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Research of the Causes of Defects Type "Dent" on the Linear Part of the Main Pipelines

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Abstract. This article discusses the main reasons for the formation of defects such as dents on the main pipelines. As a rule, the presence of dents is typical for laying in conditions of rocky soil or permafrost. In this case, fairly large rock fragments appear at the base of the trench, which act on the pipe with a force equal to the weight of the pipe and the weight of the back fill soil. This is why most of the dents form on the bottom surface of the pipe. As a method of combating the formation of dents, back filling of soft soil at the base of the trench is usually used, but these measures lose their effectiveness because over time the soil from the base of the trench is washed away and the metal of the pipe comes into contact with the stone fragment. This article examines the process of dent formation through numerical simulation. The procedure for modeling is considered, and the results obtained are analyzed. The dimensions and shape of the dents obtained during numerical modeling coincide with the parameters of the dents recorded on real objects. The purpose is to study the mechanism of death formation on large diameter pipes under the influence of static load caused by external force factors. The scientific novelty lies in the refutation of the theory suggesting the possibility of dents on large diameter steel pipelines solely as a result of dynamic action from moving parts of the construction equipment or pipe impact during a fall. The study proved that a dent can form under the influence of static load. The parameters of the dent obtained during the simulation coincide in shape and size with the dents found on real pipelines, which confirms the nature of the formation of dents due to the static effect of the pipe's own weight and the weight of the filling soil.

Keywords: rocky soil, defects, numerical model, dents, pipeline, static load.

Introduction

When inspecting the linear part of the main oil and gas pipelines, geometry defects often occur, which include dents. A dent is a local change in the shape of the pipe surface that is not accompanied by a thinning of the wall. A dent is formed as a result of the interaction of a pipe with a solid body that does not have sharp edges, and this interaction is usually dynamic in nature [1 - 10].

According to diagnostic data carried out by specialized organizations, similar defects in the shape of pipe sections were recorded during in-line flaw detection (ILFD) on a section of the linear part of the main gas pipeline (MG) with a total length of 450 km. A total of 14 dents were found on the investigated section of the route. All detected dents were located in the lower part of the pipe. The hourly orientation of the locations of detected defects along the pipe cross-section is presented in Figure 1. The depth of the detected dents varies from 15 to 33 mm, which is 1.1 – 2.4% of the outer diameter of the pipe, the length of the dent along the longitudinal axis of the pipe ranges from 390 to 1830 mm. A similar situation is revealed during diagnostics of the linear part of oil pipelines. To a greater extent, this problem manifests itself in sections located in mountainous areas, as well as in areas characterized by permafrost. Thus, we can say that the problem of the formation of defects in the shape of a pipe section is a pressing issue for both the oil and gas industries

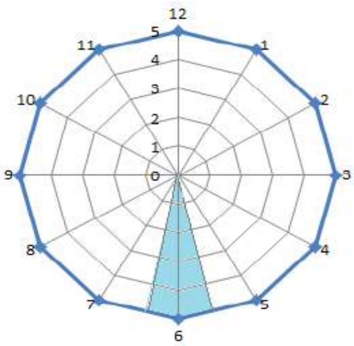


Fig. 1. - Clockwise orientation of the dent locations, discovered during the technical inspection of a section of the main pipeline (compiled by the authors)

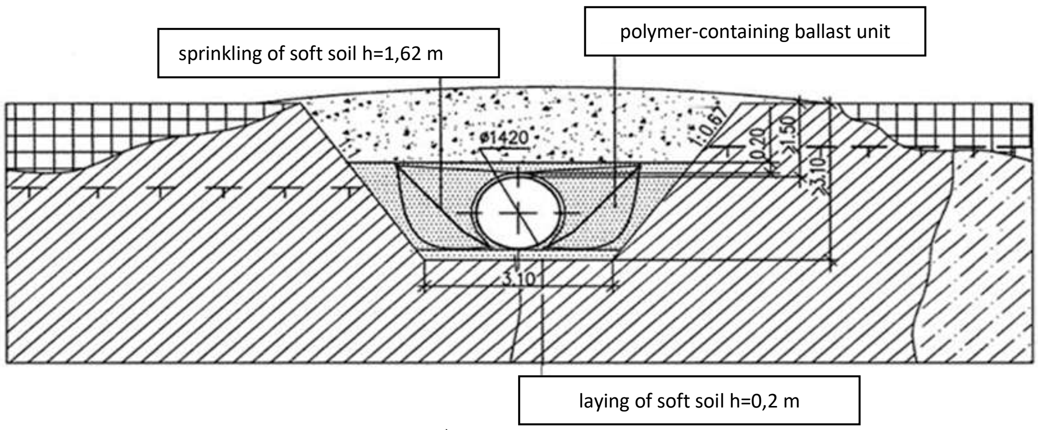
The purpose of this work was to identify the causes of the formation of such defects while complying with all design decisions made by the project.

