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Seismic Behavior Assessment of The Historical Tomb of Sheikh Shahab-edin Ahary

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ABSTRACT: This study aims to investigate failure mechanism of historical tomb of Shahab-edin Ahary elements and determines areas prone to structural failure. Since Ahar is one of the most earthquake-prone cities of Iran with relative risk of large earthquakes, the presence of multiple faults in this area as well as historical, cultural and tourism importance of the building, makes its vulnerability assessments and retrofitting inevitable. Because of low adhesion strength of masonry used in the building and regarding its vulnerability records on previous earthquakes, the building seems weak against relatively intense earthquakes. The aim of this study is to investigate vulnerability of this building against possible earthquakes. Selected earthquakes for seismic loading are modified for the maximum horizontal acceleration obtained for this region. Various results have been studied after utilize finite element model using Ansys software and various analyses.

Keywords: Seismic Behavior, Historical Buildings, Dynamic Analysis, Sheikh Shahab-Edin Ahary, Macro Modeling.

INTRODUCTION

Cultural, artistic and aesthetics importance of Iran historical monuments are obvious, since they have retained cultural identity of the past and consolidate national unity. These valuable monuments have been threatened in the past by natural and unnatural phenomena, many of which today have no trace. No trace of earthquake has been observed during design and construction of the buildings, therefore, function of these buildings against this natural phenomena should be considered and finally necessary measures done to retrofit the building and in some cases for its reconstruction. Because Ahar is one of the earthquake-prone cities of Iran with high relative risk of earthquake, and due to the historical, cultural, and tourism importance of historical monument of Shahab-edin Ahary, pathology and retrofitting the building is inevitable (Pouraminian M, 2008).

Recognition of Shahab-edin Ahary monument

Sheikh Shahab-edin monument, the tomb of Sheikh Shahab-edin Mohammad Ahari, the great mystic of seventh century AD, is located in Sheikh Shahab-edin Park. The building is 1497 m^2 including Khaneghah, mosques, tall porches, minarets and numerous booths. The great space of Khaneghah is located under the two capped dome and has a square cross section, each side is 11.20 m, 18 m height, and 1.30 m wall thickness, locally known as "Ghoushkhaneh". Building facades and architectural and structural plans are indicated in figures 1 and 2, respectively.

Khaneghah: a great space under two capped dome and has a square cross section, each side is 11.20 m, 18 m height, and 1.30 m wall thickness, locally known as "Ghoushkhaneh".At the sides of Khaneghah symmetric rooms are made with dimensions of6.30*9.60m, known as Chinese House(location of storing Chinese containers).

Mosque: located in the eastern part of the monument with the dimension of 60.90*9.30 m, Decorated with stuccocarvingsand paintings, all around the walls containing auto graphmanuscripts, among them that of Sheikh Bahai, Shah Abbas III, Abolghasem Nabati is known.

Figure 1. Sheikh Shahab monument

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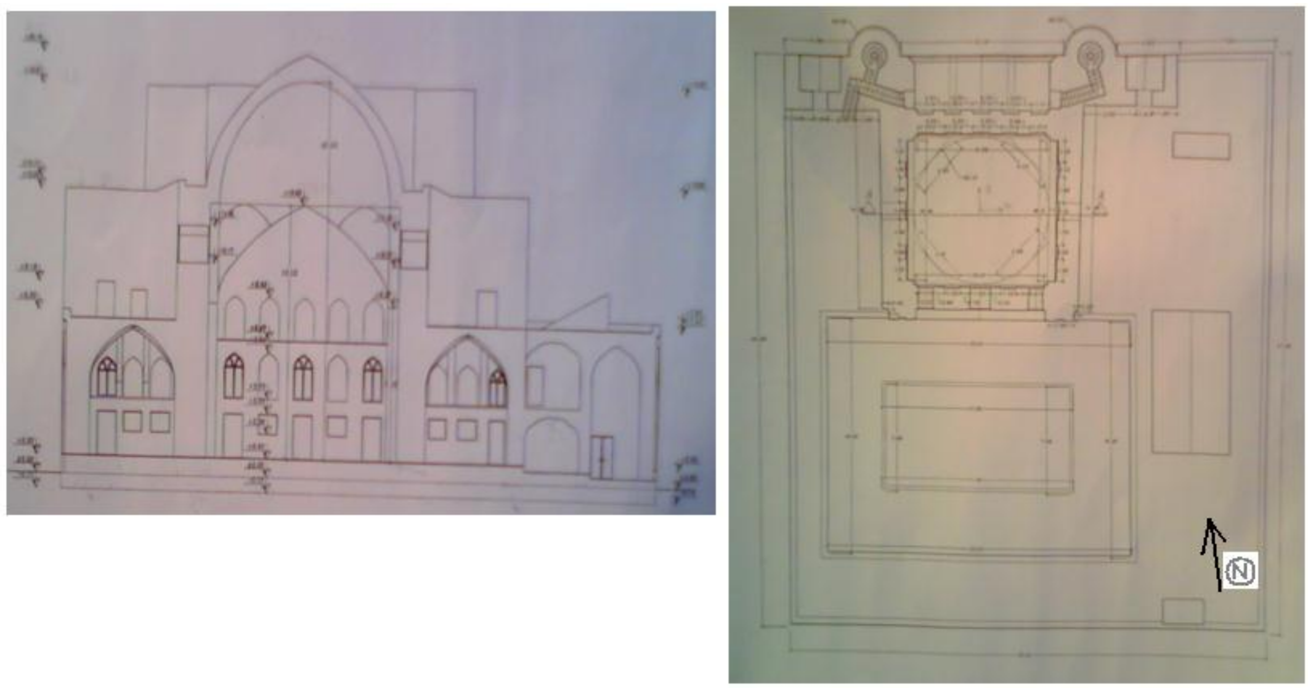

