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Finite Element Model of Trenchless Pipe Laying

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Abstract. The paper focuses on the stress and strain state of the underground main pipeline section using Autodesk Inventor software.

1. Introduction

Pipeline transfer is currently faces the problems of industrial safety, in particular, the safety of underwater lines. These problems are connected with difficulties of the current state control and the low possibility of timely identification and elimination of causes of pipeline breaks. Underwater main pipelines are the most critical sections of petroleum pipeline construction although their share in its total volume is comparatively small. In case of possible environmental incidents, the safety of underwater lines should meet strict requirements even at minor failures of petroleum pipelines [1]. The problem of the reliability improvement of pipelines is relevant at both design stage and construction and operation stages. The effect on petroleum pipeline due to external loads resulting in irreversible processes can be prevented by ensuring its adequate behavior. This can be achieved by the construction modeling allowing for both operational characteristics accepted in standards and regulations, and external effects on petroleum pipelines.

The trenchless pipe-laying technique is widely used alongside with traditional techniques of pipe-laying. This technique is currently the most cost-effective way of pipeline construction. Another factor that provides its wider use is the progressive development of new construction technologies by design organizations. Today, it is quite obvious that trenchless technology has no alternative to solve the problem of pipeline laying and reinstatement using the specific equipment. Presently, there are basically three possible ways of pipe laying below the water. The oldest traditional way includes not only a great deal of earthmoving operations, manpower, and long-term construction works but, first of all, an adverse environmental effect and creation of uncomfortable conditions in cities. The second way is tunneling or microtunneling with constructing of launch and reception shafts. This method is characterized by the accuracy control of tunneling paths.

The third way is horizontal directional drilling. It is a controlled trenchless laying of underground pipes using specialized drilling rigs. Lately, horizontal directional drilling is being widely used allowing to reduce time and labour consumption especially in constructing underground pipes below natural barriers, such as rivers, ravines, lakes, woodlands, quick grounds and in urban conditions, namely: railways, highways, parks, etc. Horizontal directional drilling is more acceptable for landscape and ecological balance preservation as compared to other ways of pipe laying. It eliminates the man-induced impact on flora and fauna, stream-bank erosion, benthal deposits, and minimizes the negative influence on living conditions in the area of pipeline laying and reinstatement works. One of the main problems that must be solved for the infield pipeline design, is the construction of the linear pipeline portion. As the pipeline routing is often laid together with other linear communications, it is necessary to take all possible measures to preserve its integrity. In crossing automobile roads, the pipelines are usually cased in protective steel tubes [2].

Let us consider Aleksandrovskoe – Anzhero-Sudzhensk main pipeline which crosses 98 water barriers on its way. The territory includes the undeveloped, mixed-forested land along Aleksandrovskoe – Anzhero-Sudzhensk main pipeline at its 208th km distance. The broad, even, and peaty floodplain is represented by oblong alternating low hummock ridges and bogs covered with medium thick undergrowth of ledum and osier and birch. Undergrowth with sedge meadows are observed along the river bed. The bogginess of the river bed is 20%, forest coverage is 90%. Within the area of underwater line, the river sand bed is tortuous and one-armed. In dry weather period the width and the depth of the river bed is 10-15 and 1,5-2 m, respectively.

The financial and economic aspects are also important in horizontal directional drilling. Estimated cost of pipeline laying can be reduced due to the reduction of work execution terms, supplementary employee costs, and heavy excavation equipment. While designing underground structures, the stress and strain state should be calculated for soil adjacent to the pipeline and that located at a certain depth from the surface. To solve this problem, in most cases it is necessary to solve the elastic boundary value problem using the finite element method (FEM). The advantages of this method are minimum requirements for the source information and optimum forms of results.

2. Results and discussion

The aim of this work is to construct the finite element model of trenchless underwater pipe lining within the peaty floodplain area.

The strain-stress state analysis of pipeline structures based on methods of mechanics of materials and the structural theory does not allow the adequate and accurate analysis of the fuel and energy facility strength, and in some cases, it can show an incorrect pattern of stress and strain state of the structure. The structural analysis using FEM is, in fact, the worldwide standard of strength and other kinds of analysis. This is because FEM is a universal method allowing to simulate different structures having different material properties. Results obtained by FEM make possible to detect pre-emergency areas including those still having no defects, and take whatever necessary measures to increase the reliability of the pipeline system [3-8]. The longitudinal section of oil gathering pipeline was constructed based on the accepted design solutions, in which the point of crossing with the automobile road was indicated as shown in Figure 1. This section of the pipeline routing is laid in a protective steel casing having 45 m length and 426 mm in diameter. Figure 2 shows the schematic layout of the pipeline across the automobile road.