The study was carried out using the example of individual areas with identified defects. Based on the results of an analysis of soil conditions in the areas under consideration with recorded violations, it was established that the trench was laid either in icy frozen soil containing coarse material (pebbles and gravel) or in rocky soil. Both cases of the project assume the presence of a leveling layer of sand 0.2 m high (Figure 2).

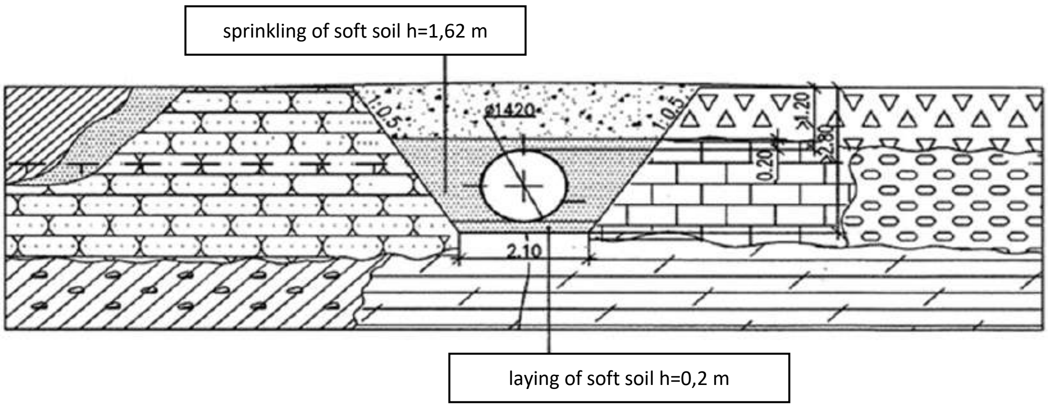
Thus, taking into account the peculiarities of laying MG in rocky and frozen icy soils, taking into account this definition, it was assumed that the formation of dents is possible with the simultaneous presence of the following factors:

– in the soil of the base of the MG there are large rock fragments or protruding fragments of underground rock masses;

– the MG route passes through rough terrain with successive alternation of ascents and descents, which can lead to the washing out of the leveling layer.



a)



b)

a - in frozen, icy soils; b - in rocky soils

Fig. 2. - Trench execution schemes (Instructions for evaluating the operability and rejection of pipes with corrugations (dents), 2002)

In addition, an analysis of the conditions for the formation of dents showed that some of the detected defects are located at the border of rocky and frozen soils. This fact can be explained by the fact that during the seasonal thawing of frozen soils, significant settlement occurs, as a result of which rock ledges are formed at the border with non-subsidence rocky soil. Such ledges can also lead to dents.

1. Materials and Methods

The assumptions made were verified by computer modeling of the interaction of the pipeline with a rock fragment. The modeling was carried out using the ANSYS universal calculation complex. The problem was solved in a static formulation.

During the solution, two main models of dent occurrence were considered:

– the presence of large rock fragments under the pipe (size up to 0.2 m);
– the presence of a protruding fragment of a rock mass at the border with frozen loam.

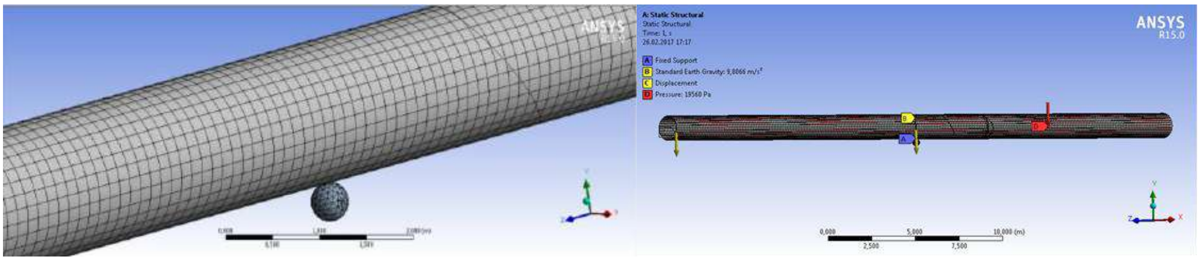
Thus, in both cases under consideration, the contact problem of interaction of a pipeline with an absolutely rigid body is solved. The loads were set by the pipe's own weight, as well as vertical pressure corresponding to the weight of the back fill soil. In order to solve this problem, the length of the modeled section was taken to be 30 m. The choice of length was carried out based on the condition that the value of free loss from the action of external load should exceed 0.2 m.

