Investigation of the vulnerability of Arge Tabriz (Tabriz Citadel)

SADEGHI, ARJANG[1] ; POURAMINIAN, MAJID[2]

ABSTRACT: Arge Tabriz is a masonry historical building in the city of Tabriz, NE of Iran. This structure is composed of a U shaped wall with varying thicknesses. The average height of the building is 33 meter. To assess the seismic behavior of Arge Tabriz, a three dimensional model of the structure was established by ANSYS code. For the analysis of the masonry body of the building Solid65 and Solid95 elements was utilized. The results of nonlinear dynamic analyses show that the structure is very vulnerable to the earthquakes even with moderate PGAs as 0.3g.

Keywords: *Arge Tabriz, Historical building, seismic behavior, nonlinear dynamic analysis.*

1 BACKGROUND

Arge Tabriz or Tabriz Citadel is a huge historical brick masonry structure (Fig. 1) which has been built in Ilkhanid era (1336~1360 AD) in Tabriz, while it was the capital city of Iran in that period. This building seriously damaged during a strong ground motion in 1706. However, the remnants has been utilized as part of a military camp until 1931, when it was registered as a national heritage.

Fig. 1. Arge Tabriz general view

This building has been admired by many explorers for its glorious and adorned facets. However, at the time being, the remainings of Arge Tabriz are only three huge brick walls arranged in U shape

1 Assistant Professor, Civil Engineering Department, Azarbaijan University of Tarbiat Moallem, Tabriz, Iran, a.sadeghi@azaruniv.edu
2 M Sc of Civil Engineering, Azerbaijan University of Tarbiat Moalem

without the vault roof and any facets. The height of the building is 33 meter and its length in web side is 51.2 m and along flange walls is 21.1 m. There is an altar in the middle of inner side of the web wall. Also there are two openings in this wall at both sides of the altar. The average thickness of the wall is 10 meter.

Arge Tabriz is situated in a region that is very earthquake prone and has experienced several strong ground motions during last centuries especially the event of 1706. Although Arge Tabriz have survived these events, but it has gained some serious cracks which may lead it to collapse in future earthquakes. For this reason, it was decided to study seismic behavior of Arge Tabriz under expected earthquakes of Tabriz in both statically and dynamically.

2 MASONRY WALLS MODELS

Currently, there are three strategies to investigate masonry walls behavior by finite element method. These modeling strategies are categorized as a) detailed micro modeling, b) simplified micro modeling and c) macro modeling.

In detailed micro modeling strategy each brick or masony unit and mortars are modeled separately. In simplified micro modeling method, each masonry unit and half depth of its surrounding mortars is taken as an element. However, in macro modeling the units are neglected and the body of the masonry structure is modeled as a homogenous material.

3 STRUCTURAL MODEL

Arge Tabriz has about four millions bricks used in its construction and it is not possible to apply micro model strategies to this building, so macro model has been adapted in this research. The structures major cracks are modeled too (Fig. 2). Throughout this research, code of ANSYS is used to perform linear and nonlinear static and dynamic analyses of the building. In both static and dynamic linear analyses, element Solid45 is selected for modeling the body of the structure. However, for nonlinear static and dynamic analyses element Solid65 is used as the matrix body for nonlinear analyses. Since in threshold of initiation of crack, some numerical instability appears in finite element calculations of this type of elements, to overcome this problem, element Solid95 is used around existing cracks or wherever cracks are expected. Solid95 element is a singular element that resists singularity near tips of cracks.

The material physical properties are considered to be $\rho = 18000 N/m^3$, $\nu = 0.2$ and $E = 2200 MPa$.

Static analysis of Arge Tabriz under its own weight shows that the web and both the wing walls are tending inwards. However, their inward leaning magnitudes are not so large and vary from 7 mm on the western wing wall to 10 mm on the web wall. Also static analysis shows that both compression and tension stresses induced by dead load are considerably under permissible ones.

To investigate dynamic characteristics of Arge Tabriz, eigenvalue analysis was carried out with element Solid45. The results of eigenvalue analysis showed that in two longitudinal and transverse horizontal directions the main modes are among the few first modes. As another result the most significant modes in both directions were torsional modes (Fig. 3). This may be interpreted as the wing walls are not symmetric, so the building is very viable of torsion.

