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Effect of Remolding and Reconsolidation on the Touchdown Stiffness of a Steel Catenary Riser: Observations from Centrifuge Modeling

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Abstract

Steel catenary risers (SCRs) can be economical to construct and install compared to conventional vertical risers. However, accurate evaluation of the fatigue life of an SCR remains a major challenge due to uncertainty surrounding the interaction forces where the riser ‘touches down’ on the seabed. Fatigue life predictions for the pipe in the vicinity of the touchdown zone (TDZ) are heavily dependant on the assumed vertical stiffness between the riser and the seabed. For accurate fatigue life predictions to be made, a reliable evaluation of the seabed stiffness is required.

This paper describes a series of model tests that were conducted within the University of Western Australia’s geotechnical beam centrifuge. These tests aimed to assess typical vertical stiffness values during large and small amplitude cycles of riser motion, and the influence of remolding and reconsolidation effects. The tests used a short section of riser pipe which simulated part of an SCR. The soil comprised soft kaolin clay, consolidated to an undrained strength that increased approximately linearly with depth, mimicking typical field conditions.

A wide range of riser motions were simulated, encompassing sequences of both large and small amplitude movements, under load and displacement control, with intervening pause periods to investigate the effects of reconsolidation. The associated changes in vertical pipe-soil resistance are reported, and converted into appropriate values of secant stiffness which would correspond to a linear idealization of the vertical pipe-soil response. It is shown that the vertical pipe-soil stiffness rapidly reduces during an episode of large-amplitude cyclic motion, with a steady cyclic stiffness being reached within ~10 cycles as the soil remolds. The influence of cyclic load amplitude is identified, and is shown to match a hyperbolic model. Episodes of reconsolidation are found to create a significant increase in vertical pipe-soil stiffness. This recovery can lead to a pipe-soil stiffness that exceeds the initial intact stiffness (prior to remolding). The implications for design are summarized.

The riser pipe test results are supported by data from a site investigation of the centrifuge soil sample using a miniature T-bar penetrometer. Cyclic T-bar tests were used to assess the strength and cyclic sensitivity of the soil, and the tendency for a recovery of undrained strength after periods of reconsolidation. The trends of changing soil strength from these T-bar tests match the patterns of changing pipe-soil stiffness from the riser tests.

Introduction

As fossil fuel reserves in shallow water continue to be depleted and offshore technology advances, the development of fields located in deep water is increasingly common. Typically, a deep water offshore development consists of a floating vessel or platform with a mooring system, and risers that transport the hydrocarbon product between the seabed and the platform. Steel catenary risers (SCRs) can be a more cost effective option than vertical or flexible risers in deep water and consist of a 200-500mm diameter steel pipe, suspended from the platform.

Storm loading on an offshore vessel can cause large amplitude motions of the SCR at the TDZ. While these events impose large strains on the riser pipe and cause gross deformations of the underlying seabed material, they occur relatively infrequently. In certain locations, such as the Gulf of Mexico, storm seasons are generally an annual event. During a storm the riser will be subjected to large amplitude cycling, after which time the loading regime will return to the regular day-to-day, small motions and will generally remain so for the remainder of the year. The period of inactivity following the severe cycling allows the pore pressure in the seabed soil in the vicinity of the pipeline to return to hydrostatic. In normally or