The vertical pressure from the weight of the soil was taken equal to 27,220 Pa. This value was obtained under the assumption that the back fill soil is loam with a density of 1630 kg/m^3, the height of the back fill above the upper pipe formation is 1.2 m.

During the modeling, it was assumed that a large fragment was exposed as a result of erosion of the leveling layer. Within the framework of the model, it was assumed that the foundation soil is not subject to deformation and erosion, that is, pipeline movements are limited by the thickness of the leveling layer and, according to the condition, should not exceed 0.2 m. This limitation allows us to simulate the gentlest situation. If the movement of the edges of the modeled area is greater due to the compliance of the foundation soil under certain conditions, then the load on the point of contact between the MG and the rock fragment will be even higher, which will lead to more significant deformations in the contact area.

A large rock fragment was modeled in the form of a solid body having the regular shape of a ball with a diameter of 0.2 m (Figure 3, a). The size of the rock fragment was determined by the size of the bedding layer of soft soil, which was assumed to be 20 cm in accordance with the design. Since the presence of sharp corners increases the perceived load due to the small contact area, the use of a solid body in the shape of a ball when modeling a rock fragment artificially "softens" the contact conditions pipeline. Thus, the occurrence of a dent upon contact with an absolutely solid ball will indicate that the formation of a dent is inevitable upon contact with a solid body of some other shape.

The boundary conditions of the model were determined by limiting the vertical movement of the edges of the modeled pipeline section (0.2 m), as well as by prohibiting the movement of the end sections of the section along the pipeline axis (Perelmuter & Slivker, 2002; Kuzbozhev, Birillo & Shishkin, 2014; Alexander & Kiefner, 1997). A solid body that imitates a large rock fragment is considered rigidly fixed. When modeling the loading, the weight components of the external load were considered. The weight of the pipeline itself was determined by its parameters (external diameter and wall thickness), as well as the properties of the material from which the pipe was made. The back fill soil was not modeled and was taken into account by additional impact in the form of vertical pressure on the surface of the pipeline, Figure 3, b.



a) b)

a – finite element model; b – loading diagram of the pipeline model

Fig. 3. - Computer modeling of a pipeline and a large rock fragment (compiled by the authors)

As part of the creation of the second possible model for the occurrence of dents, it was assumed that a protruding fragment of the rock mass formed at the border of rocky soil and frozen loam due to significant settlement of the loam during the period of seasonal thawing or soil thawing for some other reason. In this case, as in the first case, it was assumed that contact of the pipeline with a rock fragment is possible only if the leveling layer is washed out.

When modeling the base of the pipeline section, it was assumed that a protrusion formed at the boundary between rocky soil and frozen loam, represented in the model as a difference in heights of the upper boundary of the base of the pipeline (Figure 4). Moreover, within the framework of this model, the difference in heights was taken to be equal to the thickness of the leveling layer (0.2 m). In fact, the amount of settlement can be significantly higher, which, accordingly, will lead to an increase in pressure at the point of contact of the pipeline with the protruding part of the rock mass.

The base along the entire length of the modeled section is assumed to be absolutely rigid.

When solving, two contact pairs were specified: "pipeline - protruding fragment of the rock mass" and "pipeline - section of the base corresponding to frozen loam." Thus, when solving, the pipeline model will not "fall" through the base, but will come into contact with it.

As boundary conditions, the fastening of the lower surfaces of both parts of the base, as well as symmetry on the end surfaces of the modeled section of the pipeline, are accepted. As in the previous case, the loads were taken to be the pipe's own weight and the vertical pressure on the pipe surface, numerically corresponding to the weight of the back fill soil.

