Testing and Modeling of Fixed and Rolling Buoyancy Sections

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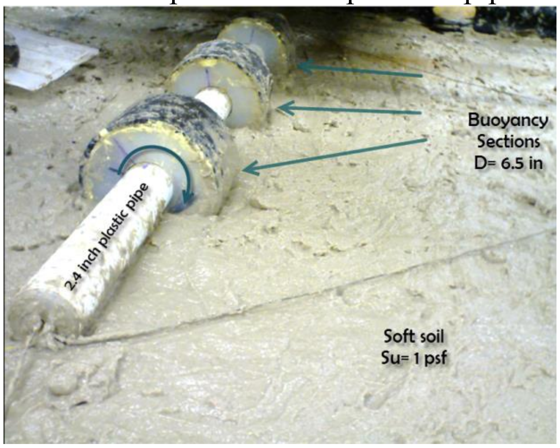
Abstract: This study was focused on investigating and quantifying the effects of fixed and rolling buoyancy systems on the lateral pipe soil interaction. Hence, First Physical models have been designed and constructed at the CIGMAT Laboratory to investigate the pipeline responses on soft soil seabed and then non-linear Finite Element Analysis is developed for comparison.

1. Introduction: Deep-water oil pipelines rest on very soft seabed and are susceptible to axial and lateral movement of pipelines due to cyclic thermal and pressure changes due to thermal expansion under operating conditions. The concern is that an isolated buckling may generate a bending high enough to compromise the strength or fatigue of the pipe. It is more realized by the industry to initiate such global flow line buckling in a controlled manner so to release the compressive load and to avoid the excessive expansion and pipe bending at predefined locations by utilizing buckle initiators such as buoyancy sections (flow line section with much reduced submerged weight). Lateral buckling was first analyzed by Hobbs (1984). More studies have been done in recent years for the deepwater HPHT pipelines with detailed Finite Element Analysis (FEA). Field observations have been reported in the literature (Harrison, Brunner, and Bruton, 2003). Procedures have been developed to design and mitigation of lateral buckling, represented by the joint industry projects, such as SAFEBUCK and HOTPIPE. The DNV recommended practice is DNV-RP-F110. The commonly used design strategy against lateral buckling for the deep-water HPHT pipelines is to control the pipeline thermal expansion and lateral buckling, in location and scale. The mechanisms are to trigger the lateral buckling in multiple locations by placing the vertical offset, namely sleeper and by reducing the pipeline section submerged weight, namely distributed buoyancy (module) section. Also new methods are being developed to minimize buckling

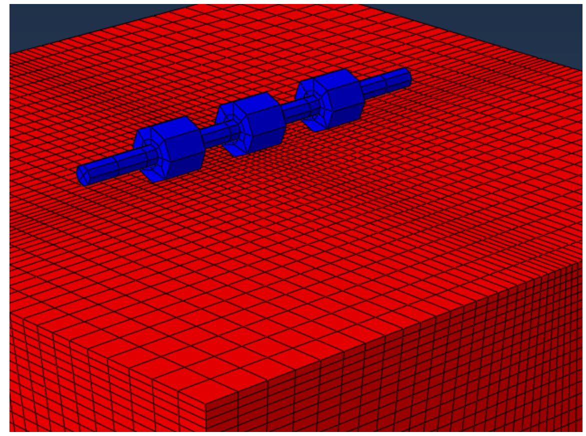
2. Objective: he main focus of this study was to investigate the pipe-soil interaction of fixed buoyancy (infinite rotational stiffness) and rolling buoyancy (zero rotational stiffness) using model tests in the soft clay with undrained shear strength of 1 psf to represent the seabed.

3. Materials and Methods: Large test box with dimension of 8 ft. length 8 ft. width and 6 ft. depth was used to simulate the pipe interaction with the soft clay soil representing the seabed (Fig 1.a). The thickness of the soft soil profile used in this study was 1 ft., about 3 times the diameter of the pipe. The resistance to pipe sliding on the soft soil was monitored using a load cell. The pipe displacement and excess pore pressured were monitored using linear variable displacement transducer (LVDT) and pore pressure transducers.

