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# Stress-strain analysis of pipelines laid in permafrost

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**Abstract.** Increasing reliability of pipelines becomes a real challenge at all stages: design, construction and operation of pipeline systems. It is very important to determine the behaviour of the constructed pipeline under the operational and environmental loads using the design model in accordance with that one adopted in the rules and regulations. This article presents the simulation of pipeline in permafrost. The evaluation of the stress-strain state is given herein and the areas of the stress concentration are detected with the account for different loads occurred during the pipeline operation. Information obtained from the assessment of the stress-strain state of the pipeline allows determining sections in pre-emergency state (even before damages) and take all the necessary measures for eliminating them, thus increasing the pipeline system reliability. It is shown that the most critical pipeline cross-section is observed at the point of transition from one environment to another. The maximum strains decrease the level of the pipeline reliability. The finite element model is presented to determine the pipeline sections in pre-emergency state.

## 1. Introduction

The total length of the main pipelines in Russia is currently about 50 thousand kilometers. Despite the fact that the problem of the pipeline safety is constantly the focus of attention, over 40 thousand pipeline malfunctions and accidents occur annually in Russia, the losses being over 3% of the total volume of oil and gas production. A considerable part of accidents is conditioned by beyond-design loads received by pipelines. Thus, the assessment of technical conditions of pipelines must include monitoring of their stress-strain state during the operation. One of the main factors that define the operating reliability of underground pipelines is the soil-pipe interaction system.

The pipeline is subjected to soil effects, such as load, temperature, moisture, chemical and biological attacks, corrosion, and others. In turn, the pipeline affects the soil either through dead loads (pipe weight, pipe pressure, etc.) and live loads produced by temperature changes and the internal pressure of the pumped product [1-7].

The additional loads which occur during the pipeline operation, result in a rapid lifespan exhaustion. Beyond-design loads induced by landslips or seasonal soil movement are the most prevalent and dangerous and impossible to be accounted in designing. Beyond-design loads can be detected at the stage of construction and during the operation by measuring the stress-strain state of the pipeline.

As it is known, the main oil fields in Russia are located in West Siberia and the Far North. Therefore, the main pipelines inevitably cross the permafrost areas. Presently, the investigation and forecasting of the stress-strain states of the underground pipelines is a relevant problem nowadays.

Laying of the pipelines in permafrost conditions is usually carried out when the soil is frozen, since a seasonal thawing makes it impossible to move the construction machinery along the pipeline route. Herewith, the original state of the underground pipeline is determined by the position of the pipes laid in a frozen soil, and their stress-strain state should be analyzed with the account of the mechanical-and-physical properties of frozen soil [8].

## 2. Results and discussion

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With the beginning of exploitation, the pipeline heats the frozen soil under the pipe which melts at the oil temperature of 0°C and higher. Due to the change of the mechanical-and-physical properties of frozen soil along the pipe, the area of thawing out is different at different pipe sections. This leads to bending, sagging and large spatial deflections (often with buckling) of the pipeline sections and, sometimes, to its destruction. The strength analysis allowing for the real operating conditions, is one of the main procedures that assure the high reliability of the pipeline. The strength analysis is mostly focused on the stress-strain state of the pipeline modified by the external loads [9-11]. It is conducted using the ANSYS finite element program. The pipeline section under research is laid in terrains with the temperature range from –46 to –49 °C of most cold five-day period. Thus, the northern-type pipes are used having the following characteristics: K56 strength class; 820 mm diameter; 14 mm wall thickness; 9.2 MPa internal pressure; 12 m pipeline section length; 09G2FB1[1] steel type.

The elastic properties of the pipe material are described by the Young's modulus and Poisson number. The analysis of the stress-strain state includes the circular stresses induced by the internal pressure and longitudinal or axial stresses due to all external loads. A solid model is designed using the ANSYS finite element (FE) program, is subjected to the boundary conditions and loads in accordance with the original data.

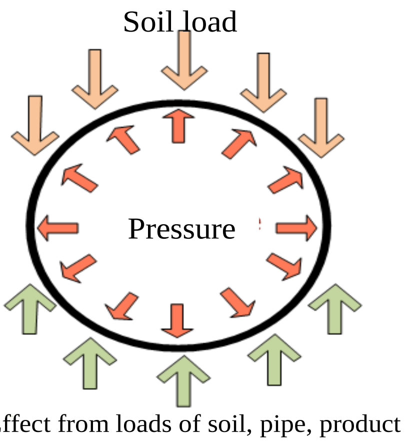


**Figure 1.** Pipeline walls exposed to loads

The three-dimensional models are obtained for the distribution of the stress-strain state observed in the most critical areas of the pipeline, that present all loads affecting the given structure. The FE models are shown in Figures 1–6.