Another eigenvalue analysis of the building was carried out without considering existing cracks. Comparison of the results of two models shows that there in no considerable difference between the periods of the models with crack or without crack (Fig. 4). This is resulted because of low depth of cracks (depths of cracks are supposed to be between 30 and 90 cm) in comparison with the walls thicknesses, i.e. 10 m.

In nonlinear analyses, Drucker-Prager yielding criteria was utilized with the material properties of the masonry walls as $\phi = 20^\circ$ and $\eta = 15$ and $c = 10^5 Pa$. Also to model crack behavior, William-Warnke criteria was accepted. Following values are taken: $\beta_t = 0.01$, $\beta_c = 0.65$, $\sigma_c = 2.2 MPa$ and $\sigma_t = 0.2 MPa$ to satisfy this criteria.

4 STATIC NONLINEAR ANALYSIS

Static nonlinear analysis usually produces a good view from overall behavior of a structure. So, for both longitudinal and transverse directions, horizontal pushover analyses were performed. Pushover analysis in the direction of the web wall (x direction) showed that the structure enters nonlinear phase under a base shear around 20MN and fails under 30 MN. It is worth noting that equivalent static base shear according to Earthquake Loading Code of Practice of Iran (Code 2800), taking a behavior factor R=1.25, is 300 MN. It is obvious that the building is very weak against such an enormous natural induced force.

The second pushover analysis in the direction of flange walls (y direction) showed even less elastic base shear capacity, namely 20 MN. However, this direction showed more ductility, and the same amount of final resistance (Figs. 5 & 6).

