Bitlis Eren Univ J Sci & Technol
6 (2), 59-65, 2016

E - ISSN 2146-7706

Research Article

Performance Evaluation of a Historical Tomb and Seismicity of the Region

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Abstract

Hüseyin Timur Tomb was analytically investigated on engineering perspective. Hüseyin Timur Tomb is one of the important monument of Turkish architecture. It is also located within the Unesco cultural heritage. The most stressed elements are the bottom walls at the ground level with a maximum value of compressive stress of about 6.1 MPa. Also, displacement resultant distribution suggests that the maximum displacement of around 13 mm will occur at top of dome. The goal of this study is to take attention for special historical tomb in Ahlat that is open air museum. Evaluation of these structures was important for cultural heritage and transferring them to future. It is very important to protect them by taking measures from structural aspect. The paper also included seismicity of the region and properties of Ahlat stone. Due to results it can be said that tomb has a high vulnerability.

Keywords: Tomb, Cultural Heritage, Seismicity, Seismic Behavior, Hüseyin Timur

1. Introduction

Cultural Heritage is an expression of the ways of living developed by a community and passed on from generation to generation, including customs, practices, places, objects, artistic expressions and values (ICOMOS, 2002). Cultural Heritage can be distinguished in:

- Built Environment (Buildings, Townscapes, Archaeological remains)
- Natural Environment (Rural landscapes, Coasts and shorelines, Agricultural heritage)
- Artefacts (Books and Documents, Objects, Pictures) (Feather, 2006).

As a first step to protect the historical buildings should definitely be to understand the structural behavior of these buildings. The conservation and restoration of historical structures are great challenges for the engineering community in terms of robust analytical models. Modelling and analyzing the historical structures require not only the knowledge of geometrical and material properties of the structure but also the skills to use the best elements to model different parts of the structures and how to connect the different structural elements in order to get the correct results (Ertek, 2007).

In this study, Hüseyin Timur Tomb in Ahlat in Lake Van Basin and seismicity of the region will be investigated.
Lake Van Basin with its traditional historical fabric bears the traces of many civilizations such as The Ottoman, The Seljukian and The Urartian. In order to convey our historical heritage to the posterity, the involvements to be applied historical structures, to know the properties of mortars and plasters used for holding construction materials together forms the first step of the involvements to protect the historical structures.

Ahlat is a historical town and a district in Turkey's Bitlis Province in Eastern Anatolia Region. Ahlat and its surroundings are known for the large number of historic tombstones left by the Ahlatshah dynasty. The center town of Ahlat is situated on the northwestern coast of the Lake Van. Lake Van is the largest lake (3600 km^2) in Turkey and the fourth largest one in the World (Fig. 1).

The medieval Muslim cemetery of Ahlat is located nearby the town of Ahlat, Bitlis Province Turkey, and is known for its many Islamic tombs (kümbets) and tombstones dating to the 13th-16th centuries when the area was under control of various Muslim states. There are hundreds of richly carved tombstones and several tombs. During the middle ages, Ahlat was the largest city in the Van region and one of the largest cities of Minor under Turkish control. In the 12th century it was the capital of the Ahlatshahs. One of the historic legacies of the medieval period is the extensive remains of the cemetery. The town eventually declined and depopulated in the 16th century. Today the cemetery is tentatively listed in the list of World Heritage Sites in Turkey (Wikipedia, 2016).

