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Modelling of Underground Natural Gas Storage Openings in the Basin of Tuz Gölü Lake with FEM

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Abstract
The need to energy is increasing in the world with the increasing of industrialization day by day. In this context there is a growing need for energy obtained from natural gas. In Turkey, parallel to the world the demand for natural gas is also increasing. Annual natural gas consumption in Turkey is about 50 billion cubic meters. Distribution of Turkey's natural gas consumption according to usage areas is as follows; 53% in electrical energy, 25% in industry, 22% in residential use. These demands rates are varying according to different times of the year. Moreover, due to political crisis, differences in the gas flow may occur. It is possible to become inadequate to meet immediate demand for these differences. Creation of underground natural gas storage is considered as a solution to eliminate this risk. While, the world storage volume is 380.4 billion cubic meters, Turkey has one store with 2.6 billion cubic meters capacity. It is also planned for storage capacity as 10% of the demand in Turkey. In this study, the stress around natural gas storage underground openings, designed by BOTAŞ in the Basin of Tuz Gölü Lake, and the resulting deformation were investigated. For this purpose, Rocscience RS2 (Phase2) using finite element analysis was performed. Analysis were carried out for a single opening and also multiple neighbor caverns. Working gas pressures are suggested for each modelled situations.

Keywords: Tunneling, Rock mass classification, Support design, FEM.

1. Introduction

Energy requirement is increasing along with industrial growth worldwide. Electrical energy is at the top of these energy needs. A majority as 37.8% of electricity production are supplied by the natural gas conversion plants in our country according to 2015 data (MENR, 2016). At the same time, natural gas usage in the different branches of industry and housing is quite common. This situation increases the demand of natural gas day by day.

Although dependence on natural gas is so much natural gas production in our country is quite low. It means that the majority of this gas is imported from abroad. The difficulties may be encountered some time due to a variety of reasons in meeting the natural gas needs. The main causes are as follows: Failing of the gas provider countries in meeting the natural gas demand of our country, political reasons and fluctuations in demand for natural gas. Demand for natural gas is increased, especially with the increased need for heating in winter. But the summer demand in the residential use of natural gas fairly decreases because natural gas usage for heating is not needed. Natural gas consumed in our country is used as 53% percentage in the production of electricity and as 22% in residential housing and as 25% in the energy production for industry as shown in Figure 1 (Özarslan et al., 2007). When we look at the amount of natural gas consumed in housing at summer and winter months the ratio between the months is seen as a serious fluctuations.

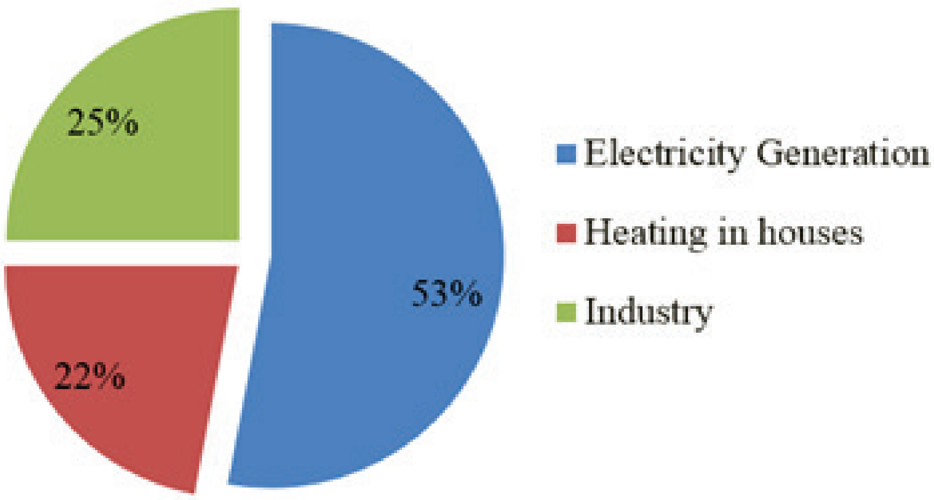

Figure 1. The purposes of the natural gas usage in Turkey

Gas quantity to be stored in Turkey and Europe, respectively, should be 10% and 20% based on the amount of total usage. When we look at these figures and consider the increased supply, the gas quantity to be stored is inadequate by the ratio 2.1% according to the laws of Turkey and by 4.2% of Europe today. In 2030 this ratio is expected to be insufficient by 4.9% as compared to Turkey and as 9.8% to Europe (Dülger, 2013). Therefore, it is increasing the attention paid to the storage of natural gas.

Underground storage is safer as well as more economical according to the surface storage tanks. Underground reservoirs can hold much more gas on site according to the surface tanks. Underground reservoirs also vary among themselves. One of the ideal solutions is openings which are formed by solution mining in rock salt. Gas can be stored safely in these spaces. In addition, an impermeable reservoir can also be provided with the self-repair of cracks that may exist in the salt (Özarslan et al., 2007). Openings can maintain their stability without artificial supports (Özarslan et al., 2007). Natural gas storage in rock salt is opened with the aid of solution mining. Dissolution of the salt is provided by giving fresh water to the drill hole at the appropriate depth. Large underground cavities can be opened in this way. These opened cavities is important to have a desired geometry. In particular, the uncontrolled growth of the openings upwardly is undesired. Substances such as oil, helium gas and etc. is sent into the drilling hole to prevent the uncontrolled dissolution. These substances should remain above the water and also not react with the water, salts and natural gas.

