Study the Behaviour of Underground Oil Cavern Under Static Loading Condition

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Research Article

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Abstract

The country population is increasing rapidly and the needs to make lives easier daily. Some of the essential needs for this generation are crude oil and electricity. India unfortunately does not possess any oil reserves to meet the needs of the country's demands. So, India is importing oil from other countries. Whenever there are situations like war, pandemic (COVID-19) and other emergencies, the natural oil reserved countries cannot export the oil to other countries which will lead to great chaos in the country. To avoid this situation storing the crude oil is necessary. Building surface giant structures for storing the oil is difficult and won't be economical. So, India is constructing giant underground structures called caverns, which will reserve the oil. The present study is focused on the stability of the underground cavern structure and understanding the importance of water curtaining system. To analyze the stresses and displacement 2D modelling has been done. In this, wet and dry models are prepared and analysed based on the available geological and geo-technical data to determine the stresses around the cavern and the displacement which will reach on surface due to excavation.

1. Introduction

In current Scenario, the population is increasing rapidly and the needs to make lives easier in day to day life. Some of the needs for this computer generation are electricity, petrol and diesel. The crude oil became essential source to almost every household in the world. The country's economy is also dependent on these essential commodities. Not every country is fortunate enough to have these essential commodities. So, most of the countries are dependent on the oil reserved countries such as Brazil, Saudi Arabia, United Arab Emirates, Gulf countries, Russia and other countries. In other words, the countries which possess the oil reservoirs will fix the price of the crude oil and it directly affects the Gross domestic product(GDP) of those countries which doesn't possess the fortune. Even when there are conflicts between two nations, the oil reservoirs will play a prominent role. Every country should possess at least some oil reserves so that it is not completely dependent on the oil reserved nations.

India's population is nearly 1.3 billion and these numbers are increasing daily. Around 70-80% of the population is completely dependent on the petrol, diesel and other required needs. India doesn't possess any kind of natural oil reserves. It is completely dependent on the oil reserved nations like United Arab Emirates, Brazil, Iran etc. Whenever there are situations like war, pandemic (COVID-19) and other emergencies, the natural oil reserved countries cannot export the oil to other countries which will lead to great chaos in the country. In order to eliminate these problems, India is planning to reserve the oil for emergency purposes. For storing the oil on the surface, Giant structures with impenetrable walls are required, even the smallest hole can lead to the complete destruction of the giant structures. With advanced technology, no doubt one can construct giant structures with airtight capacity. The main problem with giant structures is the cost. These structures are too expensive. By storing the oil on the surface will ultimately lead to the increase in the cost of the crude oil which is not appreciable. The other option left is Underground. The Underground is the best option for storing the crude oil because here giant structures are not needed, the only thing which is important in storing the crude oil is to maintain pressure around the stored area. For storing materials, excavation is carried at a depth generally ranging from 40-50 m from the surface and the minimum height and width of the excavation are 20 m and 10 m respectively. These excavations are termed as caverns. These are used for different types of purposes such as storing of food & crude oil, electricity generation, military purposes, storing of explosives etc.

1.1 Essential conditions and Background

1.1.1. Essential conditions

When the cavern is closed, the gas will be left in the cavern, above the crude oil and under the maximum operational pressure of 2 kg/cm^2. To prevent the gas from leaking out of the cavern, a water curtain system with water pressure of 2 kg/cm^2 is to be adopted for both the construction period and operation period of the cavern [Lee et al]. The proper function of oil storage in underground caverns relies on the following three conditions: (1) The specific gravity of the oil must be less than that of water. (2) The oil is anti-decomposition and insoluble in water. (3) The groundwater pressure around the caverns must be higher than the stored oil pressure [Wang et.al.]. The water-sealing effect and rock mass stability are two key problems for the construction of underground storage caverns [Jie et.al.]

1.1.2 Background

Caverns are derived from the word Caves which means the left-out space or area in the underground due to the geology. So, cavern is the word used for the structure or space left out in the underground naturally or man-made. These caverns are generally used for storing materials like food grains, crude oil, military ammunition, compressed air energy etc. Storing these materials in the surface structures won’t be economically efficient. This study deals with the storing of crude oil in the cavern. Construction of the cavern is based on Heading and Benching method. The Geology and the height of cavern decides the number of benches in excavating the cavern. The excavation of the cavern is being carried out by Drilling and Blasting method. For maximum efficiency, same crew for drilling, hauling, scaling team and charging were used to excavate at several tunnel faces. This helps in constructing the cavern in minimum time.

When the cavern is filled with crude oil after its construction, there are some gases leftover in the cavern due to the crude oil. As the hardest rocks are impermeable, but there are at least 5-10% of the pores available in almost all rocks including hard rocks. The gases inside the cavern try to escape from the cavern through pores of the rock when the crude oil pressure is higher, this result in the propagation of cracks and at last leading to form joints or spacing between the rocks. This phenomenon damages the cavern stability leading to failure of the cavern.

In order to restrict the above mentioned problem, water curtaining system is developed around the cavern in such a way that the trapped gases in the cavern should not escape. The water curtaining system is generally developed 15-20 m above from the crown of the cavern. This water curtaining system includes water curtain tunnels and bore holes which are placed at regular intervals around the cavern. The design of the water curtaining tunnels and size of the bore holes depends on the geological and Geo-technical properties. This system is constructed before the excavation of the cavern, if the system is constructed after the excavation of the cavern then the chances are that water may percolate in the cavern making it unstable. With this system, the pores of the rocks are filled with water and the trapped gases cannot be able to escape from the cavern. And the water pressure in the water curtaining tunnels and bore holes are in such a way that it should be greater than the pressure of the crude oil inside the cavern making the entire structure a hydrodynamic containment leading to a stable structure and economically efficient.

2. Model Development

The model is developed using FLAC 8.0 Software which is based on explicit finite difference method:

2.1 Properties Used in the Model

To analyse the stresses and displacement occurred, 2D modelling has been done. The Physical and Geo-mechanical properties used to develop the model are given in Table 1 and Table 2 below:

Table 1 shows the data of Physical properties used in the model

Lithology	Physical Properties					
	Dry Density, kg/m^3	Wet Density, kg/m^3	Specific gravity	Porosity (%)	Absorption (%)	P-Wave Velocity, (m/sec)
Granitic Gneiss, Medium to Coarse grained, slightly weathered	2747	2751	2.75	0.4	0.14	5163

Table 2 shows the data of Geo-mechanical properties used in the model

Lithology	Geo-mechanical Properties						
	Compressive Strength, MPa		Elastic modulus, GPa (dry)	Poisson's ratio (dry)	Tensile Strength, MPa (dry)	Triaxial Compression test (Saturated)	
	Dry	Wet				Cohesion, MPa	Friction angle, (degrees)
Granitic Gneiss, Medium to Coarse grained, slightly weathered	146	120	57	0.23	12.25	40	50

2.2 Dry State

Fig. 1 Model before excavating cavern.

Fig. 2 Model after excavating cavern**.**

2.3 Wet state

Fig. 3 Model before excavating cavern.

Fig. 4 Model after excavating cavern.

3. Results And Discussion

3.1 Dry state

3.2 Wet State

3.3 Discussion

From the above graph (Fig. 13) of Sxx stresses, shear stresses in dry state slightly increase after excavation than before excavation. It happened because whenever an excavation is made stresses develops around the excavation. Shear stresses in wet state slightly increases after excavation when compared to the wet state before excavation. Shear stresses in wet state are higher than the stresses in dry state. It is because of the pore pressure applied in the boundaries of the model and the pore pressure around the cavern boundary.

From the above graph (Fig. 14) of Syy stresses, shear stresses in dry state model slightly increase after excavation than before excavation. It happens because whenever an excavation is made stresses will develop around the excavation. Shear stresses in wet state model slightly increase after excavation when compared to the wet state model before excavation. Shear stresses in wet state model are higher than the stresses in dry state model. It is due to the pore pressure applied in the boundaries of the model and the pore pressure around the cavern boundary. It follows the similar trend as Sxx graph.