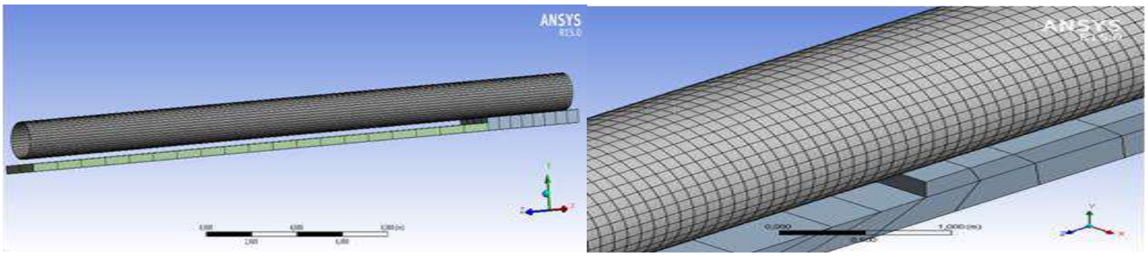


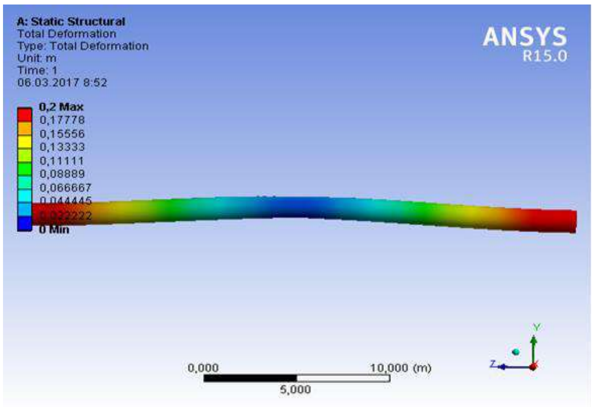
Fig. 4. - Finite element model of the pipeline and its foundation (compiled by the authors)

1. Results

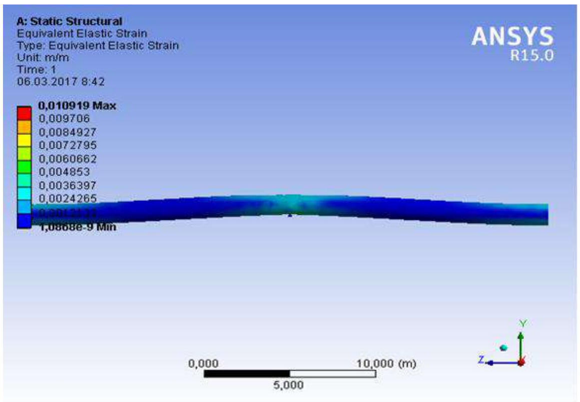
As a result of the given loads, a solution was obtained that included pipeline movements, as well as deformations in the contact zone. The solution to the first problem is presented in Figure 5.

Figure 5a indicates that the boundary conditions are set correctly and the edges of the modeled area do not "sink" into the foundation soil. The maximum pipeline movements do not exceed 0.2 m. In this case, the contact area does not move due to the rigid fastening of a solid body simulating a large rock fragment. The simulation showed that under the given conditions, the maximum deformation is observed at the point of contact and is 10.9 mm. The resulting dent is oval in shape and stretched along the axis of the pipeline. The length of the dent is about 2 m. The shape of the resulting dent is shown on an enlarged scale in the section shown in Figure 5, c, d.

Thus, the results of the modeling show that at the point of contact of a large rock fragment with a pipe, caused by settlement or washout of the leveling layer of sandy back fill soil, a dent may form under the influence of the weight of the pipe and the back fill soil. At the same time, the shape and dimensions of the dent obtained during modeling correspond to the in-line diagnostic data.



a)



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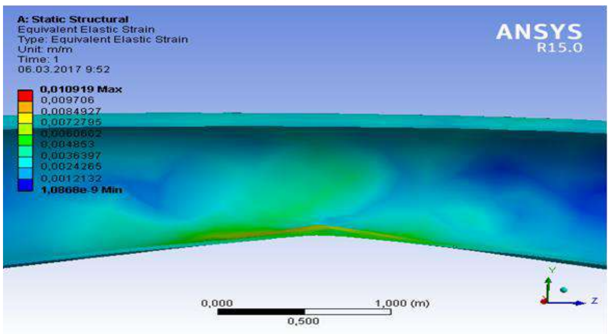

