Modeling of Seismic Impacts on the Main Pipeline

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Abstract. In this article, a seismic calculation of a section of an underground pipeline is performed using the Ansys software package. The linear-spectral analysis of this calculation was based on the response spectrum obtained from a variety of real records of seismic ground vibrations at the Petropavlovsk seismic station. This method makes it possible to take into account the experience of past earthquakes, reducing the likelihood of exceeding the expected loads on the structure during a new earthquake. The results of the seismic calculation of the pipeline made it possible to form a complete picture of the distribution of stresses in the pipeline for various forms of the trench and the material of its backfill. A comparison is made of the maximum stresses in the pipeline for various methods of its seismic protection.

1. Introduction. Relevance of the issue
When designing the routes of main pipelines, it is impossible to avoid zones of increased danger, including zones of seismic activity and intersections with active tectonic faults. Seismic regions of Russia, where earthquakes with an intensity of 6-8 points on the MSK-64 scale are possible, account for about 28% of its entire territory, and areas with earthquakes with an intensity of 8-10 points - about 6%, and these are areas of active industrial development. These include the North Caucasus, the Baikal region, Yakutia, Sakhalin, Kamchatka and the Kuril Islands [1].

Seismic waves harmonize vibrations of the ground and of the thin-walled shell of pipelines (since the pipelines are pinched in the ground), causing internal inertial forces in the pipeline [2]. Under the action of these forces, the shell of the pipeline, which does not possess sufficient seismic resistance, can either collapse or lose the stability of the initial form of equilibrium [3].

2. Selection of initial data for calculation and problem statement
For the calculation, a three-dimensional model of the pipeline was proposed and, accordingly, an element of the Solid type (regular tetrahedron) was used, intended for modeling three-dimensional objects [4].

The model should be of sufficient length so that the boundary conditions do not have a significant effect on the critical area near the main load (fault, earthquake source). Thus, based on the analysis of the possible sizes of tectonic faults for all finite element models, a length of 48 m was chosen (4 pipeline sections 12 m each) [5].

Low-alloy structural steel for welded structures 17GS-1U, which is used for various parts and elements of welded metal structures operating at temperatures from -70 to +425 ° C under pressure, with the following initial data:

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Low-alloy structural steel for welded structures 17GS-1U, which is used for various parts and elements of welded metal structures operating at temperatures from -70 to +425 ° C under pressure, with the following initial data:
- yield point $\sigma_y = 350 \text{ MPa}$;
- ultimate strength $\sigma_{ut} = 510 \text{ MPa}$;
- modulus of elasticity $E = 210000 \text{ MPa}$;
- Poisson's ratio $\mu = 0.3$ [6].

The design maximum permissible stress for steel is determined by the ultimate load of the structure [7]:
$$[\sigma]^p = \frac{\sigma_{pr}}{k} = \frac{510}{1.2} = 425 \text{ MPa},$$

where $k$ is the reliability factor.

For the calculation, a fragment of a pipeline with the following technical characteristics was modeled:
- pipeline diameter $d=1220 \text{ mm}$;
- pipe wall thickness $\delta = 15 \text{ mm}$;
- the length of the pipeline section $l = 48 \text{ m}$.

An element-by-element model of a pipeline fragment was created using the ANSYS software product (figure 1) [8].

![Figure 1](image.png)

**Figure 1.** Element-wise model of a fragment of a pipeline and a pipeline in the ground for calculating seismic effects.

In the course of the calculation, it is necessary to assess the stress-strain state of the pipeline under seismic influences of various directions with various forms of the pipeline trench and various backfill materials.

3. **Seismic pipeline analysis in ANSYS**

Pipeline seismic design in ANSYS consists of three stages (figure 2):
- structural (strength) analysis in a static setting;
- modal analysis;
- linear spectral analysis [9].

![Figure 2](image.png)

**Figure 2.** Stages of seismic pipeline analysis in ANSYS.
Modal analysis is carried out to determine the frequencies and modes of natural vibrations of structures. Also, modal analysis can be the first step for other types of dynamic analysis, such as transient analysis, harmonic and spectral analysis. Modal analysis assumes that the system is linear. All types of nonlinearity - nonlinear material behavior, contact boundary conditions, finite displacements - are ignored. Contacts, depending on their initial state, remain open or closed. It is assumed that external forces and damping are equal to zero [10].