From the graph (Fig. 15) of displacement, it is observed that there is a constant value before excavation of the cavern structure in both dry and wet state models. When there is an excavation in dry state model, displacement is increased slightly, compared to the dry state before excavation. When excavated in wet state model, there is an increment in the displacement compared to the wet state model before excavation. After excavation, the displacement in wet state model is higher than the dry state model. It explains that the pore pressure around the cavern is causing more displacement than the dry state model.

4. Conclusions

In study stresses and displacement has been analysed very carefully:

1. Shear stresses in wet state model before and after excavation are higher than the shear stresses in dry state model before and after excavation.
2. In wet state model before excavation the displacement is same compared to dry state model which means presence of pore pressure did not affect the displacement on the ground surface. Also
3. After excavation in wet state model, the displacement is slightly increased compared to dry state model which indicates presence of pore pressure while excavation affects the displacement on the ground surface.

Thus, presence of pore pressure is important in keeping the structure stable to counteract the escaping gases from the cavern. The pore pressure is developed through the water curtaining system which includes, water curtaining tunnels and boreholes at regular intervals around the cavern.

Declarations

We hereby declare that this submission is our own work and that to the best of our knowledge and belief. This research work is done pertaining the M.Tech degree of the first author.

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paper are those of the authors and not necessarily of the organization they represent. This paper forms a part of the M. Tech dissertation work of the first Author.

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Figures

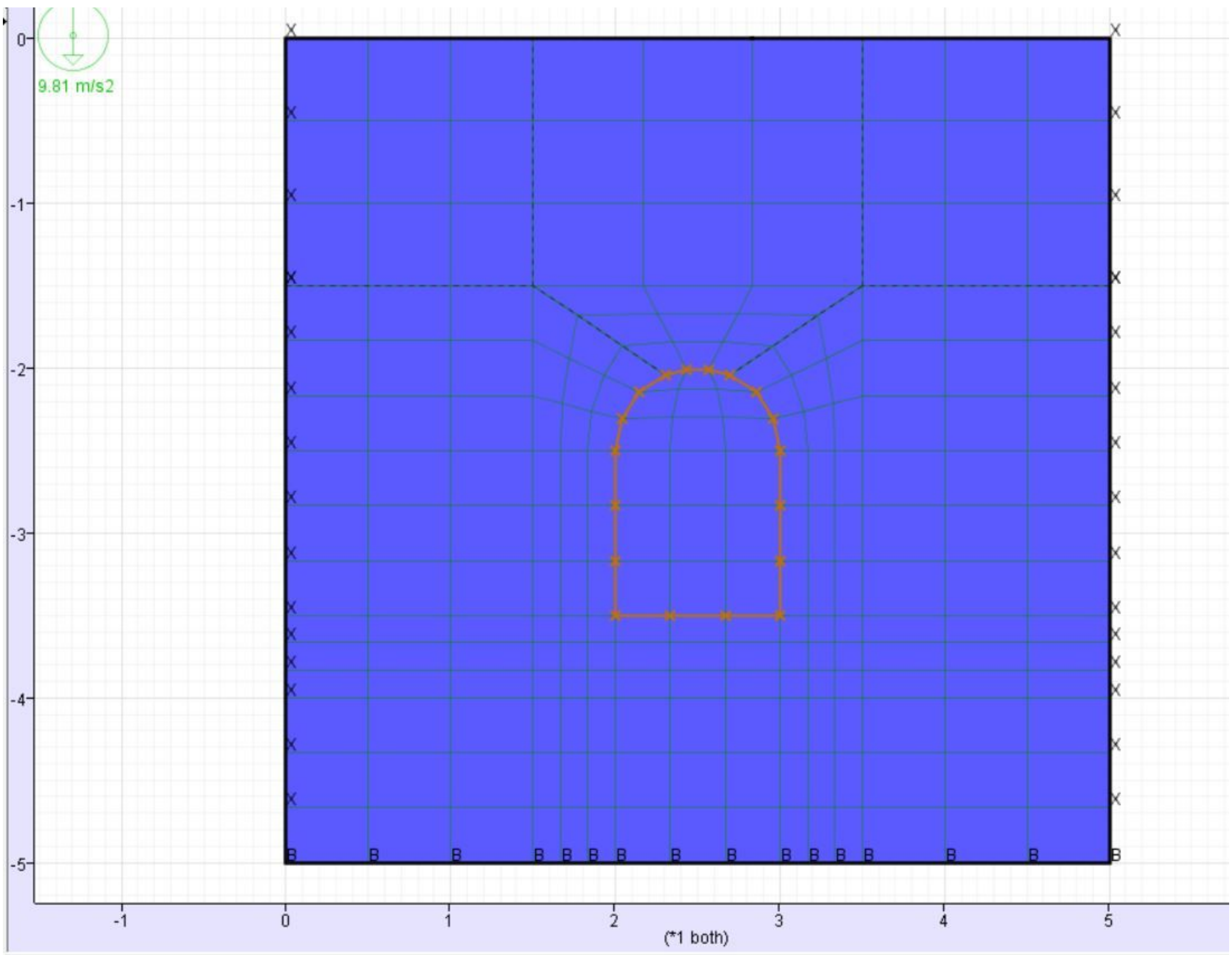

Figure 1

Model before excavating cavern.

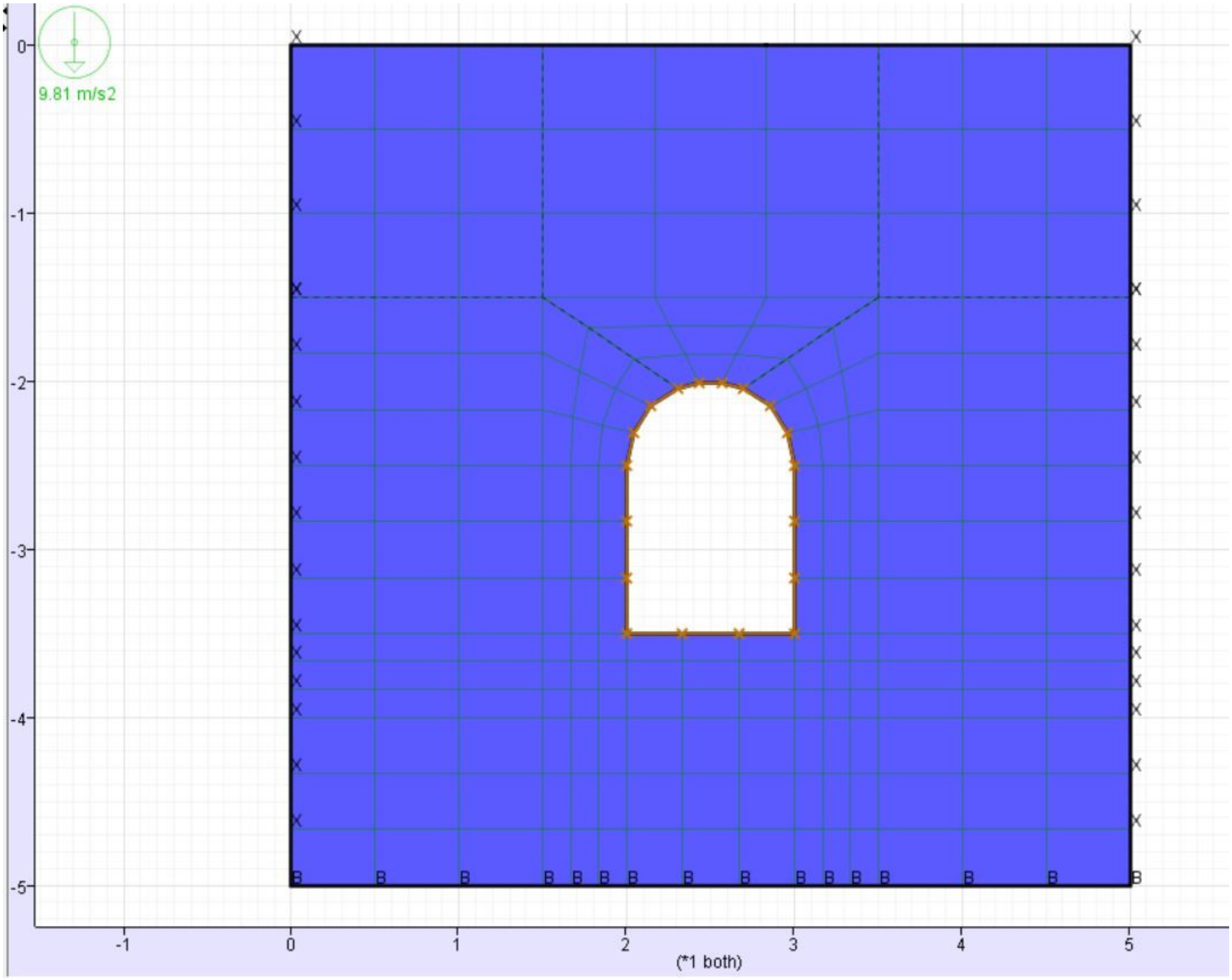

Figure 2

Model after excavating cavern.

