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Effect of Damping Ratios on the Seismic Behavior of a Historical Masonry Guesthouse Building

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ABSTRACT

The dynamic parameters obtained depending on the existing structural properties, material properties, boundary and damage condition are quite effective on the behavior of the structures under the effect of dynamic loads. These dynamic parameters have characteristic features for each structure. In this study, the effect of damping ratio, which is one of the dynamic characteristics, on the seismic behavior of historical structures was studied. For this aim, historical masonry Guesthouse Building belong to the Church of Santa Maria was selected to examined. Linear time history analyses were performed for three different damping ratios as 2%, 5%, and 10%. The horizontal component of Erzincan Earthquake (1992) was used in linear time history analyses. The maximum displacement, principal stress and strain values obtained from performed linear time history analyses for different damping ratios were compared. It is observed that, displacement, stress and strain values increase as the damping ratio decrease when the results are examined. It is concluded that, damping ratio is the important parameter for the evaluation of seismic response of historical masonry structures which are weak to external effect especially earthquake. Therefore, the damping ratios should be obtained with experimental tests before the numerical evaluation of seismic behavior.

Keywords: Damping ratios, Historical masonry structures, Finite element method, Seismic analysis

Sönüm Oranlarının Tarihi Bir Yığma Konukevi Binasının Sismik Davranışına Etkisi

ÖZET

Mevcut yapı özelliklerine, malzeme özelliklerine, sınır ve hasar durumuna bağlı olarak elde edilen dinamik parametreler, yapıların dinamik yükler etkisindeki davranışları üzerinde oldukça etkilidir. Bu dinamik parametreler her yapı için karakteristik özelliklere sahiptir. Bu çalışmada, dinamik özelliklerden biri olan sönüm oranının tarihi yapıların sismik davranışına etkisi incelenmiştir. Bu amaçla Santa Maria Kilisesi'ne ait tarihi yığma Konukevi binası incelenmek üzere seçilmiştir. %2, %5 ve %10 olmak üzere üç farklı sönüm oranı için doğrusal zaman alanı analizleri yapılmıştır. Erzincan Depremi'nin (1992) yatay bileşeni doğrusal zaman tanım alanı analizlerinde kullanılmıştır. Farklı sönüm oranları için gerçekleştirilen doğrusal zaman alanı analizlerinden elde edilen maksimum yer değiştirme, asal gerilme ve gerinim değerleri karşılaştırılmıştır. Sonuçlar incelendiğinde, sönüm oranı azaldıkça yer değiştirme, gerilme ve gerinim değerlerinin arttığı gözlemlenmiştir. Sönüm oranının, başta deprem olmak üzere dış etkilere karşı zayıf olan tarihi yığma yapıların sismik davranışının değerlendirilmesinde önemli bir parametre olduğu sonucuna varılmıştır. Bu nedenle sismik davranışın sayısal olarak değerlendirilmesinden önce sönüm oranları deneysel testler ile elde edilmelidir.

Anahtar Kelimeler: Sönüm oranları, Tarihi yığma yapılar, Sonlu elemanlar yöntemi, Sismik analiz

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1. Introduction

Historical structures were built with simple materials such as stone, brick, mortar and wood. However, their structural behaviors are very difficult to evaluate and cannot be made with easy numerical calculations. This is because of the non-homogeneity form of the material, complex geometric construction, different workmanship etc. Although it is difficult to evaluate their structural behavior, historical buildings are the focus of researchers due to their cultural values.

Historical masonry structures have a big place in the cultural heritage. These structures have become an advertising tool for the regions they are located in and have guided societies in social, cultural and economic terms. However, these structures are seriously threatened by both natural and manmade forces over the course of time (Altunışık et al., 2017). Historical structures can be exposed to many different reasons such as earthquakes, floods, fires, wars, vandalism, deterioration in construction material, support settlement, deformations etc. (Toker and Ünay, 2004). Therefore, in order to survive them they must be preserved well. Conservation and restoration is a private and serious business. Any intervention without a comprehensive knowledge of the building to be restored can often do more harm than good to the building. Therefore, such structures should be examined experimentally and numerically before starting the restoration.

The finite element (FE) method has been widely used to evaluate the structural behavior and safety of historical structures. FE analyses can give good prediction about structural behavior of these structures (Altunışık et al. 2018). However, the input parameters of FE models should be corrected in order to supply precise results. For this aim, non-destructive experimental methods are used in the literature. Numerical studies validated and updated using non-destructive experimental measurement results are more suitable and reliable for the historical masonry structures (Gentile and Saisi, 2007; Votsis et al., 2012; Altunışık et al., 2016). With the help of experimental studies, the strength values of the building material can be estimated, and the dynamic characteristics of the structure such as frequencies, mode shapes and damping ratios can be obtained. Thus, numerical models can be improved or updated with obtained experimental data.

