Influence of Tanks Design Features on Earthquake Resistance in Permafrost Areas

T A Belash¹, E A Dymov¹

¹Buildings Department, Emperor Alexander I Petersburg State Transport University, Saint-Petersburg, Russian Federation

E-mail: belashta@mail.ru, shekadym@mail.ru

Abstract. Tanks for the storage of oil and gas play a special role in the oil and gas industry. During the construction and design of such structures in difficult geological conditions, increased attention is paid to their safe operation. The combined manifestation of seismic impacts and the presence of permafrost can pose an increased danger. The article presents an analysis of the various components of an oil and gas storage system. A comparative analysis of the seismic resistance of storage tanks was carried out, taking into account the presence of a thawed permafrost base in the base. It is shown that during thawing, the permafrost base can greatly affect the seismic resistance of the structure.

1. Introduction

The oil and gas industry plays one of the leading roles in the Russian economy, and its development directly depends on specialized equipment. The main task of the oil and gas industry is the extraction of natural resources, but an equally important task is the purification of resources and the manufacture of finished fuel. To store and provide many enterprises with such resources, they use not only a gas pipeline, but also capacitive structures in the form of reservoirs. Most of the gas fields are located in the eastern part of Russia, in the territory of permafrost. However, in some regions of Eastern Russia, there are zones of joint manifestation of permafrost and seismic activity, which carries an additional danger during design, because seismic load can have a significant negative impact on the properties of permafrost soils. Ensuring reliable operation of reservoirs in areas with increased seismic activity can be considered one of the important issues from the point of view of earthquake-resistant construction, since the resulting destruction of structures can entail not only material losses, but damage to the ecological environment.

Currently, there is a certain practice of constructive implementation of storage tanks for oil and gas products, which shows that these design solutions are very diverse [1-6]. The existing solutions can be used both in seismic regions and in permafrost regions. Meanwhile, the nature of the work of these structures in the areas of joint manifestation has been insufficiently studied to date. Cases of damage to one or another structural solution of reservoirs in areas of seismic activity are widely known. For example, in seismic regions, vertical cylindrical tanks for storing petroleum products are widespread (Fig. 1).
In this structure, the most dangerous place during an earthquake is the support part, in which, under seismic load, the anchoring anchors of the tank bottom are broken on one side, and on the opposite side, the wall stability is lost, as a result of which an "elephant's leg" is formed (Fig. 2) [7-10]. If there are weak soils in the form of permafrost bases at the base of such a structure, the influence of two natural factors will have a negative impact on the operation of the entire tank, and the risk of its loss of bearing capacity increases dramatically.

Cylindrical tanks for storing liquefied gases (gas tanks) have a more complex design under low negative temperatures. Such gas tanks can be made in the form of a multi-layer structure consisting of several containers. The external tank is a container made of metal sheets or monolithic reinforced concrete, the inner part is made of 9% nickel steel [11-16], insulation is placed between the tanks to maintain the negative temperature of the liquefied gas (Fig. 3). During the seismic impact, the most vulnerable places are the lower belt of the structure. In such a structure, if there is permafrost with different properties at the base, there are risks of possible damage to such a structure during seismic impacts.
Figure 3. Design diagram of an LNG storage tank.

Spherical tanks for storage of liquefied gases under high pressure are widely used in the oil and gas industry (Fig. 4). The spherical shape is characterized by an even distribution of the load and allows you to store more gas due to its liquefaction under high pressure [17]. This constructive form is widely used both in seismic regions and in permafrost regions.

Figure 4. Design diagram of a spherical tank.

The most vulnerable place in these tanks is the support part in the form of support posts. It is established that significant bending moments can occur in flexible support structures during seismic impacts [18-20], which leads to a complete loss of stability of the structure. In the areas of permafrost distribution, this part of the tank structure also becomes the most dangerous, since various kinds of subsidence may occur in it, because of which an emergency arises.
An analysis of the design features of oil and gas industry reservoirs shows that a large variety of design forms and solutions of these reservoirs have been developed and implemented in construction practice, but the reliability and trouble-free operation of these structures in areas of joint permafrost and seismic activity requires additional research. Some of the results of these studies are presented in this article.