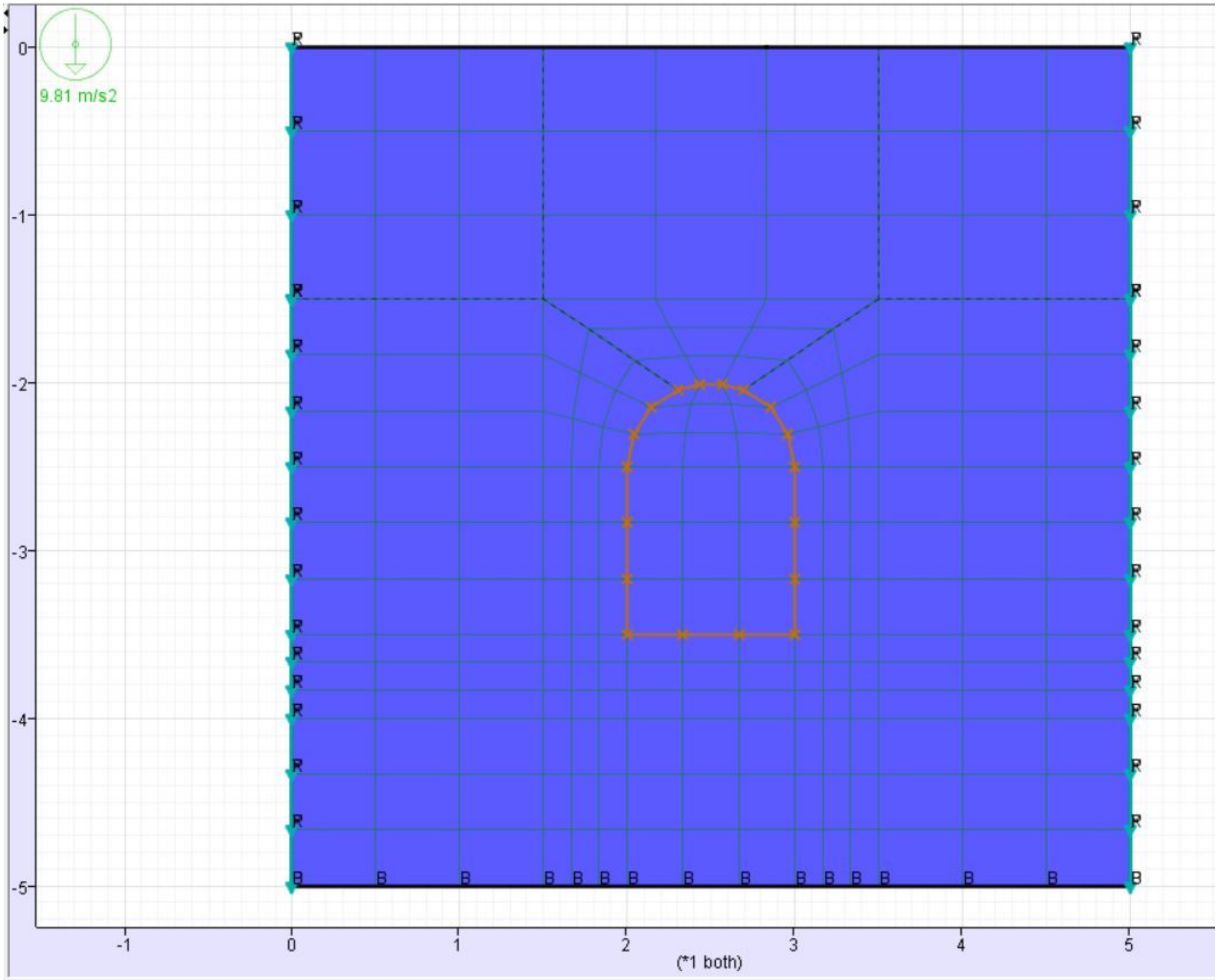

Figure 3

Model before excavating cavern.

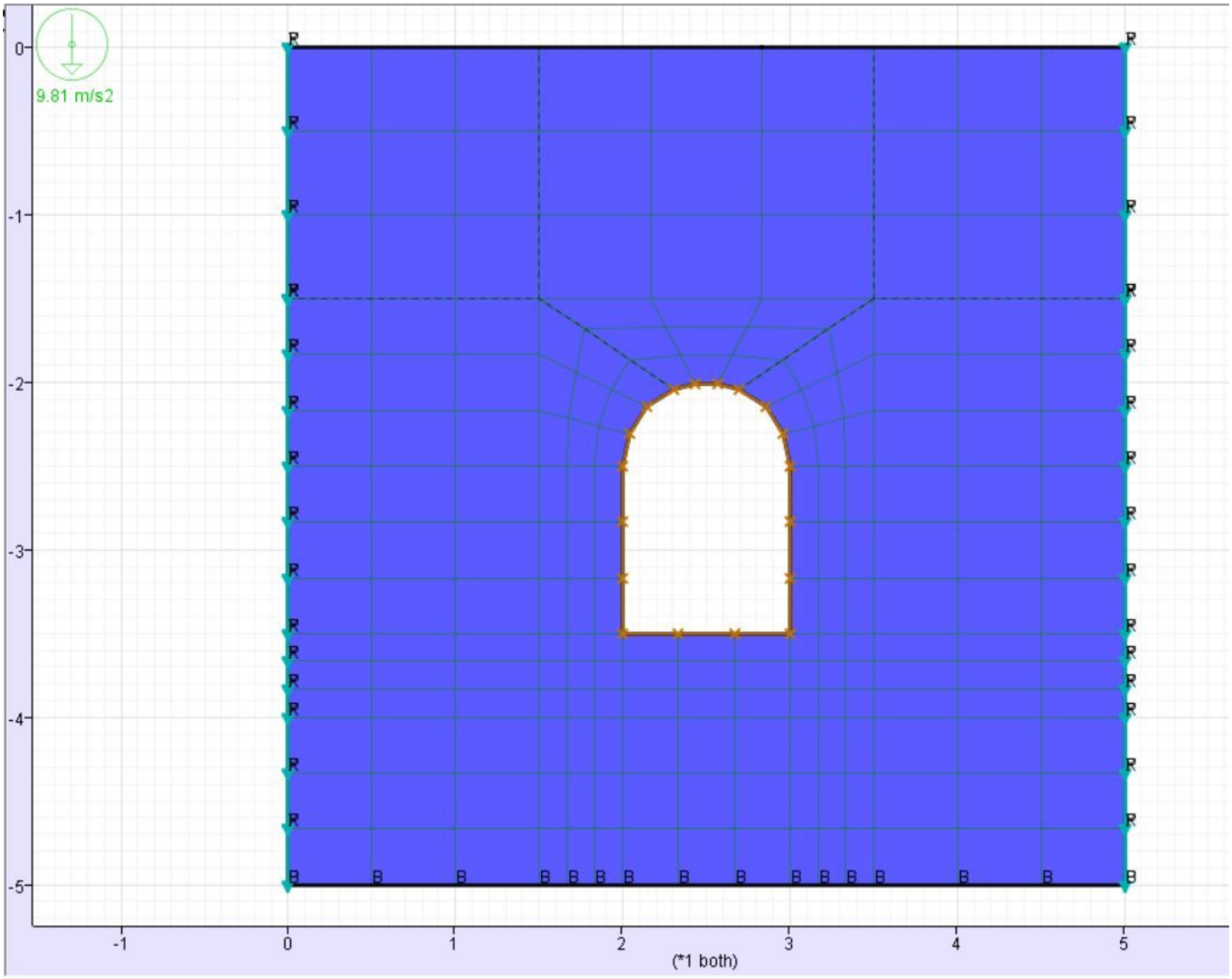

Figure 4

Model after excavating cavern.

