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Assessment of architectural heritage characteristics and seismic behavior of Ziyaeddin Han Tomb

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ABSTRACT

Historical structures built by different civilizations that have survived to the present day have an important place within the scope of the protection of cultural heritage. Bitlis province, where many different civilizations lived and located in a strategic position on the Silk Road, contains many different types of historical structures. Within the scope of this study, the Ziyaeddin Han Tomb, which was built in masonry during the Şerefhans under the rule of the Ottoman period, has been taken into account. Besides, the architectural features of the tomb, detailed information are given about the current structural situation. As a consequence of on-site measurements, a numerical model of the historical tomb was formed using the finite element method (FEM) and structural analyzes were enforced. Structural analyzes were performed for the tomb, in which the macro modeling technique was applied, considering four different earthquake ground motion levels, 2%, 10%, 50%, and 68%, with a probability of exceedance in 50 years. Besides, the time history analysis was applied to take advantage of the acceleration record of an earthquake that occurred in the near region and the recent history of this tomb located in the city center of Bitlis. The structural performance of the tomb was tried to be determined by using the displacement and drift ratio obtained.

1. Introduction

In our country, which has many historical and cultural structures, preserving these structures and transferring them to the next generations is one of the most important research topics of today. Historical buildings are an important indicator of people's economic status, engineering-architecture accumulation, and belief styles at the time they were built. The protection of these precious structures is a common problem of humanity and there are many studies on this subject (Karaşin et al. 2016a; Hadzima-Nyarko et al. 2018; Gunes et al. 2021; Karalar and Cavusli 2020; İzol et al. 2022a). As the studies cover different fields of specialization, they are often studied in engineering, architecture, art history, etc. interdisciplinary studies of fields of science may be required. (Giordano et al. 2002; Işık et al. 2019; Özodabaş and Artan 2021; Milani et al. 2018; Bilgin and Ramadani 2021; Akan et al. 2021; Berto et al. 2022).

In the province of Bitlis, which is strategically located in the Vangölü basin and on the Silk road, there are many historical buildings built by many different civilizations due to being a very old settlement. Among these structures, mosques, minarets, bridges, baths, and tombs are prominent and there are limited studies in the literature about these structures (Oğuz and Aksulu 2016; Işık et al. 2018; Işık et al. 2019b). This study can also be regarded as a case study to determine the architectural features of historical buildings, to model and strengthen them with the finite element method, to determine the material characteristic used, and to determine their seismic behavior using different seismic analysis methods. On the other hand, Karasin et al. (2016b) made structural analyzes of

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the Ulu Mosque based on observation. Structural analyzes were carried out by Işık et al. (2022a) for all of the Five Minarets, the significant historical buildings of Bitlis, and the subject of songs. In the study by Işık et al. (2022b), the exhaustive structural and architectural analyzes of the Ziyaeddin Han Tomb were performed considering the different probabilities of exceedance according to the current earthquake code used in Turkey.

In the context of this investigation, structural analyzes were performed for the masonry Ziyaeddin Han Tomb, located in the city center of Bitlis, in terms of both architecture and engineering. Tombs are generally built with a cylindrical or polygonal body, covered with a dome from the inside and a conical or pyramidal roof from the outside. The purpose of choosing this tomb is that it differs architecturally and structurally (Doğru et al. 2017). This tomb, which has a very rigid structure, has walls that start with a square prism-shaped lower section from the outside, end with a dodecagonal plan at the top, and has a flat roof cover. Current earthquake regulations were used in structural analysis. Literature was used for the properties of Ahlat stone as given below used in the construction of the tomb, and a FEM of the tomb was formed by using the macro modeling method with on-site measurements. First of all, modal analysis was performed, stresses were calculated for four different earthquake ground motion levels, and finally, displacements in the historical tomb under the effect of the 2011 Van earthquake that occurred in the near region and the recent history were found.

