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Full Length Research Paper

Investigation into the usage of Sanliurfa limestones in Turkey as underground storage cavern with regard to some engineering properties

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Sanliurfa limestone of Turkey is used as an underground deep freeze food storage cavern, because of its high **isolation characteristics. Therewithal, the Sanliurfa limestone includes high amount of clay minerals. Clay minerals makes limestone weak and the excavations become cheap but dangereous. In this study, for choosing the optimum excavation method in Sanliurfa limestone, the first part of the excavation was done with blasting and the second part of the excavation was done with excavator. Then, the results are compared with each other in terms of efficiency, security and costs. Finally, for determining the characteristics of limestone in terms of another rock types, the blasting results in granite and surface storage when compared with limestone. Sanliurfa limestone is a good isolator and it prevents approximately 20% heat losses. It is affected less by blasting, because of its natural properties. By machine excavation, the stresses around the cavern was maximum 0.06 MPa in the roof, minimum 0.01 MPa in the sidewalls and the safety factors of 4. By the blasting excavation, the stresses around the cavern rised to maximum of 0.1 MPa in the roof, minimum of 0.04 MPa in the sidewalls and the safety factors of 3. It is interpreted that no supporting around the cavern was needed. Also, the construction costs are too much, less than excavations by machine and surface stores (almost half). By the results of these investigations, it can be claimed that Sanliurfa limestone is a suitable formation for underground storages.**

Key words: Sanliurfa limestone, underground storage, heat transfer cost, excavation cost, blasting, finite element method (FEM).

INTRODUCTION

Caverns has gained considerable importance in recent years and its significance is thought to exponentially increase in the future. Especially, cavern tourism and need for fresher and healthier food would undoubtedly be more requiring the construction of new caverns. However, food storage tanks constructed at surface require very good isolation in order to decrease energy consumption imposing high capital investment whereas, energy needed for cooling of the tank is still very high especially at hot summers in Sanliurfa. Figure 1 shows a typical pattern of power consumption for a storage tank in Korea for a month (Park et al., 1999). It can be clearly seen from the Figure 1 that, although, the food storage tank was isolated by using commercial products, the power consumption difference between day-time and night-time is very high. This phenomenon suggests that, even if a surface food storage tank is isolated, the energy loss is still the most important concern during operation (Aydan et al., 1999).

Turkey lies between 26 and 32 north parallels where the seasonal changes are very sharp at south-east areas. Coastal line is usually warm during winter and hot in the summer. At Sanliurfa, the typical terrestrial climate is seen where the summers are hot and dry, and the winters are cold. To specify the severity of hot summer in Sanliurfa, a typical seasonal variation of average air temperature between years 2000 and 2010 is presented in Figure 2.

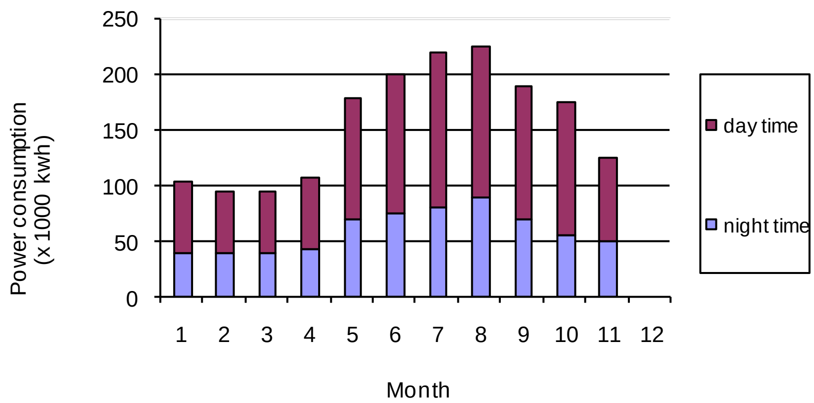

Figure 1. Typical pattern of power consumption for a storage tank in Korea (Park et al., 1999).