Figure 2. Architectural and structural plans of the building

Analysis of historical buildings

In general, analyzing historical buildings is complex, first because of the limited resources to study mechanical behavior of masonry, such as non destructive testing in place, experimental testing, dimensional testing and expanding valuable numerical tools, and second, difficulties in applying existing data in analyzing historical buildings, which is more important factor (Betti and Galano, 2012). The most common of these difficulties can be referred to as (Sadegh and Pouraminian, 2010):

- Lack of information about the geometry of destroyed parts of the building
- No available information about material forming the inner core of structural elements
- Difficulty and costly recognizing mechanical properties of applied material
- Many changes in the mechanical properties of materials due to the construction quality and the use of natural materials
- Dramatic changes in the composition and structural elements of buildings with long periods
- Unknown sequence of construction
- Unknown damages to the building
- Non-functional guidelines and regulations

Most of these structures are weak against lateral load; numerical models are used because of high costs of their maintenance, testing and retrofitting (Khodayari et al., 2013).

Seismotectonics, quaternary and fundamental faults in East Azerbaijan

Large and destructive earthquakes in the past in Iran, especially in Alborz Mountain range in north and Zagros in the South West Iran and Azerbaijan is due to north ward movement of the Arabian plate and pushing Iran plate. Eastern Azerbaijan is one of the earthquake-prone areas in Iran. Multiple historical seismic events have important and significant effect on the genesis and evolution of this area. In general, three active seismotectonics of Tabriz-Zanjan, Zarrineh Rood-Arak and Aras has influenced Azerbaijan (Zokka, 1989). Northern fault of Tabriz can be introduced as the most vacillator seismically active area in Azerbaijan and is expected the most important seismic events on the future of the province occur due to reactivation of this fault (Zare and Shahpasand Zade 1995). Therefore, the most significant structural trends in the province would be introduced in the following. These trends are indicated in seismotectonics plans of figure 3. In general, the active tectonic earthquakes have influenced earthquake trends of Tabriz-Zanjan, Zarrineh Rood-Arak and Aras. Due to being located in the vicinity of the south fault of Ahar, Ahar city in seismically a risky area, accordingly, the maximum horizontal acceleration of this area is calculated 0.36g (Table 1). Qualitatively, it can be said that historical monuments of Ahar are in danger, and earthquake is sever threatening factor for historical buildings of the city. However, considering historical monuments according to criteria based on architectural value of buildings and their vulnerability against earthquake, it can be concluded that Sheikh Shahb monument is in priority.

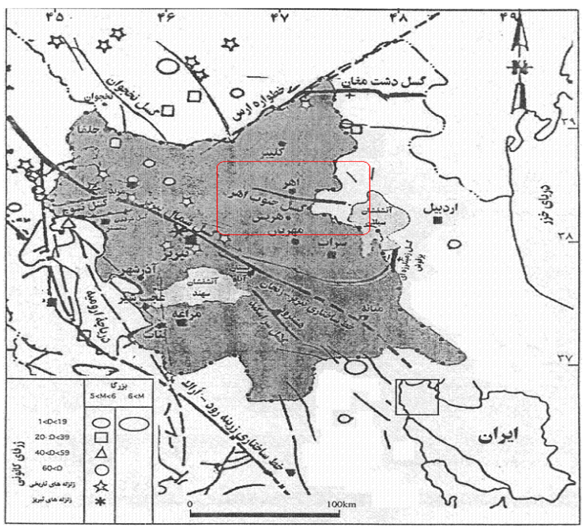

Figure 3. seismtectonics plan of East Azerbaijan province

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Table 1. calculation of maximum sever kinetic parameters of ground in East Azerbaijan province

Linear seismic source(main seismic source over town)					**Maximum credible earthquake parameters**		
Fault	Length (km)	Rupture length (km)	Magnitude	Maximum intensity of the fault I(MSK)	Distance to fault (km)	Maximum horizontal acceleration (%g) PGA	Maximum intensity in place
South fault of Ahar	62	23	6.5	VII^{+}	8	%36	VII^{+}

Finite element modeling (macro modeling methods)

Based on this method of masonry modeling, single units and connections can not be distinguished from one another, and masonries are considered united, means that thebricks, mortar and the interface of bricks and mortar are assumed as a homogeneous material. Physical properties of this environment are determined by testing and/or average weighing of physical properties of brick and mortar environment. One of these parameters significantly influencing analysis results is the modulus elasticity of the masonry. In the following a relationship is presented to precise determination of this parameter.

Equivalent modulus for masonry: to evaluate equivalent modulus of masonry for eccentric loading, the following relationship is presented (Blasi, 2007):

Influential factors on formula 1 include geometrical characteristics and mechanical properties of the essential components of masonry.

$$\frac{1}{E_M} = \frac{\eta_b}{E_b} + \frac{\mu_m}{E_m} + 2\eta_m\eta_b \frac{\nu_b E_m - \nu_m E_b}{\eta_m(1-\nu_b)E_m + \eta_b(1-\nu_m)E_b}\left[\frac{\nu_m}{E_m^2} - \frac{\nu_b}{E_b^2}\right]$$

where, volume fraction of mortar and brick is calculated using formula 2 and 3

$$\eta_m = \frac{t_m}{(t_m + t_b)}$$

$$\eta_b = \frac{t_b}{(t_m + t_b)}$$

t_m, t_b are thickness of mortar and brick, E_m, E_b elastic modulus of mortar and brick, and ν_m, ν_b Poisson's ratio of mortar and brick, respectively.

