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Experimental investigations on seismic response of riser in touchdown zone

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Abstract

A series of indoor simulation tests on a large-sized shaking table was performed, which was used to simulate the earthquake ground motion for the pipe—soil interaction system to be tested. The purpose of this study is to examine the dynamic characteristic and seismic response of a length of PVC pipeline lay on a clay seabed under seismic load. The pipeline was fully instrumented to provide strain and acceleration responses in both transverse and in-line. Dynamical modal tests show that corresponding mode shapes vertically and horizontally are basically the same. But the absolute values of the natural frequencies vertically are all higher than those corresponding values in transverse. It turned out that the geometry configuration of riser affects its stiffness. Seismic response of pipeline depends significantly on the waveform, and Peak Ground Acceleration (PGA). As the seismic loading progressed, the strain response was severe around both TDZ and catenary zone. Additionally, strain responses in top and bottom positions were more severe than the result in left or right side of the pipeline in the same section.

Keywords: Steel catenary riser; Touchdown zone; 3D experiments; Modal analysis; Seismic response

1. Introduction

With the development of offshore oil fields to the deep sea environment, Steel Catenary Riser (SCR), connecting Floating Platform System (FPS) and subsea pipeline on the seabed, becomes an important structure (Park et al., 2016). It consists of catenary zone, touchdown zone and surface zone (Bridge et al., 2003). The critical point when the catenary riser firstly contact the seabed is the Touchdown Point (TDP). The area where the riser interacts with the seabed in deep sea environment becomes the Touchdown Zone (TDZ), as shown in Fig. 1. The structure is relatively flexible compared with the fixed offshore platform. The riser in service operates in the ocean for a long time and is subjected to complex work and environmental loadings, including ocean wave, current, inner pressure, outer pressure and also earthquakes. Besides, most of oil/gas field in South China Sea are in the Circum Pacific seismic belt, the most active seismic zone in the world (Duan et al., 2010). This greatly reduces the service life of the riser in TDZ, so the impact of earthquake would be very significant. Seabed of soft clay is usually generated in deepwater oil and gas field in South China Sea (Zheng et al., 2004). Earthquake action on the seabed could induce a complex interaction process of pipeline and soil in TDZ (Arifin et al., 2010; Elosta et al., 2013; Yu et al., 2013, 2015). In this extreme condition, resistance and suction effect of the seabed on the pipeline in TDZ may cause an increase in the local riser stresses and strains (Madani et al., 2015).

Many researches have focused on examining the interaction mechanics of pipe and soil (Bridge et al., 2003; Hodder and Byrne, 2010; Wang et al., 2013, 2014; Ryu et al., 2015; Yu et al., 2017). Main techniques for investigating TDZ include numerical analysis method and experimental method. A variety of assumptions were put forward by scholars for exploring the dynamic behaviour of riser in TDZ. Bai et al. (2015)

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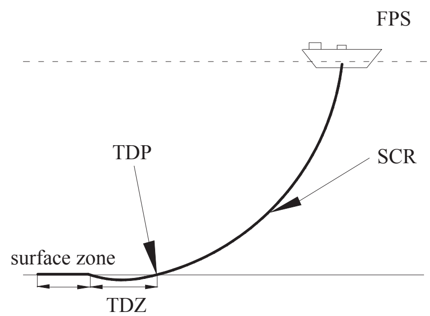

Fig. 1. Sketch of SCR in touchdown zone.

established the finite element contact model of riser and soil spring by using the equivalent spring element based on pipeline large deflection curve and the theory of elastic beam. Hawlader et al. (2016) proposed a numerical model to simulate suction and trench formation at the TDZ of SCR. Hejazi and Kimiaei (2016) developed a simplified equivalent linear soil stiffness formula in fatigue design of SCR based on the studied parameters based on the nonlinear results. Dai and Zhou (2016) proposed a solid-spring model to explore the dynamic characteristics of pipeline in TDZ and revealed dynamic response of some feature points. Kim et al. (2017) investigated the fatigue performance of touchdown zone based on a nonlinear soil model through time domain approach. Whereas, the effect of earthquake on dynamic behaviour of riser in TDZ have not been investigated. In experimental study of pipe–soil interaction, Bridge et al. (2003), Hodder and Byrne (2010), Wang et al. (2014) have conducted full-scale test and laboratory scale model test of pipe–soil interaction in TDZ. Their previous work on the interaction mechanism of pipe and soil laid a foundation for the numerical model assessment and validation. However, their researches just modelled the riser from surface zone to touchdown zone, ignoring the catenary zone. Moreover, seismic loading has not been considered, either.