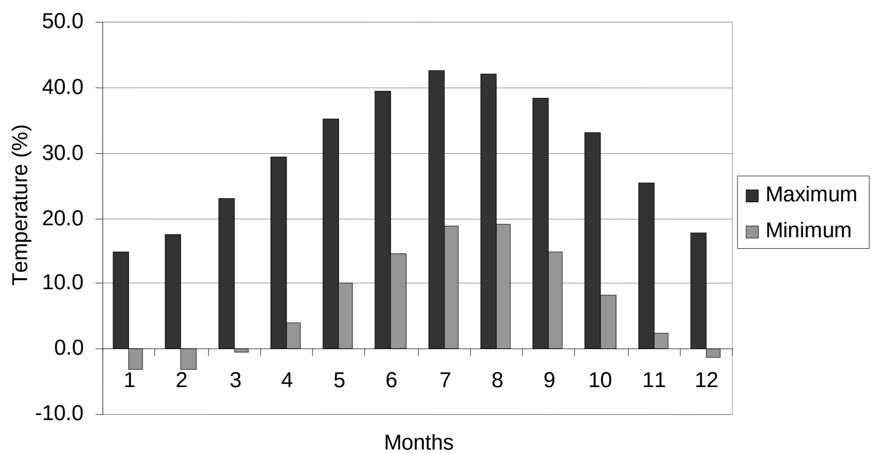

Figure 2. Seasonal variations of air temperature in Sanliurfa Region (SMI, 2010).

In Sanliurfa, 300 kg of tomatoes per day, could not withstand the hot weather thrown for decay (SMB, 2010). This data reveals the importance of food storages in hot places.

In order to decrease power consumption and effectively control the temperature inside a food storage area, on ground or underground, food storage space should be as isolated as possible. Obviously, food storage tanks constructed at the surface would only yield a certain degree of isolation whereas in underground condition, when the storage cavern is excavated in a rock mass having low thermal conductivity, the control of the environment would be achieved in a much efficient manner.

Food storage could be divided into two main categories namely chilled and frozen food storage. In the case of frozen food storage, the temperature difference between inside the cavern and surrounding environment is high leading to higher amount of heat transfer. Therefore, the energy consumption would be obviously more critical in the case of frozen food storage.

In this study, the pilot underground caverns opened in limestone by excavator and blasting, have been used for investigations; then, the effects of excavation methods on heat transfers, operational and excavation costs and stresses around caverns opened in limestone for food storage were determined. Then, these limestone caverns were compared with the underground cavern, which was supposed to be excavated in granite and with surface store. This study aimed to evaluate the underground cavern which was excavated in Sanliurfa limestone and which required less energy than the surface storage for climatization.

Brief information of Sanliurfa region and man-made caverns

Sanliurfa has been a land for settlement for various civilizations, since BC 10000 to 12000. The area extends