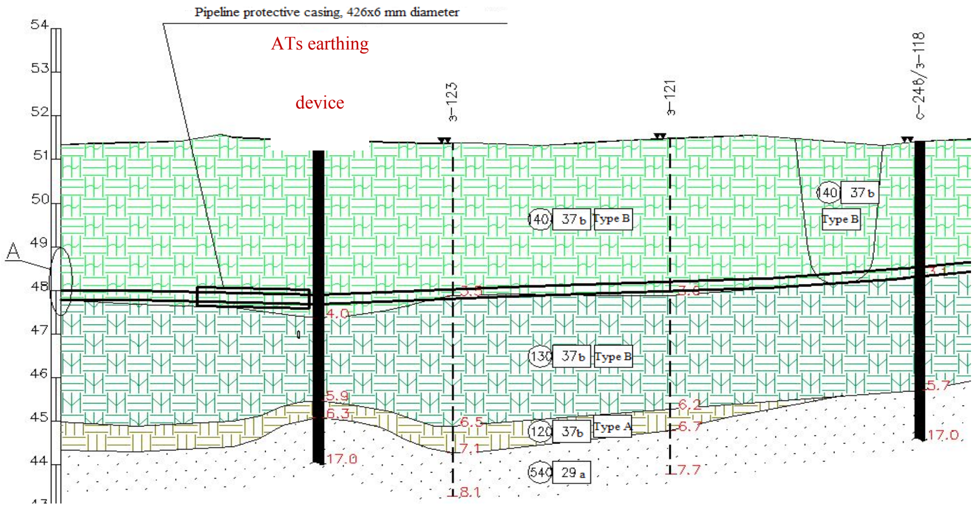

Figure 1. Cross-sectional plan view of the pipeline portion

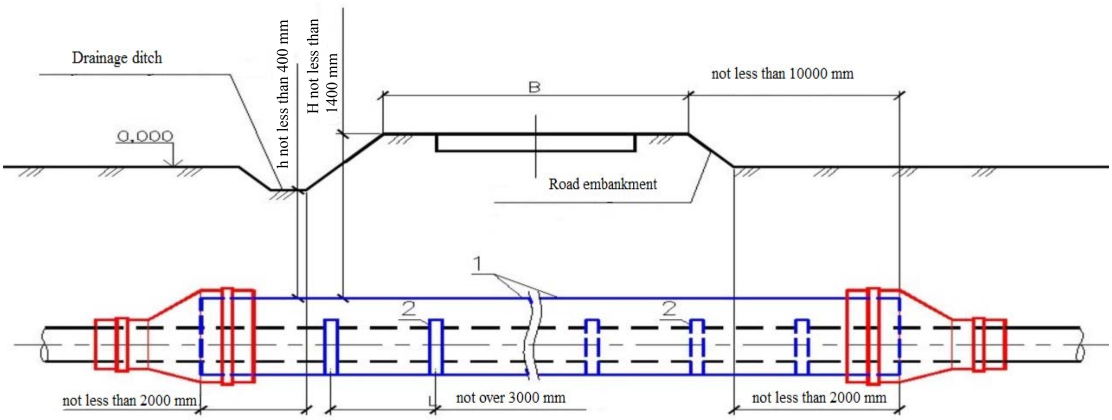

Figure 2. Schematic layout of the pipeline across the automobile road

The stress and stain state of the pipeline in protective steel casing was analyzed by the finite element method using Autodesk Inventor software. Once the solid model of the pipeline was invented, the stress and strain state analysis is conducted accounting for all loads that have been calculated at the design stage. The solid model of the pipeline is illustrated in Figure 3.