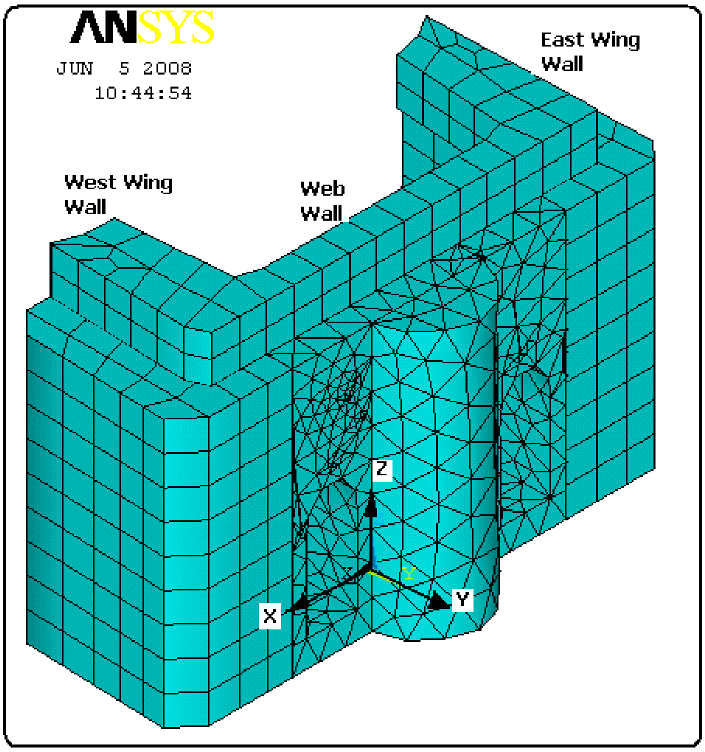

Fig. 2. Finite element model of Arge Tabriz

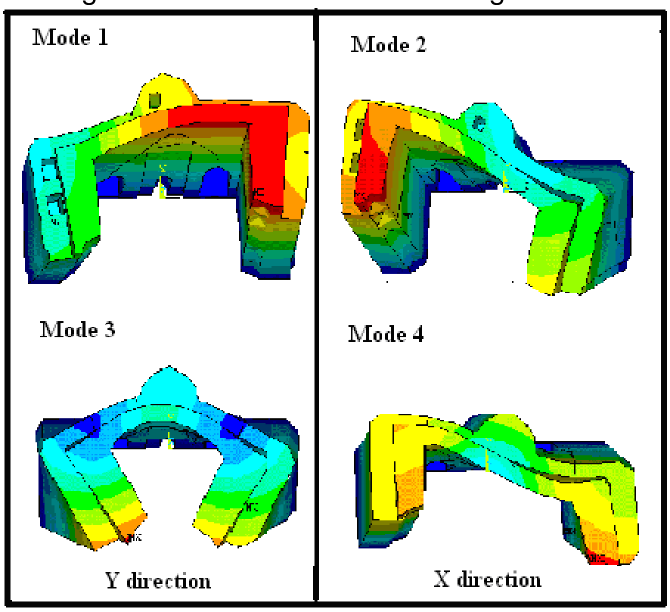

Fig. 3. Some effective modes of Arge Tabriz

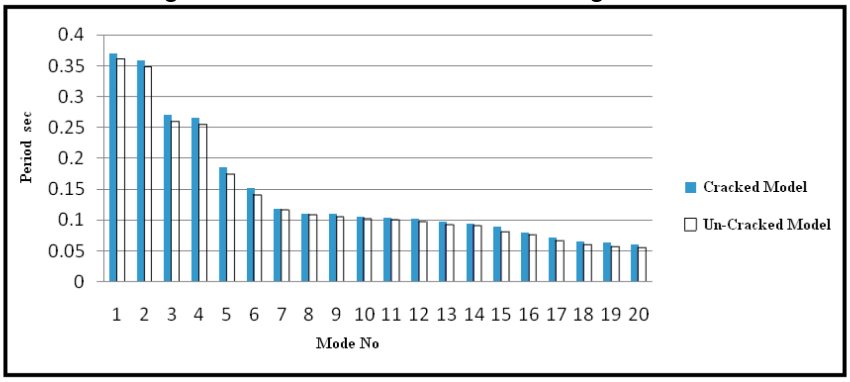

Fig. 4. Comparison of cracked and uncracked models

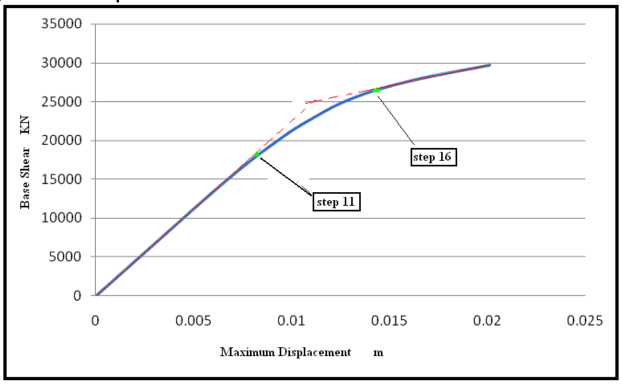

Fig. 5. Pushover analysis result of x direction

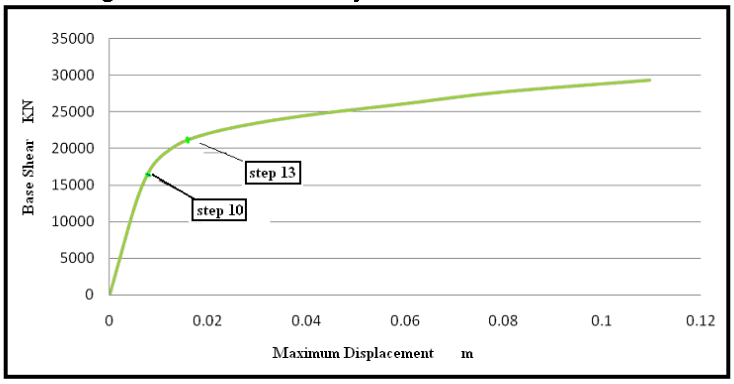

Fig. 6. Pushover analysis result of y direction

4 DYNAMIC LINEAR AND NONLINEAR ANYALYSIS

A recent site investigation supported by Cultural Heritage Organization of Iran (1) has shown that Arge Tabriz is built on an earth type 4, that is weak soil, with T_0 =1 sec. In this regard, from a set of selected strong accelerograms, a record of Chi-Chi 1999, Taiwan, in soil type 4 having PGA= 0.3g was selected (accelerogram No 1) for dynamic analysis. To accommodate the accelerograms to formal regional design spectrum, it was scaled to 0.53 g (accelerogram No II) following UBC97. Another scaling was performed to achieve 0.64g corresponding to Maximum Credible Earthquake (MCE) of Tabriz (accelerogram No III) introduced by Zare and Shahpasand Zade (2).

