EVALUATION OF SOIL-PIPE INTERACTION OF UNDERWATER PIPELINES IN SOFT SOILS

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Abstract. The paper presents a comprehensive approach to the uniting of models implemented in application-oriented packages. Research findings can be used to design the main pipeline. The modeling and analysis of the stress-strain state of the soil-pipe interaction system are presented herein. This paper analyzes the stress-strain state of the pipeline wall using the ANSYS software package. After the creation of the pipeline solid model, the stress analysis is carried out for all loads calculated at the design stage. The calculation results show that the stress-strain state of the pipeline depends on the depth of its location.

1. Introduction

The oil production in Russia will be gained due to the field development in the Northwestern Federal District, Siberian Federal District, and Far Eastern Federal District. The remoteness of natural gas consumers from these Districts stimulates the development of pipeline transportation. A long range of pipelines and climatic and geological conditions result in toughening up the requirements for their reliability and lifetime improvement.

Giant oil-gas condensate fields that have been discovered for the past few years in northern and central parts of the Caspian Sea are very promising in the light of onshore field depletion and increasing the demand for petroleum. 19% of the Caspian Sea shoreland, i.e. approx. 4,1 billion tons of oil equivalent belong to the Russian Federation [1]. In the opinion of some experts, one third of the world hydrocarbon reserves falls on deposits in the Caspian Sea.

A host of deposits discovered in the Caspian Sea is located on the sea shelve. The oil extraction in the sea shelve is 2-3 times more expensive than onshore extraction owing to the high-technologies and more efficient equipment required for the development of underwater oil-gas deposits. In northern shallow-water area of the Caspian Sea that belongs to Russia, the oil extraction is more convenient and expedient than in its depth [2]. However, the following reasons complicate the oil-gas development in this area:

1. The northern shallow-water area (not deeper than 20 m) is strongly contaminated with oil products due to the pipeline buckling in soft soil.
2. In winter, this area experiences the complicated ice conditions that results in damage of the unprotected equipment and underwater pipelines.
3. The recent years have seen a lot of accidents connected with the dense traffic that results in damages of unburied pipelines.

Consequently, in the Caspian Sea it is impossible to lay pipelines on the seabed and advisable to lay them inside trenches. The current regulatory documents do not contain an explicit design technique of laying underwater pipelines in soft soils. A strength testing methodology of water-deposited soil is not provided as well as its load-bearing capacity in relation to underwater pipelines.

This paper mainly focuses on the analysis of the stress-strain state of offshore pipelines laid in water-deposited soil to select the optimum parameters of pipeline trenching.

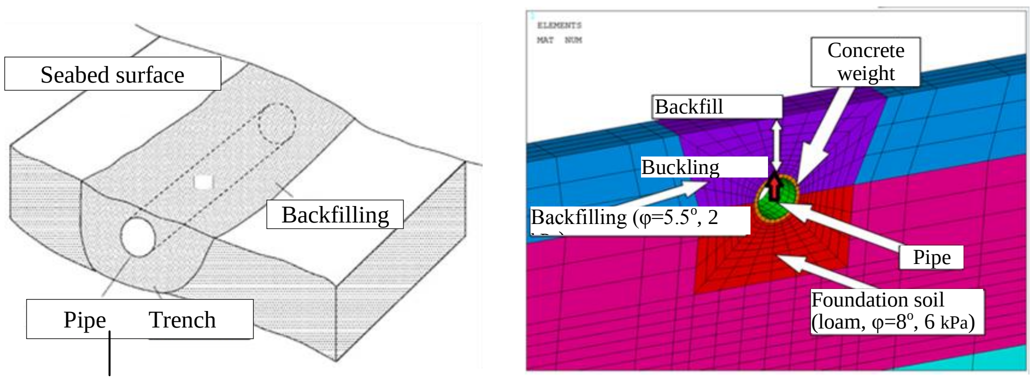
Bottom soil erosion is caused by the hydrodynamic effect. Bottom flows can be constant, tidal and other, depending on the flow rate and direction and the quality of the given soil. Bottom flows can result in the bed movement that, in turn, leads to the formation of cavities, hoppers, channels, and hollows. Underwater soil erosion facilitates the pipeline uncovering and washes away the soil from under the pipes. Cavities rapidly propagate along the pipes resulting in the space formation of considerable length [2]. These processes involve changes in the stress-strain state of the pipeline in its local areas, particularly, at its ends and centre mostly subjected to horizontal and vertical buckling. The stress-strain state of the pipeline buckled section is affected by ballasting, flow rate, temperature, and pressure [3-7]. Presently, the normal buckling forces cannot be determined theoretically and, thus, are obtained experimentally. The uniform load distribution along the pipeline, vertical and upward, is determined by multiplying the normal force value by the outer diameter of the pipe casing. Shear buckling forces result from the soil loads occurring nearby the lateral sides of the pipeline and are tangentially directed to the surface contacting with the freezing soil. Modification of the pipeline geometry due to its long-term operation in soft soils affects its stress-strain state. Therefore, a complete analysis of the stress-strain state is required allowing for the physical and geometrical non-linearity of the soil-pipe interaction system.