Macro modeling is usually used for analysis of large masonry structures (Roca P. Cervera M, 2010). Due to the massiveness of structure and large number of bricks used, this method is used for masonry environment modeling. In this regard and according to the physical characteristics of applied materials, 3D modeling was done in Ansys software and different analysis done on the model (Ansys, 2004). One of the elements applied in modeling was SOLID45. Because of massiveness and complexity of geometric model of structure, after modeling in Solid Work software it was transferred to Ansys software and then mashed. Created model (figure 4) constitutes of 224000 elements, analysis of which needs lots of time and software. According to the journal of O.P.C.M.3431, and regarding constituentmaterials ofthestructure, mechanical properties of materials can be measured without testing. In this study, according to appendix D chapter 11 of the journal, the compressive strength of masonry is considered 22 kg/cm^2, Young module 2000 Mpa, Poisson ratio 0.22 and specific weightper unit volume is 18 KN/m^3 (O.P.C.M. 3431/05, 2005)

Analysis of finite element models under gravity loading

Finite element model of the Structure created using8-node element of Solid45. Linear elastic behaviors considered for elements. Masonry environment of this model is considered homogeneous isotropic.

Possible failure mechanisms of the building can be estimated based on combination of result of structural deformation in x, y axes in the direction of the main axes. The results of the displacement contour in figure 5 indicates that minarets are willing to deform in the positively-axis, while this deformation on the area around the dome are close to zero or negative (i.e. displacement in the opposite direction of the axis y). It can represent the dome at some point along the x-axis has tensile stress. It is worth to note that cracks in the dome(Figure4) are also in the same direction, which confirms this statement.

Modal analysis

Modal analysis using subspace method was measured for 30 primary modes in the direction of main x,y axis (figure 6). The dominant mode is in the direction of first axis, the second mode and dominant mode is measured in the direction of second axis of first mode. If the building is considered 3 stories, modal deformations indicate that the first floor is stronger than other two floors. It is also observed that the third floor is softer than other two lower floors.

Analysis of time history

Selecting large number of appropriate regional accelerograms such as ChiChi, Koubeh, Tabas, Manjil, Douzsi, Arizinken, Walcenter, etc., numerical mode was seismically analyzed. To determine the structure intensifying earthquake, selected response spectra of earthquake accelerograms was prepared, and the accelerogram with high response to the structure was selected to be applied in the model. Real and scaled response spectra of these accelerograms are presented in figure 7. Manjil and Tabas spectra have the largest responses, respectively. Manjil earthquake accelerogram is selected from mentioned accelerograms. Maximum horizontal acceleration of the ground in this accelerogram is 3.53 m/s^2 and applied in the model (figure 8). In primary analysis of 30s records, it was observed that in first 15s, most of the significant results are achieved and remaining record has little or no contribution in results. Therefore, results are presented for first 15 seconds.

