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Soil Response and Stiffness Laboratory Measurements of SCR Pipe/Soil Interaction

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Abstract

A laboratory testing program was initiated to investigate potential changes in stiffness for soils in the touch down point region of a Steel Catenary Riser (SCR). The tests were performed using a T-bar apparatus, a device normally used to determine the shear strength of clay soils. The normalized stiffness obtained with the T-bar was found to match previous results obtained with pipe tests for an unload-reload cycle of loading and helped confirm that using a normalized approach with the smaller-sized T-bar could produce meaningful results. The focus of the testing program was to determine the normalized stiffness of the soil under high amplitude cyclic loading conditions and then under lower amplitude loading after a waiting period of about 24 hours. The normalized soil stiffness was compared at a consistent displacement level in all cases. As expected the large amplitude cyclic loading produced large changes in the soil stiffness. One test where the T-bar was observed to separate from the soil resulted in a further reduction the soil stiffness. For this test the stiffness was reduced by a factor of about 33 relative to the initial undisturbed load-reload stiffness of the soil. The soil stiffness did recover after the 1-day waiting period. However, this stiffness remained lower than the initial unload reload stiffness by a factor of 4. This observation could impact fatigue analyses when the soil stiffness for a fatigue event must be evaluated after prior large amplitude cyclic loading.

Introduction

Fatigue life is an important consideration for the design of Steel Catenary Risers (SCR's) and is highly dependent on the interaction of the SCR pipe with the seafloor soils. However, this interaction is one of the most challenging soil-pile interaction problems in geotechnical engineering. Although the soil response to pipe loading and unloading is quite complex exhibiting nonlinear and generally inelastic behavior, a designer desires simple linear soil springs to represent soil loading and unloading. The major design uncertainty in SCR design involves the potential change in the soil response that occurs with different number of loading cycles, different magnitudes of cyclic displacement, and the time dependent change that occurs after setup due to pore pressure dissipation and consolidation effects. Previous studies (Clukey et al., 2005; Bridge and Howells, 2007; Bridge and Willis, 2002) show that separation of the pipe and soil can cause more significant cyclic damage than repeated loading where the pipe maintains a constant contact with the soil.

The primary objective of this study was to investigate the potential degradation of the soil stiffness due to cyclic loading and the potential recovery that occurs after setup is allowed for specified setup periods. This paper presents: (1) details of the testing program, (2) a detailed description of the testing equipment and data acquisition system, (3) graphs showing the testing results for a series of testing, and (4) our general findings, conclusions, and recommendations.

The paper discusses the changes in secant soil stiffness that occur for different number of loading cycles, different magnitudes of cyclic displacement, and the time dependent change that occurs after setup. The results generally suggest that secant stiffness ratios are considerably less than the ratios associated with static loading, especially for unload-reload soil response. Some of the reduction in stiffness is recovered if the cyclic loading is temporarily stopped and then resumed after one day. Recommendations are included for future testing that will further improve our understanding of this complex pipe/soil interaction.