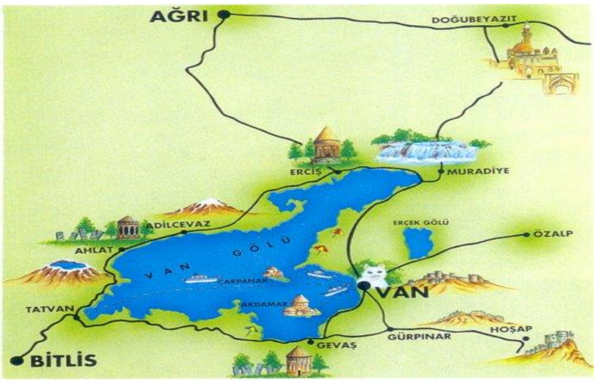

Figure 1. Lake Van Basin

Received June 15, 2016
Available online December 2016

There are numerous historical structures in the region built by many civilization that lived in the region. The structural properties of these historical structures are directly related with by standing throughout the centuries. The tomb is one of these historical structures that in case named as cupola is the special name for the monumental structures in Turkish architecture. Hüseyin Timur Tomb is one of the examples of tomb type grace style. Seismic evaluation of Hüseyin Timur Tomb was evaluated analytically in this paper. Geometrical properties of the cupola were measured and structural analysis was made. The goal of this study is to take attention for special historical tomb in Ahlat that is an open air museum. Evaluation of these structures was important for cultural heritage and transferring them to future. This manuscript provides information about historical city, Ahlat and seismicity of the region and seismic behavior of Hüseyin Timur Tomb. Protecting our historical structures in the name of cultural heritage respect needs the structural evaluation, protection, restoration and structural rehabilitation.

2. Properties of Ahlat Stone

In order to transfer cultural heritage to the next generations, we need to know structural properties of these structures. Historical structures are made of local brick and/or natural stone masonry. Hüseyin Timur Tomb was made of local stone that called Ahlat Stone. Ahlat Stone is a natural stone in the region (Fig. 2). Natural stones are extensively being used as construction materials. Natural stones qualified as geological heritage are various and are also plenty in Turkey, based on its complex geological framework. Some unique stones have been used in Anatolia since antic times, particularly for large and prestigious buildings. Most of the natural stones are typical geoheritages of the country. However there is no documented data at international level, yet. In addition, economic and scientific terminologies on the Turkish natural stones are completely different and people do not have correct geological knowledge about them. The rocks that known in regionally name as Ahlat Stone have been occurred from the spreading with cooling in kilometers in the region of lava zone by the explosion of volcanic Nemrut Crater. Ahlat Stones are geoheritages qualified natural stones that have been included micro and macro sized pores that independently each other and has high thermal and sound insulation and also durable to the effects of earthquake and fire. Ahlat Stone can be called as natural brick. These stones have various colors like brown, dark brown, ash. However dark brown colored stones are widely used at the buildings in the region. Soft Ahlat stone can be shaped by hand or by machine. Ahlat Stone has been used in the construction of residential, mosques, cupolas, tombstone, tombs and belts especially in Seljuk architecture in the past. The current use of the areas of Ahlat Stones has been limited due to its compressive strength is low from more amount of gaps, therefore Ahlat Stones have been used such as in the construction of masonry structures like mainly stone wall, tombstone, arches, mosque and tombs. They can be used also as cover materials in structures (Şimşek, 2010; Bakış et al., 2014).

Figure 2. Ahlat Stone

3. Seismicity of Ahlat

The center town of Ahlat is situated on the northwestern coast of the Lake Van. Lake Van Basin is located in very intensely deformed eastern Anatolia, which is the product of young continent–continent collision zone of Arabian and Eurasian plates.

The general tectonic setting of Eastern Anatolia is controlled mainly by the collision of the Northerly-moving Arabian plate with the Anatolian plate along a deformation zone known as the Bitlis Thrust Zone (Fig. 3). The collision drives the westward extrusion of the Anatolian plate along two well knows transform faults with known as the Bitlis Thrust Zone (Fig. 3). The collision drives the westward extrusion of the Anatolian plate along two well know transform faults with different slip directions, the right-lateral North Anatolian (NAFZ) and the left-lateral East Anatolian Fault (EAFZ) zones, which join each other in Karlıova Triple Junction (KTJ) in eastern Anatolia (Fig. 3). To the east of KTJ, however, the compressional deformation is largely accommodated within the Eastern Anatolian Block through distributed NW-SE trending right-lateral faults and NE–SW trending left lateral faults representing escape tectonics, and shortening of the continental lithosphere along the Caucasus thrust zone. East–west trending Mush-Lake Van and Pasinler ramp basins constitute other conspicuous tectonic properties within the eastern Anatolia (Şengör et al., 1985; Barka and Kadinsky-Cade, 1998; McClusky et al., 2000; Reilinger et al., 2006; Utkucu, 2013).