2. Methods
For the study, the most typical reservoirs for storing oil and gas products were selected:

- a cylindrical tank with a fixed roof without a pontoon with a volume of 5000 m³ for oil storage (Fig. 5, a). Made of metal sheets 10 mm thick. The inner diameter of the structure is 22.8 m, and the wall height is 12 m. The foundation is a pile field with a reinforced concrete grillage 0.7 m thick;

- a cylindrical tank for storage of liquefied natural gas (LNG) (Fig. 5, b). The outer shell is made of reinforced concrete with a thickness of 1 m, the total height is 48 m, the diameter of the cylindrical part is 86 m. The inner container is made of nickel steel with a thickness of 16 mm. The foundation is a pile field on a slab grillage with metal piles in the form of pipes with a cross section of 530/20;

- a spherical tank for storing liquefied petroleum gas with a volume of 600 m³ has a sphere diameter of 10.5 m, and the shell thickness is 16 mm (Fig. 5, c). The foundation is designed as a pile field to reduce uneven settlement.

The study was conducted using the SCAD program. The elements of the tank body were set by the final elements in the form of plates, the support part was set in the form of rods. The calculation models were modeled on a ground field made by volumetric finite elements. Seismic impacts were set taking into account the regulatory recommendations of SP 14.13330.2018.

The properties of the subgrade were taken in the form of a permafrost foundation with weak thawing properties and were set by different elastic moduli. The study examined foundations in a permafrost state and in a thawed state.

When constructing the models, some assumptions were made, namely: homogeneous soil mass; fuel values for assessing seismic resistance were not taken into account.

3. Results
Some results are presented in Table 1, where the maximum internal stresses and maximum displacements of the structure were compared.
The results of the study show that under the action of a seismic load on thawed frozen soil, the displacement of the structure and the values of internal stresses significantly increase. This can cause significant damage to structural elements, and in some cases, their complete or partial destruction.

The cylindrical oil storage tank is subject to less deformation compared to other tanks, which shows its effectiveness in using in regions with a joint manifestation of permafrost and seismic impacts.

Table 1. Results of the study.

| Tank                | Maximum values of displacements from the seismic load (mm) | Internal stresses of structural elements under seismic load (T/m²) |
|---------------------|----------------------------------------------------------|---------------------------------------------------------------|
|                     | X     | Y     | max    | min    |
| On the thawed ground|       |       |        |        |
| Cylindrical for oil | 45,11 | 48,92 | 1553,72| -1467,79|
| Cylindrical for LNG | 196   | 198,4 | 5359,42| -3710,02|
| Spherical           | 59,65 | 19,25 | 2843,44| 3249,9 |
| On frozen ground    |       |       |        |        |
| Cylindrical for oil | 3,4   | 5,8   | 244,42 | -279,34|
| Cylindrical for LNG | 15,24 | 16,45 | 707,74 | -836,16|
| Spherical           | 4,91  | 2,38  | 698,78 | 798,52 |

4. Conclusions
1. The analysis of the design solutions of the forms and solutions of reservoirs for the oil and gas industry indicates their great diversity, while the design solutions can be successfully used in areas of permafrost or seismic activity.

2. Assessment of damage to reservoirs after earthquakes or in the presence of thawed permafrost bases indicates the possibility of dangerous situations when they are combined.

3. It is established that in the presence of thawed permafrost soils during seismic impacts, an increase in the stress-strain state is observed in the design of a cylindrical oil tank by about 7 times, in the structures of an LNG tank by more than 5 times, and in a spherical one by 4 times. At the same time, the displacements of structural elements increase more than 10 times in each model.

4. In areas of joint manifestation of seismic and permafrost, various structural solutions of reservoirs can be used, while preference should be given to those structures that are least vulnerable both under seismic influences and in the presence of frozen bases with additional constructive measures that increase their reliability of behaviour in the conditions under consideration, for example, strengthening of frozen bases.

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