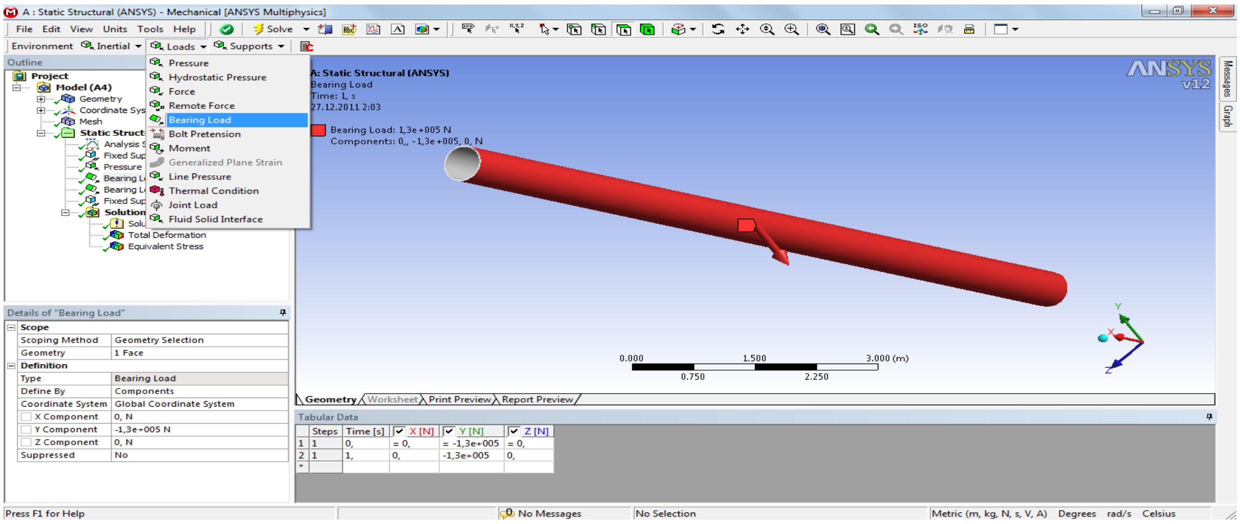

**Figure 2.** FEM of internal pressure.

[1] Steel composition: 0.09% carbon; 2% manganese; 1% silicon, 1.5% niobium, 0.1% vanadium.