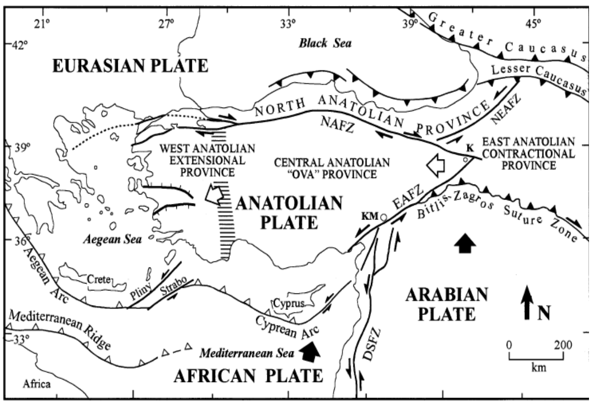

Figure 3. Tectonic map of Turkey including major structural features (Bozkurt, 2001)

The Lake Van basin has been seismically active region as indicated by historical sources. Table 1 tabulates the significant earthquakes occurred in Ahlat and surrounding area before 20th century.

Table 1. The significant earthquakes in and around Ahlat before 20th century

No	Date	Latitude	Longitude	Region	I
1	1012	39.10	42.50	Malazgirt	VII
2	1097	38.50	43.40	Van - Bitlis	VII
3	1101	38.50	43.50	Ahlat - Van	VI
4	1110	38.50	43.50	Ahlat - Van	VIII
5	1111	38.50	42.70	Ahlat - Van	IX
6	1245	38.74	42.50	Ahlat - Bitlis- Van - Muş	VIII
7	1246	38.90	42.90	Ahlat - Van	VIII
8	1275	38.40	42.10	Ahlat - Van	VII
9	1276	38.90	42.50	Bitlis - Ahlat - Erciş – Van	VIII
10	1282	38.90	42.90	Ahlat – Erçiş	VII
11	1439	38.50	42.10	Nemrut	VI
12	1441	38.35	42.10	Nemrut	VIII
13	1444	38.50	43.40	Nemrut - Van	VI
14	1582	38.35	42.10	Bitlis and Surrounds	VIII
15	1647	39.15	44.00	Van - Muş -Bitlis	IX
16	1648	38.30	43.70	Van and Surrounds	VIII
17	1705	38.40	42.10	Bitlis	IX-X
18	1871	38.50	43.40	Van - Nemrut	VII
19	1881	38.50	43.40	Van - Nemrut	IX

Based on historical and instrumented earthquakes, Ahlat is constantly under the influence of both micro and macro earthquakes. Thus, it will not be difficult to say that Ahlat will remain under the influence of larger earthquakes. Ahlat Centre City is in first degree of seismic zones in the current seismic hazard map of Turkey with a minimum effective peak horizontal ground acceleration of 0.40 g (Fig. 4).

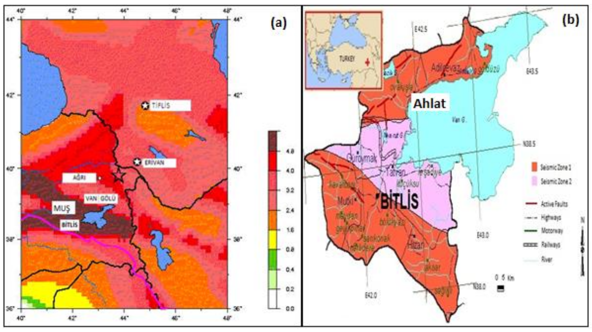

Figure 4. Seismic hazard map of Bitlis - Ahlat region where the red areas indicate the first degree zone (USGS – TEC, 07)

