# Stress-strain state of pipeline depending on complicated environment

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**Abstract.** The paper presents the 3D model and FEM analysis of the stress-strain state of the soil–pipe interaction system. The analysis shows that the geological environment has shown a strong effect on the pipelines. This stress-strain analysis is carried out using the ANSYS finite element program.

## 1. Introduction

The stress-strain state of the soil–pipe interaction system is influenced by a number of factors, such as humidity, chemical composition and geological structure of soils, water saturation, thermo physical soil properties, air temperature, precipitations, snow accumulation and snow melting, waterlogging, land configuration, etc. The operational characteristics also have an effect on the stress-strain state of the pipelines [1]. Pipelines ballasting is a method of pipelines securing by means of placing weights or concrete when laying pipes in swampy or wet lands. Weights (saddle shaped, articulate, with flexible elements and others) are laid on pipes when constructing them by a pipe layer, a swamp excavator, an amphibious crane or a helicopter. For concrete ballasting, a continuous uniform pipe coating is provided (external concreting) often on a stationary base or concreting the space between the pipe and external casing (pipe-in-pipe system).

The majority of pipelines in Siberia and even in Russia are located mostly on terrains with sharply pronounced seasonal fluctuations. This condition evokes negative processes that, finally, result in the buckling of pipelines.

The finite element method (FEM) is one of the main methods used to evaluate the stress-strain and other states of the pipeline transportation systems. The ANSYS finite element program is the most suitable for this evaluation and has such advantages as a wide spectrum of soluble problems; the high accuracy and degree of approximation to real situations; convenient interface; many types of finite elements; material models; and the embedded algorithmical programming language that facilitates the automation of certain simulation procedures [2–11].

This work is focused on the investigations of the stress-strain state of the pipeline under the complicated conditions of geological environment and internal stress. The ANSYS finite element program and Autodesk Inventor software are used to determine the conditions for the pipelines ballasting or the use of float-type systems intended for pipelines laid in bogs.

## 2. Results and discussion

The stress-strain state of the soil–pipe interaction system is affected by a variety of forces. The effect from the gravitational force, the internal working pressure, and the forces of seasonal and perennial soil bulging affecting the underground pipeline [1] is considered below.

Figure 1 presents the schematic effect from the soil–pipe interaction system represented by the force vector distributed on the lower generator line of the pipeline system subjected to the gravitational forces. The analysis of the stress-strain state of the soil–pipe interaction system is carried out for the underground pipelines of West Siberia having the following characteristics: 426 mm pipe diameter; 8 mm wall thickness; the type 09G2S[1] low-alloy steel; 206 MPa Young's modulus; 0.3 Poisson number. The following loading conditions are considered: 5 MPa internal pressure; 0.8 MPa stress due to geological forces; 0.4 MPa stress due to gravitational forces.

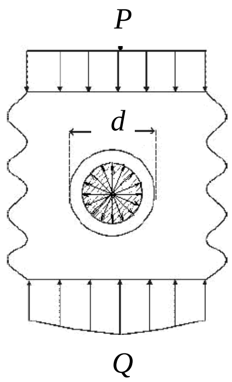



**Figure 1.** Sectional view model of the soil–pipe interaction system:
*P* – gravitational forces; *d* – pipe diameter; *Q* – force vector.

Figure 2a,b,c illustrates the finite element models of the stress-strain state of the pipeline subjected to different loads.