The Tuz Gölü salt formation is folded up to an elongated narrow salt wall by post-sedimentary halokinetic processes. Based on seismic data, the salt body exhibits a rather complex and irregular subsurface topography with rather steep dipping flanks. Within the presumed cavern area, the top of salt formation is expected in depth between 595 m and 1,085 m. Table 1 presents general geological and lithological information about the profile of the field (Onal, 2013).

Table 1. Stratigraphic preconditions of the field (Onal, 2013)

Stratigraphic formation / unit or subunit	Estimated thickness range (m)	General Lithology
Cihanbeyli to Kochisar fm.	640 – 1.080	Shale, marlstone, conglomerates and limestones
Caprock	65 – 95*	Anhydrite occasionally with thin intercalations of clay and/or carbonates
Salt	> 1.000	Rock salt with an average of about 7 to 11% of insolubles (mostly anhydrite), locally up to 26%

The main factors to be considered in the design of the opening; depth, primary stresses, opening geometry, short and long-lasting mechanical properties of the rock salt and inner gas pressure conditions. The general approach to internal gas pressure is followed as, 30% of the maximum principal stress is taken as the smallest internal pressure, and 80-85% of the maximum principal stress is taken as the greatest internal pressure. Low minimum internal pressure will cause failure in protecting the stability of the opening but excessive amount will result as uneconomical solution. The higher maximum internal pressure values can cause hydraulic fracturing of rock salt and formation of fissures and gas leaking. In contrast, the low maximum internal pressure will also result as uneconomical solution. In addition, the distance between the two openings is an essential parameter to be considered if there are other openings in the planned study area (Özarslan et al., 2007).

RS2 (Phase2) finite element program produced by the Rocscience company is used in the modelling. Mohr - Coulomb failure criterion was used in the program. The geometry of the gas reservoir was introduced into the software. The mechanical properties of the formation and the location of the gas reservoir is defined first. Then stress-deformation calculation for each node is made by creating the mesh in the software. Different internal pressures and the effects of neighboring natural gas storage were examined in the calculations.

2. Effective Parameters in Design of Natural Gas Storages Opened in Rock Salt

2.1. Depth and Principle Stresses

The storage is located at 1150 meters depth in this study. The unit weight of the cover layer in the region where underground storage exists was taken as 0.025 MN/m^3 and unit weight of rock salt was taken as 0.021 MN/m^3. Average unit weight can be taken as 0.024 MN/m^3. It was considered that the primary stress is due to gravity, and was calculated as about 27 MPa.

2.2. The Geometry of the Opening

The diameter of the opening, which is opened in rock salt is up to 64 meters and the height is 300 meters geometric form of the opening is given in Figure 2. Depth from the surface of the natural gas storage is taken as 1150 m. The area of opening is approximately 15.300 m^2 and the volume is 675.000 m^3. It is intended to establish the closest model to the real opening with that planned geometry.

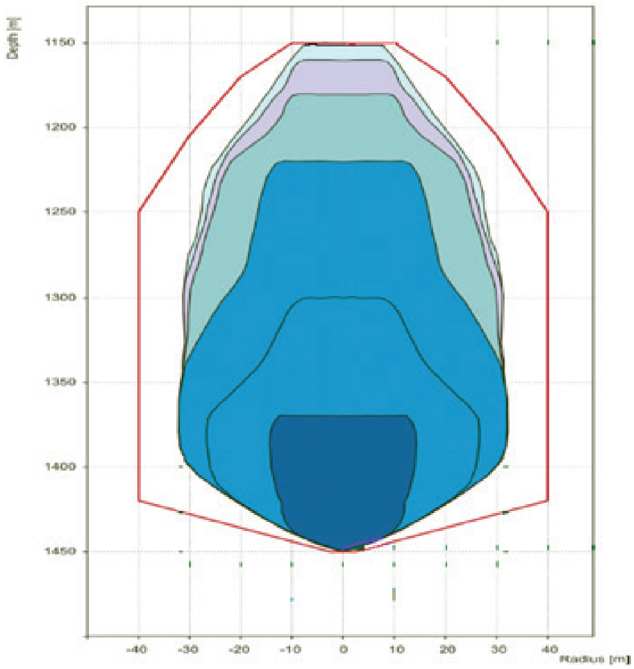

Figure 2. Geometric form of the natural gas storage opening used in the modeling study (Dülger, 2013)

2.3. Internal Gas Pressure

Internal gas pressure, is one of the most important parameters in order to maintain the stability of the natural gas storage in rock salt. The minimum gas pressure gives the minimum internal gas pressure value required to keep the reservoir stable. This value is approximately between 25-30% of the principle stress (Özarslan et al., 2007). The maximum gas pressure gives the highest value of internal gas pressure allowed in the gas storage. Maximum gas pressure value is between 75-80% of the principle stress. If the maximum gas pressure exceeds these values hydraulic fracturing may act on the wall of the opening (Özarslan et al., 2007). When these values are considered, the minimum gas pressure should be between 6.75 and 8.1 MPa, the maximum gas pressure should be in the range of 20.25 to 21.6 MPa.

2.4. Mechanical Properties of Rock Salt

The mechanical properties of rock salt, where the gas storage is opened, is an effective parameter to remain stable. The mechanical properties of the formation used in the modelling are given in Table 1.

