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Experimental Study of Optimizing the Mooring Configuration of the Tunnel-Pontoons System

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In this study, extensive experiments were carried out to investigate the optimal mooring configuration for the tunnel-pontoons system subjected to offshore waves and currents during immersion standby. For the three design mooring configurations, the motion responses of the tunnel and the tension in the mooring lines were measured simultaneously during each test. The tunnel-pontoons assembly is essentially a coupled multi-floater system, and few such experiments have been reported. The experimental results showed that the mooring configuration with longer lines leads to smaller mooring tension but larger tunnel motion, while the configuration with more lines could achieve better stability of the tunnel motion and even distribution of the mooring tensions. Based on this comparison, the configuration with six mooring lines (6-350 m) is recommended for the tunnel-pontoons system during immersion standby.

INTRODUCTION

Traditionally, immersed tunnels are seldom applied to sites exposed to ocean waves and storm conditions due to safety issues. However, nowadays some projects are building the immersed tunnels in offshore environments. An example is the immersed tunnel under construction in the Hong Kong-Zhuhai-Macau Link. The submerged tunnel is 6 km in length, consists of 33 tunnel elements, and is to be placed in the dredged trench at water depths varying from 18 m to 46 m subjected to waves and currents. The size of the largest element of this immersed tunnel is 180 m in length and 11.4 m in height with a weight of 72,000 tons in air. After the tunnel element is prefabricated in the casting yard on shore and towed to the immersion location, the next step is to anchor the element in order to allow precise maneuvering. Anchors are installed in the trenched seabed and connected to the tunnel element through cables. During standby for the weather window of immersion, the tunnel element will be moored on the sea surface above the trench. Previous experience has shown that when exposed to harsh open sea environments, the mooring lines might experience excessive tension or even breakage, and the element with a small freeboard could lose its stability and might turn over (Ingerslev, 2012). Therefore, it is necessary to predict the motion responses and mooring tensions of the tunnel-pontoons system under various mooring patterns and then determine the optimal mooring configuration during immersion standby.

In terms of the immersion standby process, essentially it is the hydrodynamic responses of a large moored floater under the action of combined waves and currents, which had been investigated extensively. Loukogeorgaki and Angelides (2005) investigated the optimal mooring configuration of the floating breakwater by analyzing the motion of the breakwater and the mooring tensions in the frequency domain. Under oblique waves, Martinelli et al. (2008) carried out an experimental study to examine the effect of the layouts of the floating breakwater on the wave transmission and the loads among the moorings and connectors. Brommundt et al. (2012) performed an analysis in the frequency domain to optimize the mooring system for floating wind turbines. Hong et al. (2015) studied experimentally the effect of mooring systems on the dynamics of a SPAR buoy-type floating offshore wind turbine. Montasir et al. (2015) performed an analysis in the time domain for a truss spar platform under various mooring configurations in terms of the number of mooring lines and their mooring angles. The motion response amplitude operators (RAOs) of the platform were found to decrease as the number of mooring lines increased.

Regarding the topic of the tunnel-element installation in the offshore environment, the majority of the existing studies focus on the immersion and transportation of the elements (Cozijn and Heo, 2009; Z. Chen et al., 2009a, 2009b; Z. Chen et al., 2012; Xiao et al., 2010; Nagel, 2011; K. Chen et al., 2012; Song et al., 2014, 2015; Huang et al., 2015). Studies of the immersion standby are scarce although the standby stage is critical for the security of the installation process. K. Chen et al. (2012) carried out measurements and a computational fluid dynamics (CFD) simulation on the horizontal drift force imposed on the mooring lines of a tunnel-pontoons system during immersion standby. In their study, however, the mooring responses of the tunnel-pontoons system were not addressed. Wu et al. (2016) calculated the nonlinear wave forces and motion RAOs of the submerged tunnel element during its towing under various wave conditions. However, there are few investigations on optimizing the mooring configuration. Song et al. (2014, 2015) studied the motion behavior of the tunnel-pontoons system and the tension in the mooring lines and hoist ropes at different stages of immersion. The results showed that both the motion responses of the tunnel and the hoist tensions were critical during the freeboard elimination and the approach to the trenched seabed. Yang et al. (2014) made a time-domain analysis of the motion responses of the tunnel element with fixed twin

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