2. Material and Methods

2.1. Ziyaeddin Han Tomb

Located in the city center of Bitlis, the Ziyaeddin Han tomb is in the complex built around the İhlasiye (Gökmeydan) Madrasa. This complex was registered by the Diyarbakır Cultural and Natural Heritage Preservation Board in 1989 together with the tomb in question. Projects for the restoration of these structures, except Şemsiye Masjid, were drawn in 1997 and then restored by the Ministry of Culture and Tourism (Url1, VKVKBKM. 2022). In addition to the madrasah in the complex; There are four tombs-cupolas and a mosque. The tomb was built in front of the gate of the madrasah opening to the south. The architectural layout plan of the complex is shown in Figure 1.

It is stated in various sources that the building, which does not have an inscription, belongs to Emir Ziyaeddin Han, who died in 1390 or 1394, and was built at that time (Arık, 1971; Erkan, 1977; Uluçam, 2002). As shown in Figure 2, one of the broken tombstones inside the tomb belongs to Emir Ziyaeddin and has the date 1621-1622 (1031 H). Looking at the genealogy of the Şerefhans Principality, which ruled in Bitlis, it is known that the 6th Ruler Emir Ziyaeddin was the administrator until 1390, and the 21st ruler Ziyaeddin Han was the administrator between 1655 to 1656 (Vilayetlerimizin Tarihi, 1968). The date indicated on the tombstones corresponds to the period of the 19th ruler Şemseddin IV (1597-1638).

Figure 1. Ziyaeddin Han tomb layout plan.

الدنيا ساعه فاجعلها طاعه
هذه؟ روضة السعيد الشهيد
المغفور المرحوم الامير الكبير
شرف؟ الامر الكبير ضياءالدين
خان
فى سنه ١٠٣١

- Ed-dünya sa'eh, fec'aelaha ta'eh
- Hâzâ ravdet'üssaid eşşehîd
- El mağfur, Errahîm, el emîr el Kebir şeref
- El emrel kebir Ziyaeddin Han
- Fî seneh 1031

Figure 2. The broken tombstone in the Ziyaeddin Han Tomb and its transcription (by Abdulhakim ARKAN)

The tomb consists of a burial section in which there are six cist graves. Arık (1971) states that the tomb was built without a prayer hall or this part was destroyed later. Its walls, which start with a square prism-shaped lower section from the outside, end with a dodecagonal plan at the top. When transiting to this plan, the corners were chamfered from the outside, as shown in Figure 3.

The lower part of the interior is also square in shape, just like the exterior. The vault was built after the 90 cm straight wall in the interior. As shown in Figure 4, the interior space forming the mirror vault supports 2 arches coming from each side.

Figure 3. Exterior view of Ziyaeddin Han Tomb

Figure 4. Interior view and mirror vault of Ziyaeddin Han Tomb

The tomb remained under the ground up to the upper level of the entrance gate in the northern part. The entrance is reached by a five-step staircase. On each of the side facades, there are two windows, one of which is mostly under the ground, and the other is on the upper level. As shown in Figure 5(a), Tuncer's (1991) drawing shows decorations on the upper side and sides of the door; there is no decoration on the door in its current situation shown in Figure 5(b). The decoration on the entrance door was probably destroyed and was not replaced during the restoration. Today, there are decorations only on the lower side parts of the entrance door. There is a passionflower motif as shown in Figure 5(c) above the lower window in the south.

Arık (1967, 1971) evaluated it in the typology of a tomb with a polygonal prism-shaped drum and a pointed cone on a cubic body. However; It is considered a unique building type due to both its incomplete/destroyed superstructure and the interior structure with arch mirror vaults.

(a) (b) (c)

Figure 5. Ziyaeddin Han Tomb (a) 1991 drawing by Tuncer (b) Decoration around the tomb entrance (c) passionflower motif on the window

In order to model the Ziyaeddin Han tomb, on-site measurements were made, and the plan and section were drawn to scale as seen in Figure 6. The tomb sits on a base of 8.99 x 8.99 meters from the outside and is 3.55 meters above the ground. The entrance gate is located below 1.23 meters of ground level. Its height from the interior floor to the mirrored vault is 4.26 meters.