2.5. Distance Between two Adjacent Openings

Distance between the gas storage openings in other words pillar thickness is important for the stability of the system. Induced stress zone created by one of the opening should not affect the other neighboring storage. If there is less distance between the openings, induced stress zones will coincide with each other, and therefore the stability of the reservoir will be affected negatively. In contrast, in an excess of the distance between the openings storage areas cannot be used effectively. Such factors should be considered and optimal distance between stores should be left. In this study, models were created for 150 m and 300 m distances between two adjacent openings.

3. Modelling of Underground Natural Gas Storage Openings using Rocscience RS2 Finite Element Method

In the modeling study is performed using the finite element program RS2 (Phase2) version 9.0 produced by the company Rocscience. Stress conditions was taken as hydrostatic and maximum stress component was considered as the stress created by overburden. Modeling was conducted in the specified elastic conditions. The values adopted to modelling is given in Table 2 (Özşen, 2009). Mohr - Coulomb failure criteria was selected and type of material was taken as plastic. Density of the overburden was taken as 0.023 MN/m^3

Table 2. The parameter values used in modelling with finite element method.

Parameter	Unit	Rock Salt
Unit Weight	MN/m^3	0.021
Cohesion	MPa	4.8
Angle of Internal Friction	Degree	61
UCS	MPa	27.8
Poisson ratio	-	0.11
Young's Modulus	GPa	2.29
Tensile Strength	MPa	2.69

The storage openings are planned to be built at 1150 m depth and maximum principle stress calculated from gravity is 27 MPa at that depth. The situations that are used in different modelling scenarios are given in Table 3.

Table 3. Different planned situations used in the models

Model No	Distance Between Openings (m)	Internal Gas Pressure (MPa)
1	0 (Single Opening)	0
2	0 (Single Opening)	8
3	0 (Single Opening)	22
4	150	0
5	150	8
6	150	22
7	300	0
8	300	8
9	300	22

3.1. Results of the Modelling Study

Stress distributions and total displacements values were calculated for ten different situations given in Table 3. Distribution of the maximum principle stress and total displacement around the opening is given at Figure 3 for internal pressure equal to zero. Internal pressure of the storage is selected as 0 MPa, 8 MPa and 22 MPa in modelling. Total displacement around the opening is given in Figure 4 for single opening. Modelling study was performed for the opening formed at 150 m and 300 m distances (Figure 5, Figure 6).

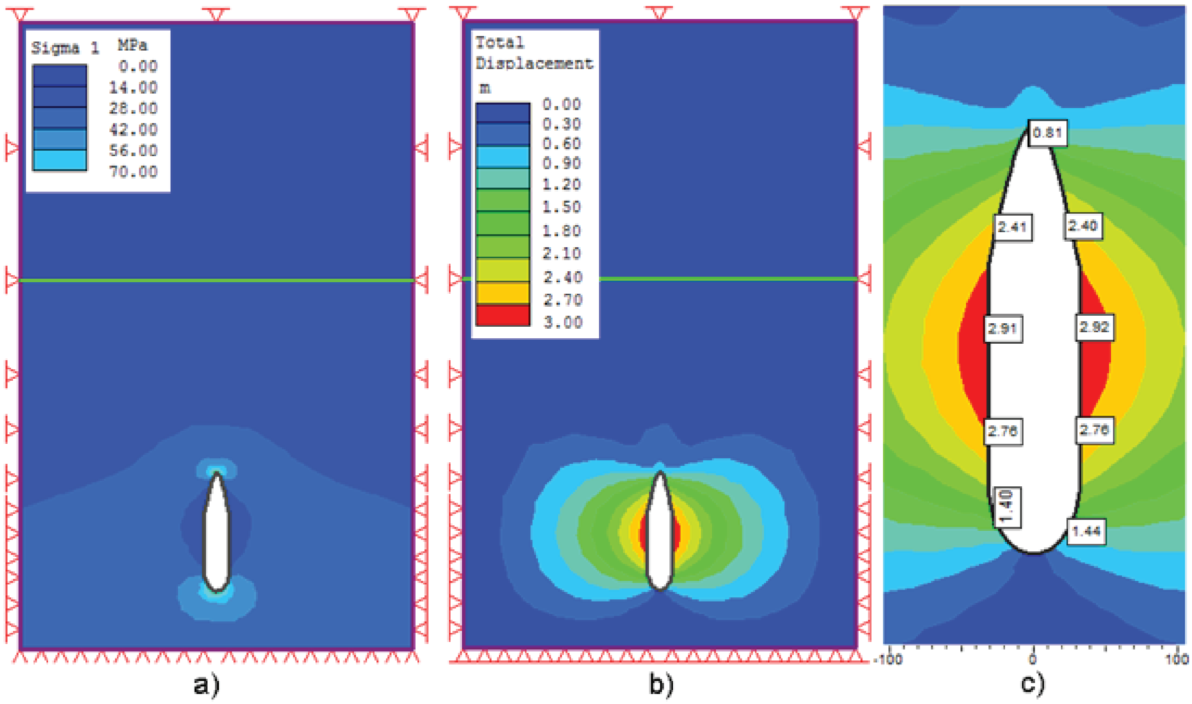

Figure 3. Maximum principle stress (a) total displacement (b) distribution around the opening, and total displacement values at different locations

