Dynamic Responses of Immersing Tunnel Element during Freeboard Elimination

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ABSTRACT

To ensure that the tunnel elements can be immersed and landed safely and accurately, an experimental study with scale model tests was performed to investigate the dynamic responses of the immersing tunnel element under random waves. The experimental measurements revealed quantitatively the dynamic behavior of tunnel element under different wave climates and negative buoyancy. From the results, the dynamic response of the tunnel element was most severe during the stage of freeboard elimination. Thus, an important conclusion is that the freeboard elimination scenario should be checked against cable breakages and the stability of the tunnel element in the design stage, which has not been highlighted in the past literatures.

KEY WORDS: Tunnel; immersion; freeboard; wave; motion; cable; tension.

NOMENCLATURE

D: Immersing depth
d: Water depth
$H_s$: Significant wave height
$T_p$: Peak frequency period
$\eta$: Negative buoyancy.

INTRODUCTION

The construction of a submerged tunnel is a complex and challenging undertaking. Many engineering design considerations are involved related to the tunnel elements (Ingerslev, 2005; Zhao, 2007), including their subsea connection, water proofing, transportation and immersion, and protection against earthquakes. These tunnel elements are typically constructed in nearby yards on shore, and then they are towed to the site location. Once a tunnel element arrives on site, it is attached through cables to large floating pontoons at the site location that are moored to the seabed. After the cable connection, the tunnel element is then ballasted, immersed and sunken in place. The analysis of the motion response of the tunnel element under ambient waves is critical during the immersion process, as the response directly affects the accuracy of placement and subsequent ease of connection among the neighboring tunnel elements.

In the past, much work had been carried out on the in-situ stability and seismic response of the tunnel elements (Anastasopoulos et al., 2007), Ding et al., 2006; Kasper et al., 2008). There had also been studies on the towed transportation of the tunnel elements (e.g. Hakkaart, 1996).

In terms of the immersion process, both experimental and numerical studies on the response of an immersed tunnel element under wave action were conducted before by Zhan et al. (2001a and 2001b), Chakrabarti et al. (2008), Chen et al. (2012) and Chen et al. (2009a, 2009b and 2009c). However, almost all of these studies were carried out in regular monochromatic waves, and investigations on the immersion of tunnel elements under random waves were rare despite the fact that random waves are prevalent in open offshore waters. Recently, Chen et al. (2012) performed one of the few investigations that examined the motion of a tunnel element under random wave action. In their experiments, the movement of the floating pontoons was assumed negligible, and the tunnel element was immersed using a fixed trestle over the wave flume instead. The fixed pontoons assumption is however only an asymptotic condition, as the wave-induced motion of the tunnel element being lowered and immersed through cables attached to the moored floating pontoons are the responses of a multi-buoys system to the wave action. In actual sea states, especially in the open offshore environment, the motions of the pontoons and tunnel element can affect each other significantly, hence the assumption of fixed pontoons may not be valid at all times. In this regard, Cozijn and Heo (2009) carried out both extensive model tests and time-domain simulations to investigate the dynamic behaviour of the tunnel element and pontoons system at different stages of immersion, with 2%, 3% and 5% overweight. Their results showed that the tunnel element and pontoons system was more vulnerable to longer period waves. The horizontal tunnel element motion was largest when the tunnel element was suspended at 0.5 m above the gravel trench bed, while the vertical motion was largest when the tunnel element was at 1.0 m below the water surface.

In South China, a “super project” - the Hong Kong-Zhuhai-Macau Link project is currently being constructed to connect Hong Kong, Macau and Zhuhai. Upon completion, the project will reduce the traveling time in the region significantly, for example from the current 4.5 hours by roads from Hong Kong to Zhuhai or Macau to only approximately 40 minutes. The project includes a 10-km long bridge section and a 6-km immersed tube tunnel section crossing the offshore water of Ling Ding...