

# Computer Simulation of Stress-Strain State of Oil Gathering Pipeline Designed for Ugut Field

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**Abstract.** The paper presents the stress and strain state modeling of infield pipeline in Ugut oil field. The finite element models of the stress field distribution in the pipeline wall are presented in this paper. The attention is paid to the pipeline reliability under stress conditions induced by the internal pressure and external compressive or tensile loads.

## Introduction

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 [1]. Underground pipeline portions laid in severe climatic conditions are especially difficult to maintain. Failures and accidents of such pipelines occur due to their excessive bending accompanied by the instability of the soil-pipe-liquid (gas) system and a non-uniform setting. In order to prevent pipelines from failures and damages induced by the excessive bending, climatic and operating conditions, soils, and potentially dangerous areas should be studied and detected. Along with engineering facilities, the problems of strength and stability are to be solved to discover potentially dangerous areas. Construction regulations that define the design procedure for underground pressure piping, namely: SNiP 2.05.06-85\* 'Main pipelines' (item 8.25), SNiP 34-116-97 'Design, construction and reconstruction of infield pipelines' (item 8.1) include the requirements for the combined calculation of the pipeline and the soil mass. The relevance of the stress and strain state design technique for underground pipelines is explained by the fact that at least 1 mm increase of the pipe wall thickness results in a considerable overexpenditure of material. This is because the soil exerts not only the external load application to the pipeline, but also is the medium in which deformations of the linear construction occur. At the same time, construction regulations do not contain directions of how to perform the combined calculations.

The remaining lifetime is estimated as the deterioration storage time until the limit state is reached by the specified failure criterion. The calculation estimation of the remaining lifetime is not usually specified. Calculations are based on formulas used to forecast the structural lifetime by the deterministic or probabilistic schemes. Deterministic schemes imply the use of fixed data on crack

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resistance in materials, structural loading, and defects. The remaining lifetime is predicted using factors of safety (crack resistance) and robustness. The remaining lifetime is determined by the non-propagation of the existing or hypothetical cracks (their non-exceedance of safe sizes) out of the realm of safe states of the system deteriorated by the criteria of fracture and robustness mechanics. Probability calculations are carried out using the reliability theory based on statistical data on mechanical properties of materials, loads, effects, and flaw detection. During the operation, the pipeline elements are exposed to external loads leading to the stress-strain state of the material. For example, in crossing points with water channels, automobile roads, pipe blowout and sagging or joints with pump station assemblies, flexural stresses are more intensive. The state of the pipeline material is directly depends on the external loads that induce stresses in it together with the internal pressure.

As is known, the local sections of pipelines subject to the increased stresses undergo degradation processes that affect the functional properties of material due to metal strain age and low-cycle fatigue. In time, this leads to the critical state of material and, as consequence, the decrease of the pipeline efficiency.

Thus, the estimation of metal properties in the pipeline is one of the preventive measures that should be taken to avoid accidental fractures.