4. Description of the Structure

Historical city buildings are an integral part of the building heritage to be preserved, and their safety is a primary requirement in seismic areas (Ramos et al., 2004). Historical buildings have demonstrated during the past to be particularly susceptible to damage, and prone to partial or total collapse, under earthquake loads, sometimes due to non-respectful restoration. As a matter of fact repairing and retrofitting techniques should always respect the original existence; any intervention not respectful of it could also create incompatibility with the original structural behavior (Betti et al. 2008; Betti et al. 2011).

Ahlat established near the shore of the Van Lake has a very ancient historical background. In Ahlat there are many ancient remains mostly from 13th Century. Hüseyin Timur Tomb is the westernmost tomb in the section of the Ahlat Cemetery known as the "Two-Domed Neighborhood". The inscriptions at the entrance of the tomb indicate that Emir Hüseyin Timur Bugatay Aka died in 1279, and those over the western window of the tomb show that Esentekin Hatun, the daughter of Hüsamettin Hüseyin Aka, died in 1280 (Fig. 5). On the eastern edge of the most ancient of Ahlat's rural settlements, north of the track leading into the Old Town, two more tombs stand close together by the roadside. One, 14 m/46 ft high, originally built in 1279 for Hasan Takin, was used for a second time in 1729 by Hasan Timor. The other, 12 m/39 ft high, was constructed in 1281 for the Emir Bugatay Aga, whose wife Sirin Hatun was also interred there (UNESCO, 2011). Hüseyin Timur tomb has a square base above which is a polygonal drum supporting a cylindrical body, covered by a conical roof with an interior tomb.

Figure 5. General view of Twin Tombs

Hüseyin Timur Tomb has a a square base. The dimension of base is 6.72 m×6.72 m. Tomb was transformed into octagonal form and closed thus in pyramidal shape. Cylindrically webbed tomb jumped from square base to dodecagon form, and then was transformed into cylindrical form ending up with a tent type ceiling. Cylindrical tomb was constructed with two storeys. Grave was placed in basement; the upper story was arranged for praying. The cupola was built as a part of a complex including a small mosque and zawiya. Authors focused on Hüseyin Timur Tomb in Ahlat with a special interest, after area visit (Fig. 6).

Figure 6. Hüseyin Timur Tomb

The plan of Hüseyin Timur Tomb was given in Figure 7.

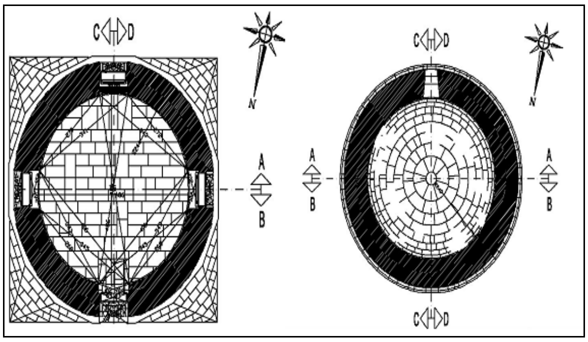
Figure 7. Plan of the Hüseyin Timur Tomb

5. Seismic Behavior of Hüseyin Timur Tomb

Damage assessment for historical masonry buildings is often a complex task. It is crucial to distinguish between stable damage patterns and damage evolution leading to a catastrophic structural collapse (Carpinteri et al., 2005). Analysis of the seismic behavior of historic masonry buildings is a quite difficult task due to the difficult numerical modeling of the nonlinear behavior of masonry material, with almost no tensile strength; the incomplete experimental characterization of the mechanical properties of the masonry structural elements; and the complexity of the geometrical configuration (Betti et al., 2011).