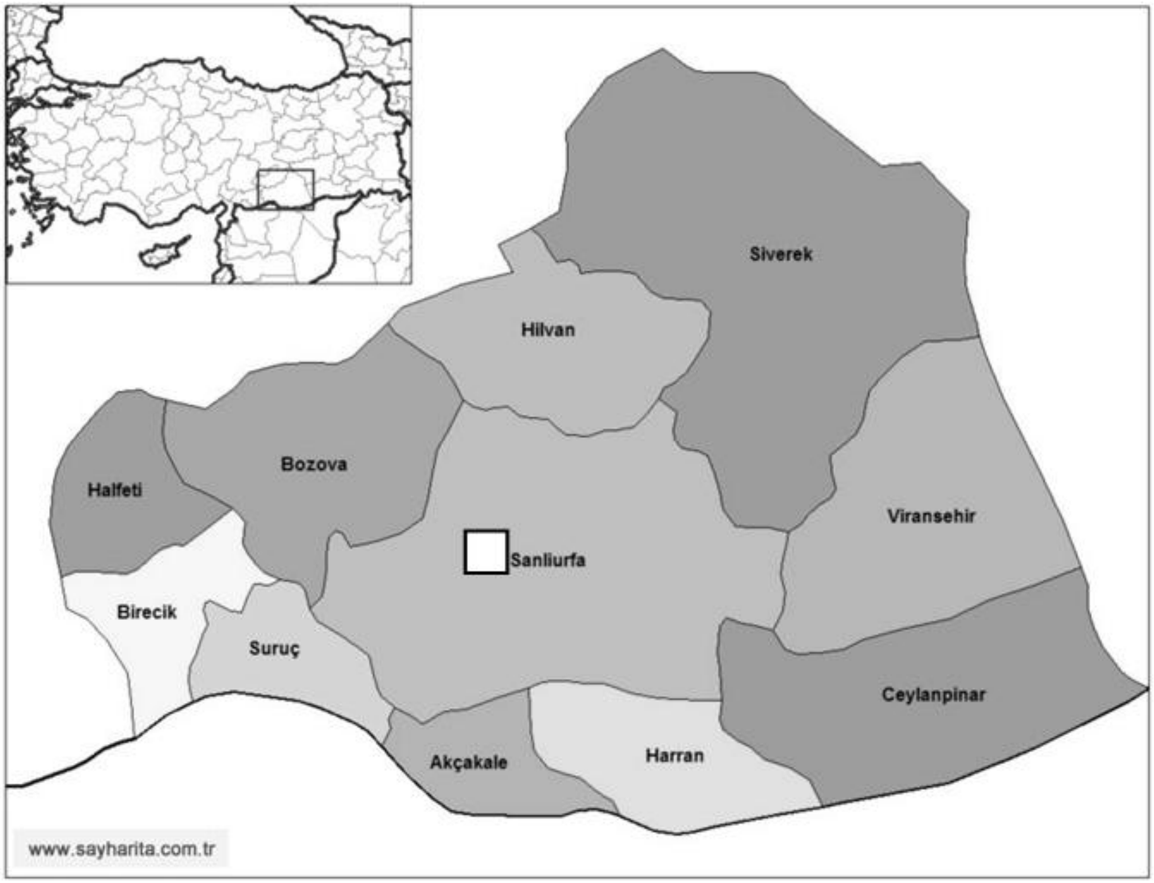

Figure 3. A location map of the Sanliurfa and cavern region.

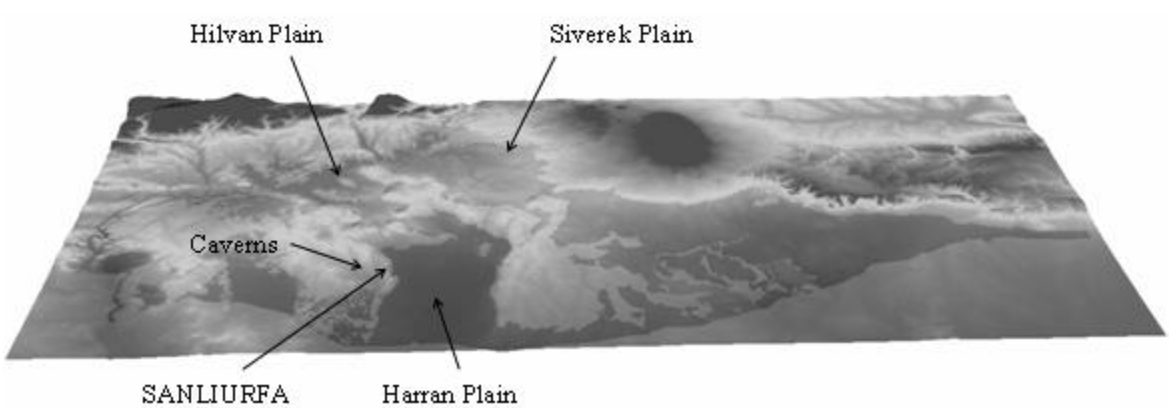

Figure 4. A satellite map of the Sanliurfa and cavern region.

extends over 18500 km^2 within the South-East Anatolia of Turkey as shown in Figure 3.

Sanliurfa is in the form of a plain (Figure 4) having an average altitude of 520 m above sea level and is covered by almost horizontally layered clay.

Quaternary clay is generally above the Miocene-Eocene argillaceous limestone having a thickness of several hundred metres and/or above the Plio Quaternary volcanic basalt having a thickness of several metre (Agan, 2010).