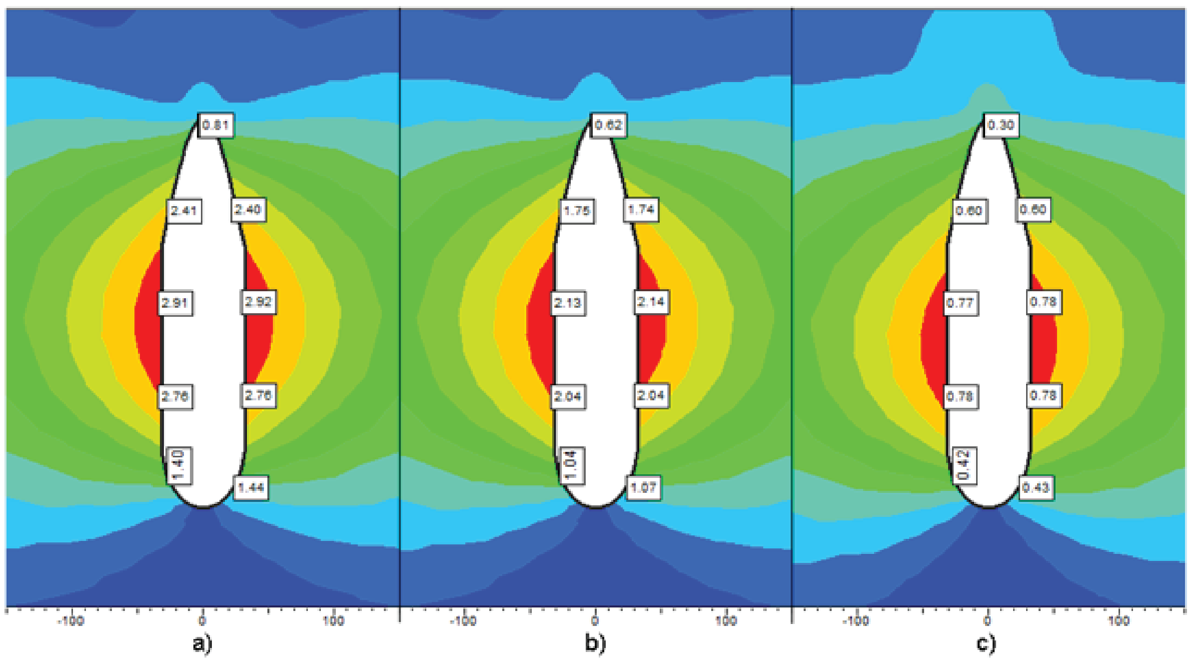

Figure 4. Total displacement values at different locations for internal pressure 0 MPa (a), 8 MPa (b), and 22 MPa (c) in single opening situation.

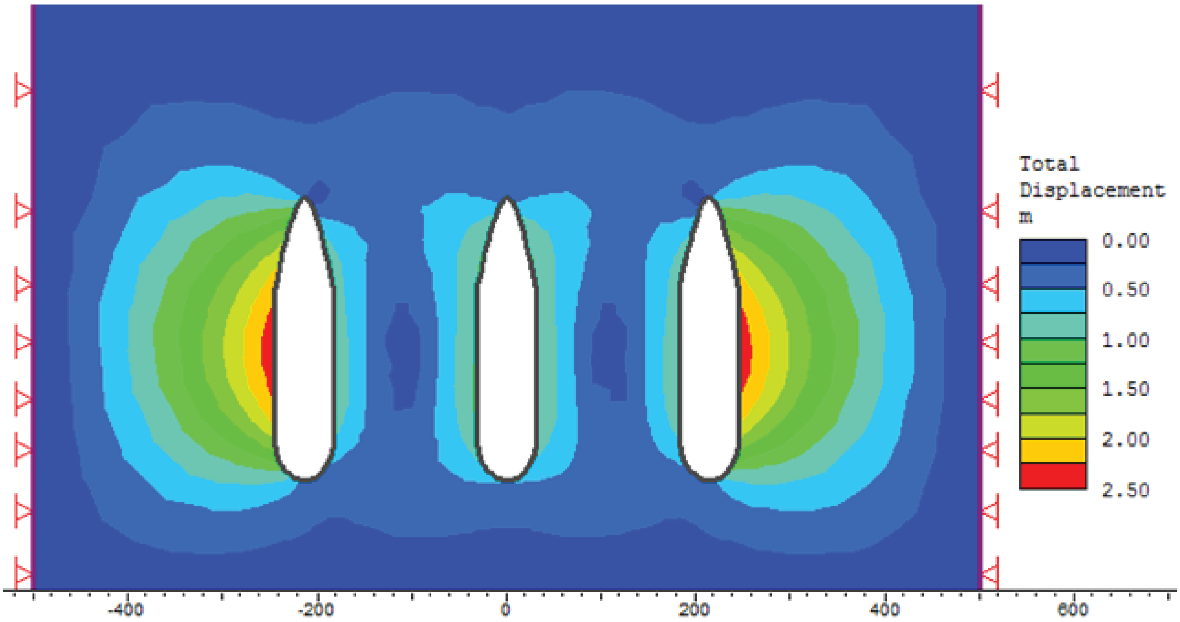

Figure 5. Total displacement values for the openings within 150 m and 0 MPa internal pressure.