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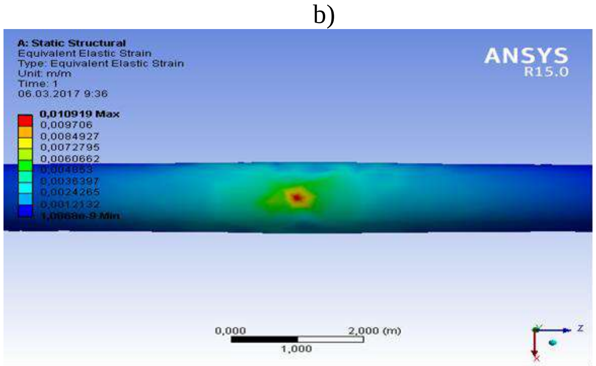
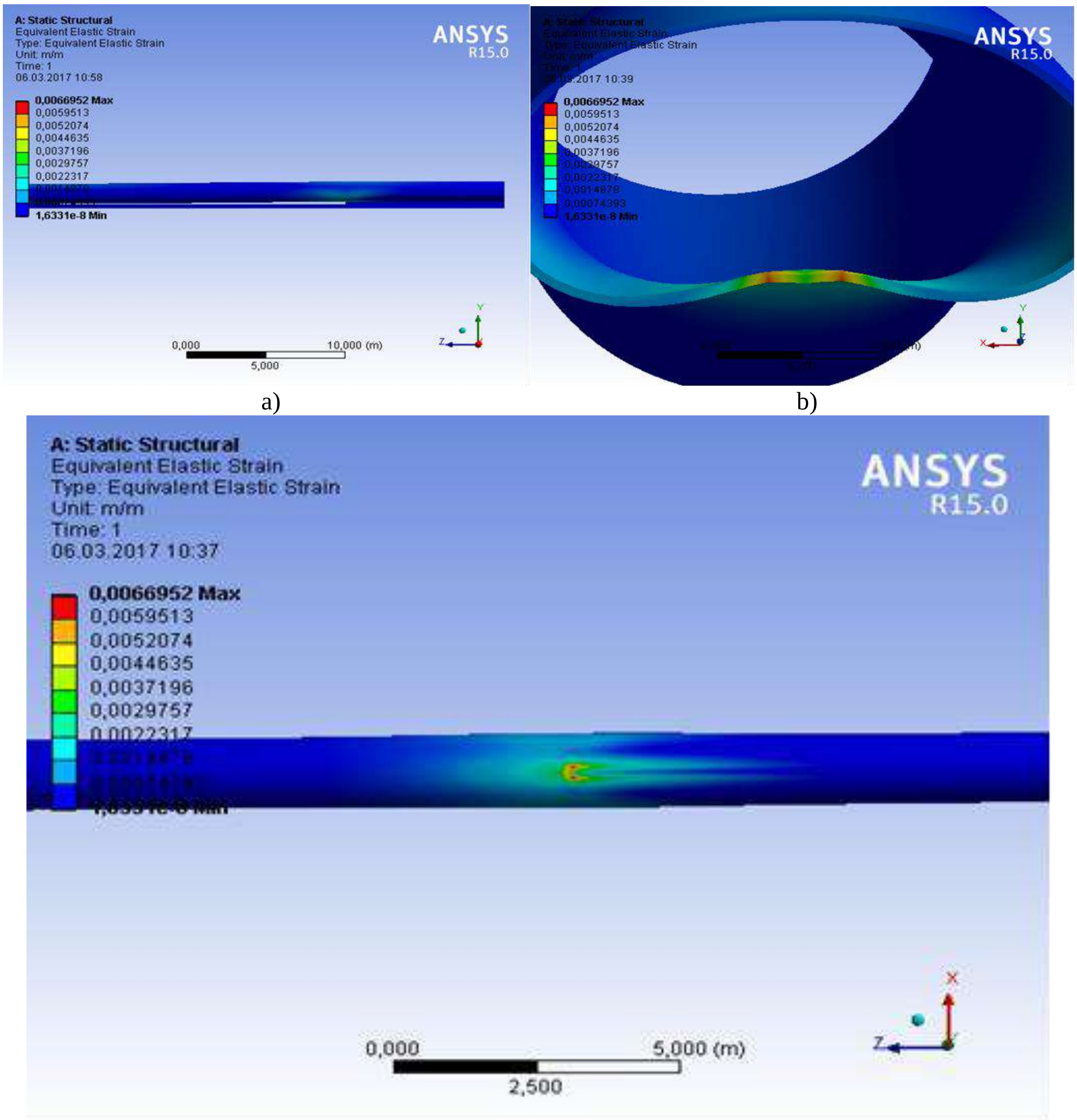


d)

a – pipeline movements; b – deformation of the simulated pipeline section; c – deformation of the simulated pipeline section (view of the contact point, display of a solid body simulating a large rock fragment is disabled); d – shape of the dent formed as a result of contact of the pipeline with a separate rock fragment