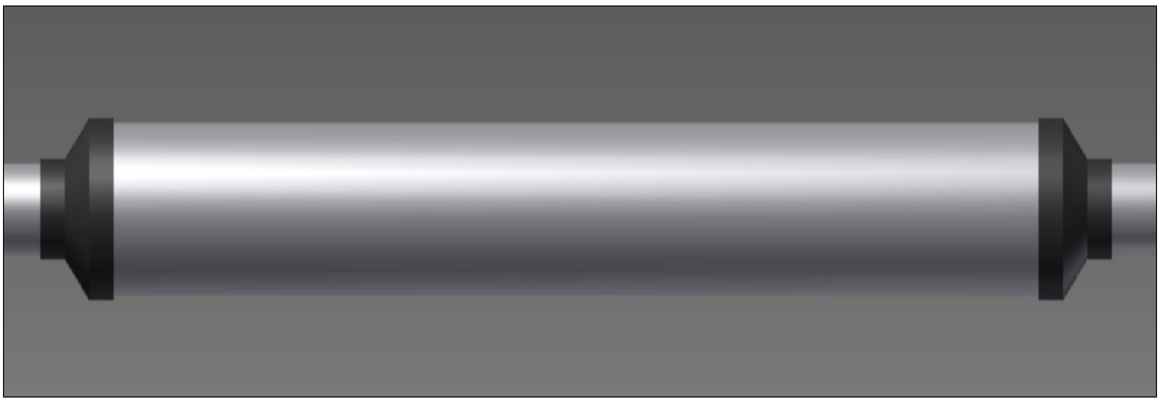

Figure 3. Solid model of the pipeline in protective steel casing

Autodesk Inventor is 3D mechanical CAD design software developed by the Company Autodesk, USA, for creating 3D digital prototypes of industrial products. Inventor's simulation tools let users create a complete design cycle and design documents.

A simulation model developed in Inventor is shown in Figure 4 and represents the interaction between the cone and soil. The cone is subjected to 10 MPa pressure. The model assumes that there are no loads acting during winter and the temperature effect on the pipeline. The Drucker–Prager pressure-dependent model was used to simulate the stress and strain state of soil.

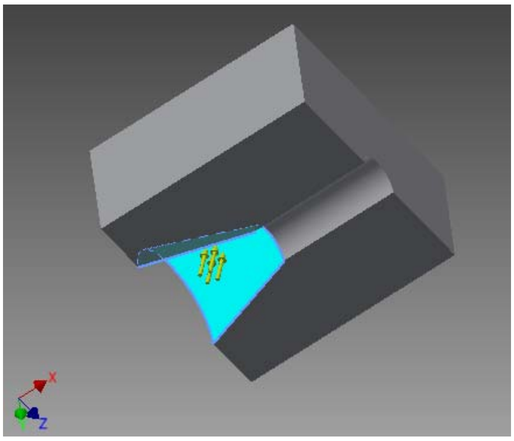

Figure 4. A simulation model in Inventor: the interaction between the cone and soil

Figures 5 -9 illustrate the results of FEM analysis of soil stresses and movements.

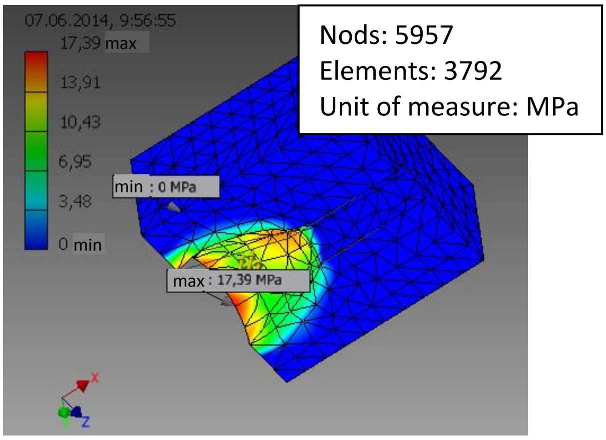

Figure 5. Von Mises stresses in soil

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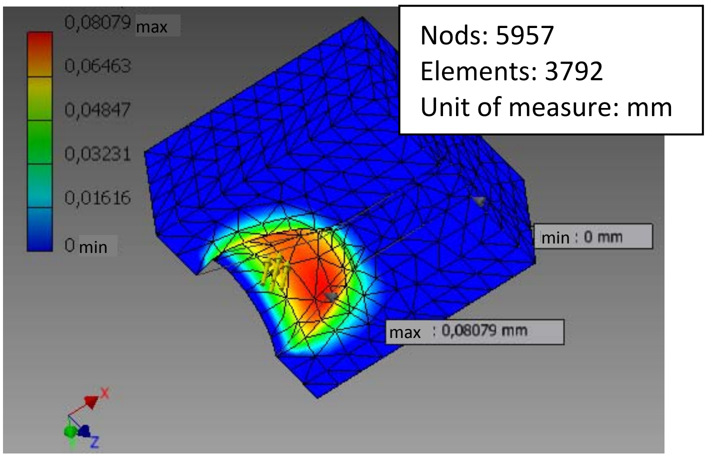