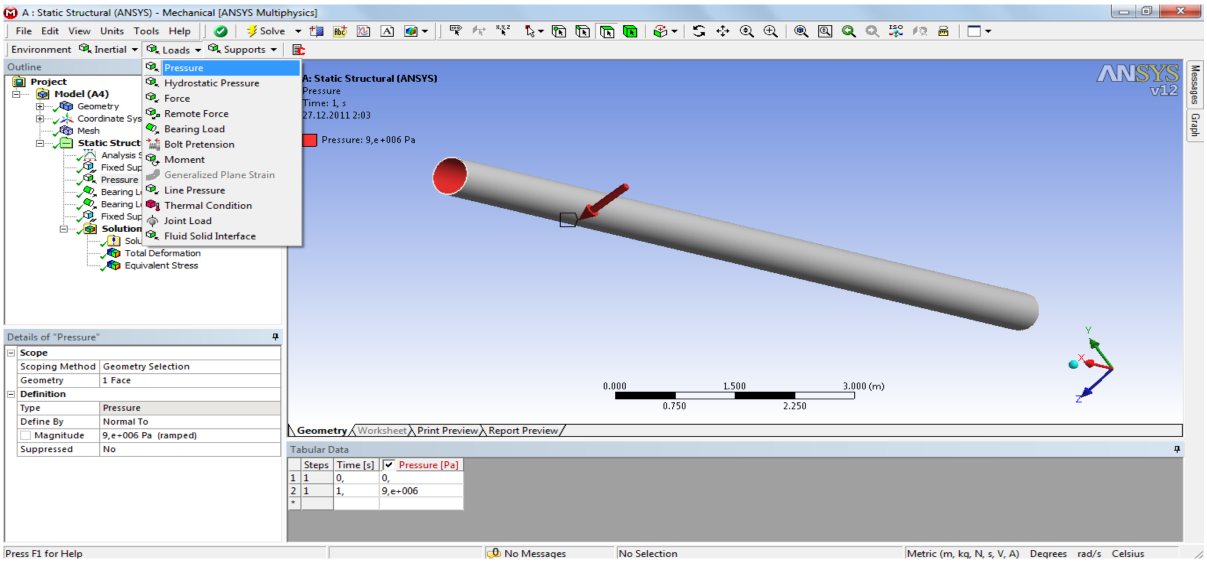


**Figure 3.** FEM of current load on soil with dead load of the pipe and product weight.

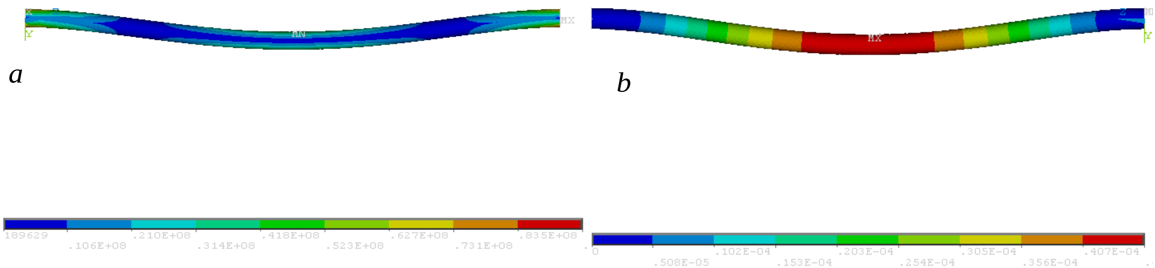


**Figure 4.** FEM of pipeline section in permafrost conditions:
*a* – maximum von Mises stress; *b* – deformation.

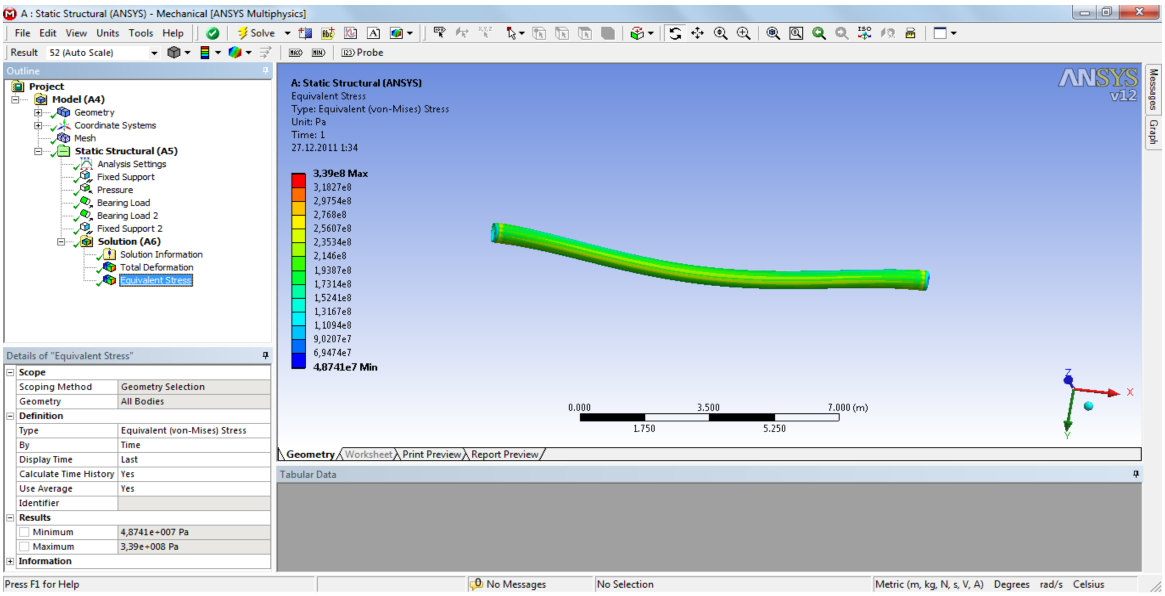


**Figure 5.** FEM of stresses in the elastic-plastic medium.

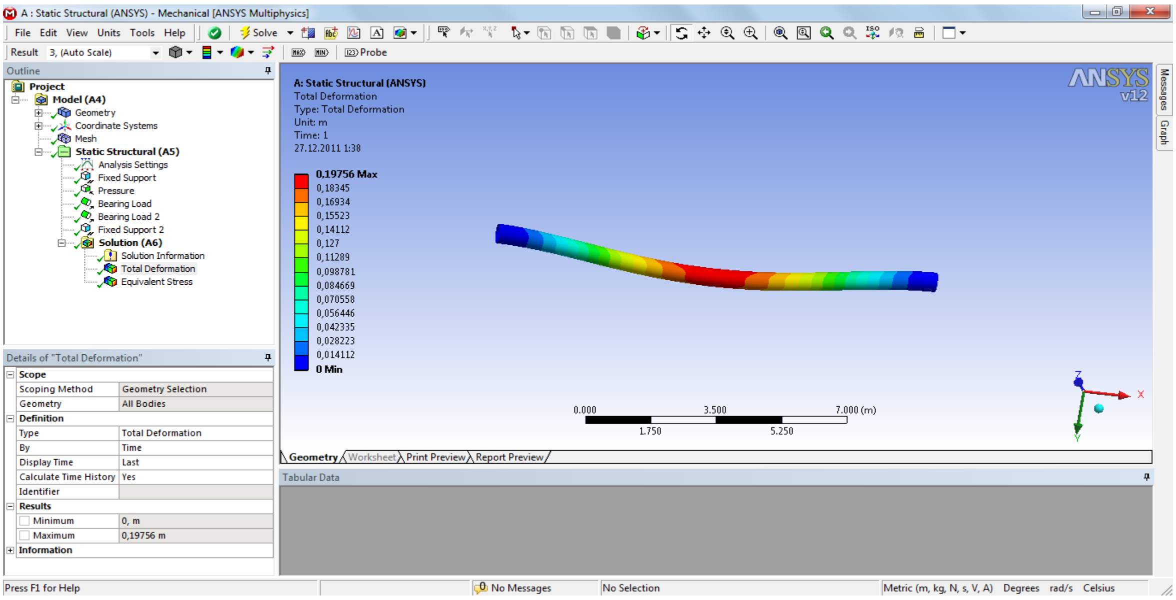


**Figure 6.** FEM of deformations in the elastic-plastic medium.

The FE models show no bending in places of the pipeline fixation. The obtained information allows constructing the diagram of the normal bending shown in figure 7.

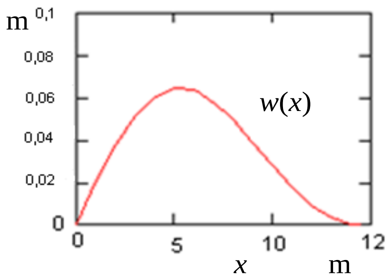


**Figure 7**. Normal bending of pipeline section in permafrost conditions: $x$ – length; $W(x)$ – bending.

The maximum value of the pipeline bending corresponds to its 5 m removal from the conjunction edge. The bending is approx. 61 mm. To estimate the strength of the pipeline, the diagram is constructed for the axial and circular stresses depending on the pipe section length, figure 8.

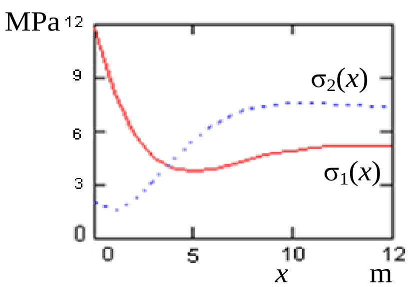


**Figure 8.** Distribution of axial and circular stresses in pipeline section in permafrost conditions: $\sigma^1$ – axial stress; $\sigma^2$ – circular stress.

The larger value of the axial stress corresponds to places of the pipeline fixation, i.e. the axial stress value nearby the internal wall of the pipeline exceeds the yield strength of the pipe material. The loadbearing capacity of the pipeline in places of its fixation is exhausted when the pressure in the pipeline exceeds its limit value at which the whole transversal section will be subjected to the plastic deformation.

The FEM analysis allows detecting the pre-emergency conditions of the main pipeline linear sections including those without defects and, taking measures for their elimination, increase the system reliability.

## 3. Conclusions

The strength analysis of the pipeline showed that buckling or sagging of its sections resulted in unallowable stresses. Larger pipeline sagging produce plastic deformations. Thus, the estimation of the stress-strain state and pipeline sections mostly exposed to loads, including those static and dynamic, is the important factor in providing a safe operation of the pipeline.

In order to increase the pipeline serviceability and estimate its technical conditions, it is advisable to timely conduct the technical diagnostics and strength analysis using the finite element method.

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