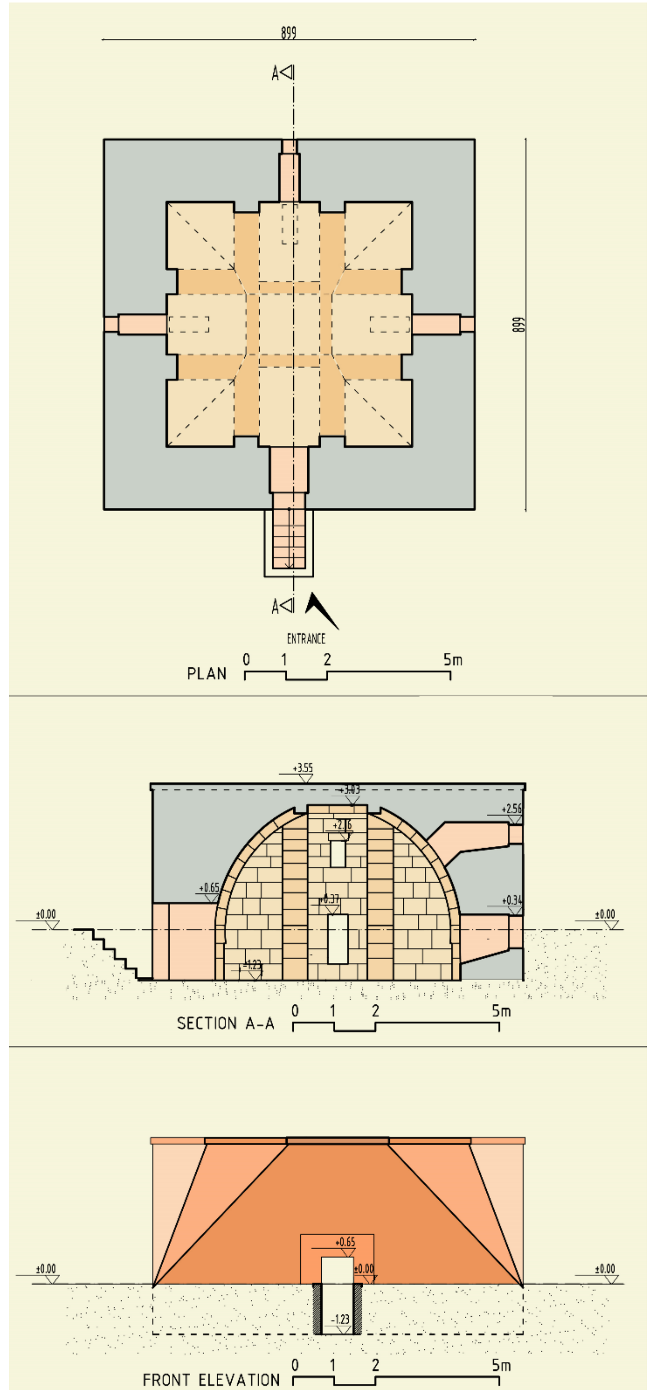

Figure 6. Plan, section, and view of Ziyaeddin Han Tomb

3. Results and Discussion

For the location of the dome, the local soil class ZB was taken into account in the structural analysis. The characteristics of this local soil class, which are determined in the soil survey reports given in the Turkish Building Earthquake Code (TBEC -2018), which are the subject of the study and made by the relevant public institutions, are shown in Table 1.

Table 1. Local soil class type ZB (TBEC-2018)

Local Soil Class	Soil Type	Upper average at 30 meters		
		(VS)30 [m/s]	(cu)30 [kPa]	(N60)30 [pulse/30cm]
ZB	Less weathered, reasonably strong rocks	760-1500	----	----

The vertical and horizontal design spectrum attained from the Turkish Earthquake Hazard Map Interactive Web Earthquake Application (AFAD, 2022) and utilized in structural analysis for the studied tomb is shown in Figure 7.