4. FEM Formulation and Parameter Selection: A PVC pipe of 2.4 in diameter (D) equipped with three evenly spaced buoyancy sections of 6.5 in × 5 in(outer diameter × length)was modeled in this study. To model the soil an Eulerian domain of 8ft × 8 ft× 0.04 m (width × height × thickness) was used (Fig.1) the soil was modeled as an elastic perfectly plastic material. $E_u=500s_{u0}$ and Poison's ration was assumed to be 0.49 with a unit weight of 1620 kg/m^3 for clay. In this study for both case of fixed and rolling buoyancy sections, the numerical analyses was divided into four steps. The first step is the geostatic step. During the geostatic step pipe is kept outside the Eulerian part and the gravity and geostatic force applied to pipe. The displacement that occur during the geostatic step is not due the external loading but due to the difference between the user predicted initial stresses and the converged stresses calculated using ABAQUS which is in equilibrium with the external loading. In the second step, the pipe is moved downward in given velocity on the seabed. Since this movement occurs only through the void, no reaction forces observed during this step. During the third step, pipe starts to penetrate into the seabed due to gravity load. And the analyses shifts from displacement controlled to force controlled. In the fourth step, during lateral loading, a fully displacement controlled analyses was conducted to measure force displacement response of pipe over subsea seabed.



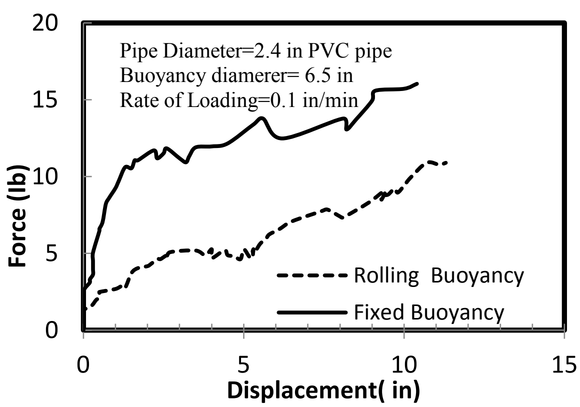
(a)



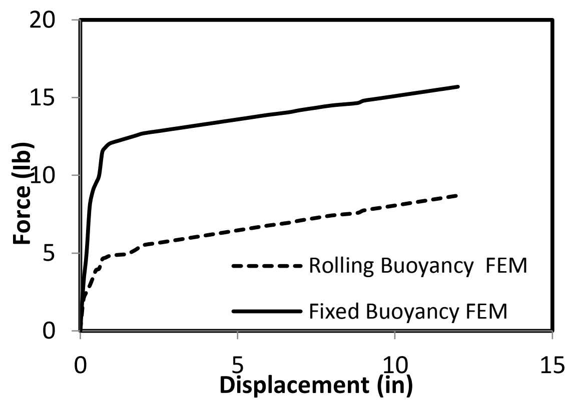
(b)

Figure 1: application of buoyancy section on lateral loading. (a)Experiments (b) Finite Element

5. Results



(a)



(b)

Figure 2: Lateral Force-Displacement responses; (a) Experimental results (b) FEM results

6. Conclusion: For both case of full-scale testing and Numerical results from CEL (Coupled Eulerian Lagrangian) finite element, Change in rotational stiffness of buoyancy from no stiffness(rolling buoyancy) to completely fixed stiffness brought in 290 % increase experimentally and 240 % increase in finite element analysis for the max force displacement responses.

7. Reference

1. G. Qui, s. Henke, J. Grabe “Application of a Coupled Eulerian–Lagrangian Approach on Geomechanical Problems Involving Large Deformations” 2011, Journal of Computers and Geotechnics, Volume 38, Issue 1, Pages 30–39
2. D.J. White, D.S. Burton, M. Bolton "Observations of Axial Pipe-soil Interaction from Testing on Soft Natural Clays" 2011, OTC-21249-MS, Houston, TX
3. Sun, J., Jukes, P., & Shi, H. "Thermal Expansion/Global Buckling Mitigation of HPHT Deepwater Pipelines, Sleeper or Buoyancy?" 2012, International Society of Offshore and Polar Engineers, I-12-253 ISOPE
4. S. Mebarkia “Effect of High-Pressure/High-Temperature Flowlines and Soil Interaction on Deepwater Subsea Development” 2005, Offshore Technology Conference, 18107-MS OTC, Houston, TX