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Cyclic Tests of Model Pipe in Kaolin

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Abstract

Soil-pipe interaction is an important factor in the design of steel catenary risers. Pertinent aspects of this issue include the backbone curve defining soil resistance under conditions of virgin penetration, equivalent soil spring stiffness during unload-reload cycles, and permanent displacements under cyclic loading. This paper presents the findings of single-gravity model tests in soft kaolin that were conducted to investigate these issues. Cyclic tests were conducted for small amplitude loading involving no reversal in the direction of the soil resisting force, and large amplitude loading involving such reversals. Presented in this paper are measured relationships of soil secant stiffness as a function of displacement and load cycle for conditions of unloading and reloading. The rate of accumulation of permanent displacements under cyclic loading is strongly affected by the magnitude of loading. Backbone curve measurements during virgin penetration are in general agreement with analytical estimates.

Introduction

Interaction effects between seafloor soils and shallowly embedded pipes are relevant to a variety of pipeline problems. A topic of considerable current interest is soil-pipe interaction within the zone where a riser pipe touches down on the seabed, which proves to be a region where changes in bending stresses are largest and therefore a critical location for fatigue (Bridge et al., 2003; Bridge et al., 2004). A P - y approach similar to that applied to laterally loaded piles is often adopted for this problem, where P is soil force per unit length of pipe (F/L) and y is deflection normal to the pipe axis. In the study presented herein the focus is on vertical motions, and y denotes vertical deflection.

Development of a P - y model requires characterization of the following aspects of soil-pipe interaction:

- The 'backbone' curve describing force-penetration (P - y) behavior under conditions of virgin penetration.
- Equivalent soil spring stiffness under conditions of unloading and reloading, and the change in stiffness during cyclic loading.
- Permanent deformations under cyclic loading.

This paper presents the results of a testing program developed for the purpose of elucidating basic aspects of soil-pipe interaction behavior with regard to the points listed above.

Test Program

The test program presented herein comprises three tests conducted under single gravity conditions. The first is a reference test that establishes the backbone curve and stiffness relationships to be used as a basis for evaluating cyclic test data. The second test involves 'small amplitude' cyclic loading conditions, which in this paper will refer to cyclic loads of sufficiently small magnitude such that no reversal of direction occurs in the net soil force acting on the pipe. The third test is a 'large amplitude' cyclic load test in which the pipe undergoes a large ($1D$) upward displacement during each load cycle and a reversal of the net soil force on the pipe occurs.

Test Apparatus. The tests were conducted in a kaolin test bed contained in strong box with internal dimensions, 650 mm by 390 mm by 325 mm deep. The consolidated thickness of the kaolin was 220 mm. The model pipe dimensions were 25 mm diameter by 125 mm long. An electronically driven actuator allows both T-bar and pipe penetration tests to be undertaken. The data acquisition and control software permits loading with either displacement or force control. A displacement control mode with load reversal at a prescribed force level is also possible, a feature which was utilized in the large amplitude cyclic load test.