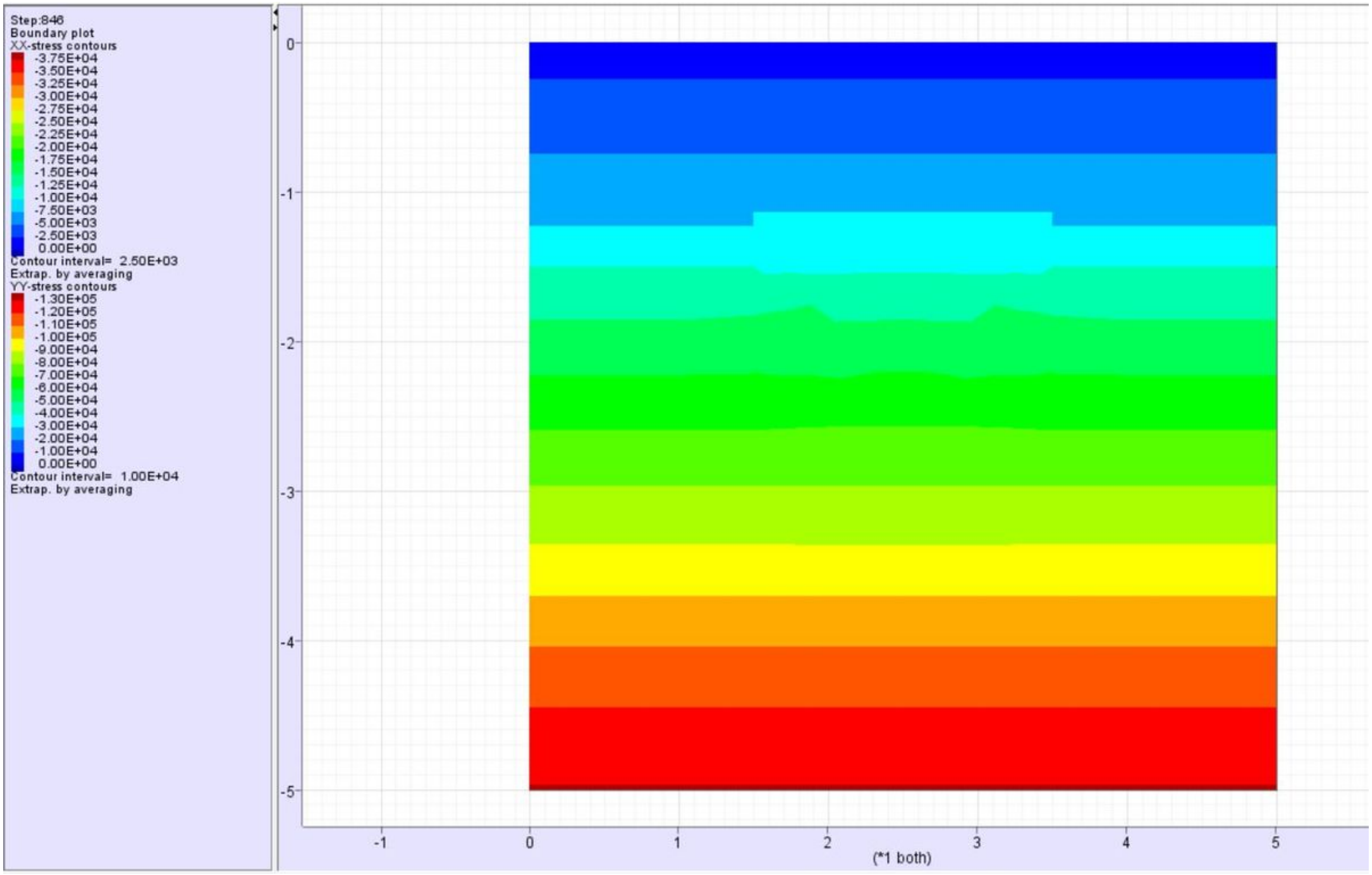

Figure 5

Shear stress for Model before excavating cavern

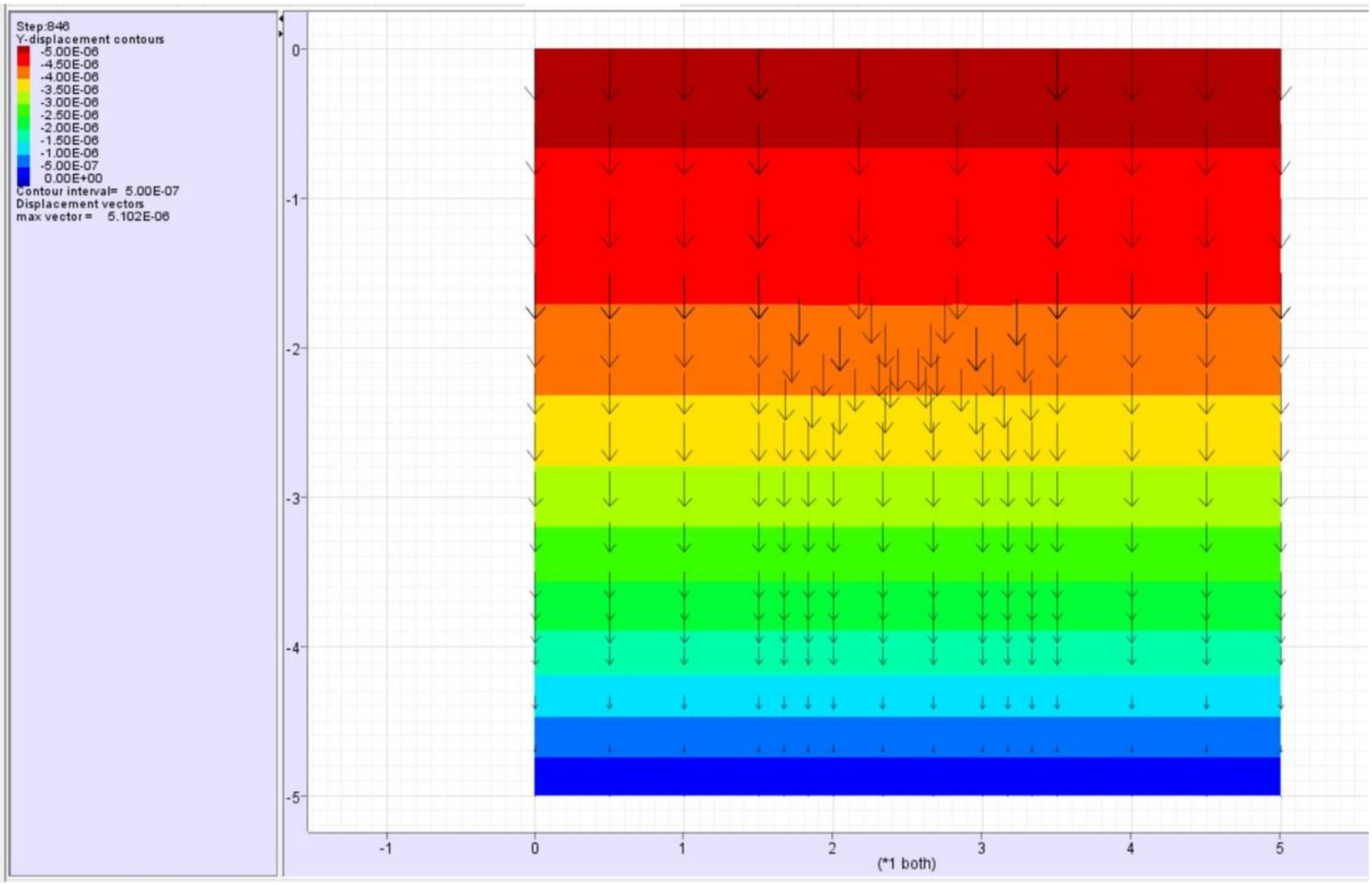

Figure 6

Y-displacement for Model before excavating cavern