When the pipe–soil system in service is subjected to earthquake, the seismic response of pipeline in TDZ is much more complex (Wu et al., 2016), becoming a challenging academic and engineering problem in offshore engineering. Merifield et al. (2009) examined partially embedment of pipelines on seabed due to the traction of the platform vertically. Elosta et al. (2013) invested SCR–seabed interaction in non-linear time domain based on the commercial code OrcaFlex. Quéau et al. (2014) studies the static stress range and its dynamic amplification factors of TDZ under oscillating loading. Hawlader et al. (2015) developed two different numerical modelling techniques, finite element and finite volume methods, to simulate riser-seabed-water interaction near the touchdown zone. Quéau et al. (2015a,b) have approximately researched the maximum stress range in the TDZ using several artificial neural networks for accessing the fatigue life of selected example SCRs. And Quéau et al. (2015a,b) explores the sensitivity of the maximum dynamic stress ranges and dynamic amplification factor (DAF) to the key dimensionless groups of input parameters and also certain individual input parameters. Firoozabad et al. (2016) proposed a failure criterion for steel pipe elbows with small curvature under cyclic loading. Although a number of models and research papers related to static load or static cyclic load have been published, there have been few reports on the seismic response of pipeline in TDZ (Arifin et al., 2010; Won et al., 2015). And most of the seismic research remains in the stage of numerical analysis.

Therefore, it is really necessary to develop better understanding of the seismic response in the TDZ when the pipe–soil system is subjected to earthquake. Both Hodder and Byrne (2010) and Wang et al. (2014) have respectively conducted lab-scale tests of pipeline from surface zone to touchdown zone by using PVC and PE material for their low material stiffness. The test in this paper focused on the seismic response of riser in TDZ, so the pipeline model of PVC was extended from surface zone to touchdown zone to catenary zone. A lab-scale seismic test program of pipeline in TDZ was adopted to examine the dynamic characteristics and seismic response of pipeline. The objective was to assess the dynamic characteristic of structure and seismic response along pipeline and pipe ring in earthquake, and to explore some critical factors in affecting the seismic response.

2. Test instrument

2.1. Pipe–soil interaction model

The lab-scale SCR model lay on the consolidated clay tank fixed on the shaking table subjected to earthquake was simulated as shown in Fig. 2. The first attempt was to observe the dynamic characteristics and mode shapes of the pipeline-soil system in this state. And the second objective was to detect dynamic time history response and spectral response of the pipeline under different seismic loadings. However, in view of the laboratory measurements and the execution conditions, it's unfeasible to simulate the whole scale of the SCR. So a reduced PVC pipeline model is manufactured due to the size and excitation parameter of the shaking table, whose geometric dimensions and excitation parameters are shown in Fig. 3 and Table 1. Thus, some properties of the PVC model pipeline and seabed consolidated by soft clay, such as diameter and additional mass of pipeline, and consolidation pressure of seabed, needed to be manufactured to accommodate the model scale.

2.2. Consolidated seabed

The model seabed in the present study was consolidated by a type of soft red clay, which was taken from a foundation pit in Dalian. With the purpose of in keeping with the soil properties in South China Sea (Zheng et al., 2004), the sample seabed preparation process contained five steps. Firstly, a metal flume with drainage valves (2 mm diameter) on the bottom was manufactured, whose size is 3 m long, 1 m wide, 0.6 m high. Secondly, cover the bottom of the flume with 60 mm thick gravel drainage layer; then place a sheet of