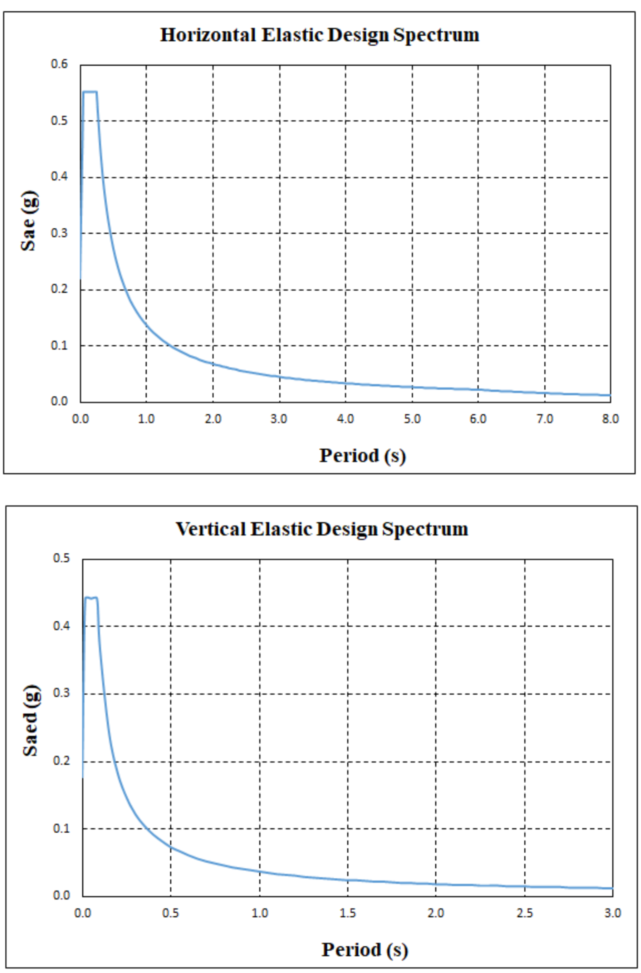

Figure 7. Vertical and horizontal elastic design spectrums

The sources in the literature were used for the material properties of the Ahlat stone used in the historical tomb. The unit volume weight (γ), modulus of elasticities (E), and the Poisson ratio (n) are taken as a constant in structural modeling. The structural parameters of Ahlat stone are given in Table 2.

Table 2. Material properties of Ahlat stone (Isik et al. 2018; Özvan et al. 2015)

	Unit Volume Weight γ (kN/m3)	Modulus of Elasticity, E (MPa)	Poisson ratio, n
Ahlat	24.5	5000	0.2

To do a comparison assessment, the local soil class ZB in the Turkish Building Earthquake Code that was established in the site-survey reports finished by the relevant public facilities for the location of the Ziyaeddin Han Tomb was taken into account. There are four distinct earthquake ground motion levels identified in TBDY 2018. The first one is the "largest earthquake ground motion level" (DD-1), with a spectral magnitude of 2% probability of exceedance in 50 years. The second is the "standard design earthquake ground motion level" (DD-2) with a spectral magnitude of 10% probability of exceedance in 50 years. The third is the "frequent earthquake ground motion level" (DD-3) with a spectral magnitude of 50% probability of exceedance in 50 years. The last is the "service earthquake ground motion level" (DD-4), with a spectral magnitude of 68% probability of exceedance in 50 years. The peak ground velocities (PGV) and the peak ground accelerations (PGA) were determined for the different probability of exceedance for the selected settlement as given in Table 3.

Table 3. PGV and PGA of the tomb for different ground motion levels

City	Peak ground velocity (cm/s)-PGV Earthquake ground motion level				Peak ground acceleration (g)-PGA Earthquake ground motion level			
	DD-1	DD-2	DD-3	DD-4	DD-1	DD-2	DD-3	DD-4
Bitlis	28.215	15.081	6.508	4.847	0.490	0.260	0.106	0.077

Updates have been made to several computer applications that help with data transfer and deliver integrated outcomes to application projects for computing and designing today's current engineering structures. Masonry constructions have different structural systems than current engineering structures. For the structural analysis of such structures, finite element analysis is chosen. The creation of a numerical model of the structure under examination is the first stage in this procedure. Numerical modeling is the mathematical representation of structural system components made up of various materials and having different cross-section geometries. Masonry structure numerical modeling using the finite element approach calls for a lot of processing capability (Pande et al. 1989; İzol et al. 2022b; Pekgökgöz et al. 2022).