2. Results and discussion

The strength analysis of the pipeline buckling is carried out using the ANSYS finite element program to ascertain the maximum allowable stresses in the pipe wall and the range of numerical characteristics of the deformation processes. ANSYS 15.0 CAD Support is used to investigate the stress-strain state. This is a universal software system of finite-element method (FEM) analysis that has proven itself as reliable tool of solving a wide spectrum of engineering problems. ANSYS 15.0 CAD Support provides the use of the partial differential equation system for computing the flow rates and water temperatures; hydrostatic and heat flows, and characteristic equations. ANSYS 15.0 CAD Support allows the user to create 3D model of the undercurrent structure, which is approximated to the real conditions and assists in the simulation of different effects exerted on the pipelines and bottom soils. The seabed is assumed to be soft, the soil is loamy. The finite element model provides for placing weights or concrete for pipelines ballasting, pipe depth, foundation soil, backfill soil, and buckling forces. In general, the design model of the underwater pipeline should include the following:

– evaluation of the bearing capacity of soft soils;

– selection of the optimum design parameters of the pipeline stability [8].



a b

Figure 1. FEM mesh geometry of buried pipeline: a – burying; b – burying implementation

Design characteristics of the pipeline include: 1067 mm diameter; 19,2 mm wall thickness; 1 m length; 100 mm thickness of concrete coating; 1 m backfill height; 0,9 m height of ground bed; 1,52 m width of foundation area; 30° slope angle of foundation.Using these parameters, the pipeline FEM is created as shown in Figure 1.

Figure 2 demonstrates von Mises stresses occurred in buckling areas of the pipeline and obtained using ANSYS 15.0 software. The different colours denote different stresses, the scale at the bottom of Figure 2 indicates the stress/colour ratio. The highest stress is observed at the bending point.