In this paper, the effect of damping ratio changes, which is the input parameter of numerical seismic analysis, on the structural behavior is investigated. In the literature, different damping ratio values suggested for masonry structures (Benedetti et al., 1998; Juhásová et al., 2008; Mazzon et al., 2009). Three different damping ratios (2%, 5%, 10%) are considered in the analyses, and displacements, principal stresses and principal strains are obtained and compared with each other.

2. Description of the Guesthouse Building

The Guesthouse Building belong to the Church of Santa Maria was selected to examined in this study. The building is located in the city of Trabzon, Turkey. Although there is no written source, the construction date of the building is estimated as the 1950s due to two dates occurrence on the wall of building indicating the years 1852 and 1854.

The Guesthouse Building consists of a total of five floors: one basement, three normal floors and one garret. The structural system of the building is masonry type. The main outer masonry walls are made of stone material, the inner walls, the northern extension and the garret are made of brick material. The basement floor ceiling of the building is crossed with a vault structure. Apart from this part, the basement floor ceiling is reinforced concrete and the slab of the bathrooms on the 1st normal floor is also reinforced concrete. Except for these parts, the floors of the building were made with wooden material. The height of the building is approximately 19m. Some views of the Guesthouse Building are given in Figure 1.

Figure 1. Views of the Guesthouse Building

3. FE Model of the Guesthouse Building

The FE model of the Guesthouse Building was constituted in Abaqus software by using macro modeling method and linear tetrahedron C3D4 finite element with 4 nodes (Abaqus, 2016). Mesh size of FE model is selected as 50cm. For this mesh size 36,234 nodes and 122,661 elements were formed. While fixed boundary condition was considered in modal analyses, displacement on the bottom of the model was released in the direction of the earthquake load in time history analyses. Figure 2 presents some views of FE model of the Guesthouse building.

The elastic material parameters considered in the FE model are given in the Table 1. These properties were obtained from the FE model updating process with calibrating the numerical model by results of Operational Modal Analysis (OMA) test.

The first three natural frequencies were achieved between 1.523Hz and 9.520Hz. Related mode shapes were obtained as transverse, longitudinal and torsional modes, respectively (Figure 3).

4. Linear Time History Analysis

Effect of the damping ratio on seismic performance of structures was examined by using linear time history analysis. The horizontal component of Erzincan Earthquake (1992) was selected as ground motion record (Figure 4). The ground motion record was applied on the 1st mode direction. Three different damping ratios, 2%, 5% and 10%, were considered in the analyses.

Table 1. The elastic material parameters used in the FE model

Elements	Young's modulus (N/m^2)	Poisson Ratio (-)	Density (kg/m^3)
Outer masonry walls	1.20E9	0.2	2300
Inner masonry walls	1.25E9	0.2	1750
Wooden floor	5.00E8	0.2	500
Jamb	1.50E9	0.2	2300
Stone Column	2.0E10	0.2	2300
Reinforced Concrete	2.0E10	0.2	2400

