Uplift Resistance of Buried Pipelines in Blocky Clay Backfill

J. Wang, S.K. Haigh & N.I. Thusyanthan†
Department of Engineering, University of Cambridge
Cambridge, Cambridgeshire, United Kingdom
†KW Ltd., Fetcham, Surrey, United Kingdom

ABSTRACT

This paper presents the results from 10 minidrum centrifuge tests conducted at the Schofield Centre, compiled with 4 additional test results from Thusyanthan et al., 2008. All these tests were designed to measure the uplift resistance of a pipeline installed into stiff clay by trenching and backfilling, then uplifted approximately 3 months after installation. All tests were conducted at 1:30 scale using soil obtained from offshore clay samples. Experimental results show that clay blocks remained intact after 3 prototype months of consolidation, and were lifted rather than sheared during pipe pullout. The uplift resistance therefore depends on the weight of the soil cover and the shearing resistance mobilised at the softening contact points between the intact blocks and within the interstitial slurry. Slow drained pullout led to lower resistance than fast pullout, indicating that the drained response is critical for design. The varying scatter shows that peak uplift resistance is very sensitive to the arrangement of the backfill blocks when the cover and pipe diameter are comparable to the block size.

KEY WORDS:
Pipeline, Uplift, Clay, Centrifuge, Backfill, Undrained, Drained

INTRODUCTION

Over the past few years, many minidrum centrifuge tests have been carried out in Cambridge to evaluate pipeline uplift resistance in soft clay. The purpose of these tests is to assist the design of pipelines against upheaval buckling. The installation of the pipeline is a trench-and-cover process, using the clay material excavated during the ploughing process as backfill. If insufficient uplift resistance is to be anticipated, the addition of rockdump would be a possibility. This process results in a blocky clay backfill which then consolidates under its own self-weight.

This paper presents the results of 10 minidrum centrifuge tests that were designed to simulate the conditions found offshore along a length of buried pipeline approximately 3 months after installation. This was the anticipated period between pipe-laying and start-up of the pipeline.

These results were then compiled with the 4 additional test results, using the same test apparatus, from Thusyanthan et al., 2008, and presented in this paper.

All the 14 tests mentioned were conducted at 1:30 scale, using two model pipes of diameter 8.7 mm (261 mm at field scale) and 13 mm (390 mm at field scale) respectively, both buried under blocky clay backfill in an artificial model trench. This arrangement is used to simulate the ploughing and backfilling process. In each experiment, the selected model pipe was pulled out at both slow and fast rates, whilst the uplift resistance and nearby pore water pressures were measured.

The results of these tests have been interpreted to provide guidance for the selection of a design uplift response. The effects of pull-out rate, trench depth and rockdump surcharge have been investigated.

BACKGROUND TO PIPE UPLIFT RESISTANCE

The uplift resistance per unit length of pipe, F, comprises (i) the weight of the soil above the pipe and (ii) the mobilised shearing resistance of soil. The peak value of F can be interpreted within either an effective stress or an undrained strength framework. To determine which framework is more applicable, the rate of loading should be compared with the rate at which water flows through the pore space of the soil. If the pipe is pulled out sufficiently quickly, there is not sufficient time for soil volume change to take place. The soil’s tendency to dilate or contract during shear therefore gives rise to negative or positive pore water pressures respectively. The measured uplift resistance then corresponds to the undrained case.

Under drained conditions, the pull-out speed is low and the overlying soil is sheared slowly. There is sufficient time for seepage to take place, so that no excess pore pressure is generated. As a result, the soil changes in volume during shear. Below a critical speed – dependent on the ratio of the pipe velocity to the soil consolidation coefficient – fully drained conditions occur. Above a critical speed, fully undrained conditions occur. There is an intermediate range of partially-drained behaviour. Since the permeability of clay is extremely low, drained conditions are only achieved at very slow pullout rates in intact clay.