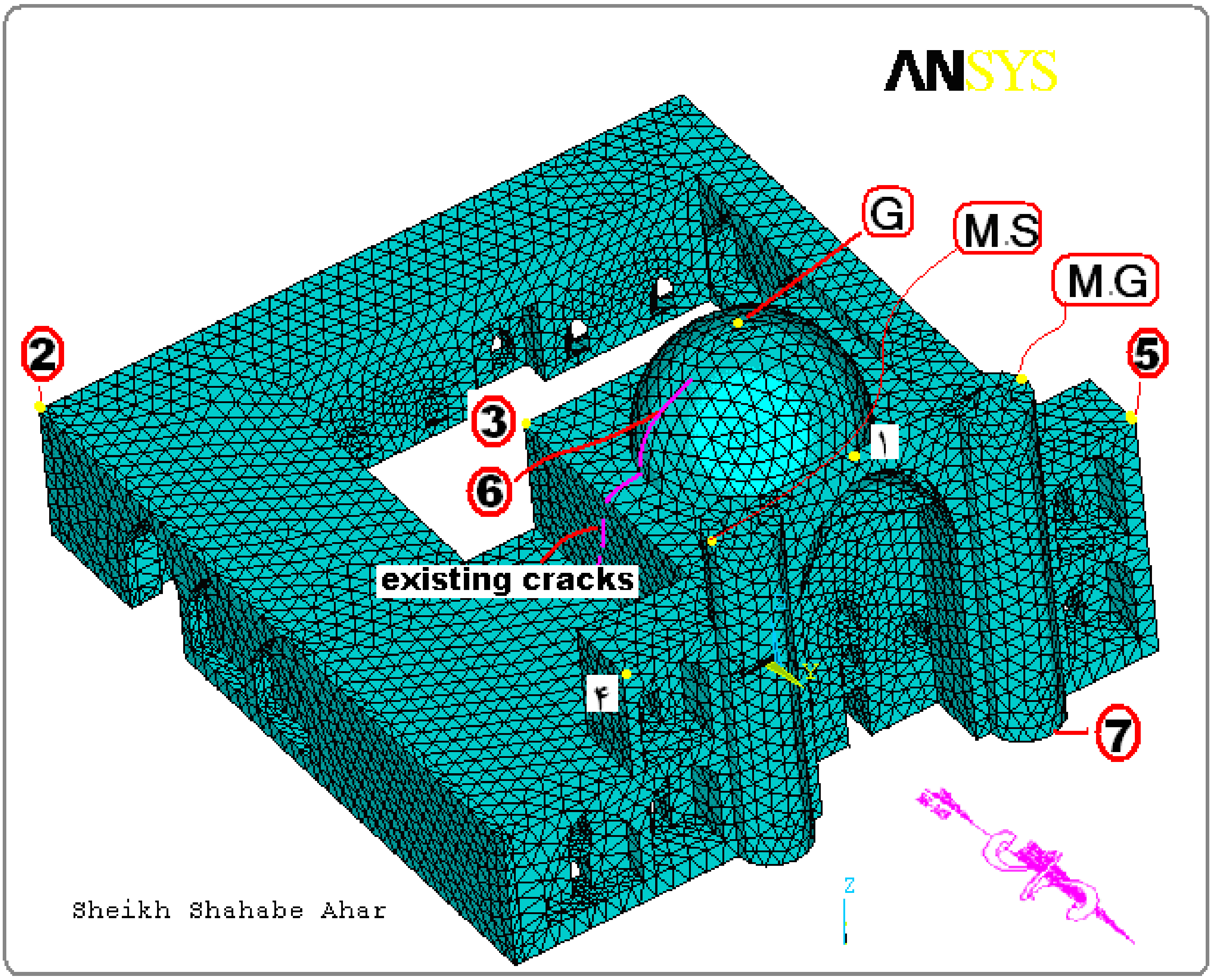

Figure 4. Finite element model of the monuments and introduction of control points