Structural analyzes for the tomb examined in the study were performed using the ABAQUS software (ABAQUS, 2011). The finite element model and the meshed structure model of the finite element model obtained in the software program are shown in Figure 8. While creating the structure, the vault, top beams, and wall were drawn separately and modeled as one part. In the finite element model of the tomb, the total number of nodes is 125353 and the total number of elements is 85958.

Quadratic tetrahedral elements (C3D10) were selected as the mesh type for the tomb.

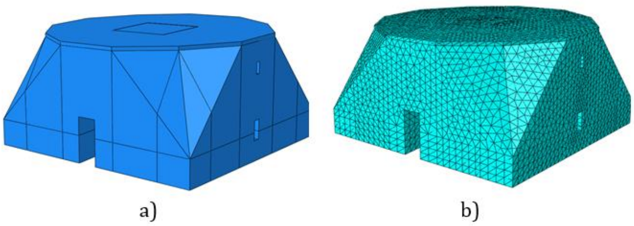

Figure 8. a) FEM of the tomb, b) Meshed model of the building

A modal analysis was first accomplished to ascertain the tomb's dynamic characteristics. The first ten modes that emerged in the building were taken into account when doing the modal analysis. Table 4 displays the effective modes' frequencies, natural vibration periods, and mass participation rates, in accordance with the model's modal analysis findings.

Table 4. Modal analysis results of the tomb model

Mode	Frequency (Hz)	Period (s)	Mass Participation Ratio (X) (%)	Mass Participation Ratio (Y) (%)	Total Mass Participation Ratio (X) (%)	Total Mass Participation Ratio (Y) (%)
1	23.426	0.043	0	0.77491	0	0.77491
2	23.837	0.042	0.77126	0	0.77126	0.77492
3	34.241	0.029	0	0.00197	0.77126	0.77689
4	41.775	0.024	0.0001	0	0.77136	0.77689
5	42.636	0.023	0	0.00034	0.77136	0.77723
6	43.462	0.023	0.00004	0	0.77139	0.77723
7	51.623	0.019	0.00004	0	0.77143	0.77723
8	52.746	0.019	0	0	0.77143	0.77723
9	55.564	0.018	0.00003	0	0.77146	0.77723
10	60.668	0.016	0.00137	0.77491	0.77283	0.77723

Analysis was performed in the ABAQUS software program (ABAQUS, 2011) for the Ziyaeddin Han tomb, considering the first five modes in which torsion occurs. The resulting mode shapes are shown in Figure 9.

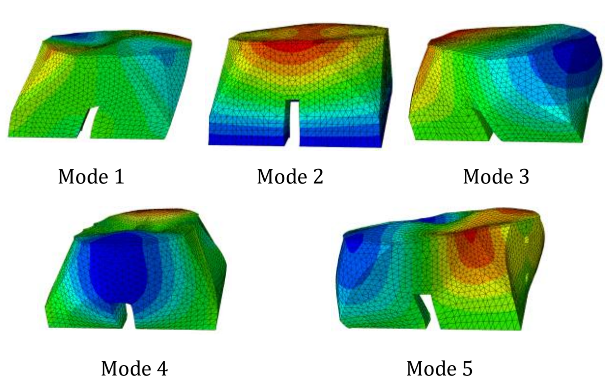

Figure 9. The first five modes of the tomb

The stress distributions obtained for earthquake ground motion levels DD-1, DD-2, DD-3, and DD-4 are shown in Figure 10 (a), (b), (c), and (d) respectively.