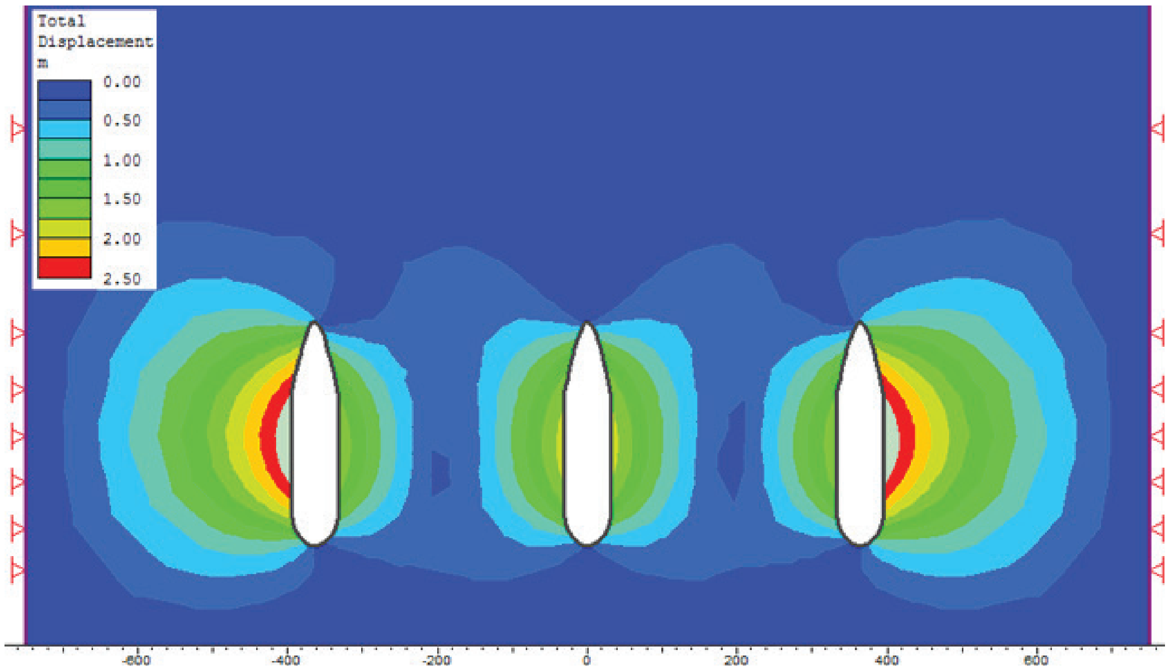

Figure 6. Total displacement values for the openings within 300 m and 0 MPa internal pressure.

In modeling with finite elements, the closer the openings are, the less the deformation between them is. According to widely accepted view, when the natural gas reservoirs approach each other, the deformation increases. But the opposite is true in the model here. The reason for this is that deformations are taken as vectors. As shown in Figure 7, the vectors are damped because of the opposite directions, and therefore displacements decrease as the openings become closer to each other. When these explanations are taken into account, when the displacement is solved by the finite element, the distance between the underground natural gas storages cannot be decided. The best decision mechanism that can be applied here will be the primary stresses when the primary tensile strengths of the underground natural gas reservoirs are not within the confluence area, they should be considered as providing adequate spacing.

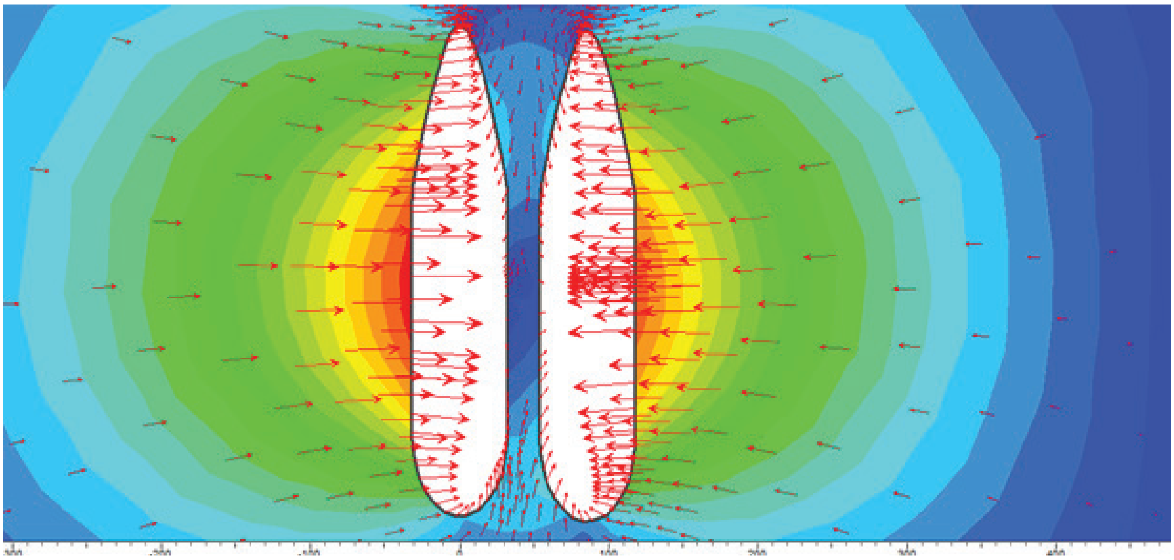

Figure 7. The displacement vectors of the two underground natural gas reservoirs, which have been reduced to extreme distances between them.

Figure 8 and Figure 9 show the state of the primary stresses as the distance between the storages changes according to the internal pressure being 0 MPa. In Figure 2, when the primary stresses on the two sides of the 1st and 3rd storages from left to the right are examined, it is observed that the differences reach about 10 MPa. It is observed that for the storage with a distance of 300 m between them, these differences reach to approximately 4 MPa. Figures 10-13 show primary stresses for internal pressures of 8 and 22 MPa. For these values taken as operating pressures, the primary stress fields can be determined in the same way. In this way, the distances between the storages in the model are determined so that the primary stresses on the two side surfaces of the first and third reservoirs are close to each other so that the tension fields of the storages are not influenced by each other.