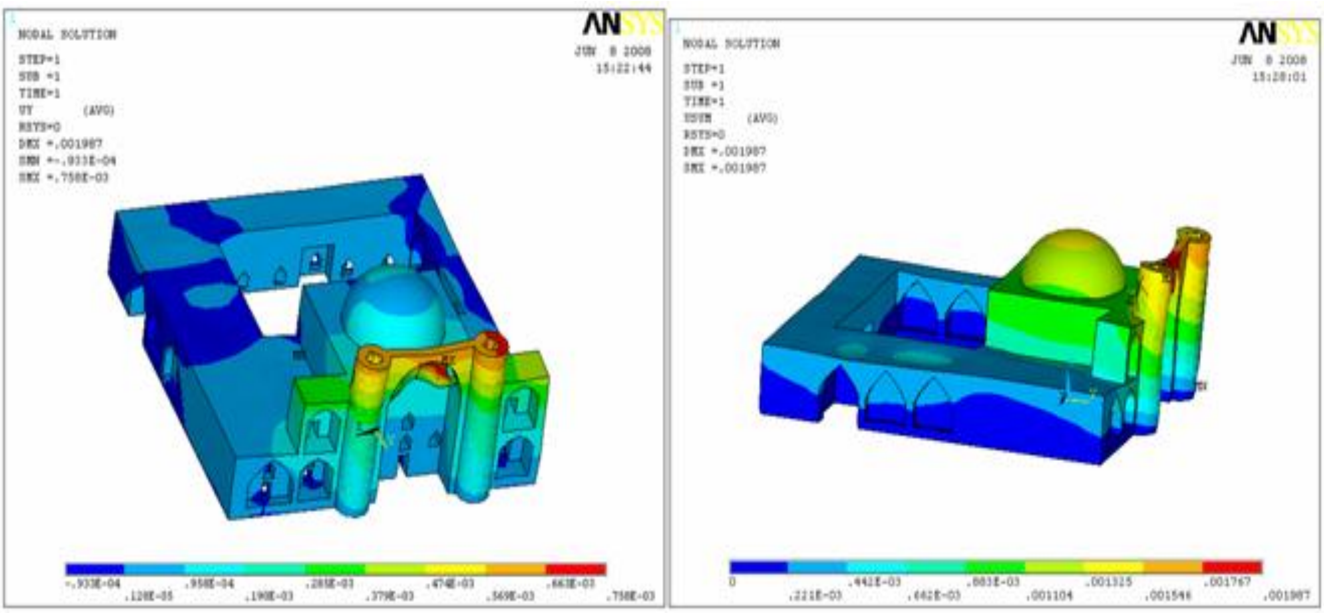

Figure 5. results of model analysis under its own weight

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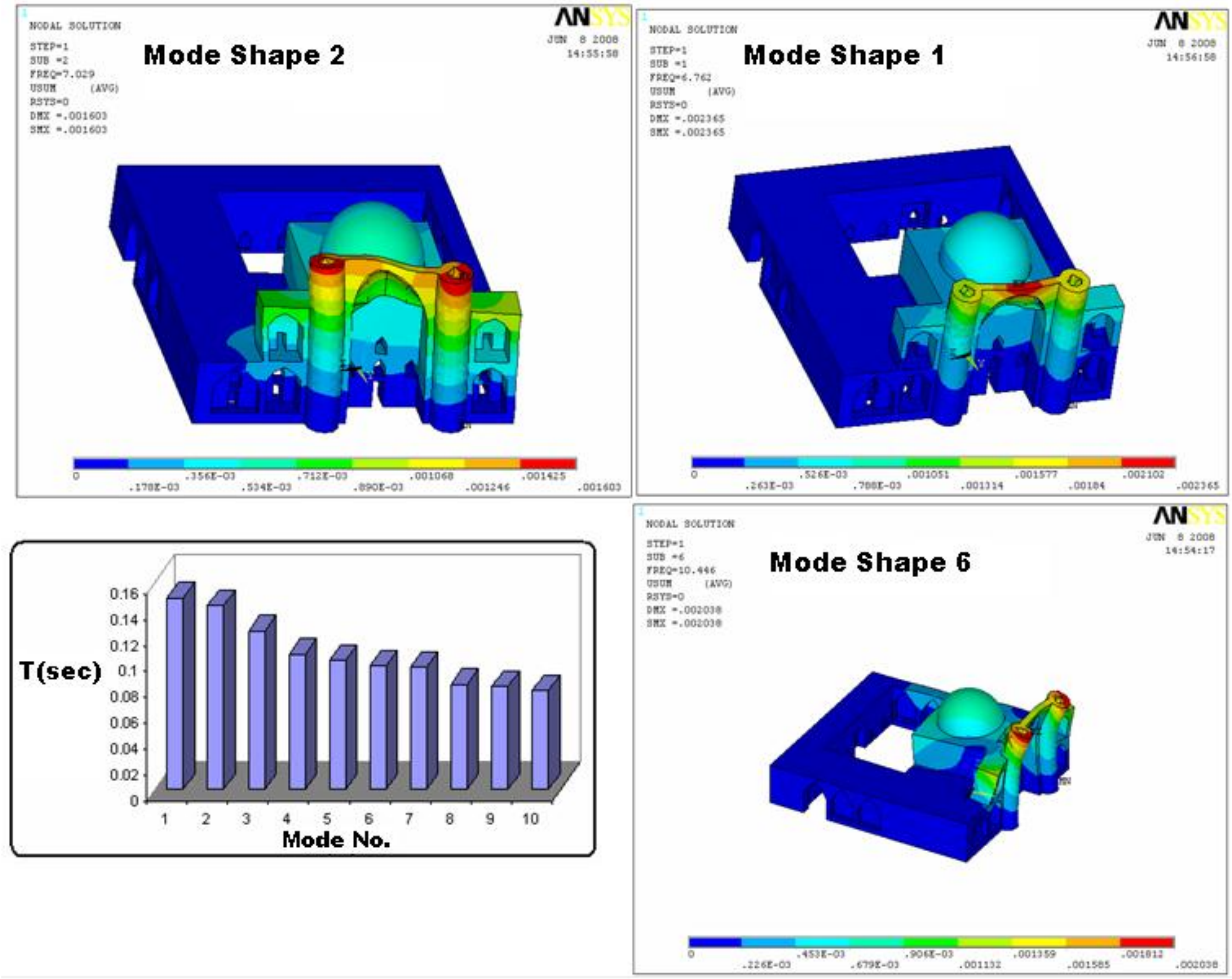