During the modal analysis, the first 6 natural frequencies of the structure and the corresponding characteristics were obtained (table 1).

| №  | Frequency, Hz | Period, s | Axe x       | Axe y       | Axe z       |
|----|--------------|-----------|-------------|-------------|-------------|
| 1  | 0.037        | 26.766    | 431.478     | 7042441     | 68418.3     |
| 2  | 0.039        | 25.823    | 7156470     | 425605      | 4.071       |
| 3  | 0.135        | 7.435     | 127877      | 0.095       | 0.005       |
| 4  | 0.317        | 3.154     | 0.375       | 1748430     | 43963.5     |
| 5  | 0.355        | 2.819     | 1665050     | 0.117       | 0.014       |
| 6  | 0.526        | 0.087     | 18680.5     | 0.115       | 0.008       |

Linear spectral analysis allows obtaining the dependences of the maximum values of the structure's responses (displacement, stress, speed, acceleration, reaction) on external vibrational loads. Spectral analysis uses modal analysis results with a known spectrum. Spectral analysis is mainly used instead of transient analysis to determine the response of a structure to random or time-dependent loads. This primarily concerns earthquakes, wind loads, the action of ocean waves, the influence of fluctuations in the thrust of a jet engine, and so on.

Two types of spectral analysis are possible: single-point response spectrum (SPRS) and multi-point response spectrum (MPRS). In "single point" (SPRS) analysis, only one spectral curve is determined for the external stimulus that is transmitted to the structure through the boundary restraints. The same impact is transmitted through each fixing node. In "multipoint" (MPRS) analysis, it is possible to determine different spectra of external influences on different groups of boundary restraints [11, 14].

The linear-spectral analysis was based on the response spectrum obtained from the set of real records of seismic ground vibrations at the seismic station "Petropavlovsk" (figure 3) [13]. This method makes it possible to take into account the experience of past earthquakes, reducing the likelihood of exceeding the expected loads on the structure during a new earthquake.

Figure 3. Frequency-amplitude characteristic of an earthquake, recorded in 1993 at the seismic station "Petropavlovsk".

In the course of the analysis, the distributions of deformations and stresses were obtained in a pipeline laid in the ground during an earthquake of 9 points (figures 4 and 5).
Figure 4. Distribution of deformations in the pipeline and soil environment.

Figure 5. Distribution of stresses in the pipeline.

The results were also obtained when filling the trench with sand and when constructing a trapezoidal trench (table 2).
Table 2. Maximum stresses in the pipeline under seismic influences of various directions, MPa

| Trench type                        | Seismic direction | Horizontal | Vertical | Amount |
|------------------------------------|-------------------|------------|----------|--------|
|                                    |                   | Along the pipeline axis | Perpendicular to the pipeline axis |        |
| Rectangular trench filled with clay|                   | 201,3      | 350,4    | 450,7  | 1002,4 |
| Rectangular trench covered with sand|                   | 185,3      | 321,7    | 435,8  | 942,8  |
| Trapezoidal trench                  |                   | 180,1      | 315,9    | 425,8  | 921,8  |

4. Conclusions
The results of the seismic calculation of the pipeline make it possible to determine both single internal stresses in the section of the pipeline under seismic loads and to form a complete picture of stress distribution (longitudinal and circular).

Backfilling of a rectangular trench with a pipeline with non-cohesive soil (for example, sand) reduces the maximum stresses in the pipeline during seismic impact by 5.5% compared to backfilling with clay, and the formation of a trench with gentle slopes (trapezoidal) reduces the maximum stresses in the pipeline by 8%.

The pipeline is able to withstand the impact of a single seismic wave during an earthquake of 9 points, but the total impact of compressional and shear seismic waves, even when using the above-mentioned seismic protection methods, will not be able to withstand. A detailed analysis and calculation of methods are needed to compensate for seismic effects.

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