At first a set of linear dynamic analyses were carried out using the above mentioned three accelerograms. Analyses results showed that under accellerograms No II and No III, compression stress (Fig. 7) exceeds the bearing strength of masonry walls, i.e. 2.2 MPa, for some regions and tension stresses overpass material yield stress, that is 0.2 MPa, for some other regions (Fig. 8).

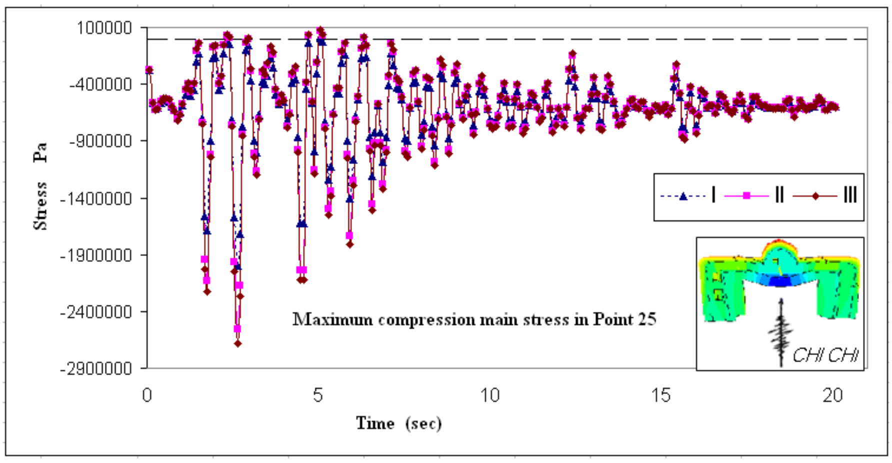

Fig. 7. Stress time-history versus scaled No II Chi-Chi accellerogram

To investigate the stress pattern in more rational state, nonlinear dynamic analyses were carried out in two methods:

a) By considering homogeneous nonlinear material behavior
b) By assuming nonlinear material behavior capable of showing cracks

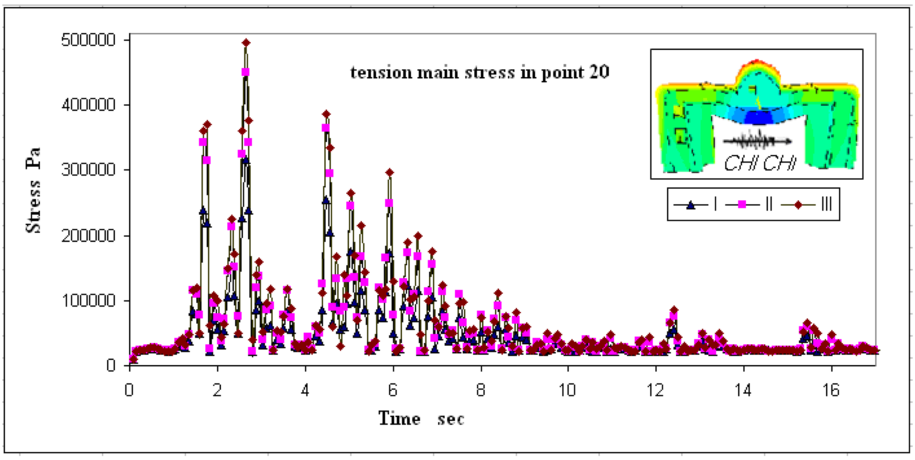

Fig. 8. Stress time-history under scaled and unscaled accellerograms

The homogenous nonlinear results showed that displacements of the structure is about two times larger than the the linear analysis results (Fig. 9). Also, compression stresses which in some points were 1.9 MPa and 2.5 MPa in linear dynamic analysis under accellerogram No II (PGA= 0.53g), (Figs. 7 & 10), approached 2.4 MPa and 3.1 MPa in nonlinear dynamic analysis, respectively, where in such stresses the material would crash.