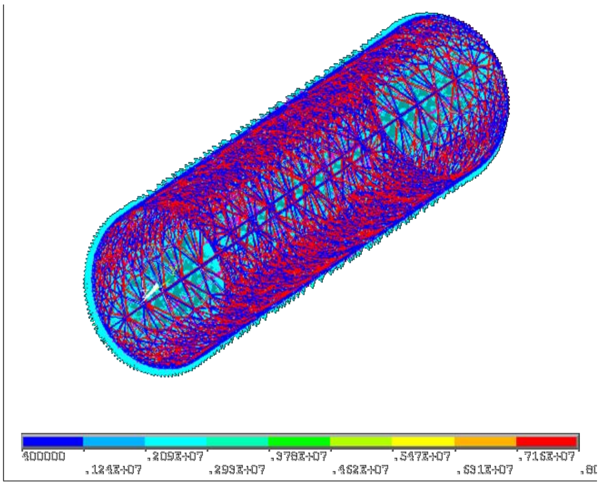



**Figure 2 a.** FEM of pipeline initial state under gravitational and geological environment forces

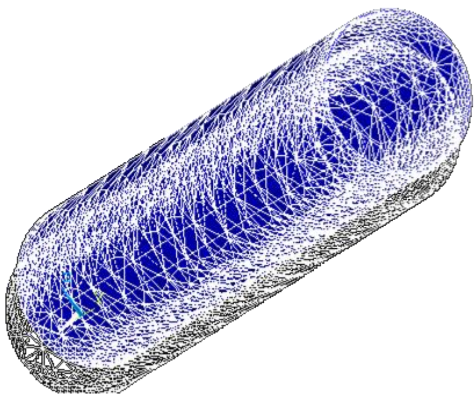


**Figure 2 b.** FEM of pipeline deformation due to gravitational forces

[1] Steel composition: 0.09% carbon; 2% manganese; 1% silicon.

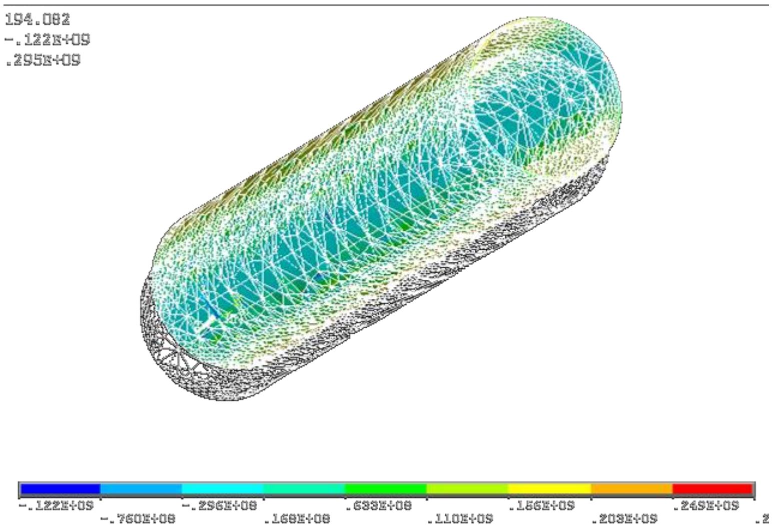



**Figure 2 c.** FEM of pipeline stress state due to gravitational forces

The graphical representation of the pipeline FE models is shown in figure 3.

