J. Marine Sci. Appl. (2016) 15
DOI: 10.1007/s11804-016-1354-x

Investigation of Pitch Motion Portion in Vertical Response at Sides of TLP

Mohammad Reza Tabeshpour* **and Ebrahim Malayjerdi**

Center of Excellence in Hydrodynamics and Dynamics of Marine Vehicles, Mechanical Engineering Department, Sharif University of Technology, Tehran 11365-11155, Iran

Abstract: Tendons vertically moor Tension-Leg Platforms (TLPs), thus, a deep understanding of physical tendon stresses requires the determination of the total axial deformation of the tendons, which is a combination of the heave, pitch, and surging responses. The vertical motion of the lateral sides of the TLP is coupled with surge and constitutes a portion of the pitch motion. Tendons are connected to the sides of the TLP; hence, the total displacement of the lateral sides is related to the total deformation of the tendons and the total axial stress. Therefore, investigating the total vertical response at the sides of the TLP is essential. The coupling between various degrees of freedom is not considered in the Response Amplitude Operator (RAO). Therefore, in frequency domain analysis, the estimated vertical RAO is incomplete. Also, in the time domain, only the heave motion at the center of TLP is typically studied; this problem needs to be addressed. In this paper, we investigate the portion of the pitch motion in the vertical response at the sides of the TLP in both the frequency and time domains. Numerical results demonstrate a significant effect of the pitch motion in the vertical motion of the edges of the TLP in some period ranges.
Keywords: tension-leg platform, heave, pitch, response amplitude operator, sides of TLP

1 Introduction

Fundamentally, the Tension-Leg Platform (TLP) comprises four circular cylinders interconnected by pontoons. These platforms are commonly configured in a square and are rarely triangular. The TLP hull is like a semisubmersible platform. Some advantages of TLPs include their small vertical motion, high stability, and low rate of cost increase with increasing depth in comparison to other platform types, as well as their deep-sea production capabilities. Disadvantages of the TLP include their high costs associated with the subsea foundation installation, sensitivity of the tethers to fatigue damage, difficulty in repairing and maintaining the tether connections, and low-capacity storage tanks.

Downie *et al*. (2000) carried out an experimental study on a model truss spar in regular and irregular waves for four different heave plates (two perforated and two solid). In terms of the Response Amplitude Operators (RAOs), the spar similarly behaved with respect to surge and pitch in regular waves. However, there were significant differences in the heave response. Bhattacharyya *et al*. (2003) developed a numerical model (finite element code) for a typical Sea Star platform at two water depths, 215 m and 1 000 m, and carried out experimental work on a scaled model corresponding to the 215 m water depth to validate the numerical model. The authors computed the RAOs for the motions and tether tensions for both prototypes using the Morison wave force model with a wave height of 2 m. Zhang *et al*. (2007) introduced a new spar concept and used numerical simulation to study its hydrodynamics in both operating and survival conditions. In addition, the authors investigated numerical and experimental RAO results on mooring lines for the surge, heave, and pitch. The predicted RAOs were in excellent agreement with test measurements. Zeng *et al*. (2007) investigated (6-DOF) coupled motions, the time history of the motions and wetted area, and the free surface and viscous drag effects. To extract the horizontal-plane-motion RAOs, the authors dynamically analyzed the International Ship Structures Committee (ISSC) TLP at a depth of 415 m in regular seas. Anitha *et al*. (2010) developed a new geometric configuration as a better alternative to existing configurations. The authors also designed a three-column mini TLP and investigated the added mass, radiation damping, transfer functions of wave force, and RAOs of motions for the three-column mini TLP in comparison to the existing four-column mini TLP. Tajali and Shafieefar (2011) carried out a hydrodynamic analysis of a floating multi-body pier interacting with incident waves and presented wave-induced motion and structural response results. They also examined the effect of relevant parameters on the pier hydrodynamic responses and computed the RAO for a wide range of wave frequencies and heading angles. Nallayarasu and Prasad (2012) conducted an experimental and numerical investigation on the hydrodynamic response of a spar and semi-submersible interlinked by a rigid yoke under regular waves. Tabeshpour *et al*. (2013) carried out a hydrodynamic analysis of the damped pitch and heave motion of TLPs and presented exact solutions for the vibration of a TLP interacting with ocean waves. Wu *et al*. (2014) investigated the influence of the legs underwater on the hydrodynamic response of the multi-leg floating structure. The authors also numerically simulated the

Received date: 2015-09-25
Accepted date: 2016-01-22
***Corresponding author Email:** tabeshpour@sharif.edu

see that the portion of the pitch response in the vertical response at the sides at higher wave periods is not dominant, but it has effect in wave periods of less than 10 s, which covers most sea states (pitch dominant).