Figure 6. Modal deformation and period of 10 first modes

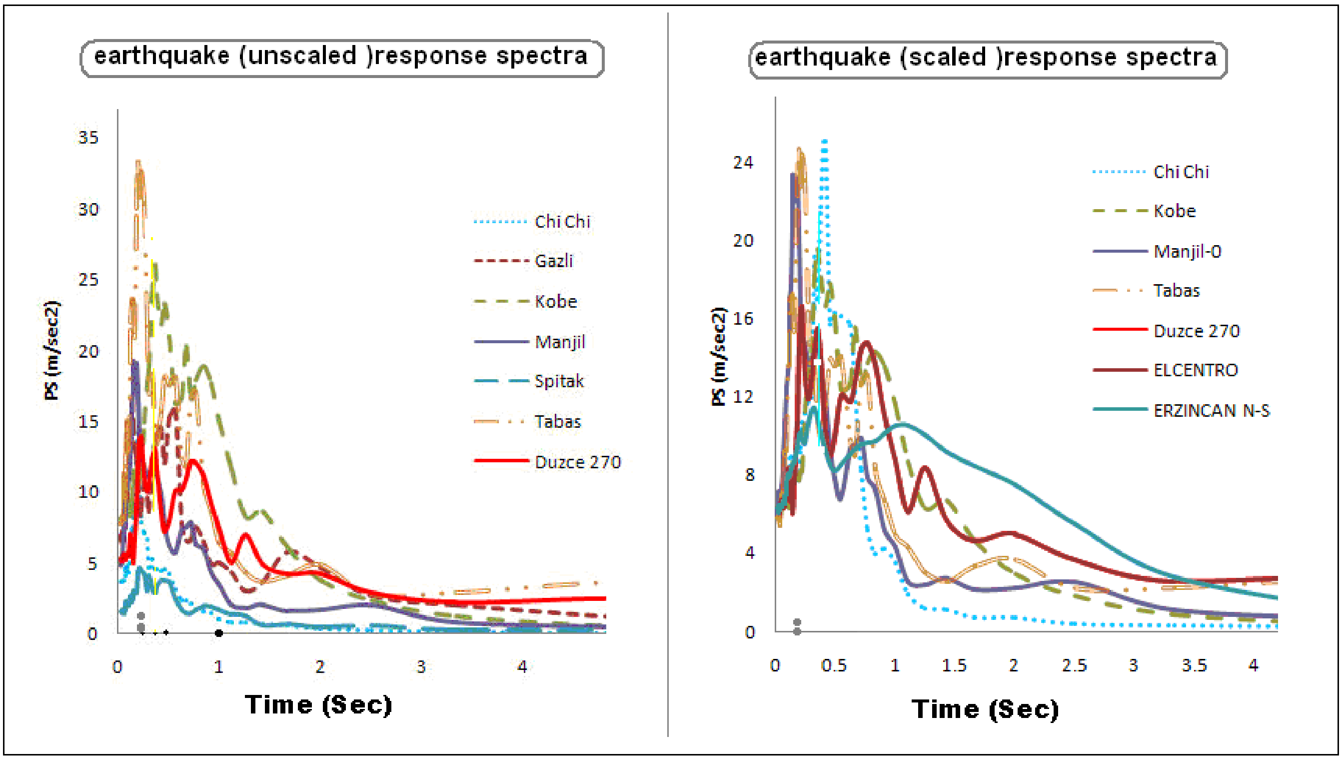

Figure 7. Comparison of selected accelerogram response spectra

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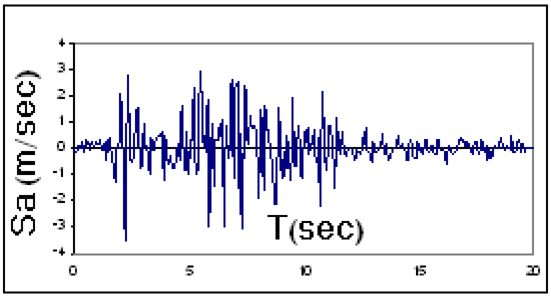

Figure 8. Manjil earthquake accelerogram

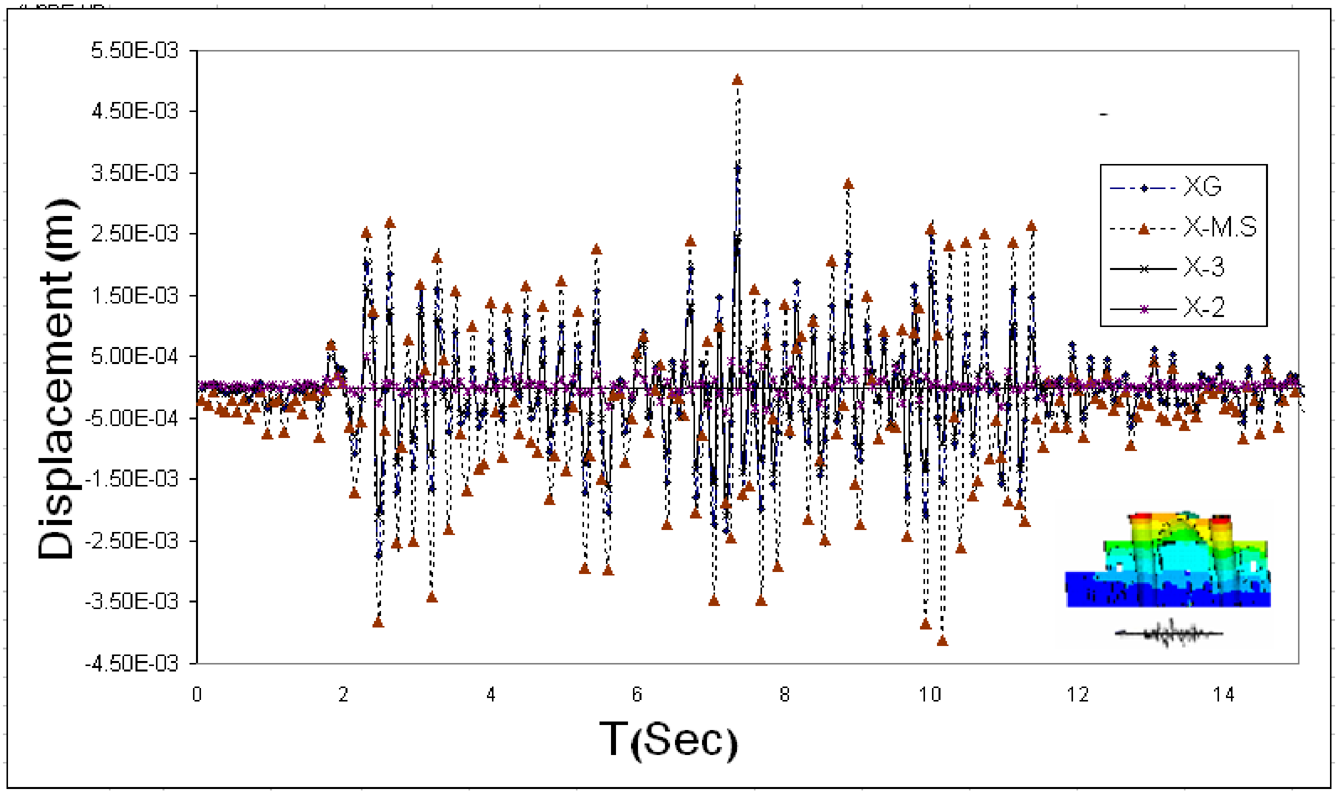

Figure 9. history of control point displacement due to seismic stimulation of Manjil earthquake accelerogram