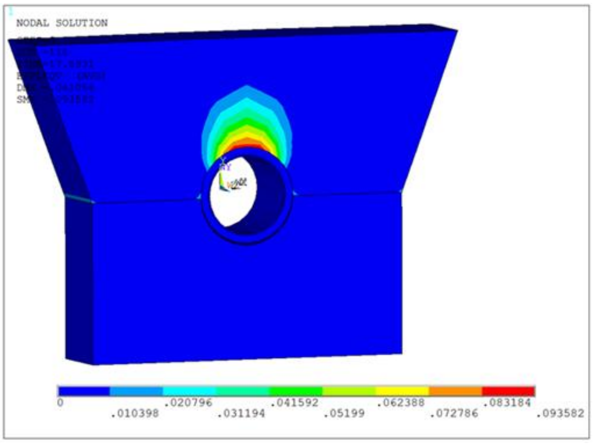


Figure 2. Von Mises stress in backfill soil

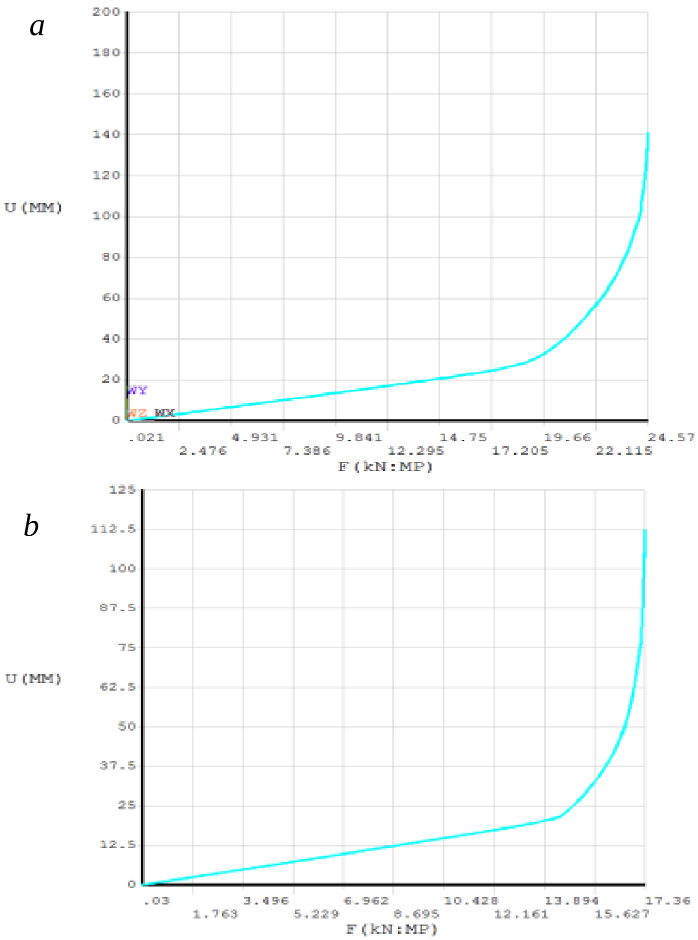


Figure 3. Dependences between vertical buckling and the load from 1 lin. m of pipeline for different backfilling heights: a – 1.5 m; b – 0.5 m