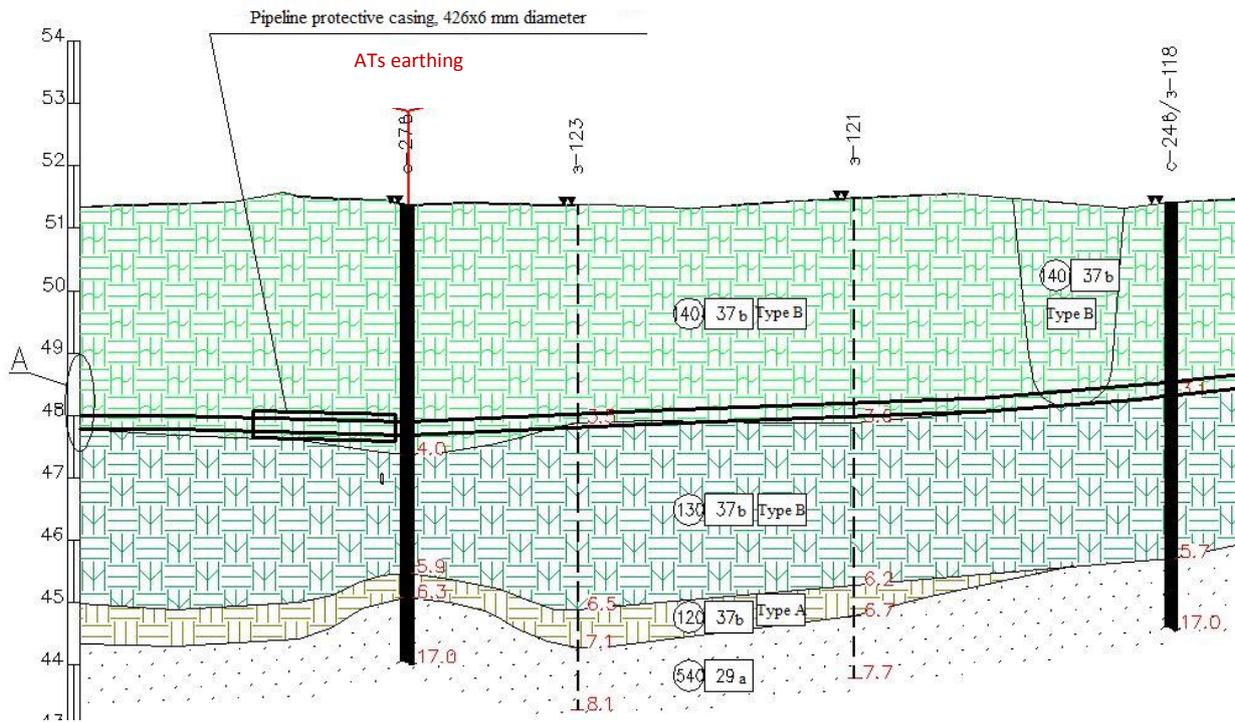
Other preventive measures include the reinforcement of the pipeline sections exposed to stresses, cutting off pipeline sections, mechanical stress relief by means of pipeline rectification.

Also, the effect of lumped plasticity in the pipeline elements observed both in manufacturing and operation should be investigated in relation to its reliability under stress conditions induced by the pressure inside the pipeline and external compressive or tensile loads.

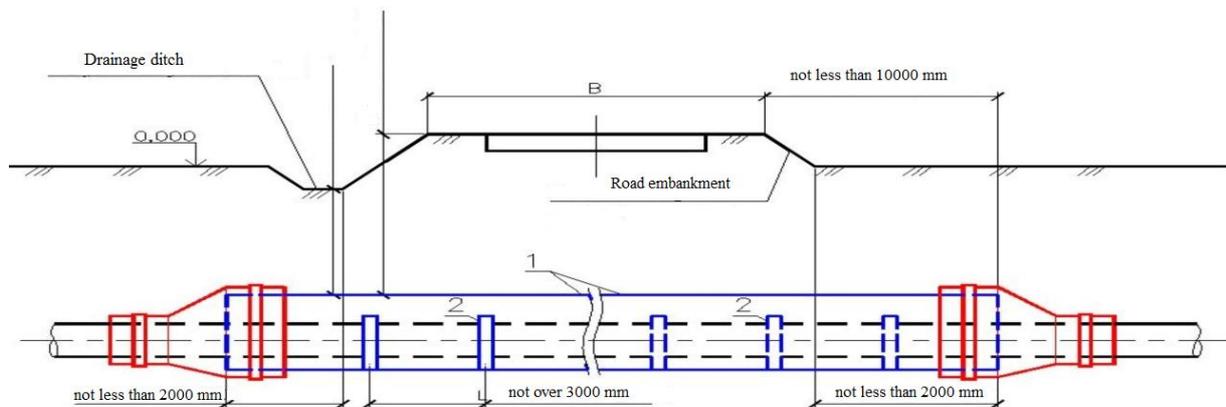
Thus, a study of the stress and strain state of such pipeline portions is a relevant problem that must be solved to provide a safe operation of the designed infield pipeline [2-10].

The portion of the infield oil-gathering pipeline being designed for the Ugut field was selected for investigations. PipeSim software was used to carry out hydraulic calculations that allowed the determination of the required diameter of the pipeline, namely 219 mm. Hydraulic calculations were made for the maximum volume values of oil extraction in the Ugut field. As a result, the preliminary pipeline routing was conducted. The standard pressure in the infield pipeline was assumed in accordance with the pressure relieve valve of the measuring equipment established on site of the group of wells and equaled to 4.0 MPa. The type 09GSF steel was accepted for the pipeline construction. This steel possesses higher strength properties. The strength analysis was then conducted in compliance with SNIIP 34-116-97. The thickness of the pipeline wall was determined as 8 mm and the minimum pipeline depth from the ground surface to the upper tube was determined as 1.8 m.