Finite element models (FEM) provide cost effective solutions compared to the experimental alternative, but true success of finite element techniques heavily depends on the constitutive models for the material and appropriate discretization of the continuum. Masonry is anisotropic due to the presence of discrete sets of horizontal and vertical mortar joints and possess orthotropic strength and softening characteristics, which depend not only on the properties of masonry constituent materials but also on their interaction reflecting the workmanship. (Dhanasekar et al., 2008). The numerical modeling of masonry structures through the FEM is a very computationally demanding task because of two different aspects: on the one hand the typological characteristics of masonry buildings do not allow us to refer to simplified static schemes, on the other hand the mechanical properties of the material lead to a widely non-linear behavior whose prediction can be very tricky (Giordano et al., 2002).

Hüseyin Timur Tomb is a good example of Turkish tomb tradition. It is made of red Ahlat stone. It is more convenient to perform elastic calculations initially for the analyses before protection and restoration of historic structures. Therefore, using SAP 2000 software, the tomb was analyzed under gravity forces due to the self-weight of the structure and under dynamic loads by linear response spectrum method. Hüseyin Timur tomb was modeled in macro modeling approach and analyzed in SAP 2000 software. Finite element model of tomb was given in Figure 8.

Linear-elastic analysis was carried out so as to specify critical parts that could exist due to various load effects and to determine overall stability of the structure. Since the structure is stone masonry, stresses and especially tensile stress concentrations obtained by the analysis were considered and evaluated basically.

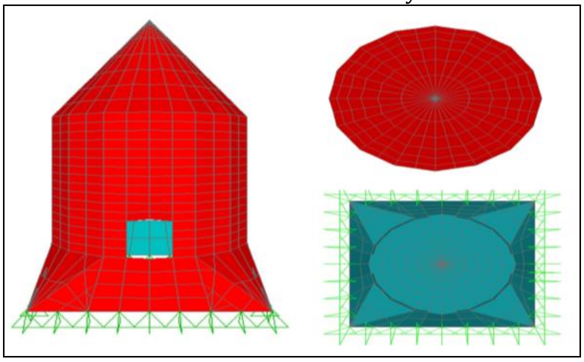
Figure 8. Finite element model of the tomb

Modeling and calculation parameters of the ingredients are presented below;

- SHELL elements were used to modeling the dome, bottom wall and body walls.
- The finite element model has been built with a total of 762 finite elements and 795 joints.
- Material properties of building components have been taken from the results of previously studies in literature and recommended values for masonry structures in Turkish Earthquake Code (TEC, 2007).
- Modulus of elasticity and unit weight assumptions have been made under that Ahlat Stone that is used in masonry structures with mortar was considered as a single material.
- 41 modes were taken for determining the earthquake effects to activate the 90% of the total mass.
- The properties of materials were used in Hüseyin Timur Tomb which were used in finite element calculation model were given in Table 2.

Table 2. Properties of Materials

Material Type	Modulus of Elasticity (kN/m²)	Specific Gravity (kN/m³)	Unit Weight (t/m³)
Dome, Body walls, Bottom wall	5000000	24	2,45

The spectrum curve that used for dynamic analysis of Hüseyin Timur was given in Figure 9.

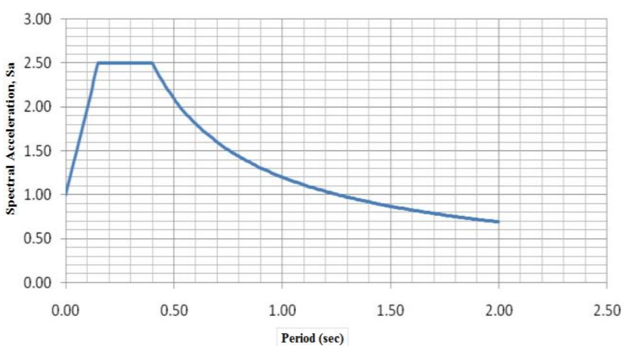

Figure 9. Spectrum curve for dynamic analysis

Periods of model shapes and ratios of the effective mass of modes to the total mass for X and Y direction of Hüseyin Timur Tomb were given in Table 3.