The cavern region was added to the list of "conservation areas" by the Ministry of Culture. Due to the regions history, culture and natural scenery, there is an ever growing deserved international tourist potential.

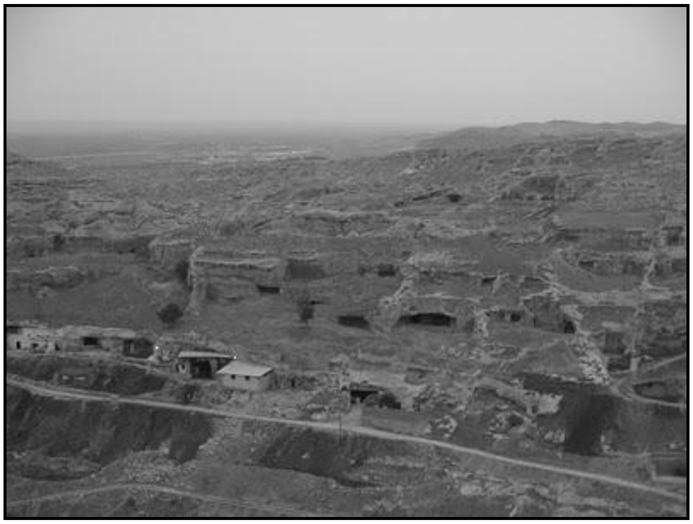

Figure 5. A view of the surface with ventilation pipes of underground storage rooms.

Figure 6. A view of the surface with entrance of caverns.

Figure 7. Pillars of a cavern which used for quarry

Figure 8. A view of the cavern restaurant.

When Prophet Abraham was born, he lived in one of these ancient caverns.

At all storage rooms, a ventilation opening located at the roof is opened. Figure 5 shows the surface where there are underground storage rooms beneath. Ventilation chimneys at the surface and entrance places to some of the underground rooms can be seen in the picture.

There are too many old caverns in Sanliurfa and it shows that the people discovered the high isolation properties of Sanliurfa limestone.

Massive structure and easy carving characteristics of limestone made possible excavate self-stable underground openings.

There are tens of these caverns and lie up to a depth 10 m below surface having sometimes 2 to 3 levels as shown in Figure 6.

The size of pillars and rooms vary 3 × 3 m widths and up to 20 m heights as shown in Figure 7 (Kulaksız and Agan, 2009).

There are more than 300 small underground storage rooms in and around of Sanliurfa. Most of the storage rooms have been in use for a long time. These caverns have been used as shelter house for hot summer. Also, there are a lot of caverns in Sanliurfa which are used as restaurant, cafe, etc., as shown in Figure 8.

INVESTIGATION METHODS

After the perceive of high isolation properties of limestone, the investigations on operational conditions, excavation costs, strata

Figure 9. Heat conductivity measurements in the wall of the cavern.

control and confident excavation methods began. At first, two pilot caverns are excavated. One of them was excavated by excavator and the other by blasting. Tractor excavator is used for machine excavations. For blasting excavations, Bar-ANFO-100 explosives were used.

For investigation the effects of excavator and blasting excavation, some *in-situ*, laboratory tests and computer analyses were applied. The computer analyses programs, need some inputs. For this, some laboratory tests and *in-situ* tests were done. At first, for determining the effects of excavator and blasting excavations to original rock, samples taken from a similar formation with blocks from the surface and from the roof with a 3 to 5 m level. Excavation blocks are also used for sampling from the caverns for laboratory tests.

The caverns were designed with a depth of 5 m from the surface. These results would be compared with the samples taken from the cavern roof after excavation. Heat conductivity coefficients are determined by, hot wire method as shown in Figure 9.

For investigation of strata control, stress distributions and durability conditions, phase 2 (Rocscience, 2011) computer analyses program have been used for blasting and machine excavation.

Then, the investigations were directed to heat transfer analyses. For the analyses, MARC 3-D (MSC, 2011) computer program was used. Characteristics of the heat flow were in a vertical direction around a room, when the heat flow rate become constant. At first, the cavern which had been excavated by excavator was investigated. Then, the analyses of cavern which had been excavated by blasting were undertaken.