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

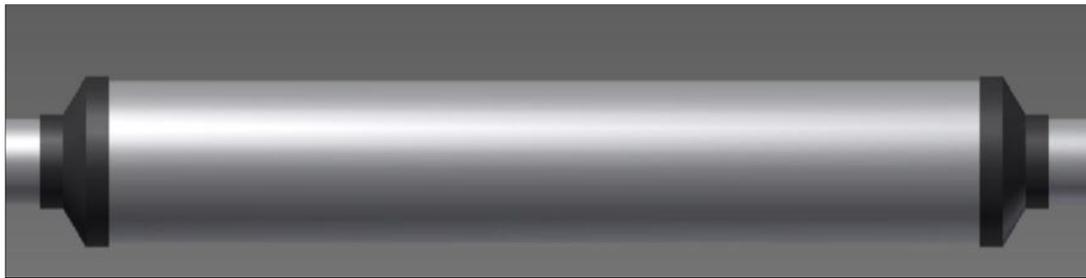
### Results and discussion

The internal changes in metal lead to its fracture and are called a limit stress state. The structural reliability is provided by the comparison of maximum stresses which appear at the most dangerous point and admissible limit values of the given material. The limit stress state of a structure is just the limit beyond which its operation is impermissible. The structural reliability is higher when the level of actual internal stresses is farther from the limit state. Autodesk Inventor software allows the strain-stress computation of the pipeline wall and obtaining output data in the form of three values of primary stresses which are presented by roots of a cubic equation defined by the stress vector components.

The strain-stress computation is based on the calculation methodology of allowable elastic stresses. The stress and strain state of the displacement type defect located on a cylindrical pipe casing is

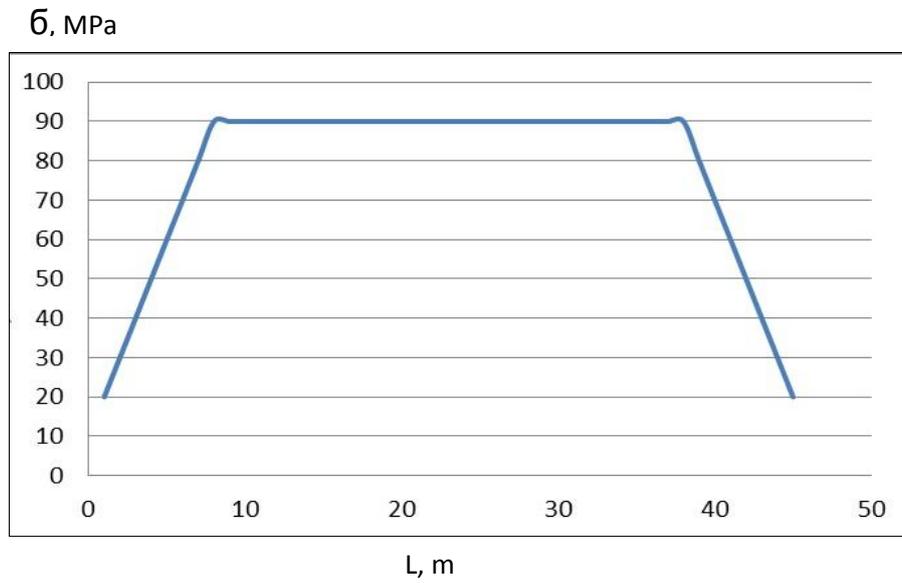
determined by a three-dimensional design model subjected to combined service loads. Since the aim of this work is to study stresses occurring within the defective portion of the pipeline, the design model can be reduced to its defective portion. The internal excessive stress is the service load applied to the pipeline. The dead load of the pipeline portion, wind and snow/ice loads also should be taken into account. In order to provide a static determinability of the model, the boundary conditions include a pin-edge fixing of the pipeline portion to prevent linear motions.