Table 3. Periods of modal shapes and mass participation proportions

Mod	Period (sec)	The ratio of cumulative effective mass to total mass	
		X (%)	Y (%)
1	0,19377	75.848	1.42
2	0,19258	75.99	75.98
3	0,165357	75.99	76.102
4	0,098516	75.991	76.102
5	0,095325	76.762	76.111
40	**0,027006**	**89.92**	**90.431**
41	**0,026908**	**90.118**	**90.756**

Analysis results are;

- The total weight of the tomb is 2.899 kN,
- The total base-shear of tomb in southwest northeast under earthquake is 1940 kN (X direction),
- The total base-shear of tomb in southwest-northeast under earthquake is 1929 kN (Y direction),
- The total base-shear of tomb in X direction is 70% of the total weight of tomb,
- The total base-shear of tomb in Y direction is 65% of the total weight of tomb,
- The maximum displacement in X direction ΔX=13 mm,
- The maximum displacement in Y direction ΔY=13 mm.

Authors used S22 (tensile/strain stress) and S12 (shear stress) models that defined in SAP 2000 software for descriptive results under earthquake. The results of tensile stresses were given in Figure 10.

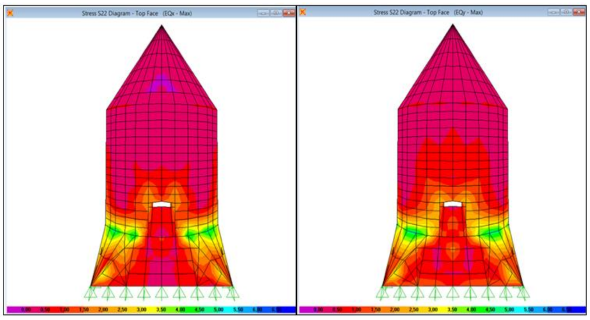

Figure 10a. S22 tensile stresses in Hüseyin Timur Tomb

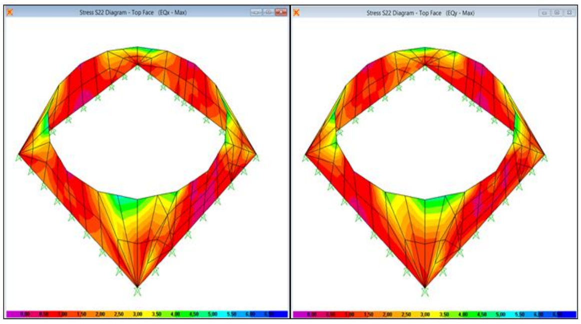

Figure 10b. S22 tensile stresses at bottom walls

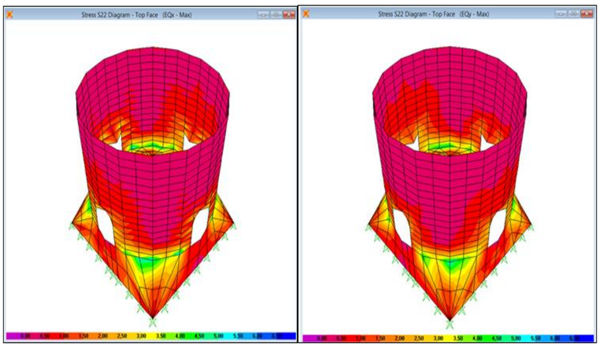

Figure 10c. S22 tensile stresses at body walls

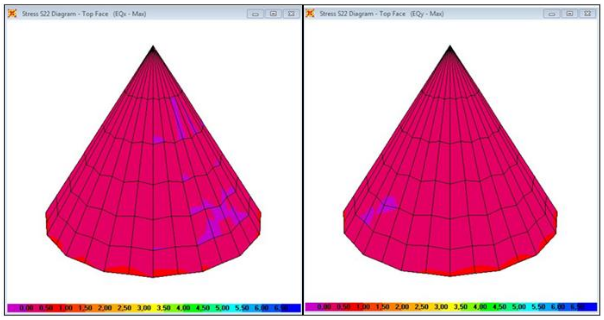

Figure 10d. S22 tensile stresses at dome

The results of shear stresses were given in Figure 11.