To notice the importance of this heat loss increasing, the limestone caverns was compared with the cavern which was excavated in granite and a surface storage.

Finally, the excavation and construction costs analyses were undertaken, while the discussion with blasting engineers and Bar-ANFO-100 explosives were determined to be suitable for excavation (Ipek, 2010). Then, the comparison of minimum excavation and construction costs of caverns with a 750 m^3 volume, have been conducted.

Additionally, heat transfers, excavation costs and security conditions are investigated and compared with cavern in granite and surface store.

RESULTS

For investigation of the effects of excavator excavation, some in-situ, laboratory tests and computer analyses were applied. All the results of the investigation methods explained earlier, are presented as follows.

Laboratory and *in-situ* tests

The samples of natural rock, machine excavated rock and blasting excavated rock were sent to the laboratory. By the results of the laboratory and *in-situ* tests, it can be seen that blastinghave been affecting the surrounding rock more than machine excavation. Laboratory test results are shown in Table 1.

Strata control, stresses, deformations and security

At the end of the first pilot cavern excavation, no abnormal cases have been observed. By the computer analyses program that have been used (Phases 2 software), the stresses around the cavern have been shown in Figure 10. The stress around the cavern is maximum 0.04 MPa, and it is applied to the roof of the cavern. The minimum stresses are 0.01 MPa and they are applied to the sidewalls of the cavern. No tension stresses are determined. This is also an advantage, because tension strength of rocks are less than compressibility.

By the results of computer analyses, it can be seen that, in Figure 11, excavator excavation does not cause deformation at surrounding limestone rock much. No dangerous stress had occured, because the safety factors are too high around the cavern. The safety factor of cavern is greater than 4 at all sides of the cavern. This means, this cavern needs no support.

To notice the effects of blasting deformations, the computer analyses were conducted again (Figure 12). As seen in the Figure 12, the maximum stresses are 0.1 MPa, and they are applied to the roof and floor of the cavern. Tension stresses are about 0.04 MPa and they are applied to the sidewalls.

For determining the importance of these stresses, safety factor analyses of cavern had been undertaken again. By the results, it can be seen that, the safety factor is greater than 3 and these deformations does not cause dangerous conditions with blasting.

Table 1. Average strength and index values of limestone.

	Turgut et al. (2008)	This study		
		Original rock	After excavation	After blasting
Young module (GPa)	10-16	18	17	16
Poisson ratio (v)	0,27-0,33	0,24	0,21	0,20
UCS (MPa)	16-20	15	14	12
Thermal conductivity (W/m.K)	1,33-1,54	0,91	0,85	0,78
Unit weight (kN/m^3)	19,7-21,5	20,6	20,4	20,3
Internal friction angle (°)	-	35	29	23
Cohesion (MPa)	-	2,3	1,5	0,9

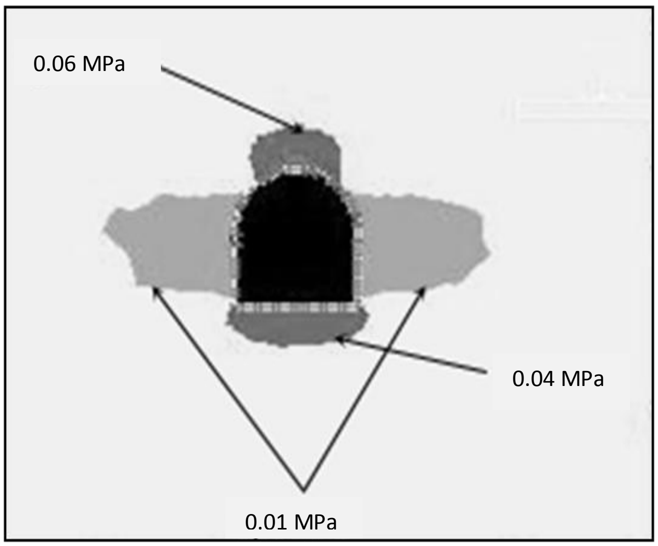

Figure 10. Stresses around the cavern, which is excavated by excavator.