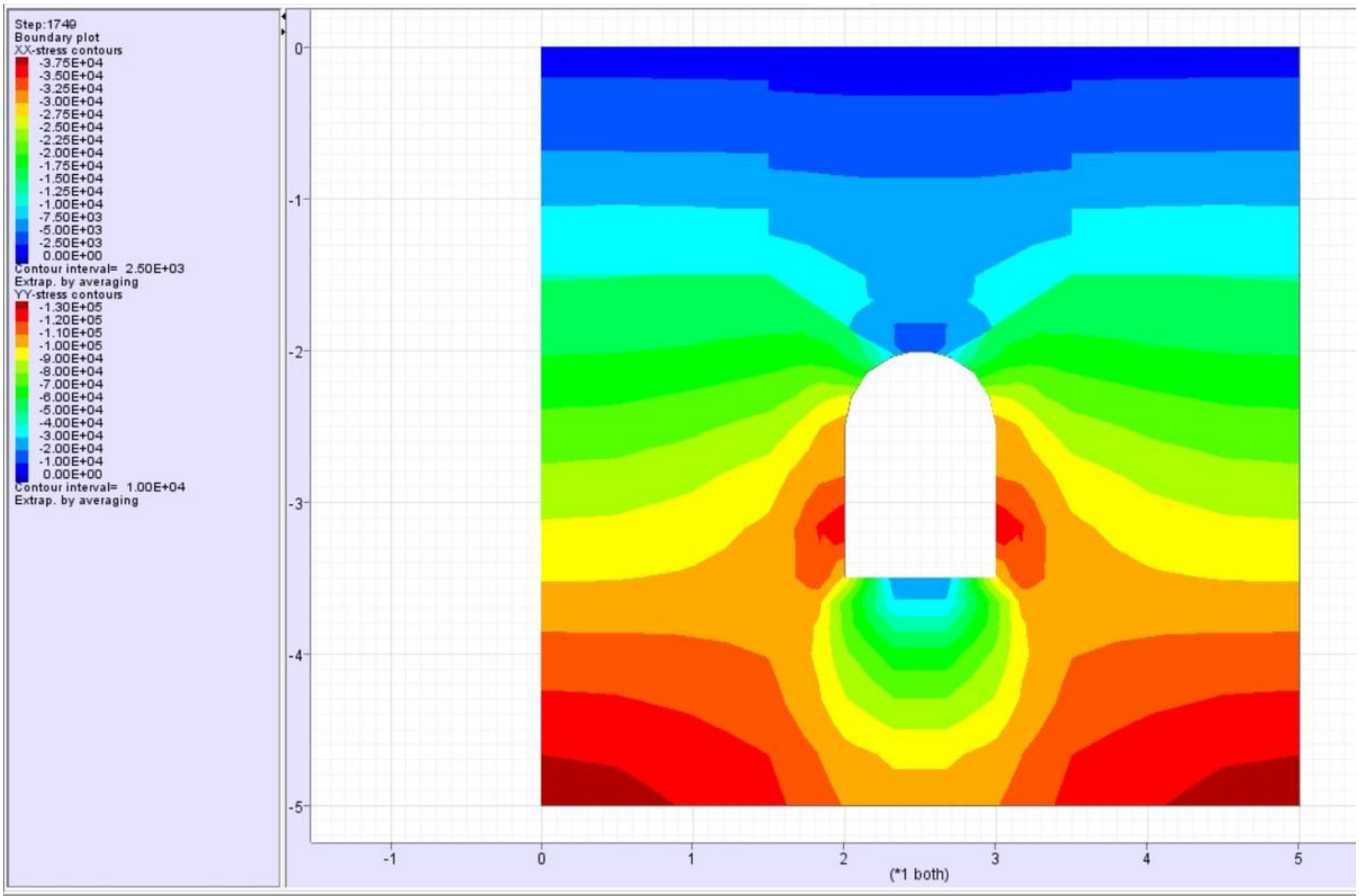

Figure 7

Shear stress for Model after excavating cavern

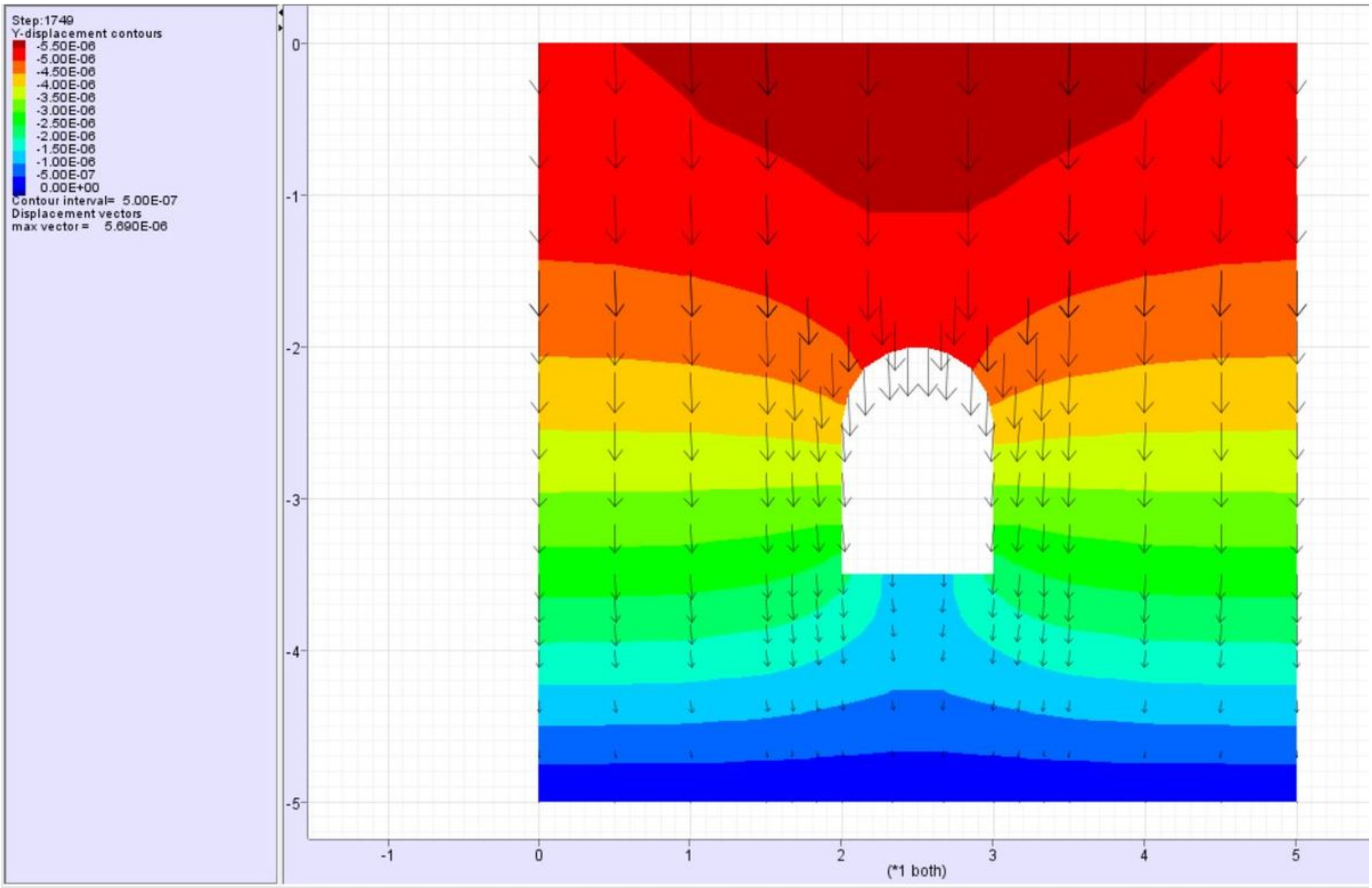

Figure 8

Y-displacement for Model after excavating cavern