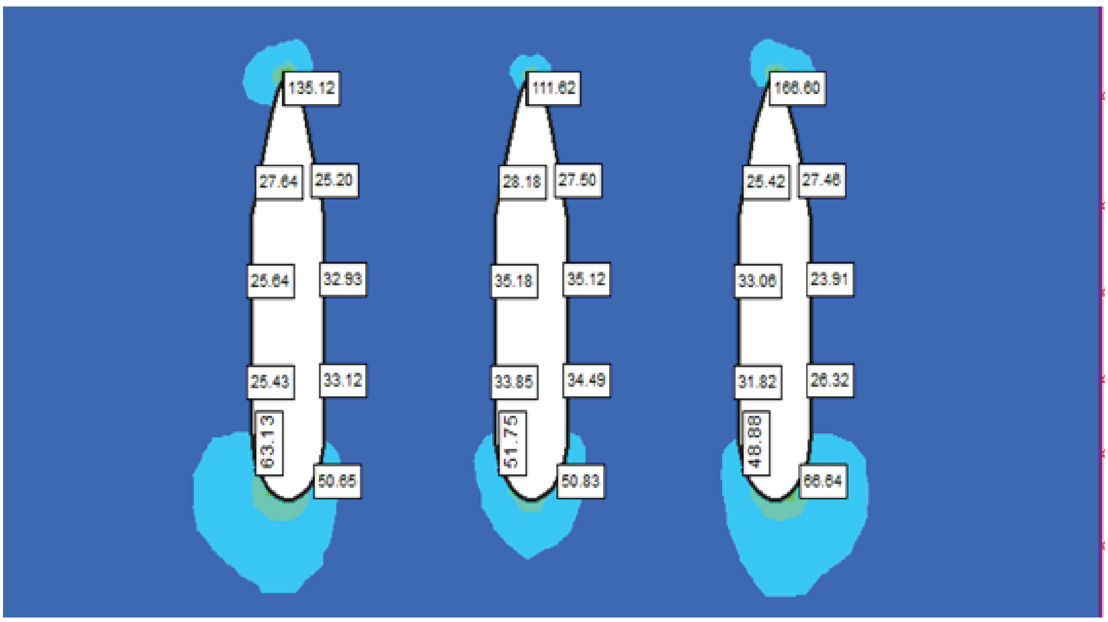

Figure 8. 0 MPa internal pressure and distance between openings 150 meters.

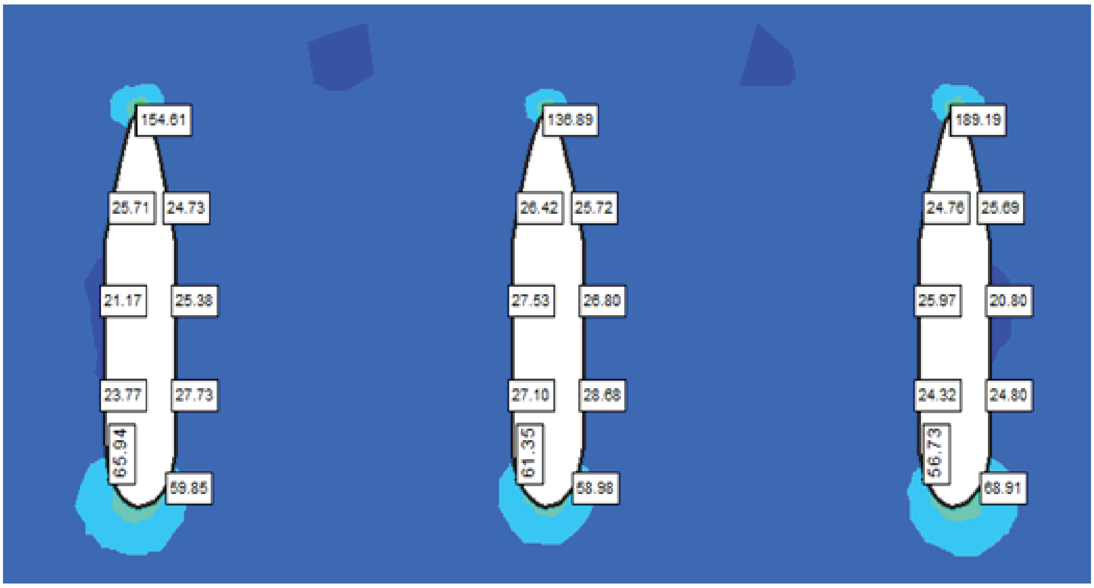

Figure 9. 0 MPa internal pressure and distance between openings 300 meters.