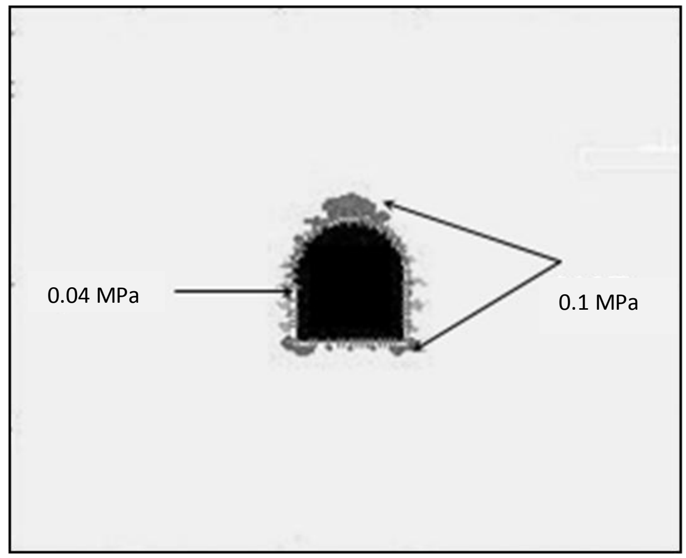

Figure 12. Stresses around the cavern, which is excavated by blasting.

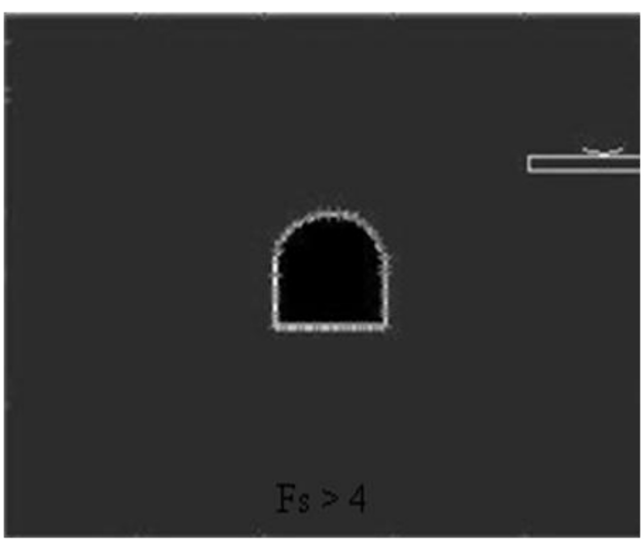

Figure 11. Safety factor of the cavern, which is excavated by mechine.

Heat transfers

By the examination of risk analyses, the investigations has been directed to heat transfer analyses. For the analyses, MARC 3-D computer program was used (Unver and Agan, 2003). Characteristics of the heat flow were in vertical direction around a room, when the heat flow rate become constant, as can be seen in Figure 13.

At first, the excavated cavern was analyzed, then the blasted cavern was analyzed. By the comparison of results, it can seen that blasting causes much heat losses.

To notice the importance of this heat loss increasing, the limestone caverns was compared with the cavern which is excavated in granite and a surface storage. Heat transfer analysis results of each cavern are presented in Table 2.

By the results, it can be seen that heat loss increases by blasting but they are not critical. Limestone are affected much from the blasting, because of its