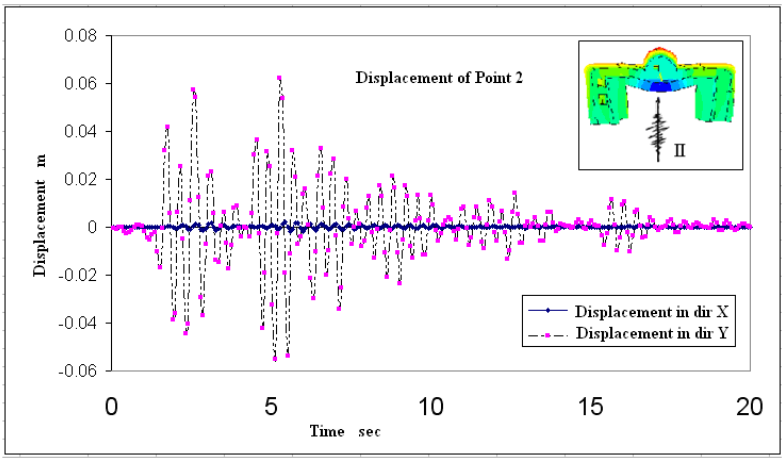

Fig. 9. Displacement time-history under No II Chi-Chi accellerogram

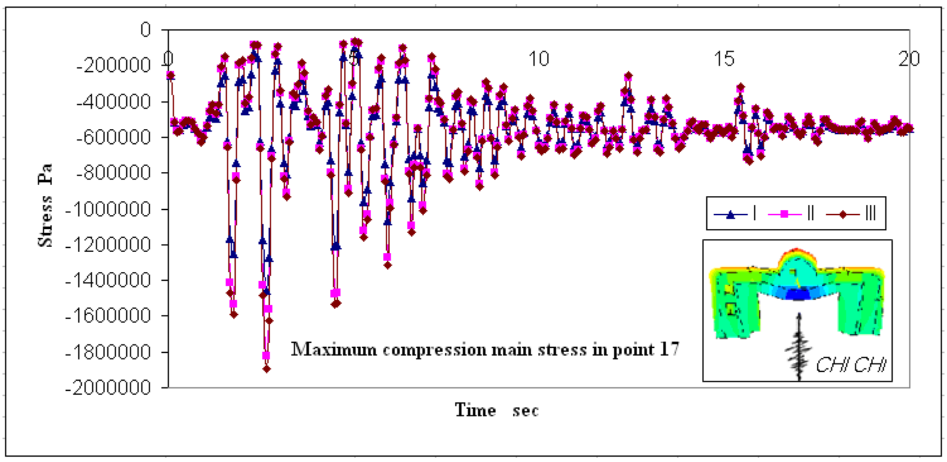

Fig. 10. Stress time-history under scaled and unscaled accellerograms

Tension stresses, too, in some points reached 0.7 MPa which is much higher than the material yield stress, namely 0.2 MPa. Although this method is not capable of showing potential cracks, but the stress amount implies that some points in the structure will experience cracks (Figs. 11 & 12 above alter).