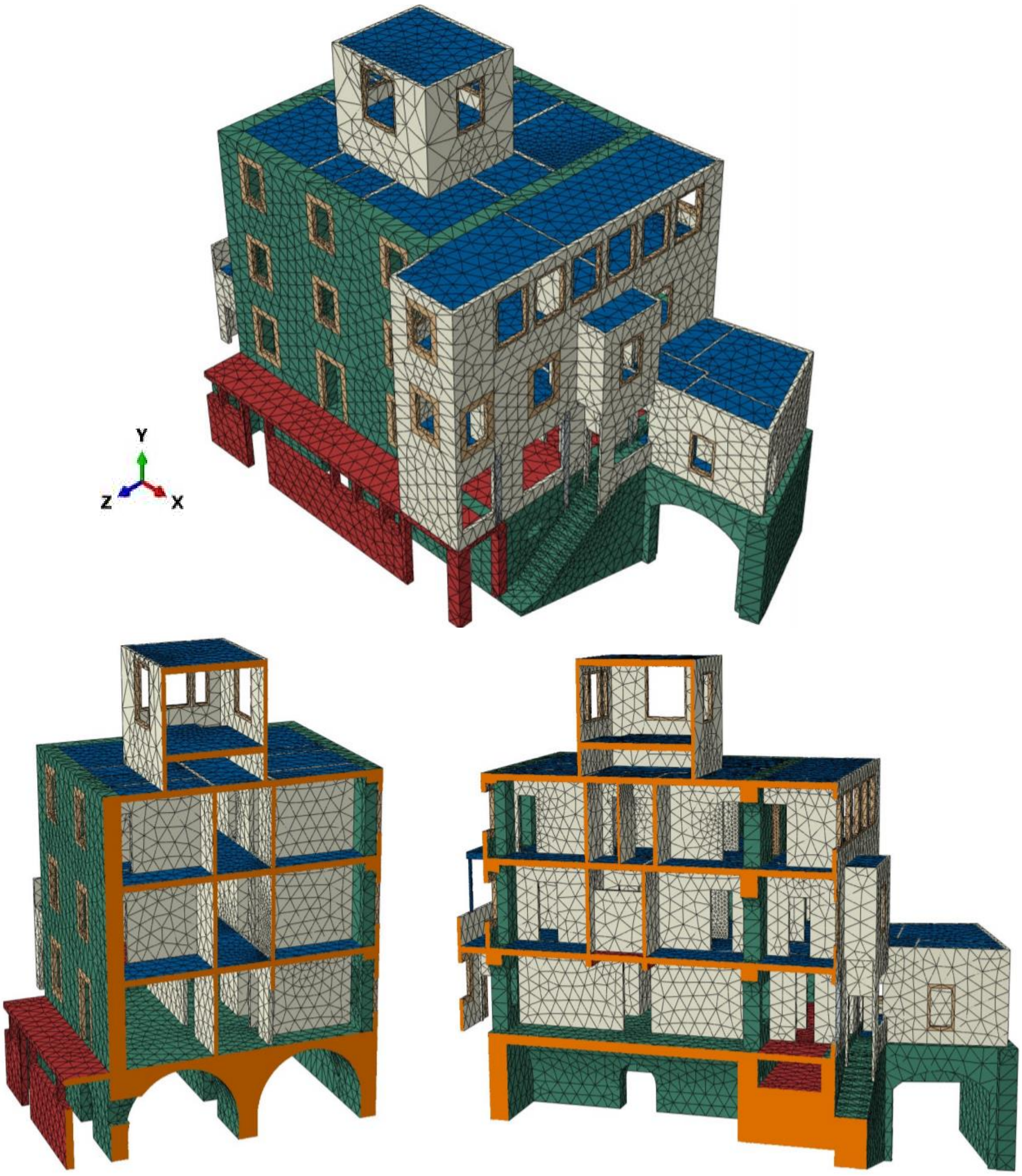

Figure 2. Some views from the FE model of the Guesthouse Building

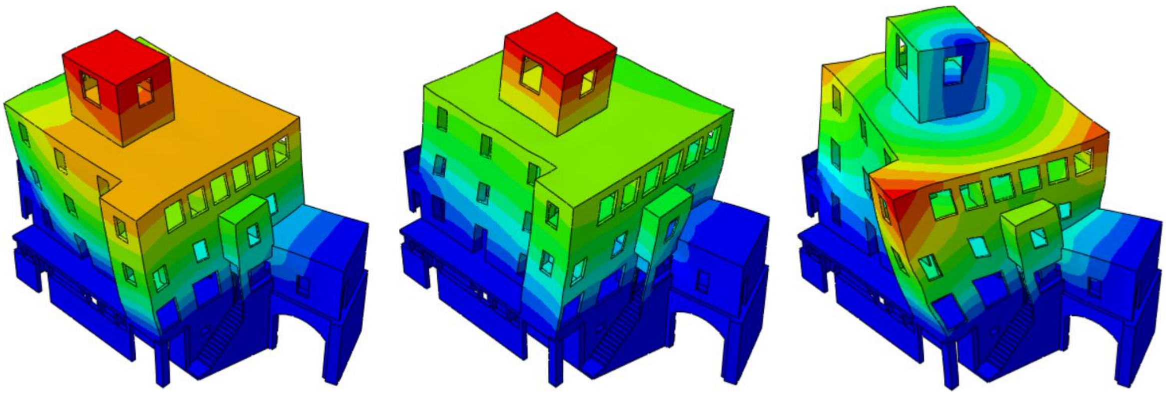

Figure 3. The first three natural frequencies and related mode shapes

The maximum displacement contour diagrams and time histories of drift ratios obtained from the linear time history analyses are given in Figure 5. It can be seen that the displacements show an increasing trend from the base to top point of the Guesthouse building. Also, the drift ratios decrease with the increasing of damping ratio. Maximum drift ratios were calculated as 0.13%, 0.11% and 0.08% for 2%, 5% and 10% damping ratios, respectively.