The stress and strain 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 length of the pipeline casing is selected such that to exclude the possible effect of end connections on the estimated area. The pipeline crossing over the road is modeled in conformity with the measurement results obtained during technical diagnostics. Loads distributed across the casing area are applied to its defect area. Welded joints are neglected. The finite element model contains five casing objects unified with each other by the bonded contact, i.e. the complete dependence of displacements is provided in all assemblies. Cartesian system is used for this model. The finite element mesh reproduces the surface curvature and is superimposed automatically. The minimum mesh size was obtained at mash condensation within the defect area and equals to 0.6 mm. Mesh size of 10 mm was accepted for all other structural elements. The non-linear model simulation was carried out using the iteration technique. The values of the equivalent stresses are distributed in the sectional area of casing under the maximum load, i.e. in its outer surface. The finite element models of the stress field distribution in the pipeline wall are presented in figure 5, 6.

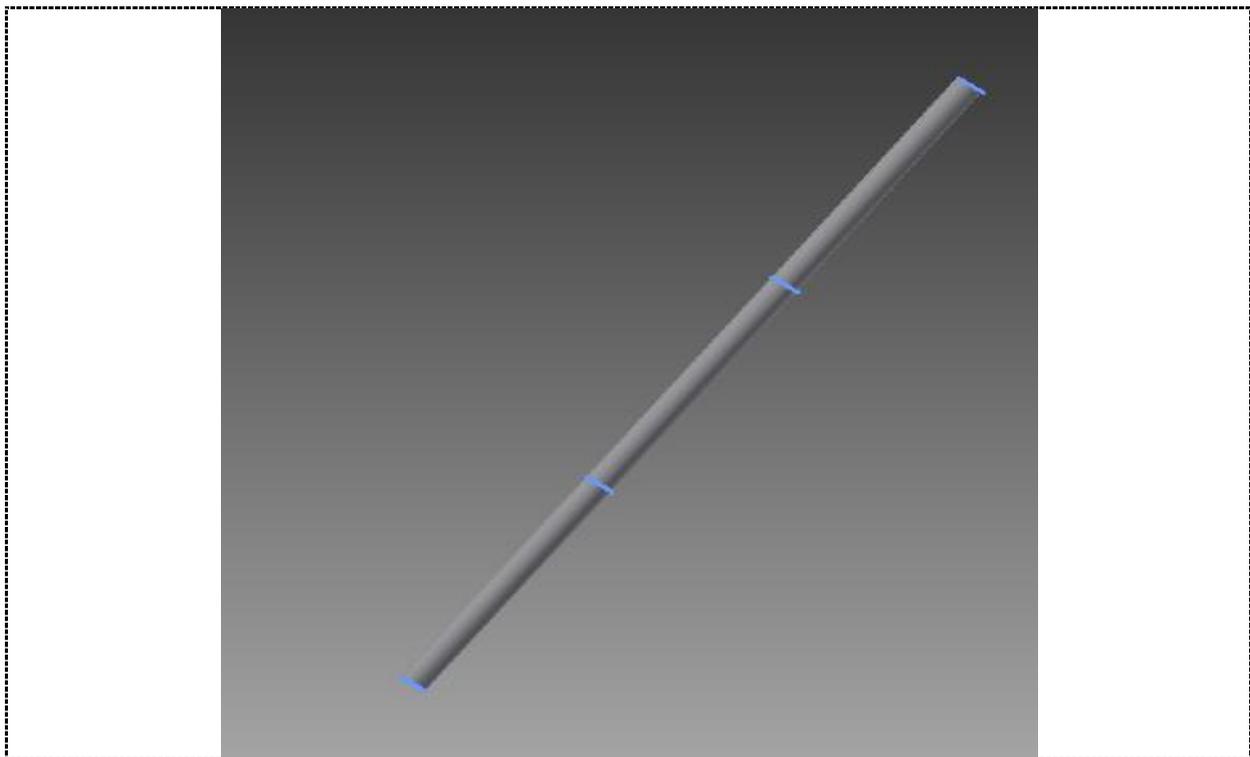