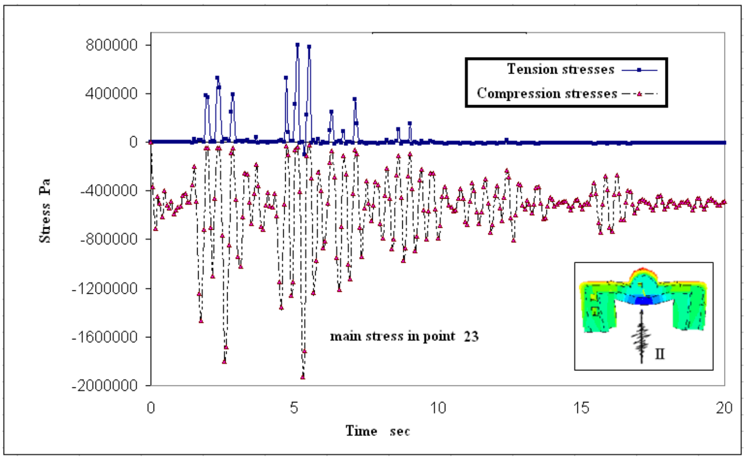

Fig. 11. Stress time-history under No II Chi-Chi accellerogram

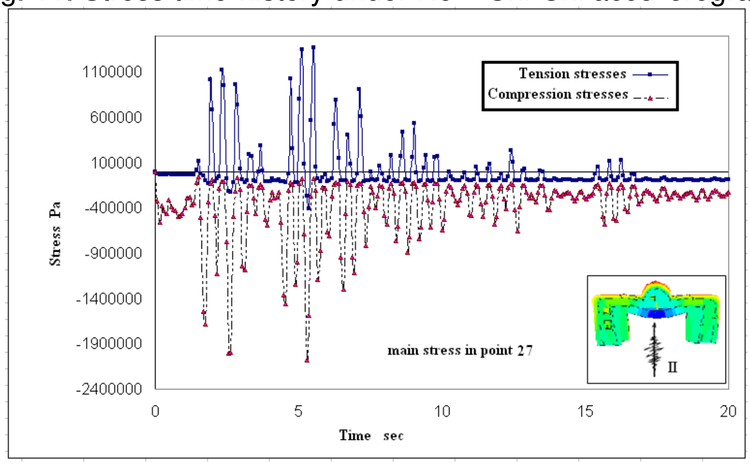

Fig. 12. Time-history under No II Chi-Chi accellerogram

Nonlinear dynamic analysis by the second method (smeared) is a suitable method to check the possiblity of crack appearance. So this method was carried out using capabilities of element Solid 95 of ANSYS. In this case, nonlinearity of material was introduced through William-Warnke criteria.

The analysis results indicated that under Chi-Chi earthquake along x direction (Fig. 13) with scaled PGA= 0.3g and along y direction (Fig. 14) with scaled PGA=0.12g, the masonry building collapses. More investigation with accellerogram of Erzincan 1992, Turkey, also showed that the structure collapses with scaled PGA=0.3g. Erzincan earthquake was selected because it is the nearest record to Tabriz and its source fault is in the same seismic belt. As Fig. 15 illustrates, the collapse of the structure is simultaneous with reaching compression stress to 2.2 MPa in point 17.