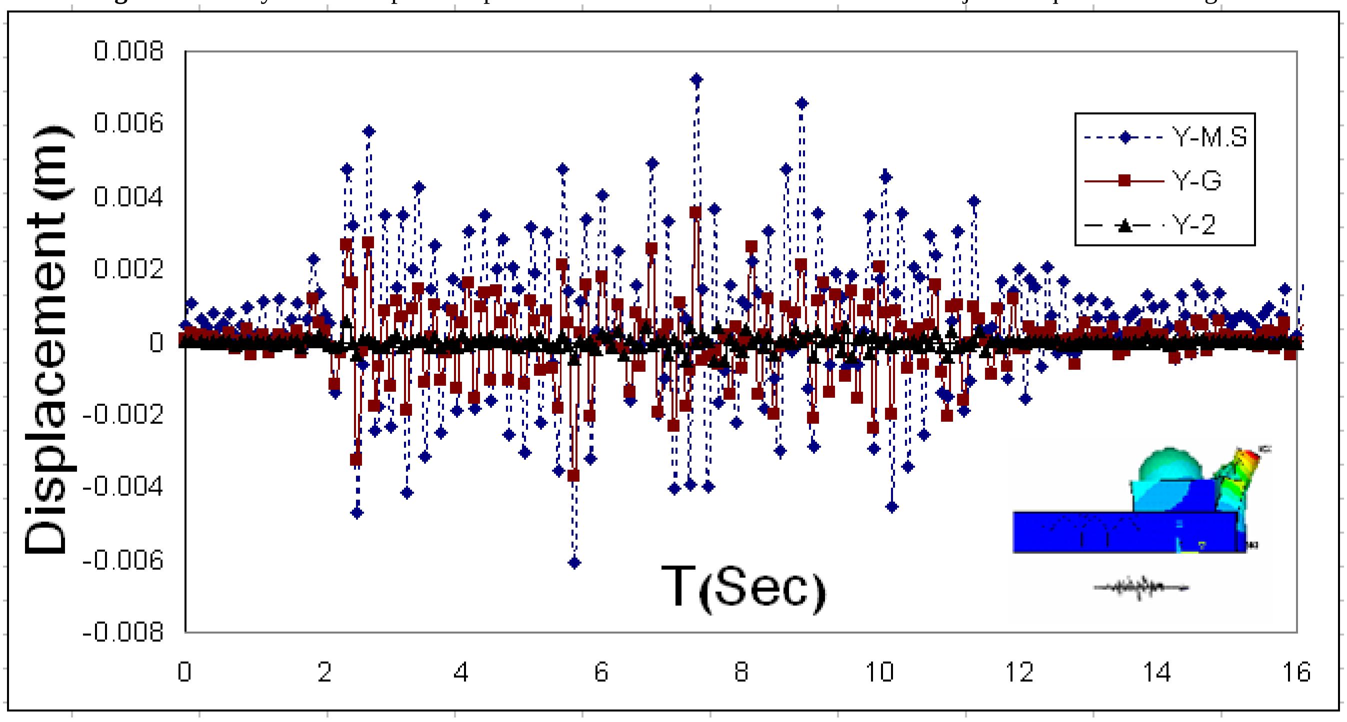

Figure 10. history of control point displacement due to seismic stimulation of Manjil earthquake accelerogram

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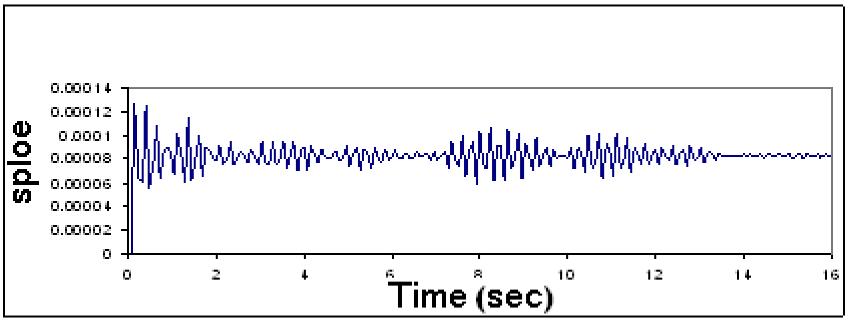