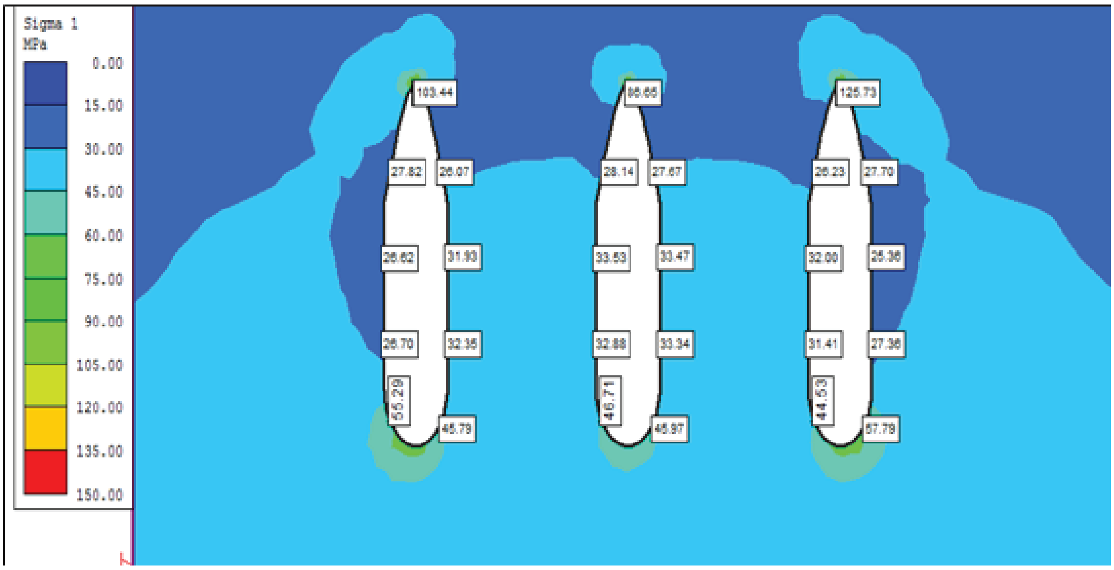

Figure 10. 8 MPa internal pressure and distance between openings 150 meters

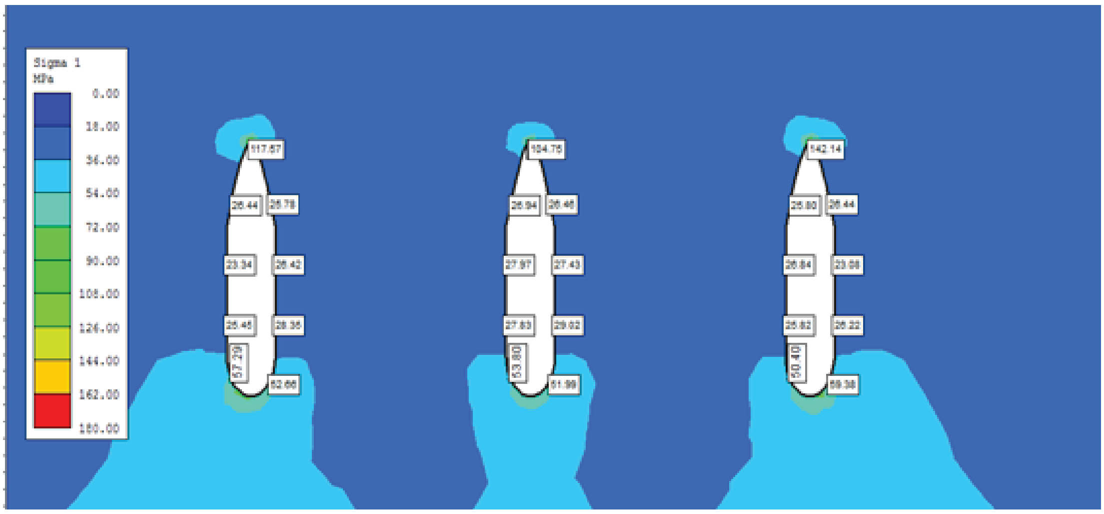

Figure 11. 8 MPa internal pressure and distance between openings 300 meters.

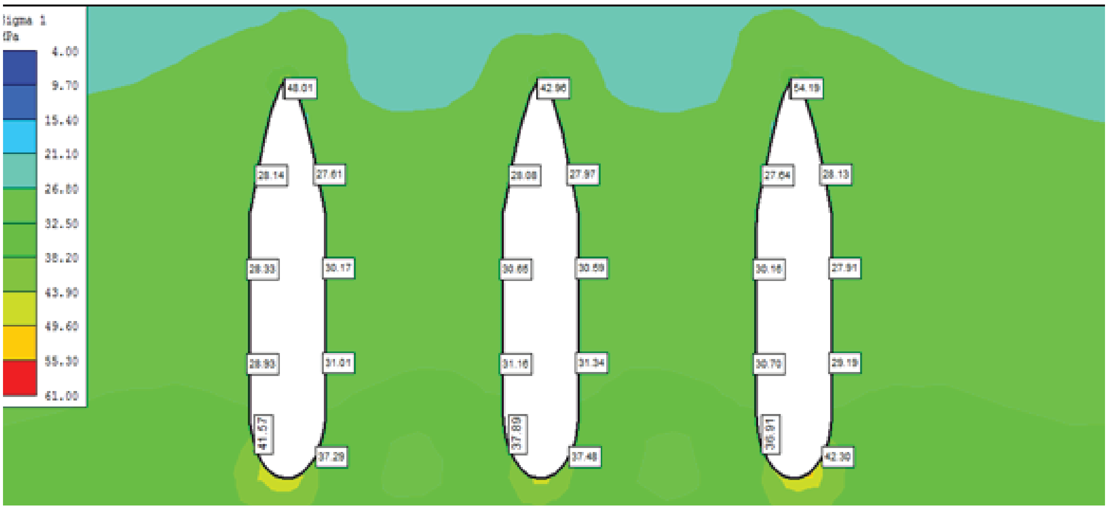

Figure 12. 22 MPa internal pressure and distance between openings 150 meters.