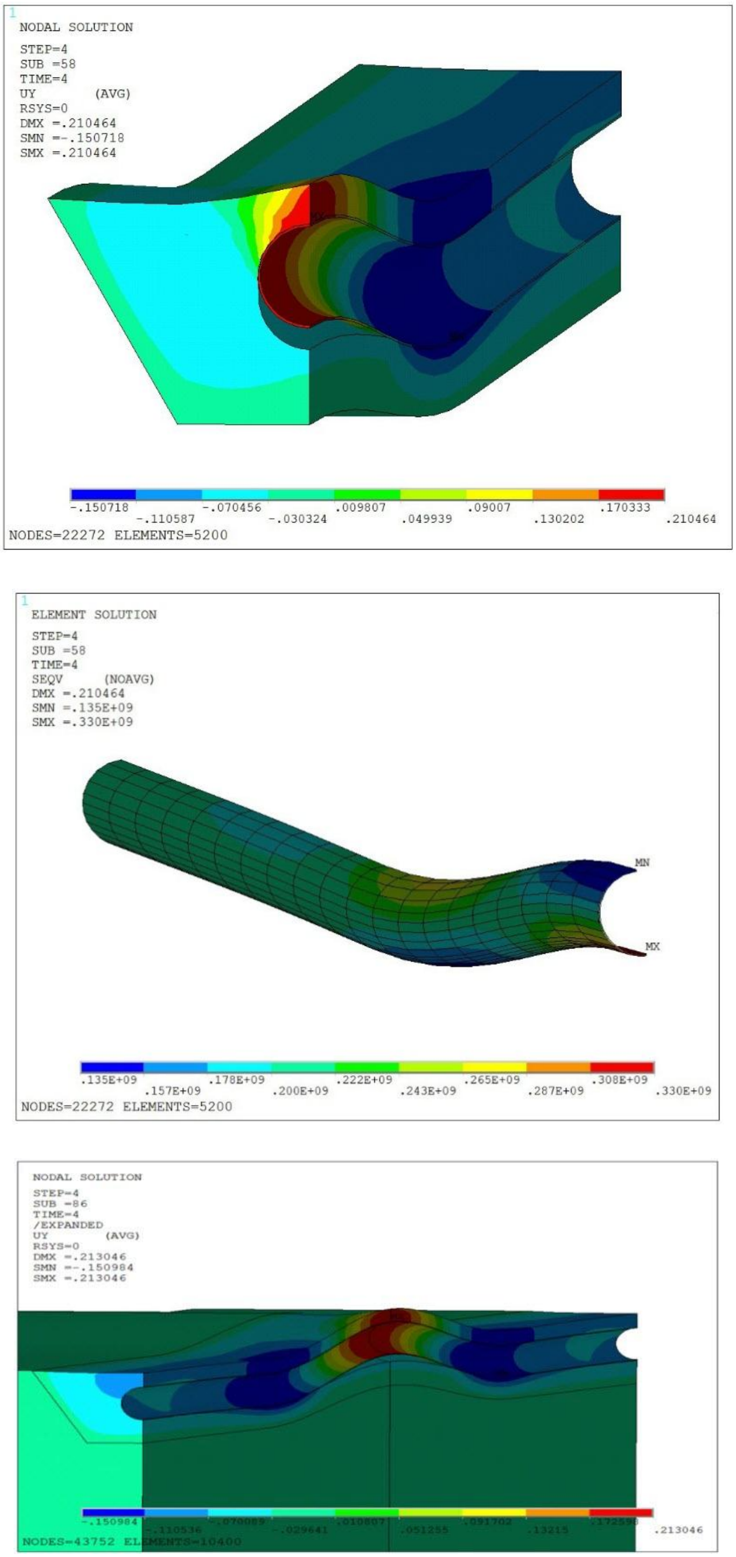


Figure 4. Equivalent stresses: a – in soil; b – in pipeline; c – in buckled pipeline

Table 1. The values of pipeline buckling depending on the backfilling height at 60o temperature and 1 m level differences

Height of backfill, m	Level difference, m	Max von Mises stress, MPa	Buckling due to dead load, m	Vertical buckling due to temperature load, m	Vertical buckling due transportation, m	Total buckling, m
0,25	1	370	-0,0630	0,2107	0,3171	0,5278
0,5	1	327	-0,0751	0,1024	0,1700	0,2724
0,75	1	290	-0,0868	0,0633	0,0778	0,1411
1	1	272	-0,0980	0,0545	0,0342	0,0868
1,25	1	267	-0,1088	0,0521	0,0228	0,0749
1,5	1	266	-0,1193	0,0505	0,0202	0,0707

3. Conclusions

The evaluation of stresses induced by the pipeline buckling and the properties of soft soils showed the relevance of the soil-pipe interaction modeling and the mathematical formalization of this problem. As a result of these investigations, the design model of the soil was suggested and the boundary conditions of this problem were determined. Numerical modeling of the stress-strain state of underwater pipelines during their interaction with the surrounding bottom soils allowed selecting the optimum parameters of the soil-pipe system stability. Thus, the following conclusions have been drawn:

Stresses occurred at the pipeline buckling achieved values close to the yield stress of steel, thereby resulting in degradation of its reliability.

The stress value varied throughout the pipe length. The pipeline sections adjacent to the solid ground were characterized by a higher stress level.

The modified conditions of the soil–pipe interaction system complicated the deformation processes in the pipeline. Therefore, more detailed investigations of the stress-strain state are required with the account for mechanical-and-physical properties of soils.

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