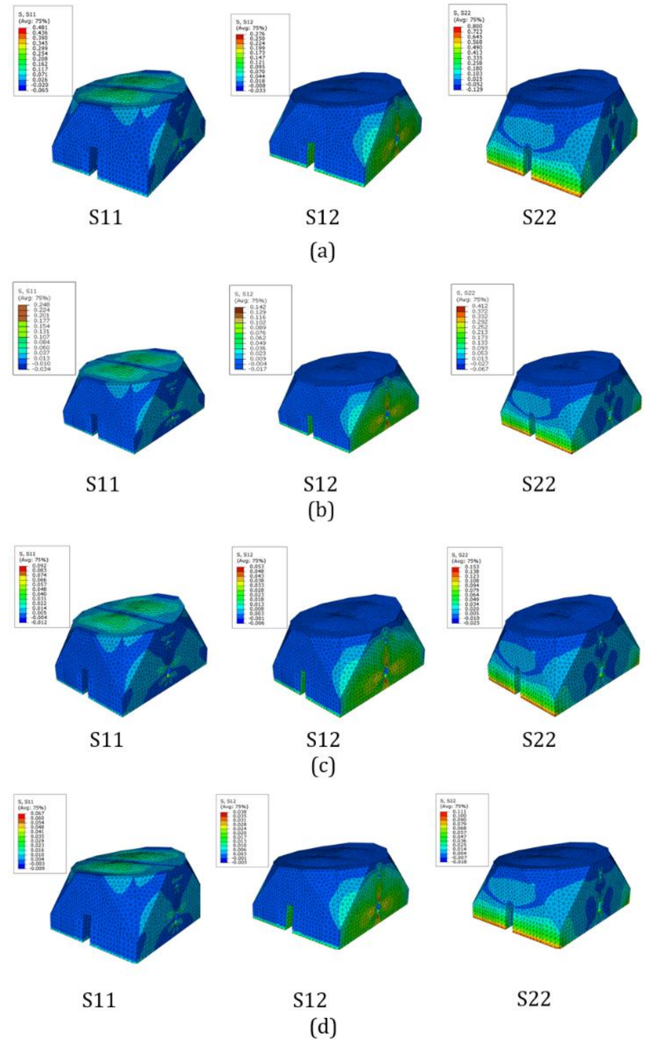

Figure 10. Stress distribution according to ground motion levels (a) DD-1, (b) DD-2, (c) DD-3, and (d) DD-4

The maximum base shear forces, displacements, and stresses obtained for different earthquake ground motion levels are shown in Table 5.

Table 5. The maximum base shear forces, displacements, and stresses found for the various earthquake ground motion levels

Ground Motion Level	Base Shear Force(N)	Displacement (mm)	S11(MPa)	S12(MPa)	S22(MPa)
Bitlis DD-1	5.087×10^6	0.702	0.481	0.276	0.800
Bitlis DD-2	2.619×10^6	0.361	0.248	0.142	0.412
Bitlis DD-3	0.971×10^6	0.134	0.092	0.053	0.153
Bitlis DD-4	0.705×10^6	0.097	0.067	0.038	0.111

The displacements obtained during the study were used to determine performance levels. Limit value hypotheses from the Turkey Earthquake Risk Management Guide for Historic Buildings (TERMFHB-2017) were applied for this purpose. The use of linear computation for the “immediate occupancy” (IO) performance level and either linear or non-linear computation techniques for the "life safety" (LS) and "collapse prevention" (CP) performance levels were considered to be sufficient. Figure 11 shows the minimum limits that must be provided if one of these computation techniques is chosen.

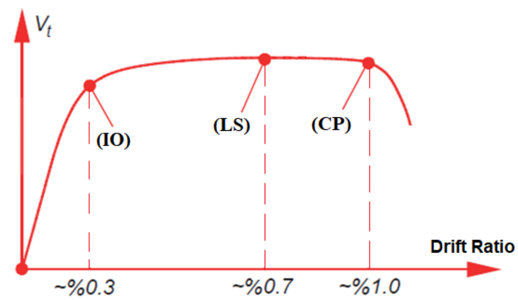

Figure 11. Limit states and pushover curve (from TERMFHB-2017)

In this section of the paper, a time history analysis will be performed under a selected acceleration record. Acceleration records of the Van (located in eastern Turkey) earthquake, which is in the closest region to Tomb and occurred in 2011, will be used. Figure 12 shows the Van South-North acceleration-time curve utilized in the analysis for this earthquake. Figure 13 displays the displacement-time graph that was produced as a consequence of the time history analysis.