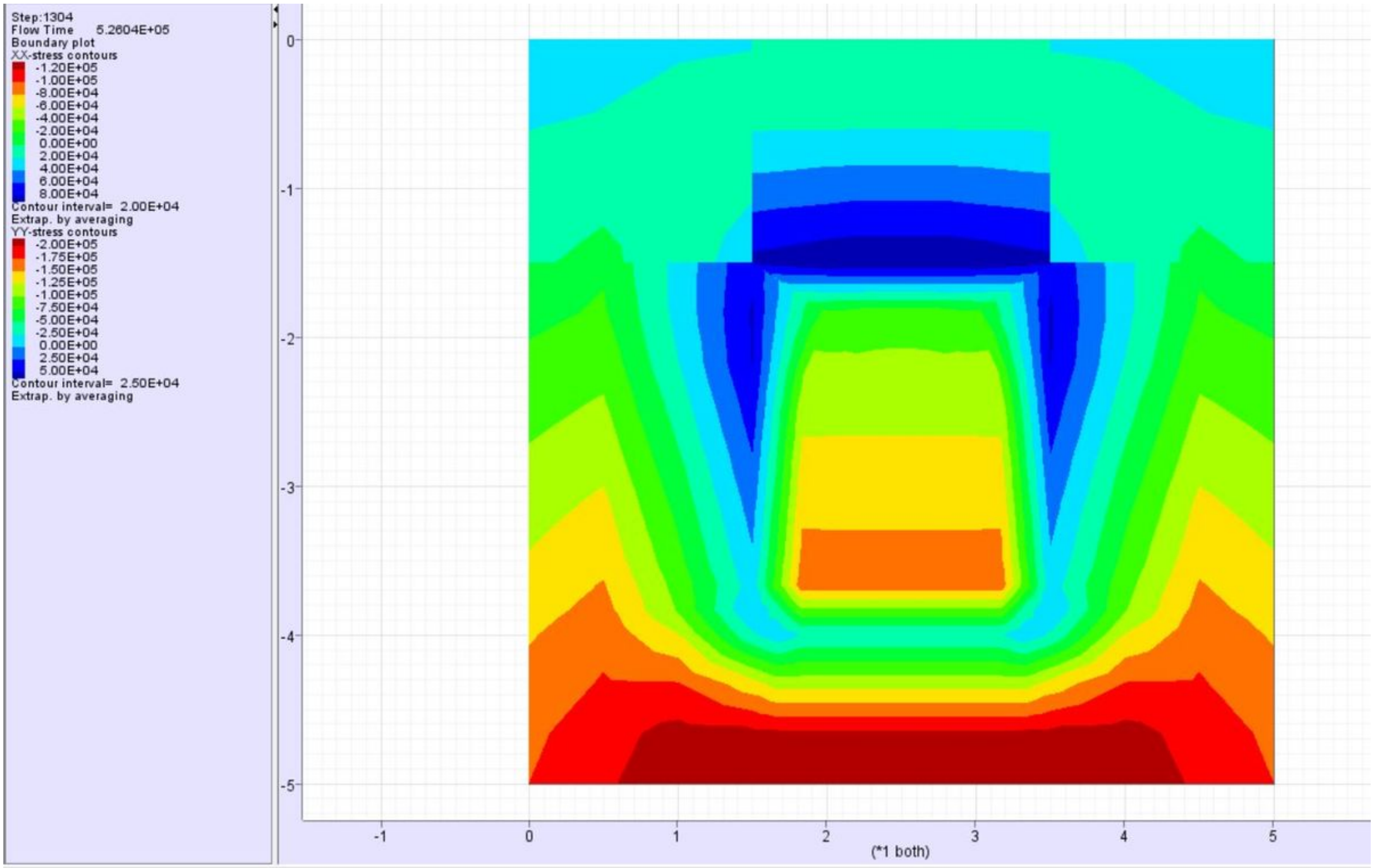

Figure 9

Shear stress for Model before excavating cavern

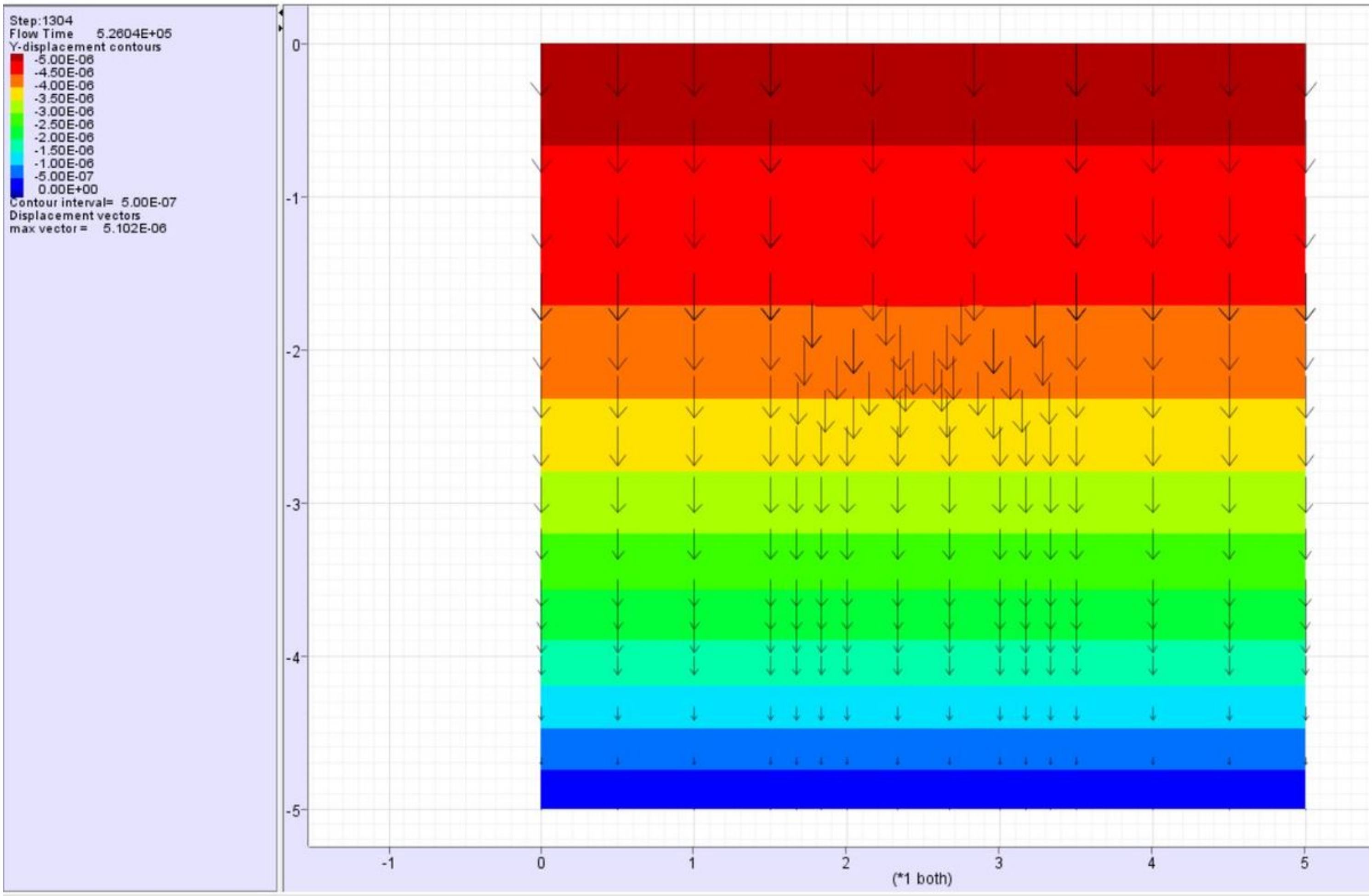

Figure 10

Y-displacement for Model before excavating cavern

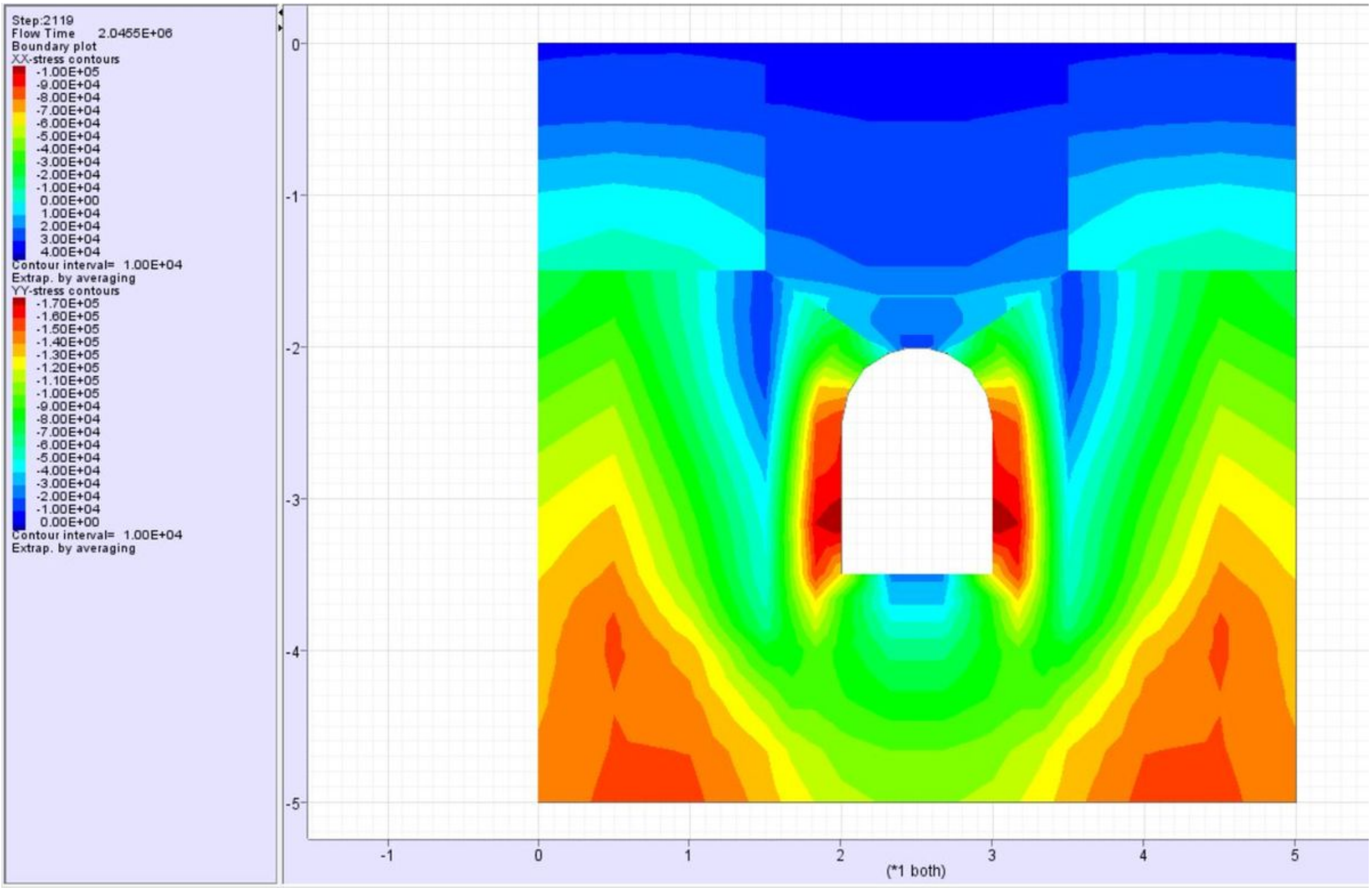