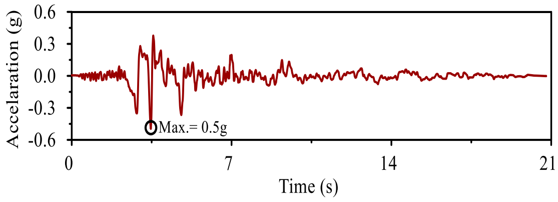

Figure 4. The time-history of ground motion acceleration record

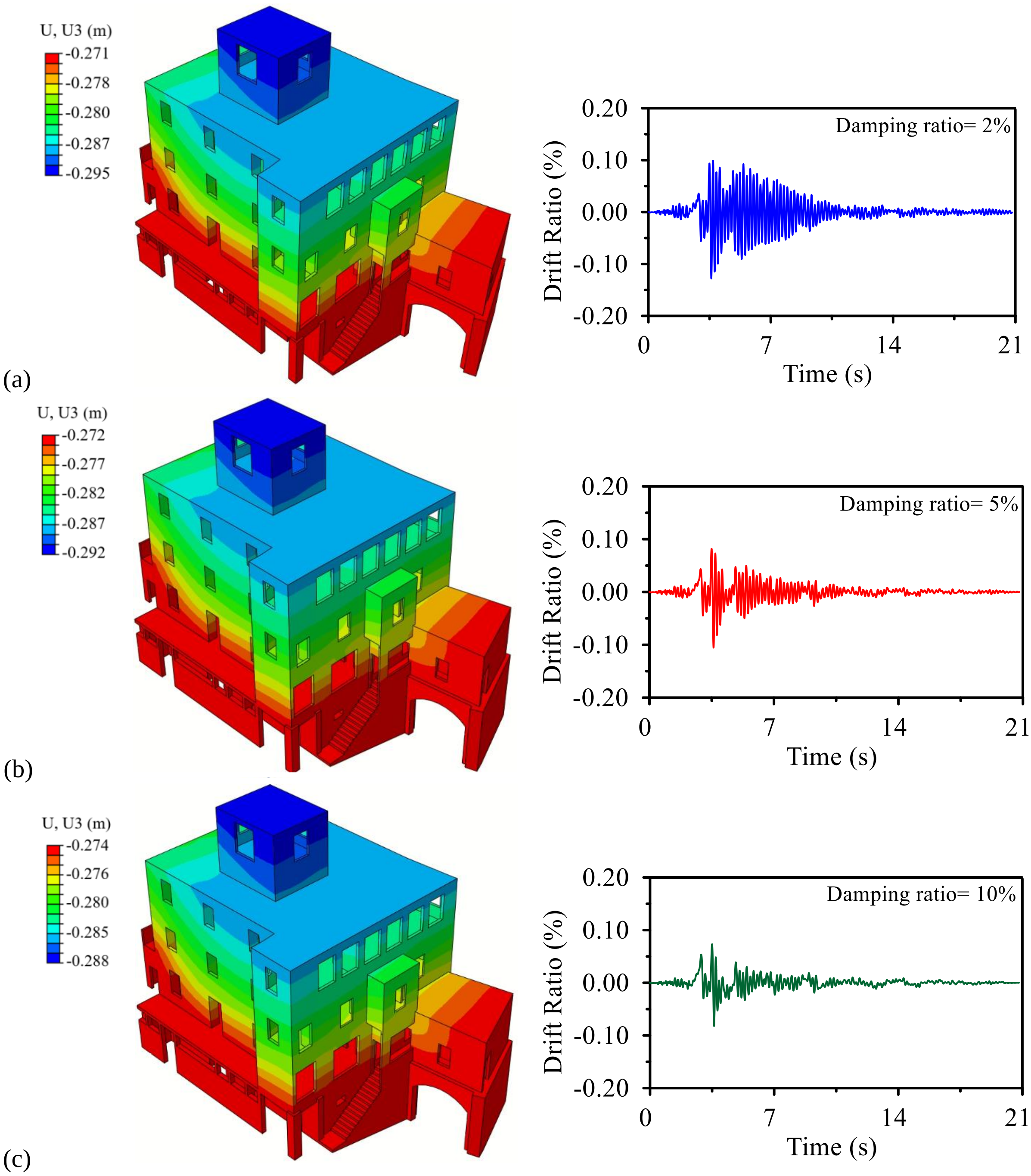

Figure 5. Maximum displacement contour diagrams and time histories for (a) 2%, (b) 5% and (c) 10% damping ratio

