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# An Experimental Study of Pipeline Flotation

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## Abstract

This paper presents and discusses the phenomenon of flotation of pipelines buried in shallow soft soils typically found in near shore and offshore areas. Laboratory flotation tests were conducted on model PVC pipes embedded in soil-water (slurry) mixes with varying bulk densities of three different soil types. The depth of embedment varied from 1.5 to 2 times the diameter of the pipe. The soil types used in the tests include a) Sandy Lean Clay (Liquid Limit, LL = 49) b) Fat Clay (LL = 85) and c) Bentonite mixed with Sandy Clay (LL = 350). The pipelines were studied for flotation phenomenon at slurry water contents varying from LL to about 2.5 times LL. For each mix, the unit weight of the pipe plus contents was measured at point of flotation (when the embedded pipe in the slurry was just about to float). The unit weight of the slurry ($\gamma_s$) and the pipe plus contents at point of flotation were plotted against the moisture content of the mix normalized with the liquid limit of the soil (w/LL). The slurry resistance per unit volume of the pipe was calculated to be the difference in the unit weights of the slurry and the pipe plus contents at point of flotation. The mix resistance reduced exponentially with increasing water content. It was observed that (1) at moisture contents about 1.2 to 1.4 times the LL and lower (irrespective of the type of soil), no flotation behavior was observed and (2) at moisture contents about 2.3 to 2.5 times LL (irrespective of the type of soil), the net uplift force (the unit weight of slurry less slurry resistance) acting on the pipe was maximum with a negligible slurry resistance. The significance of the obervations from the present study is that the maximum flotation force on a pipe line acts at slurry moisture contents at about 2.3 to 2.5 times the liquid limit of the soil. The design of anchor systems for pipelines against flotation based on the above findings could provide potential cost saving oppurtunities as current design practices may be very conservative in some cases.

## Introduction

Buried pipelines transporting petroleum products (both onshore and offshore) more than often traverse through varying subsurface soil and ground water conditions. These pipelines are buried to protect them from damage caused by external sources such as fishing gears, ship anchors, collision, vehicular traffic, and environmental impacts or for other reasons (development of real estate). Buried pipes, when installed below the ground water table (e.g., pipelines submerged offshore, under river crossings, under streams, under swamps or loosely backfilled trenches below water table), are subjected to buoyant forces and therefore are prone to float out of the ground either during construction or during their design life (Bonar and Ghazzaly, 1973; Teh et. al., 2003). Pipelines that are prone to flotation are protected by providing adequate soil cover or loaded down with concrete weights or saddle weights, or are anchored to the ground.

Quantitatively, the buoyant force is the weight of the displaced volume of the fluid. Thus, for any object immersed in water, the buoyant force acting on the object equals the unit weight of the water times the volume of water displaced by the object. For soils under water, the buoyancy force is a function of the state or the condition of the soil below the water table. As the moisture content reduces, the soil behaves as a frictional (semi-solid) material and exerts no buoyancy.

Remolding due to monotonic shearing can render very soft to soft cohesive soils to be in a fluidized state at very high moisture contents (Seed et. al., 2001). Loose cohesionless soils under water can liquefy rendering them to behave as a dense fluid. The source for liquefaction or fluidization of soils can be environmental factors such as vibrations, wave action, currents, earthquakes, tidal and groundwater table fluctuations (Sumer et al., 1999; Siddharthan and Norris, 1993; Ishihara and Yamazaki, 1983). In a liquefied or fluid state, the buoyant force exerted on the pipe will be higher than the buoyant force exerted by water since the unit weight of slurry is more than the unit weight of water.

The unit weight of slurry, $\gamma_s$ is typically more than the unit weight of water, $\gamma_w$. Thus, ideally, buried pipelines in these conditions should be designed using an appropriate value of $\gamma_s$ of the soil-water mixture. As can be intuitively seen, more are the soil particles in suspension more will be the value of $\gamma_s$ and higher will be the flotation force in the slurry state. The behavior of the