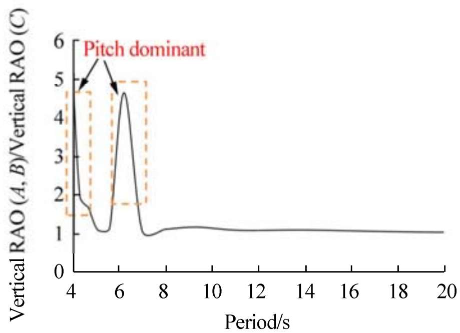

Fig. 10 Ratio of vertical response at points *A* and *B* to point *C*

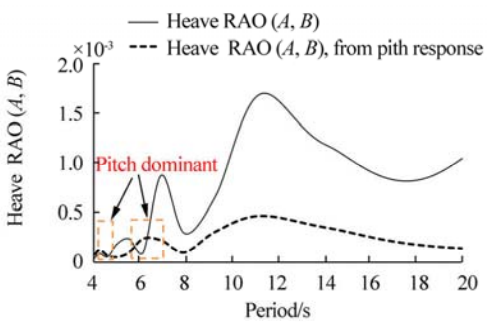

Fig. 11 Comparison of RAOs of vertical motion at points *A* and *B*

5 Conclusion

An accurate determination of the vertical response at the sides of TLPs is important. The vertical motions at these points are directly related to the stress in the tendons. Usually, time histories and the RAO of the motions of the TLP are noted at the center of gravity and other points are not directly reported. In this study, we investigated the vertical motion at three points: the center of the TLP (point *C*) and the corner sides (points *A* and *B*). From the numerical results obtained in this study, we can make the following conclusions:

The RAO of the corner sides are different from and greater than that of the center of the TLP. The ratio of the total RAO of the vertical response at the sides to the RAO of the center of the TLP in wave periods less than 10 s is significant. Therefore, by considering this portion, we can obtain the true vertical motion of the sides and the strain of the tendons. Combining the vertical portion of the pitch and heave responses facilitates the calculation of the RAO of the stress in the tendons.

The vertical motion at the center of the TLP consists of two periods (the natural period of the heave and the wave period), but at the sides it consists of three periods (the natural periods of the heave and pitch and the wave period).

The vertical response at the sides of the TLP is significant when the pitch response is dominant, rather than the heave response being dominant, at the center of the TLP.

References

Abaiee MM, Ahmadi A, Ketabdari MJ, 2015. Analytical discussion on stochastic hydrodynamic modeling of support structure of HAWAII WTG offshore wind turbine. *Journal of Advanced Research in Ocean Engineering*, **1**(1), 55-62. DOI: 10.5574/JAROE.2015.1.1.055

Bhattacharyya SK, Sreekumar S, Idichandy VG, 2003. Coupled dynamics of SeaStar mini tension leg platform. *Ocean engineering*, **30**(6), 709-737. DOI: 10.1016/S0029-8018(02)00061-6

Das SK, Baghfalaki M, 2015. Modeling of response amplitude operator for coupled sway, roll and yaw motions of a floating body in sinusoidal waves using frequency based analysis. *Journal of Offshore Mechanics and Arctic Engineering*, **137**(3), 031303.

Downie MJ, Graham JMR, Hall C, Incecik A, Nygaard I, 2000. An experimental investigation of motion control devices for truss spars. *Marine structures*, **13**(2), 75-90. DOI: 10.1016/S0951-8339(00)00010-1

Joseph A, Mangal L, George PS, 2010. Coupled dynamic response of a three-column mini TLP. *Journal of Naval Architecture and Marine Engineering*, **6**(2), 52-61. DOI: 10.3329/jname.v6i2.2789

Nallayarasu S, Prasad PS, 2012. Hydrodynamic response of spar and semi-submersible interlinked by a rigid yoke–Part I: regular waves. *Ships and Offshore Structures*, **7**(3), 297-309. DOI: 10.1080/17445302.2011.552208

Nallayarasu S, Sreeraj R, Murali M, 2014. Effect of hull geometry on the hydrodynamic response of spar in regular waves. *Ships and Offshore Structures*, **9**(1), 22-37. DOI: 10.1080/17445302.2012.704172

Tabeshpour MR, Ataie Ashtiani B, Seif MS, Golafshani AA, 2013. Hydrodynamic damped pitch motion of tension leg platforms. *International Journal of Marine Science and Engineering*, **3**(2), 91-98.

Tabeshpour MR, Golafshani AA, Ataie Ashtiani B, Seif MS, 2006. Analytical solution of heave vibration of tension leg platform. *Journal of Hydrology and Hydromechanics*, **54**(3), 1-10.

Tajali Z, Shafieefar M, 2011. Hydrodynamic analysis of multi-body floating piers under wave action. *Ocean Engineering*, **38**(17-18), 1925-1933. DOI: 10.1016/j.oceaneng.2011.09.025

Wu HL, Chen XJ, Huang YX, Wang B, 2014. Influence of the legs underwater on the hydrodynamic response of the multi-leg floating structure. *Ships and Offshore Structures*, **9**(6), 578-595. DOI: 10.1080/17445302.2013.867646

Zhang F, Yang JM, LI RP, Chen G, 2007. Numerical investigation on the hydrodynamic performances of a new spar concept. *Journal of Hydrodynamics*, **19**(4), 473-481. DOI: 10.1016/S1001-6058(07)60142-5

Zeng XH, Shen XP, Wu YX, 2007. Governing equations and numerical solutions of tension leg platform with finite amplitude motion. *Applied Mathematics and Mechanics*, **28**(1), 37-49. DOI: 10.1007/s10483-007-0105-1