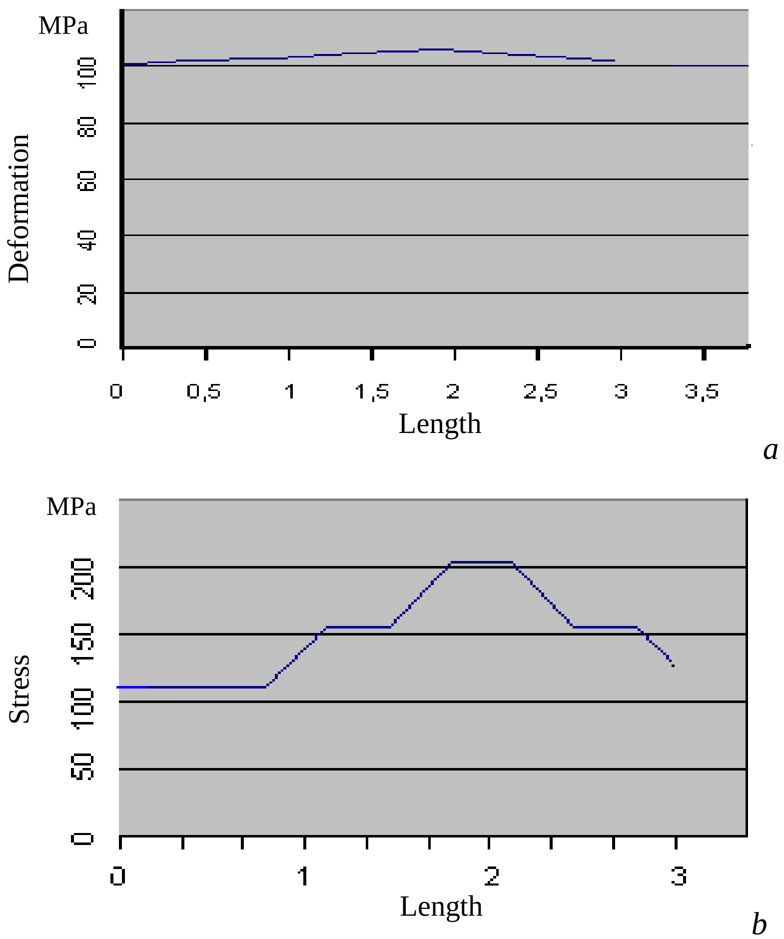



**Figure 3.** Stress-strain state of the pipeline: *a* – deformation; *b* – stress.

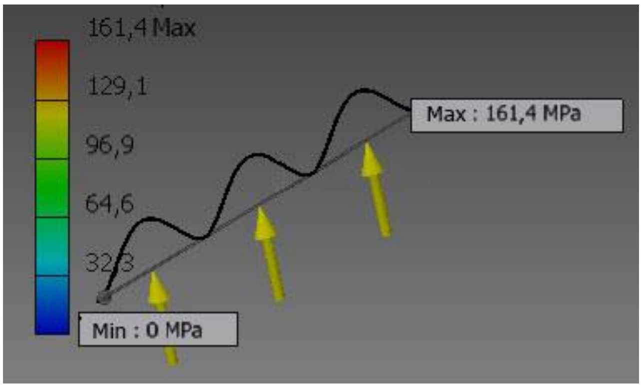
The analysis of research results shows that the pipeline displacements due to the geological environment forces can be rather essential even during a short-term operation. The practical experience shows that during 4.5–6 years of operation, the pipeline deformation due to the geological environment comes to one meter and more provided that the range of the pipeline laying depth is 0.8–1 m at different route sections. Under these conditions, the main pipelines require rather expensive diagnostics and repairs. Otherwise, further operation of the main pipelines will lead to the accidental events. The FEM analysis allows detecting the points of the pipeline strains induced by the geological environment forces.

The stress-strain state of any bearing element of the pipeline linear section is defined by the loads applied. The underground pipelines laid in bogs are affected by the dead load of the environmental buoyancy forces and the internal pressure load of the delivered product similar to the dead load of the pipeline section in case of its rigid embedding in soil. This pipeline section is laid in terrains with the most cold five-day period raging from –46 to –49 °C. Thus, the northern-type pipe is considered herein, the original data of which are given in table below.

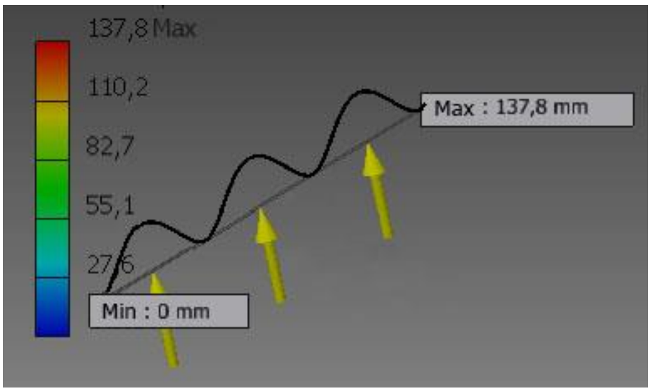
**Table.** Original data of the northern-type pipe

| | |
|---|---|
| External diameter, m | 0.325 |
| Wall thickness, m | 0.008 |
| Pipeline section length, m | 48 |
| Density of water, kg/m$^3$ | 1000 |
| Density of oil, kg/m3 | 850 |
| Stress limit of steel, N/mm$^2$ | 502 |
| Yield stress of steel, N/mm$^2$ | 353 |
| Weight of 1 m pipe, kg/m | 62.14 |
| Buoyancy forces of water, N | 39004 |
| Dead load of pipeline, N | 29231 |
| Working pressure, MPa | 7.4 |