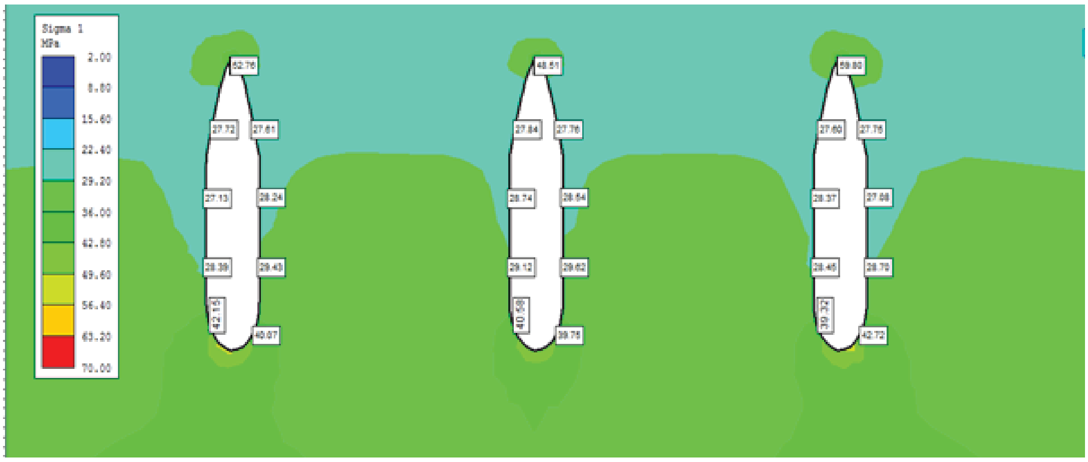

Figure 13. 22 MPa internal pressure and distance between openings 300 meters.

The relation between the stress differences observed at the side wall of the openings and the distance between the openings is given in Figure 14. When the internal pressure is increased, the pressure differentials on the lateral surfaces will decrease.

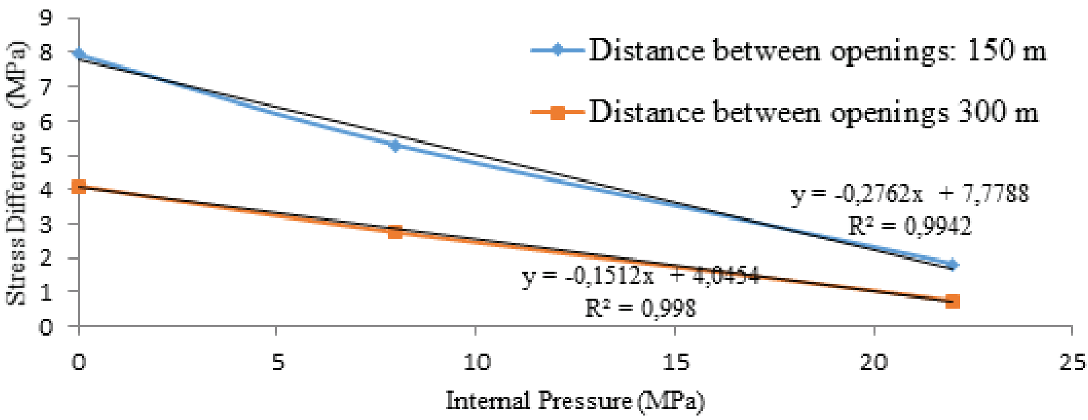

Figure 14. Variation of the stress difference between the lateral surfaces by the internal pressure values for the distances between the different openings

4. Results and Conclusion

The study of design parameters of gas storages was performed using the numerical analysis based on the finite element modeling (FEM), using a commercial software RS2 9.0 by RocScience. The analysis included geometrical parameters of the cavern i.e. shape and size, depth, specific gravity of overburden rocks and thus the in-situ stresses, ratio of lateral stress, elastic properties of rock, and strength of rock salt. The results of the study can be summarized in Table 4.

Table 4: Results of gas storage opening numerical analyses

Modelling Scenarios	Maximum Stress, σz MPa	Maximum Total Displacement, m	Maximum Shear Strain	Maximum Volumetric Strain
1	55.23	2.92	0.057	0.10
2	47.05	2.14	0.041	0.07
3	33.16	0.78	0.012	0.02
4	43.25	2.37	0.030	0.06
5	38.37	1.73	0.021	0.04
6	33.08	0.66	0.006	0.01
7	46.72	2.72	0.034	0.07
8	40.88	1.99	0.024	0.05
9	33.13	0.74	0.007	0.01

Maximum displacement often occurs on the sidewalls where the long unsupported span is located. Maximum displacements of less than 2% of diameter is often considered as acceptable for stability of underground structures, and can be used as a general measure of acceptability of wall displacement for given cavern sizes, shapes, and depth. The models in this study provided suitable results for this issue and in most cases, this requirement was met.

Study of loading and unloading of the cavern by injection/storage, and withdrawal of the gas during the life cycle of the caverns during the operation and its impact on the displacements and cavern stability has to be investigated.

Apart from this work, the formation of three-dimensional model will give different angles of stress and strain components. Furthermore, to determine the mechanical properties of rock salt, the changes that occur over time should also be considered. Also, the modeling must be done in different geometries.

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