Figure 11

Shear stress for Model after excavating cavern

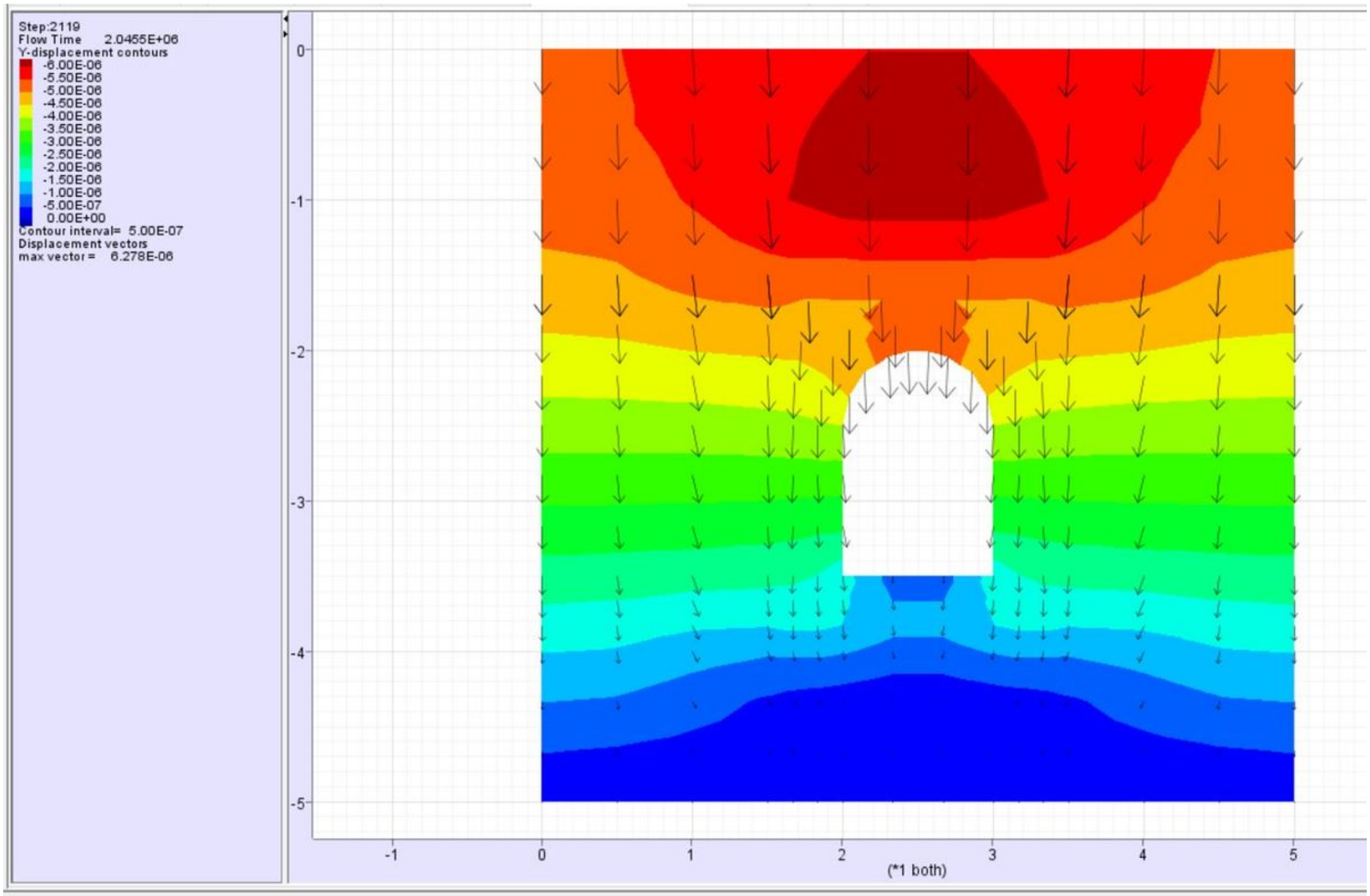

Figure 12

Y-displacement for Model after excavating cavern

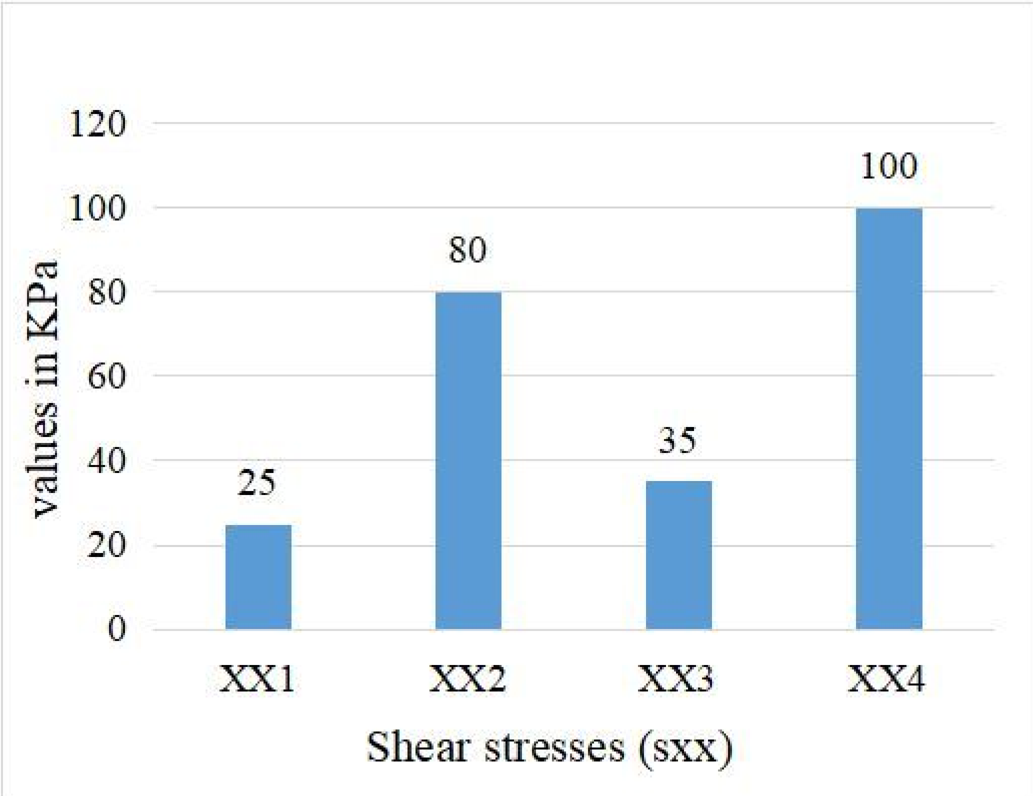