Figure 11. slope of the imaginary line connecting the tip of the minarets

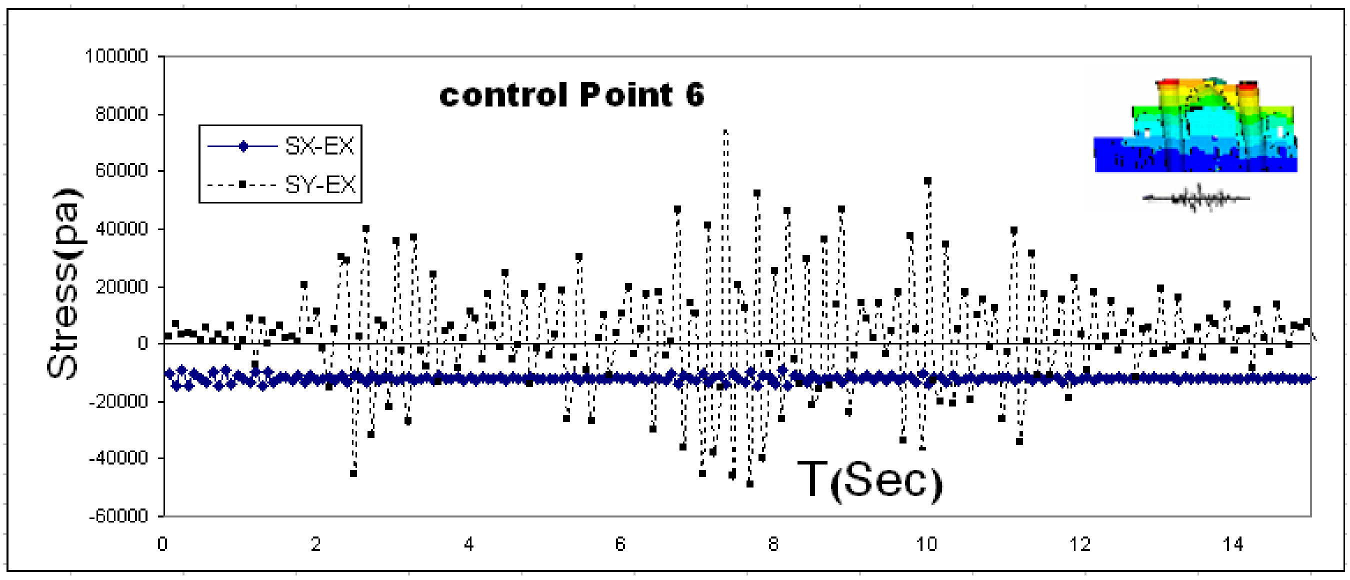

Figure 12. history of stress changes in the control point6 due to seismic stimulation of Manjil earthquake accelerogram

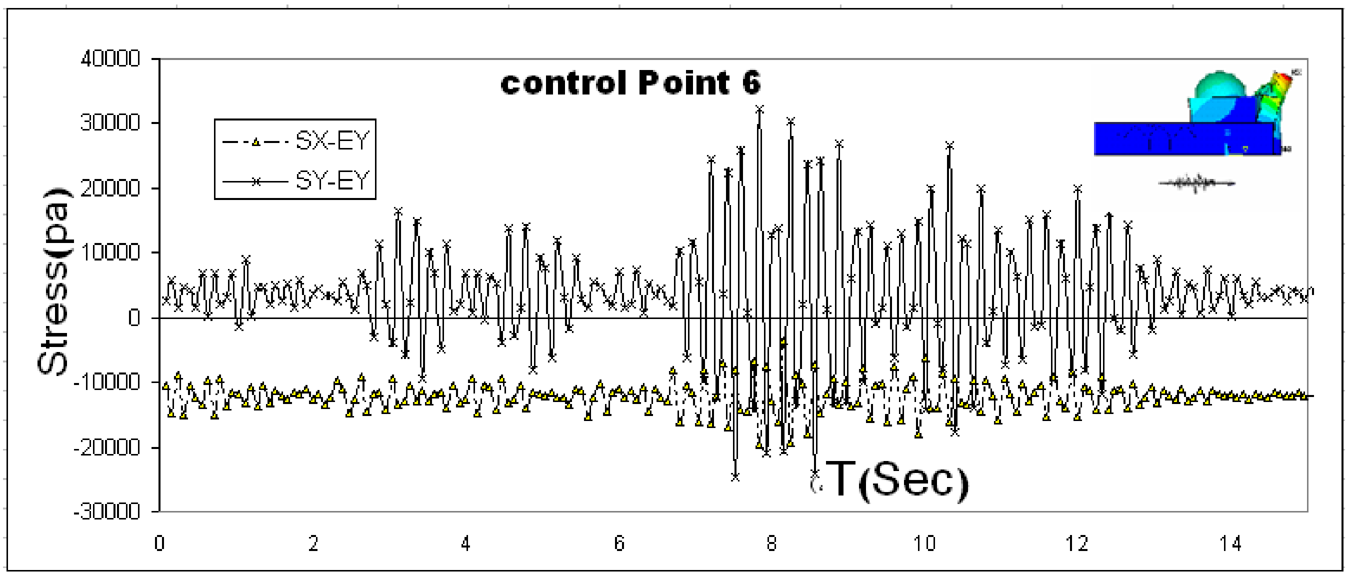

Figure 13. History of stress changes in the control point6 due to seismic stimulation of Manjil earthquake accelerogram

Figure 9 indicates history of control point's displacement due to seismic stimulation of Manjil earthquake accelerograms in the direction of the first axis. Great stiffness of the first floor is observable from this graph. Results of loading in the direction of second axis are presented in figure 10. Comparison of displacements in figures 9 and 10 indicate that maximum displacement of the top of minaret happens due to stimulation in the direction of second axis.

Figure 11 shows slope of the imaginary line connecting the tip of the minarets. However, using an imaginary lineconnecting the tip of the minaret, with positive counterclockwise slope in the direction of first axis, the history of an imaginary line slope is indicated in this figure. As it was considered in modal figures, this type of displacement relates to 2nd mode in the direction of first dominant axis. Figure 11 is also results of loading in the direction of the same axis.

Figures 12 and 13 also indicate history of stress changes in the control point6 due to seismic stimulation of Manjil earthquake accelerogram. As it is shown, seismic loading in the direction of first axis create a lot of tensile stresses in the direction of axis y of this point of the structure

.

CONCLUSION

Historical monument of Sheikh Shahab-edin Aharyis irregular in elevation and plan and is under its own weight loading under tensile stresses of the dome, and cracks of the dome is perpendicular to the normal tensile stresses.

In the first floor, the building is in good reinforcement and stiffness, and the third floor is softer than two other floors. In the case of providing a reinforcement plan, it should be stiffened in the upper levels. To load in the direction of second axis, higher values are available for displacements and tensions. Therefore, the building is vulnerable in this direction. Offering a plan for reinforcement of the building against seismic loads is of priority. Minarets, walls connecting the minarets that are considered as their couple arm, dome and the wall under it need reinforcement and improvement.

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