EFFECT OF SOIL CONSOLIDATION ON THE STRESS AND DEFORMATION OF PIPELINE IN MUSKEG

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1. Introduction

Pipeline stress response to mechanical loading is typically intricate when crossing soft soil. The pipelines in muskeg are subjected to unstable loadings due to seasonal water table variation, fluid pressure change, and soil consolidation. These loading can alter the mode of large deformation, which sometimes results in stability issues, e.g. global buckling. In addition, settlement due to soil consolidation for liquid pipelines may result in sustained stress concerns. Pipe-soil analysis typically involves finite element method with beam elements and discrete soil-springs. However, the soil-spring calculation methods, e.g. as suggested by The American Lifeline Alliance or The Pipeline Research Council International, are not considered applicable for peat/muskeg soil. Three-dimensional continuum modeling thus become necessary to better understand effects of unstable soil loadings on pipeline stress. The objective of the present study is to determine the stress and deformation due to soil settlement as a function of time for pipelines buried in soft soils.

2. Methods

The model consists of a 20-m long pipe buried in a soil that is 12.5-m deep and 4-m wide. The overburden is 2-m thick. The outer diameter of the pipe is 0.508m (20 inches). The chosen dimensions are found to be sufficient to minimize the boundary effect on the pipe stress analysis.

Three-dimensional parametrical pipe-soil interaction models were built in ABAQUS finite element package with 8-node brick elements for the pipe. It was assumed that the pipe was supported at both ends with solid foundation such as concrete. The soil was meshed with 20-node hexahedral pore pressure elements. Large sliding between the pipe and soil was modeled with the surface-surface contact in ABAQUS. Large pipe deformation was also modeled. Different scenarios were considered: frozen muskeg, soft clay and water-filled soft clay; internal oil pressures were included in some of these cases. Soil settlement due to consolidation was simulated to show the pipe stress and displacement as functions of time.

The modulus and Poisson's ratio of pipe steel are 207 GPa and 0.3 respectively. The default modulus and Poisson's ratio of soil are 5 MPa and 0.2 respectively unless otherwise used for comparison.

3. Results

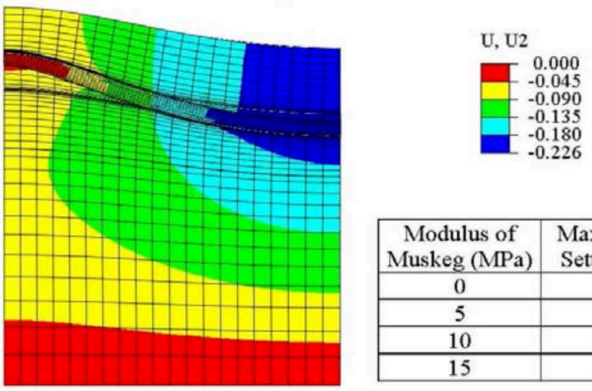
Pipe deformation and stress are sensitive to soil properties with very soft soil such as muskeg, but insensitive after soil stiffness reaches a level of magnitude (Fig. 1). It takes more than one month for the pipe settlement to complete and the stress increased to the maximum if a pipe is laid in a frozen muskeg that is suddenly defrosted (Fig. 2). Soil consolidation could produce much larger stresses than any other factors alone.

4. Discussion

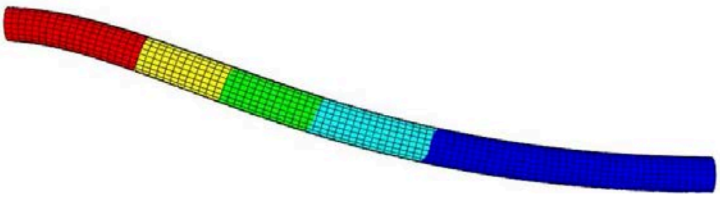
In contrast to commonly used soil-spring elements in the oil and gas industry to account for the soil support, only continuum elements were used in the present study. The pipe-soil interaction is thus more realistically modelled leading to interesting and potentially more accurate results.