Figure 13

Comparison of Sxx stresses

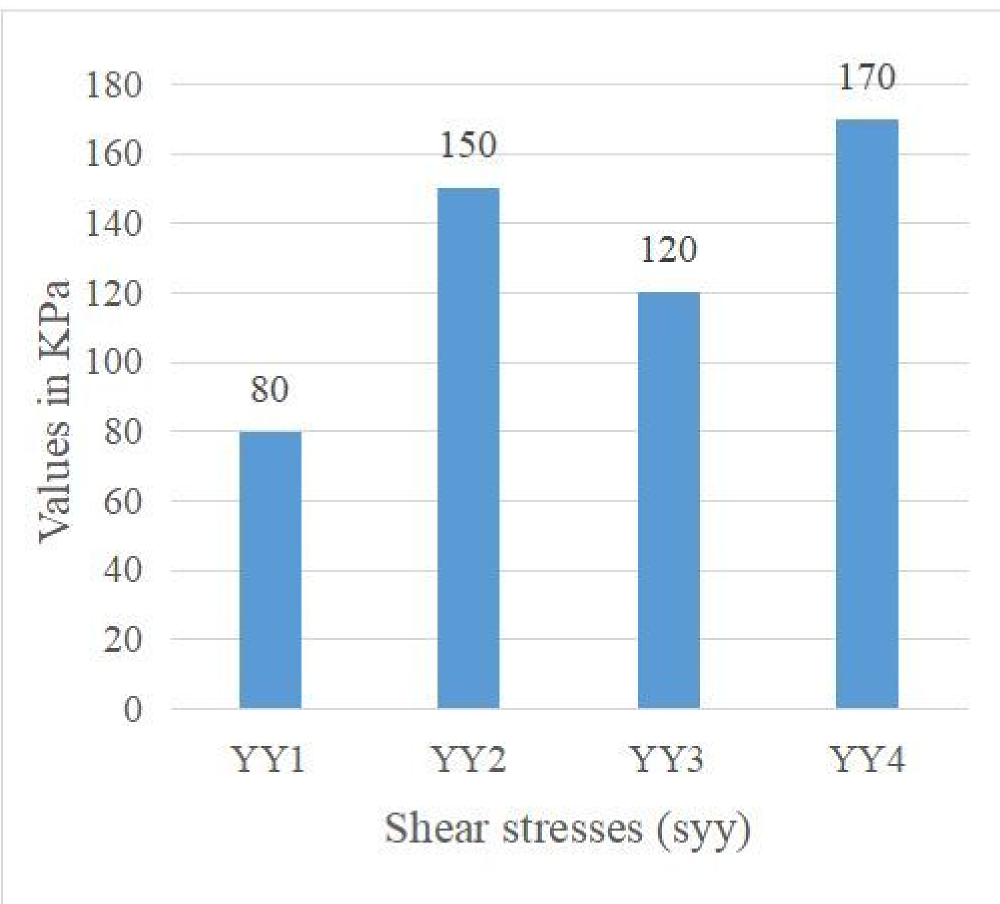

Figure 14

Comparison of Syy stresses

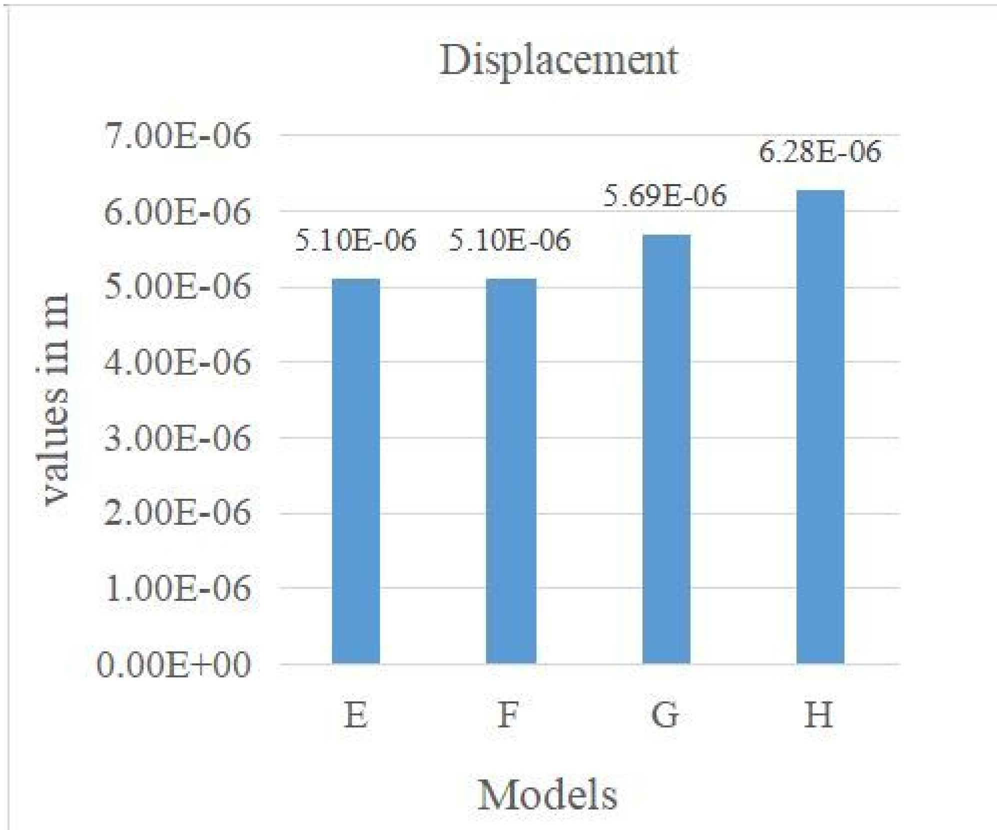

Figure 15

Comparison of displacement