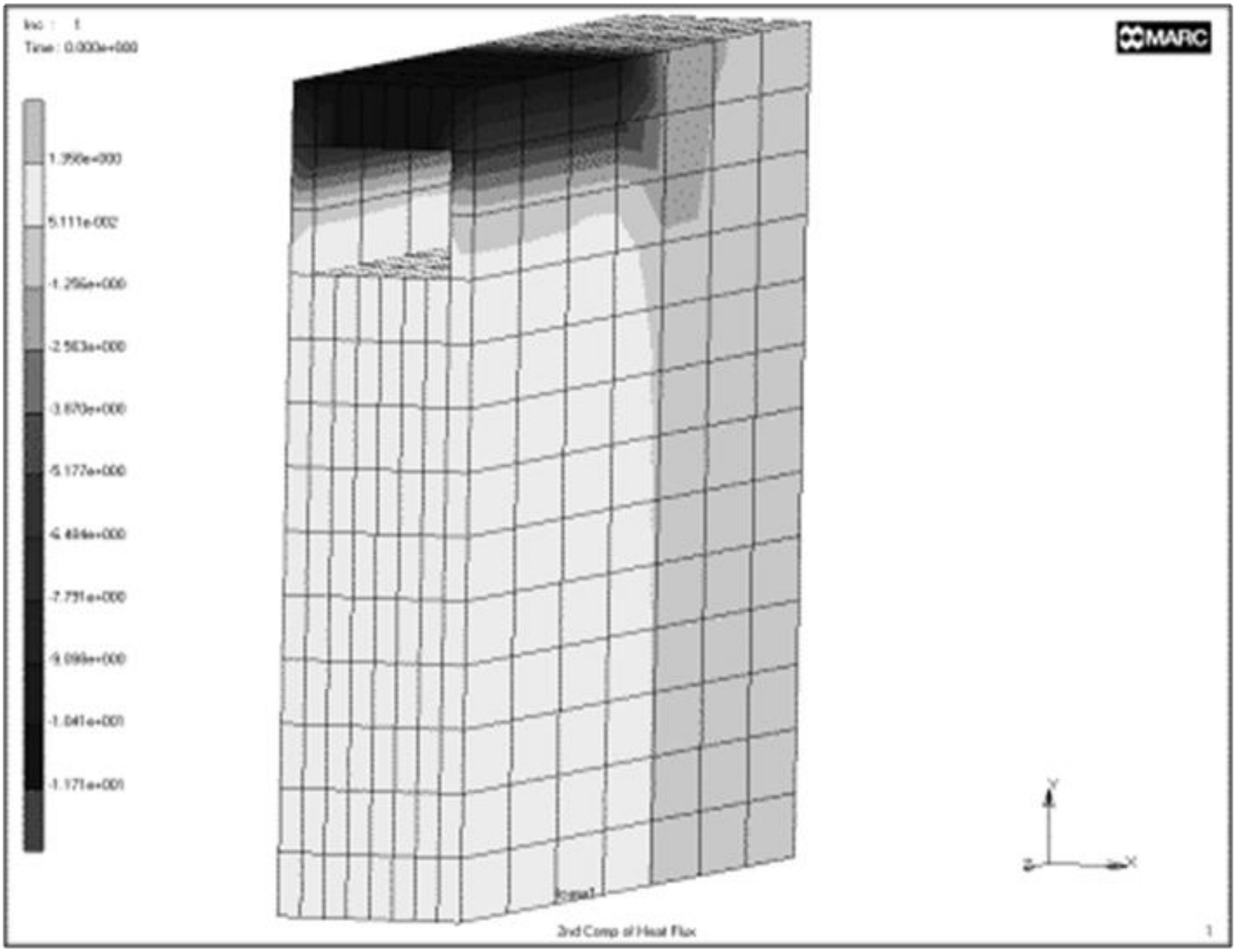

Figure 13. Heat transfers around the underground caverns.

Table 2. Heat transfers around the caverns.

	Side walls (W/m^2)	Roof (W/m^2)	Floor (W/m^2)	Front wall (W/m^2)	Back wall (W/m^2)	Total (W/m^2)
Limestone (excavator)	2.467	2.874	579	585	372	6.877
Limestone (blasting)	2.533	2.928	612	598	399	7.070
Granite	5.708	5.875	1.373	776	514	14.246
Surface	3.769	2.088	1.246	656	569	8.328

brittleness and porous structure.

Costs

Finally, excavation and construction costs analyses were conducted. While the discussions with blasting engineers, Bar-ANFO-100 explosives determined as suitable for excavation. The explosive quantities and prices are presented in Table 3.

Then, the comparison of minimum excavation and construction costs of caverns with a 750 m^3 volume, have been conducted as shown in Table 4.

It is seen that, to construct a storage cavern in limestone, the cavern is cheaper than surface storage and underground storage which is excavated in granite.

Table 3. Quantities and prices of explosives.