Energy pipelines in muskeg in northern Canada are always built in the winter when the frozen muskeg makes the construction possible. Our results indicate that the pipe only experiences up to a few millimetres deflection at the time of construction, but hundreds of millimetres (Fig. 1) with over 2 times stress (Fig. 2) when the muskeg is defrosted in the summer. If we further consider the thermal expansion (study in progress) during operation, these additional deflection and stress could be a significant integrity concern.

Both pore fluid pressure and soil consolidation produce significant differences in pipe stress, which indicates that, in soft soil where seasonal fluid pressure changes, soil consolidation and soil particle flow is not uncommon, this additional loading needs to be considered in pipe stress and stability analysis to ensure pipeline safe operation. The study has suggested that an initial soil consolidation stage needs to be considered when calculating the springs that are to be used for conventional beam element analysis for pipe design. The study has also provided a range of settlement values for various soil consolidation conditions.



Modulus of Muskeg (MPa)	Maximum Pipe Settlement (m)
0	0.769
5	0.226
10	0.118
15	0.080



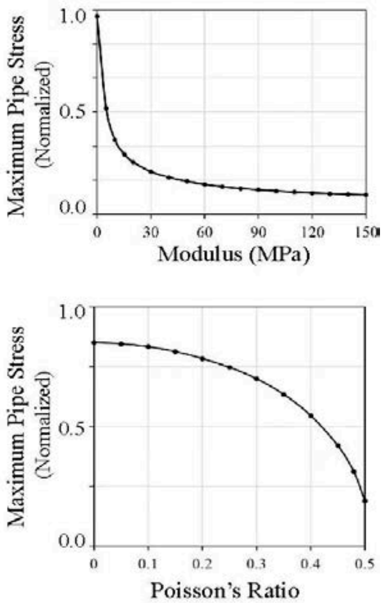


Figure 1: Final settlement of the pipe and soil (left), and normalized maximum pipe stress as a function of soil modulus (upper right) and of Poisson's ratio of the soil (lower right). The pipe is full with bitumen (900 kg/m^3). The modulus and Poisson's ratio of soil are 5 MPa and 0.2 respectively unless noted otherwise.

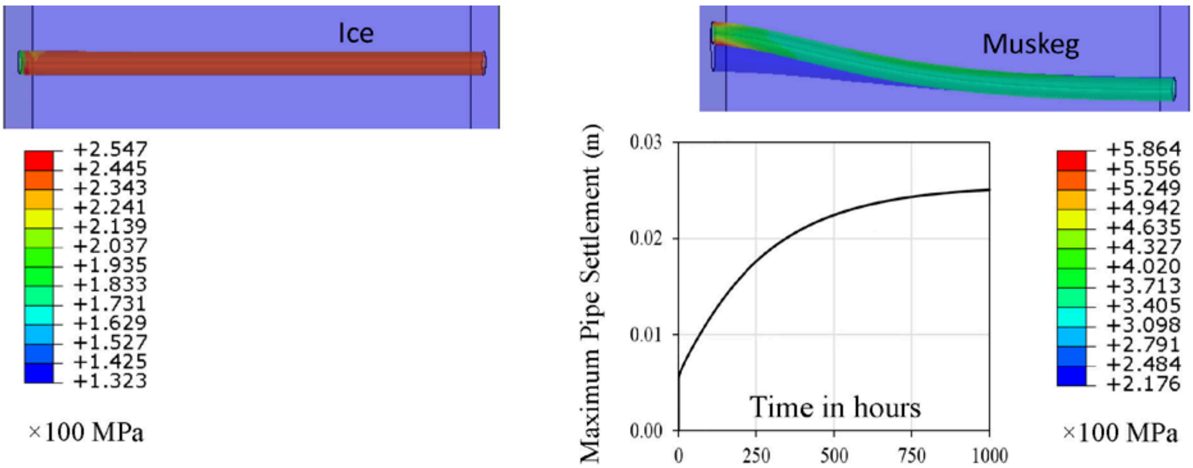


Figure 2: von Mises stress of pipe in ice (left) and settled muskeg (right), and the maximum pipe settlement as a function of time (inset).

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