_s=12m, d=600m)

Fig. . Heave response with time (H_s=12m, d=600m)

Fig. . Pitch response with time (H_s=12m, d=600m)

Fig. . Surge response with time (H_s=12m, d=800m)

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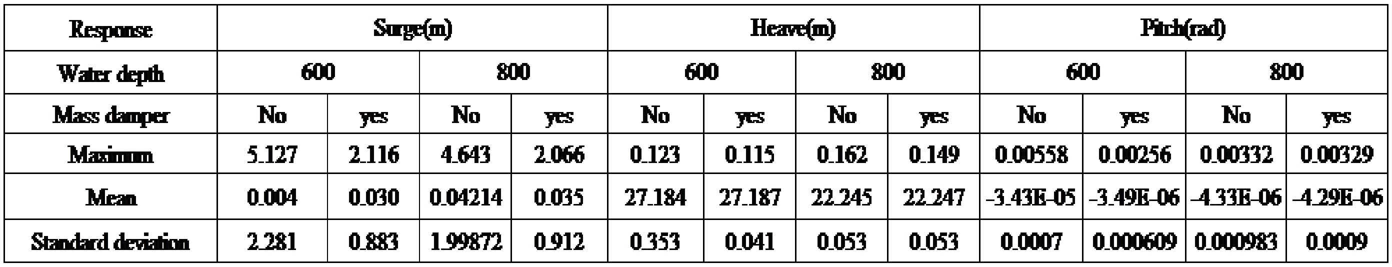
Fig. . Heave response with time (H_s=12m, d=800m)

Fig. . Pitch response with time (H_s=12m, d=800m)

TABLE

Comparison of Statistical Values of Responses for Different Water Depths (H_s=12m)



Response	Surge(m)				Heave(m)				Pitch(rad)			
Water depth	600		800		600		800		600		800	
Mass damper	No	yes	No	yes	No	yes	No	yes	No	yes	No	yes
Maximum	5.127	2.116	4.643	2.066	0.123	0.115	0.162	0.149	0.00558	0.00256	0.00332	0.00329
Mean	0.004	0.030	0.04214	0.035	27.184	27.187	22.245	22.247	-3.43E-05	-3.49E-06	-4.33E-06	-4.29E-06
Standard deviation	2.281	0.883	1.99872	0.912	0.353	0.041	0.053	0.053	0.0007	0.000609	0.000983	0.0009

Fig. . Comparison of surge response

Fig. . Comparison of heave response

Fig. . Comparison of pitch response

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Fig. . Surge response with time (H_s=14m, d=600m)

Fig. . Heave response with time (H_s=14m, d=600m)

Fig. . Pitch response with time (H_s=14m, d=600m)

Fig. . Surge response with time (H_s=14m, d=800m)

Fig. . Heave response with time (H_s=14m, d=800m)

Fig. . Pitch response with time (H_s=14m, d=800m)

Fig. . Comparison of surge response

Fig. . Comparison of heave response

Fig. . Comparison of pitch response

TABLE

Comparison of Statistical Values of Responses for Different Water Depth (H_s=14m)

Response	Surge(m)				Heave(m)				Pitch(rad)			
Water depth	600		800		600		800		600		800	
Mass damper	No	yes	No	yes	No	yes	No	yes	No	yes	No	yes
Maximum	6.39588	2.11326	6.41658	3.80444	0.15400	0.10629	0.14976	0.10700	0.0028	2.75E-03	0.0028	0.002742
Mean	0.08091	0.06705	0.07998	0.07925	27.17817	27.18712	27.17811	27.18299	-8.21E-06	-8.61E-06	-8.2723E-06	-1.31E-05
Standard deviation	3.42152	1.19747	3.42376	1.94864	0.35501	0.05493	0.35500	0.05416	0.0008	0.000691	0.0008	0.000649

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6 Conclusions

Focus was placed on implementation of mass dampers for vibration control of Tension Leg Platforms (TLPs). As an illustrative example a Tension Leg Platform under random sea environment was discussed. Surge can be effectively controlled by means of TMD. Surge is reduced by 66.9% for a significant wave height of 14m. Marginal response reduction is occurred in heave and pitch motions.

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