Numerical finite element modelling of soil resistance against upheaval buckling of buried submarine pipelines

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Submarine high-temperature and/or high-pressure (HT/HP) pipelines used to transport oil and gas in different areas of the world are susceptible to global buckling. If the pipelines are simply laid on the seabed, buckling will likely occur in the horizontal plane, while if buried in a trench, buckling will probably arise in the vertical direction. The latter buckling mode may lead to catastrophic pipeline failure potentially associated with massive oil leakage and severe environmental damage. Concerns about upheaval buckling have motivated a number of researchers to investigate the uplift resistance of buried pipelines. The objective of the work presented in this paper is to evaluate the effects of various parameters on the resistance to upheaval buckling of buried submarine pipelines. A numerical approach was adopted to build representative and reliable 3D models of 100 m long embedded pipelines, using the specialized finite element software ABAQUS. Starting with a baseline model of a pipe buried in a medium dense sand with fines, the effects of pertinent parameters on the uplift resistance were explored for two scenarios: (1) uplift of the full pipeline length, which in essence captures the plane strain 2D response and (2) uplift of a central middle length of 20 m. Specifically, the effects of the apparent cohesion of the soil due to the presence of fines, pipeline diameter, embedment depth and diameter to wall thickness ratio were investigated. The uplift forces obtained were normalized in reference to actual pullout and/or effective pipe lengths. The results indicated that the normalized uplift forces obtained in the 3D analyses at high pipeline displacements were in close agreement with those yielded by plane strain models. The model analyses indicated that the contribution of soil apparent cohesion to the uplift resistance was significant. The work indicated that as the level of confinement increases (due to an increase in embedment depth and/or pipeline diameter) the uplift resistance increased, whereas the relative contribution of soil cohesion to the resistance decreases. The paper includes a comparison of the FE results obtained in this study with the available predictive/analytical methods, along with a discussion of which best captured the failure mode and resistance to uplift values of the numerical model.