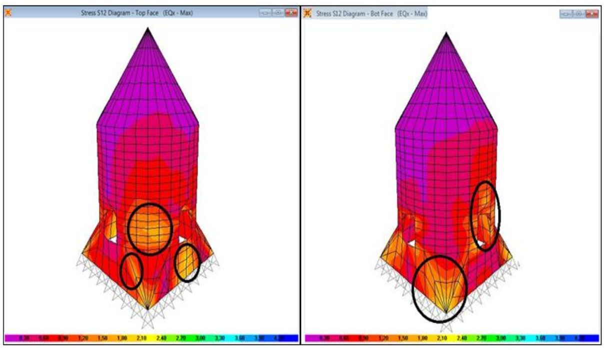

Figure11. S12 shear stresses at the tomb

Maximum stresses (S22) at various building components were given in Table 4.

Table 4. Maximum stresses (S22) at various building components

Component	Surface	Type of Stress	G+Ex (MPa)	G+Ey (MPa)
Dome	Top	Strain	-0.7	-0.6
		Tensile	0.6	0.6
	Bottom	Strain	-1.4	-1.4
		Tensile	0.6	0.6
Body	Top	Strain	-4.9	-4.8
		Tensile	4.7	4.7
	Bottom	Strain	-3.8	-3.8
		Tensile	3	3
Bottom wall	Top	Strain	-6.1	-6.1
		Tensile	4.6	4.2
	Bottom	Strain	-5.3	-5.2
		Tensile	4.1	4

Maximum shear stresses (S12) acquired at various building components were given in Table 5.

Table 5. Maximum shear stresses

Component	Surface	G+Ex (MPa)	G+Ey (MPa)
Dome	Top	0.3	0.3
	Bottom	0.3	0.3
Body	Top	1.6	1.8
	Bottom	2.2	2.2
Bottom wall	Top	1.8	2.1
	Bottom	1.6	1.7

6. Conclusions

Monumental structures are one of the most crucial parts of the cultural heritage that reflect the history of mankind. Their protection against earthquakes is a topic of great concern among the scientific community. In order to assess the structural behavior and to evaluate the seismic vulnerability of a Hüseyin Timur Tomb the behavior of a study case, has been analyzed under earthquake loading. For this purpose a 3D numerical model some analyses have been made in order to assess the seismic vulnerability.

The tomb stands on a high pedestal which is chamfered corners, 6.72 m × 6.72 m dimensions, square planned. Hüseyin Timur Tomb was an elegant building with its cylindrical structure. The tomb was also has an elegant workmanship. Due to these properties the tomb has come to the present day intact.

Hüseyin Timur Tomb was analytically investigated on engineering perspective. Hüseyin Timur Tomb is the one of important monument of Turkish architecture. It is also located within the UNESCO Cultural Heritage. It is one of the twin tomb. Tomb was analyzed under dynamic forces by response spectrum method in both global directions. Due to results it can be said that tomb has a high vulnerability.

The most stressed elements are the bottom walls at the ground level with a maximum value of compressive stress of about 6.1 MPa. Also, displacement resultant distribution suggests that the maximum displacement of around 13 mm will occur at top of dome.

The goal of this study is take attention for special historical tomb in Ahlat that is open air museum. Evaluation of these structures was important for cultural heritage and transferring them to future. It is very important to protect them by taking measures from structural aspect. In order to transferring cultural heritage to the next generations, we need to know structural properties of these structures.

The economy of Ahlat is based on also famous still for its stone and stone masons. As well as the Ahlat stone, pumice is quarried in the region.

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