Figure 6. Total soil movements

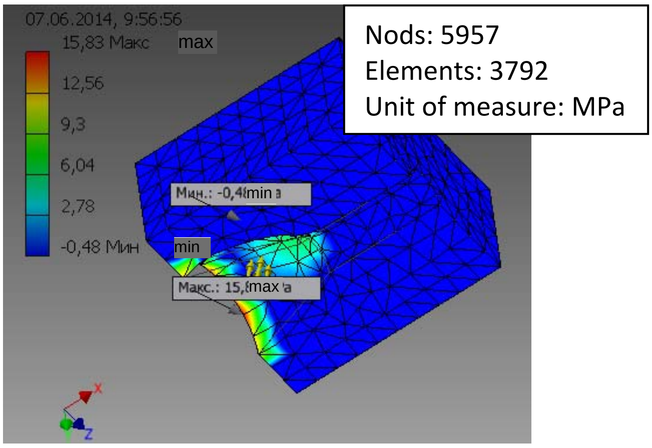

Figure 7. The first main stress

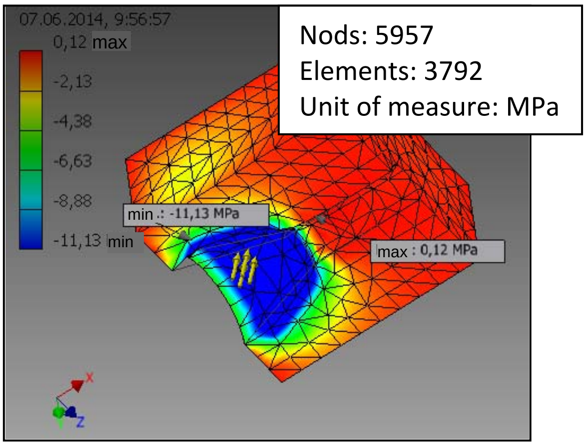

Figure 8. The third main stress

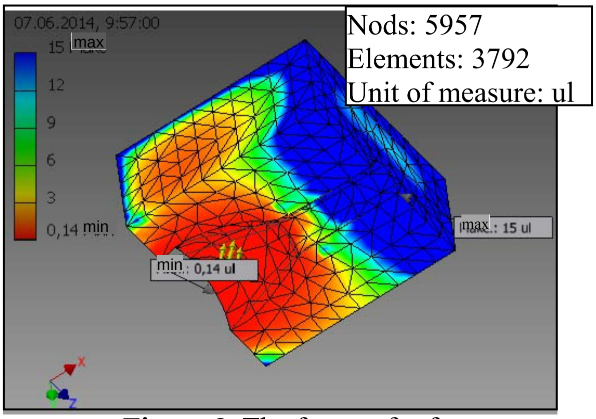

Figure 9. The factor of safety

Theoretically calculated pull forces can be provided by the up-to-date drilling rigs of the TiDrill type having pull force of 4,400 kN. Thus, the suggested model gives the adequate results. The distribution of total soil stresses and movements obtained herein are shown in Figures 10 and 11.

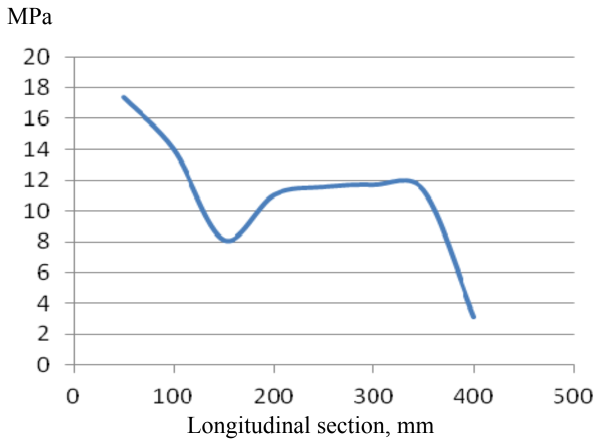

Figure 10. Von Mises longitudinal stress distribution

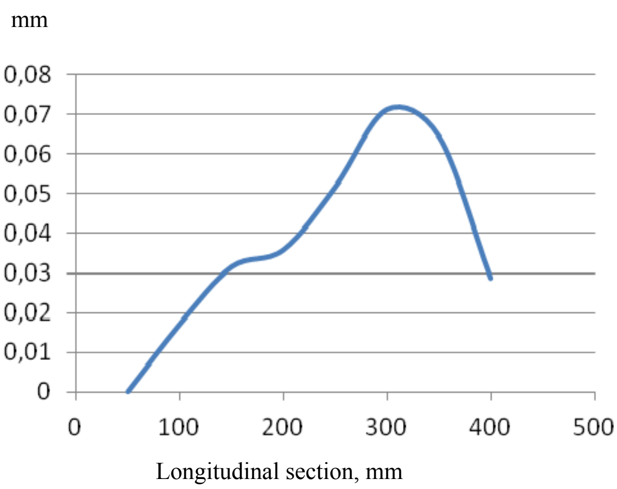

Figure 11. Total soil longitudinal movements.

3. Conclusions.

The FEM model was constructed to detect the stress and strain state of soil around the petroleum pipeline. The total soil movements vary by length and significantly depend on distributed loads applied to the cone.

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