Fig. 5. Results of the interaction of the pipeline with a rock fragment under specified loads (compiled by the authors)

When solving the second problem, the resulting solution differs in both the size and shape of the dent. The result of the contact of the pipe with the protruding rock mass is presented in detail in Figure 6.



a) b) c)

a) deformation of the pipeline metal at the point of contact with a protruding fragment of the rock mass; b) shape of the dent in plan; c) stresses at the point of contact with a protruding fragment of the rock mass

Fig. 6. Results of interaction of the pipeline with the speaker fragment of a rock mass. (compiled by the authors)

From Figure 6 it can be seen that the maximum displacements correspond to the left end of the modeled section. For a pipeline section 30 m long, which is under its own weight and the weight of the back fill soil, the maximum displacement is 0.17 m. That is, the maximum displacement did not reach the maximum permissible value, accepted according to the conditions of this problem as 0.2 m. Thus, in real life conditions where the length of the pipe is not limited, when frozen soil subsides by 0.2 m, the pressure on the area of contact of the pipeline with the protruding rock mass will be higher than in the adopted model due to the greater length of the sagging section.

The metal deformations are presented in Figure 6. As can be seen, the presence of deformations is observed only in the area of contact between the pipeline and the protruding rock fragment.

The simulation showed that under the given conditions, the maximum deformation is observed at the point of contact and is 6.7 mm. The resulting dent is oval in shape and stretched along the axis of the pipeline. The length of the dent is about 2 m. It should be noted that the dent obtained during computer modeling has an atypical shape; it is elongated along the axis and has two centers.

The shape of the resulting dent in plan is shown in Figure 6c. The wall deformation is shown on an enlarged scale in the section shown in Figure 6b.

Thus, the results of the simulation show that at the boundary of rocky soil and frozen loam on the pipe, a dent may form under the influence of the weight of the pipe and the back fill soil. The formation of a dent is possible when there is significant settlement of loam caused by its thawing, and in the absence of a leveling layer at the bottom of the trench.

2. Discussion

The results obtained have important practical significance. Today, many researchers argue that the formation of a dent is possible solely as a result of the dynamic impact on the main pipelines from the moving parts of construction machines or in case of violation of the laying technology, when the formation of a dent occurs as a result of a falling pipe [14-16].

This assumption was indirectly refuted by the results of statistics on detected defects such as dents. Since most of them were located on the lower surface of the pipe, then each such dent should have been formed during the fall, however, such a violation of technology, repeated many times, is very doubtful. In this case, static loads caused by the weight of the pipe and the weight of the back fill soil led to the occurrence of a reaction at the points of contact of the metal with a fragment of rocky soil, and the maximum values of such reactions correspond precisely to the lower surface, since in this case the load consists simultaneously of both the weight of the pipe and the back fill weight.

Thus, the results obtained confirmed the possibility of dent formation on pipelines during long-term static exposure. In this case, formation is possible only in the case of direct contact of the pipe with a protruding solid fragment. If you exclude the possibility of such contact, then the formation of dents will not occur.

Measures to prevent contact of the pipe body with hard fragments of soil include the use of supports for laying the pipeline in a trench, the use of synthetic non-woven material to hold the bedding soil at the base of the pipe, the use of wooden lining or any other protective structure [17-20].

Conclusions

As a result of numerical modeling, confirmation was obtained of the possibility of dents occurring under the influence of static load from the pipe's own weight and the weight of the back fill soil. Moreover, in both cases considered, one of the prerequisites is the erosion of the leveling layer and, as a consequence, the exposure of fragments of rocky soil. Thus, we can say that the presence of protruding hard fragments at the base of the MG is fraught with the occurrence of dents if the laying conditions suggest the possibility of their exposure.

As measures to reduce the likelihood of dents occurring, we can recommend measures to prevent erosion of the leveling layer or to prevent contact of the MG metal with possible protruding fragments.

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