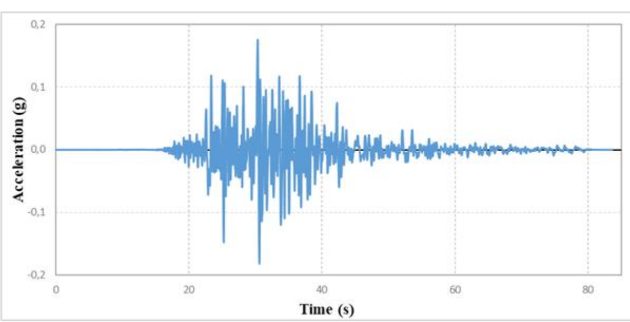

Figure 12. South–north acceleration–time graph of Van earthquake (2011)

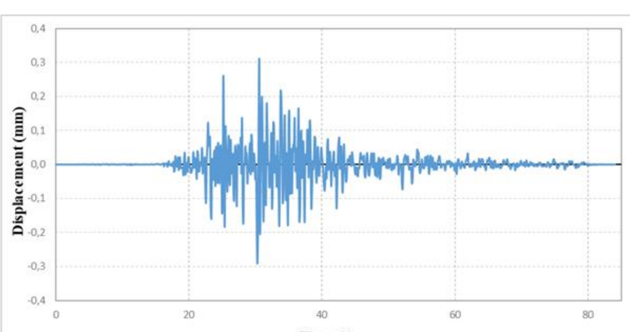

Figure 13. Time-history analysis (Van Earthquake) (Max=0.3 mm)

As a result of the 2011 Van earthquake acceleration recording, Ziyaeddin Han Tomb, whose time history analysis was performed and modeled with the finite element method, a displacement of 0.3 mm was obtained from the top of the structure. The largest drift-ratio value was calculated as 0.006%. The performance levels created by considering the displacement and drift-ratio values are shown in Table 6.

Table 6. Time-history analysis results and the limit performance level check

Regulation	Max. Displacement (mm)	Max. Drift-Ratio (%)	IO<%0,3		LS<%0,7		CP< %1	
TBEC (2018)	0.3	0.006	14.34	✔	33.46	✔	47.8	✔

Considering the largest displacement rate under the 2011 Van earthquake acceleration records used in the analysis, no damage is expected in the historical structure.

4. Conclusions

In this study, the Ziyaeddin Han Tomb, which is different from other tomb structures with its architectural and structural characteristics in the Turkish-Islamic period monumental tomb architecture, located in the city center of Bitlis, was examined. This structure, which started as a square type at the base and ended with a dodecagonal flat plan at the top, was built with Ahlat stone, its interior was created with a mirrored vault and a total of eight arches, two on each side.

To define the dynamic properties of this building, which was informed about its historical and detailed architectural features, a building model was created by making on-site measurements and analyzed with the finite element method using the ABAQUS software program (ABAQUS, 2011). Mode shapes, frequencies, and periods were found as a result of the modal analysis of this quite rigid structure. The period of this building, which is not high and was built partially in the ground, turned out to be quite low as expected.

Structural analyzes were investigated for the historical tomb, where the macro-modeling technique was performed according to the TBEC 2018, by taking into account the various earthquake ground motion levels with 2%, 10%, 50%, and 68% probabilities of exceedance in 50 years. The earthquake effect that the structure is subjected to grows as the probability of exceedance decreases, and correspondingly, the displacements and stresses grow.

As a result of the analysis made by considering the 2011 Van earthquake acceleration records, since it is in the area close to this tomb in the city center of Bitlis, the maximum displacement was found to be considerably lower than the value stipulated in the regulation. It has been observed that as long as there are no material deteriorations or material losses that may occur in the structure, there will be no negativity related to the earthquake resistance of the structure. This demonstrates how advanced engineering expertise and understanding were at the time the dome was constructed.

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