Three-dimensional modeling is used to analyze the stress-strain state of the pipeline laid in the complicated conditions of bogs of the type III. The 3D model of the stress-strain state of the pipeline is presented in figure 4.




*a*

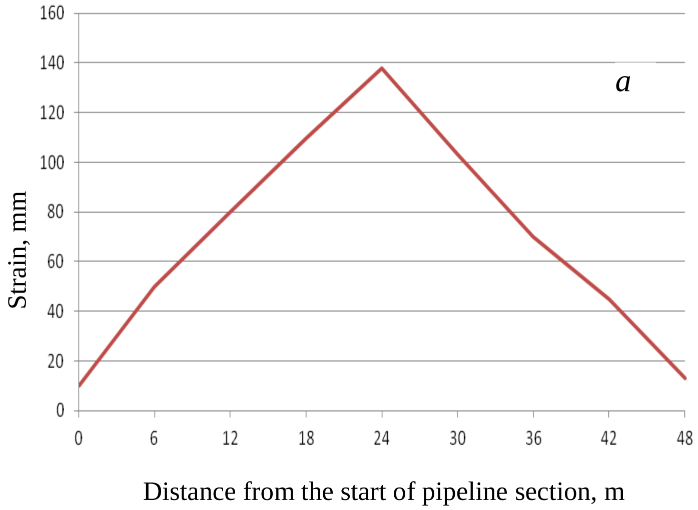



*b*

**Figure 4.** 3D models of stress-strain state: *a* – von Mises stress; *b* – strain.

Information obtained after the stress-strain state analysis of the linear section of the main pipeline allows detecting the pre-emergency situation areas including pipelines still having no defects and, taking measures for their elimination, increase the system reliability.

The graphical representation of the obtained stress-strain state are presented in figure 5.



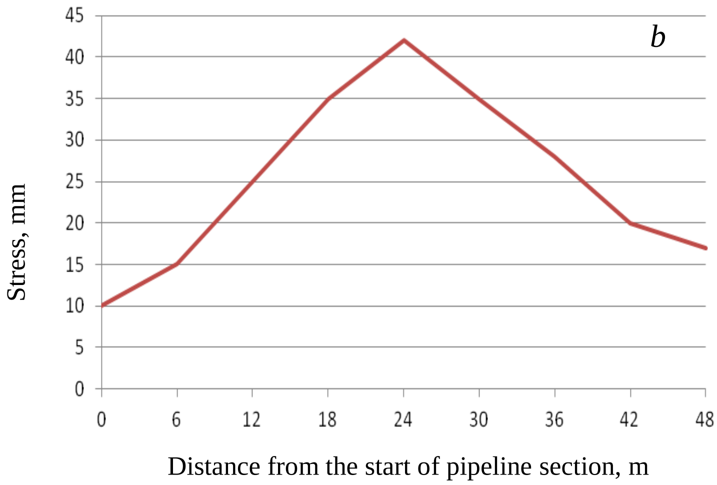




**Figure 5.** Stress-strain state of the pipeline: *a* – strain distribution; *b* – stress distribution.

The obtained results show that the maximum deformations are observed in the center of the pipeline section in which the transversal deviation from the normal is 137.8 mm, while the maximum stress is 42.6 MPa and observed inside the pipe.

## 3. Conclusions

The computation results showed that the equivalent stresses of the pipeline were 161.4 MPa. Therefore, in the described conditions, the pipeline embedded in soil from the both sides of the crossing, requires no balancing, since its deformations were insignificant.

- 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.

## 4. References

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