**Figure 3.** Solid model of the pipeline in protective steel casing

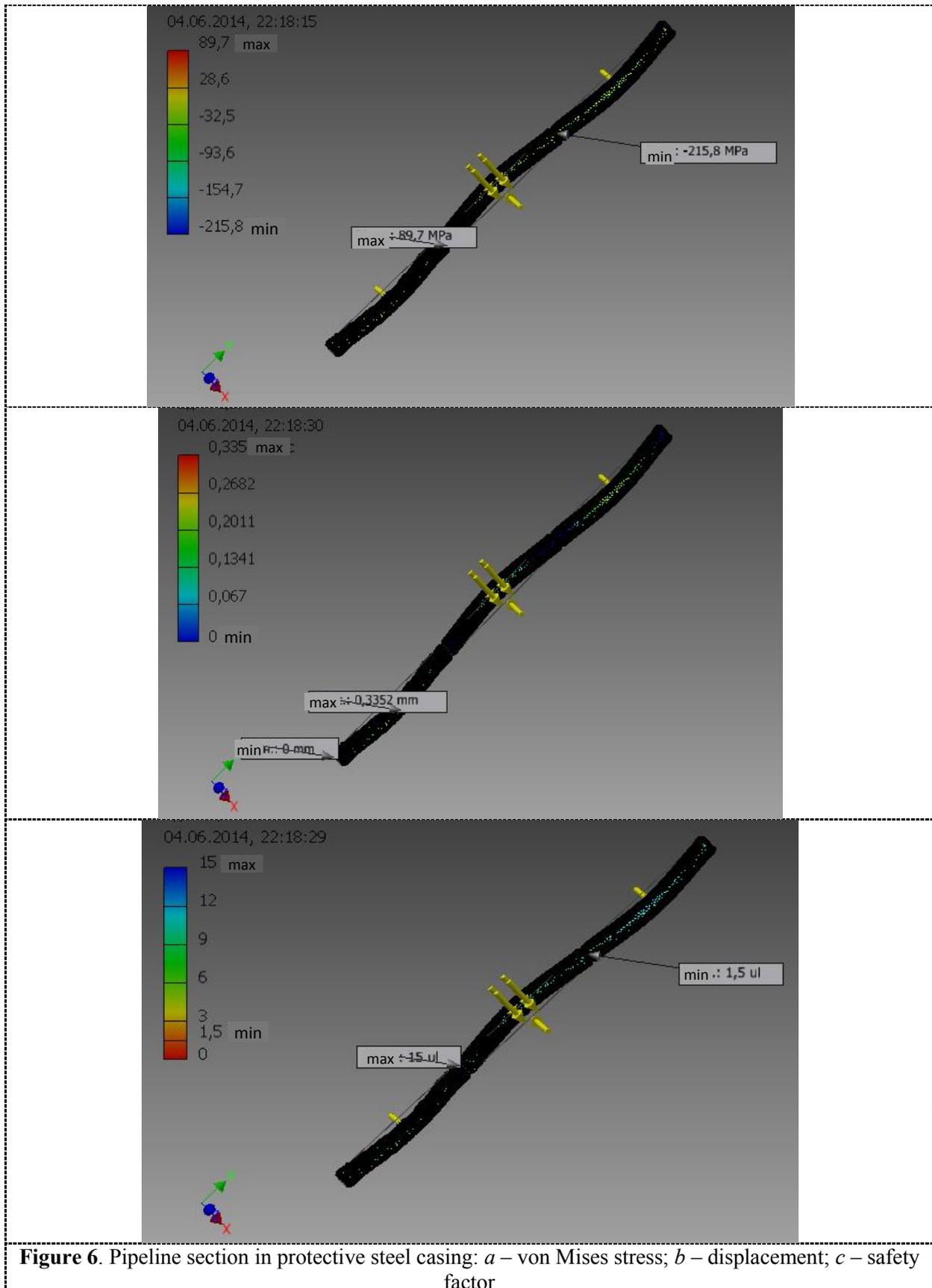
The solid model of the pipeline is illustrated in figure 3 and figure 4 demonstrates the longitudinal stress distribution.



**Figure 4.** Stress distribution ( $\sigma$ ) along the pipeline ( $L$ )



**Figure 5.** Pipeline section in protective steel casing – fixation



## Conclusion

The use of Autodesk Inventor software for the stress and strain state analysis of the pipeline portion in protective steel casing showed that the universal CAD system allows solving a variety of difficult problems. The results obtained in this work showed that all design considerations accepted in the course of this research provide a safe operation of the pipeline protective steel casing in the crossing point with the automobile road, because the maximum stress occurred in the pipeline is less than the yield point of the steel tube. Thus, the strength of the pipeline portion was provided by the design pressure of 4 MPa inside the pipeline having the wall thickness corresponding to the actual value, and the protective casing had no a considerable effect on serviceability of the suggested pipeline

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