	Limestone	Granite	Unit prices**
Bar-ANFO-100 specific charge (kg/m^3)	0.4-0.45	0.54-0.55	0.65 Euro/kg
Dynamite specific charge (kg/m^3)	0.01	0.01	1.8 Euro/kg
Capsule (piece/m^3)	0.01	0.01	0.45 Euro/piece

Table 4. Total excavation and construction prices.

	Limestone	Granite	Surface
Excavation with excavator** (Euro/m^3)	9.3	15.4	-
Excavation with blasting** (Euro/m^3)	4	7	-
Construction** (Euro/m^3)	-	-	21

**Prices of year 2010.

To excavate the cavern by blasting is cheaper than machine excavation.

DISCUSSION

From the dawn of civilization, human beings have exploited the underground space provided by natural or excavated caves for the purpose of habitation and as storage space for different agricultural products.

Choi et al. (2000) reported the details of the first real test of food storage in the underground food storage cavern in Korea. Pear and apple were selected, and the change of indices, such as the rate of soundness, moisture content, total acid and hardness were monitored with the temperature and humidity in and around cavern. The results showed that the fruits were stored in better quality, in the case of underground storage with cooling than natural underground condition or surface storage tank.

Pardo and Guerrero (2006) were concerned with the formal and functional features of vernacular subterranean architecture. By a research carried out in one of the most traditional winemaking regions of Spain-Ribera de Duero, the characteristics, excavation techniques and typological classification of the caves were discussed. They highlighted the use of very favourable conditions inside the caves for the ageing of high quality wines.

Unver and Agan (2003) investigated the usage of Cappadocian tuff of Turkey and their potential usage for frozen storage. Construction of an underground deep freeze storage cavern excavated in tuff would cost one half of a same size surface tank, whereas energy loss due to heat transfer is three times lower in the favour of underground storage cavern opened in tuff. The isolation activity of Sanliurfa limestone is almost half of Cappadocian tuff. However, it should be noted that the summer is much more hot in Sanliurfa ascompared to Cappadocian region.

On the other hand, Sanliurfa limestone is more durable than the Cappadocian tuff. As stated in Aydan and Ulusay (2003), the UCS of Cappadocian tuff varies between 1 to 10 Mpa, whereas, Turgut et al. (2008) determined that the UCS of Sanliurfa limestone varies between 15 to 18 MPa. These two successfully isolator rock were compared in same conditions in the former researches.

Conclusion

With less heat conductivity and porous properties of Sanliurfa limestone, this region supplies suitable conditions for deep freeze food storages.

Sanliurfa limestone is a good isolator and it prevents heat losses much than granite rock formations and surface conditions. So, the operation costs will be less than the surface storage especially in hot summer.

Totally, 6877 W/m^2 heat losses occured in limestone cavern, but 8327 W/m^2 heat losses occured in surface storage. Thus, approximately 20% energy savings can be achieved.

As a result of it natural properties, it is less affected by blasting than granite rock. By the controlled blasting pattern, no risk occurs in the environment, because it has absorbed the vibrations.

The stresses around the cavern was maximum 0.06 MPa in the roof, and minimum 0.01 MPa in the sidewalls. No tension stresses were determined. Machine excavation could be suggested for excavation, because the safety factors of 4 interpreted as too high, and cavern needs no supporting around the cavern. By the blasting excavation, the stresses around the cavern rised to maximum 0.1 MPa in the roof, and minimum 0.04 MPa in the sidewalls. The safety factors of 3 was interpreted as still high, and cavern needs no supporting around the cavern after blasting. The rock mechanical parameters at least was avoided by machine excavation. However, blasting reduces the parameters by almost half.

Also, the construction costs are too much less than excavations by machine and surface stores (almost half).

By the results of these investigations, it can be claimed that, Sanliurfa limestone is a suitable formation for underground storages. It can be suggest that, after the economic operating costs and safety results of blasting excavations, Sanliurfa limestone becomes more feasible for these storage purposes. NRE (2010) reported that, there are over of 300 natural caverns in Sanliurfa. Given the large number of these caverns, Sanliurfa underground storage potential is better understood.

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