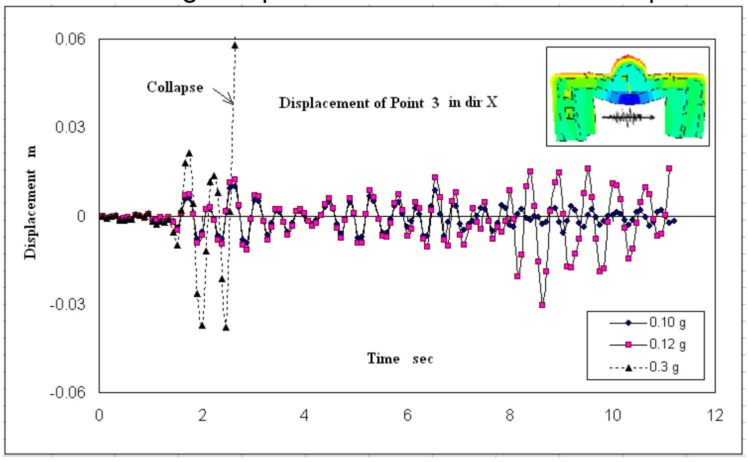

Fig. 13. Displacement time-history under Chi-Chi accellerogram

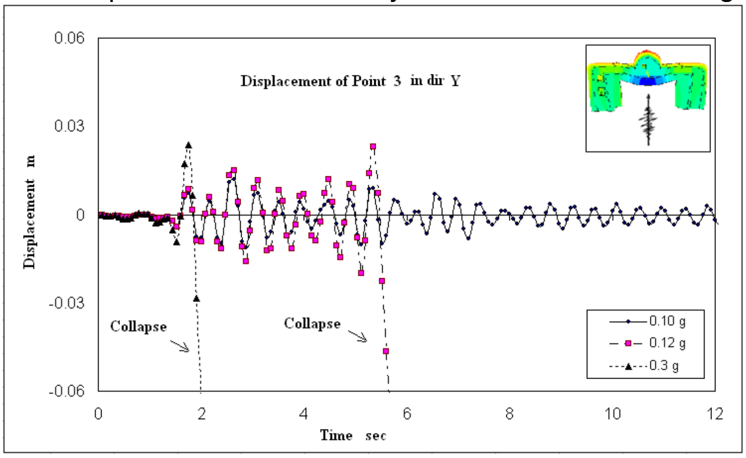

Fig. 14. Displacement time-history under Chi-Chi accellerogram

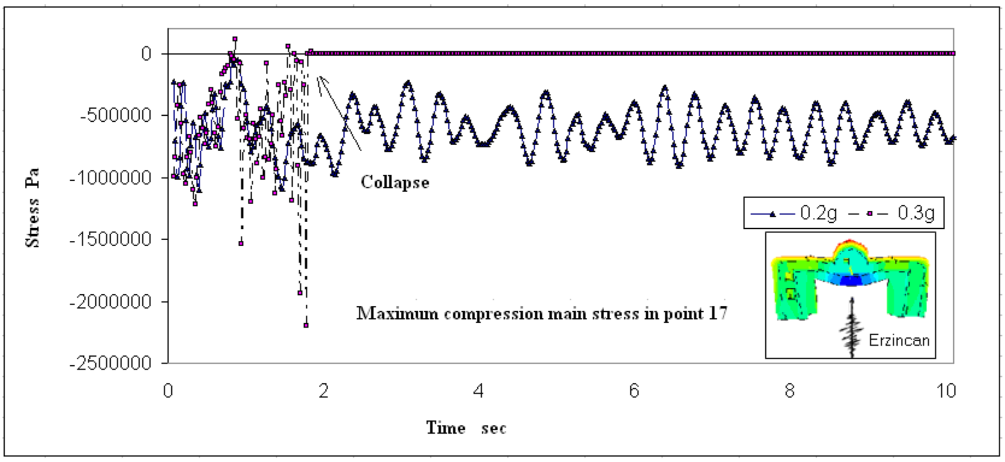

Fig. 15. Displacement time-history under Erzincan accellerogram

5 CONCLUSIONS

Arge Tabriz has been a symbol of strength and stability in the city of Tabriz for about 700 years. It has survived many natural and political crises. However, the current situation of the structure necessitates payment of more attention to this building and strengthening and retrofit of this cultural heritage.

Through different analyses carried out in the course of this research, the following results were obtained:

1- While the gravity capacity of the structure is high, its lateral resistance to equivalent static loading is not enough.
2- Dynamic bearing capacity of the structure in y direction, along wing walls, is less than x direction, along web walls. One reason for this may be the existence of numerous cracks scattered in the web wall. Therefore, web wall has the most vulnerable wall in comparison with two other walls.
3- The seismic sensitivity of two wing walls is different. Vulnerability of East wing wall under x direction excitation and vulnerability of west wall under y direction earthquake are higher.
4- Arge Tabriz walls remains stable up to 0.25g for both Chi-Chi and Erizincan accelerograms. However, the structure loses its stability in 0.3g while according to historical documents and a recent investigation, the Maximum considered earthquake for Tabriz could be as high as 0.64g.

6 REFERENCES

1- Koban-Kav consulting engineers Inc. : Geotechnical investigation Report of Imam Mosalla – Tabriz, 1998.

2- Zare, M. and Shahpasand Zade. : Elementary investigation of seismicity, seismotectonics and seismic risk of East Azarbaijan. International Institute of Seismology and Earthquake Engineering, Tehran, Iran, 1995.