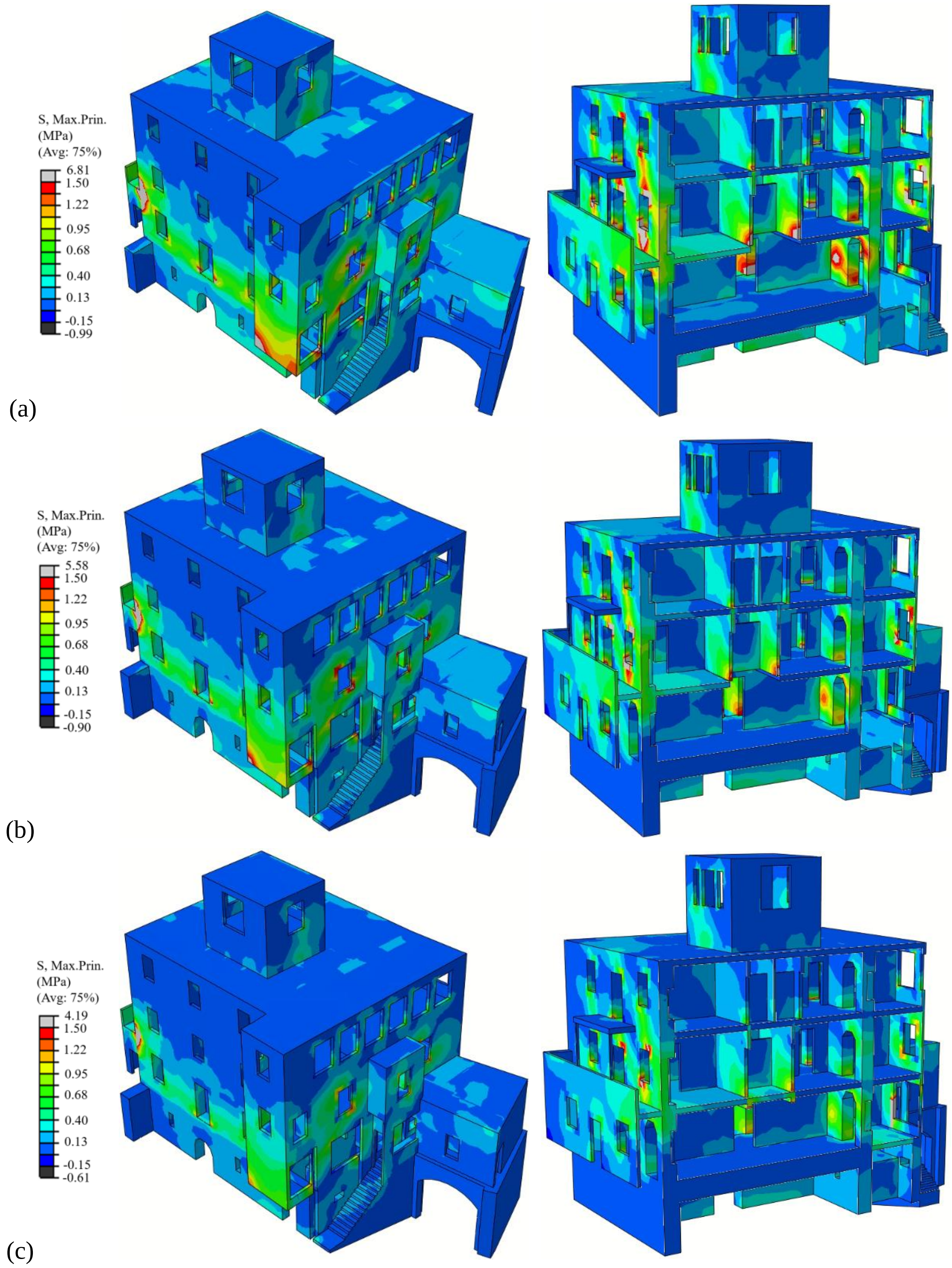

Figure 6. Max principal stress contour diagrams for (a) 2%, (b) 5% and (c) 10% damping ratio

Maximum principal stresses occurred on crossing point of inner masonry walls in all analyses carried out by using different damping ratios. Figure 6 shows the maximum principal stress contour diagrams. Figure 7 also shows the maximum principal stress time histories for damping ratios. The maximum principal stress values were obtained as 6.81MPa, 5.58MPa and 4.19MPa for 2%, 5% and 10% damping ratios, respectively. These values are the peak values obtained from the local points. The general stress distributions in the Guesthouse building are between 0.68MPa-1.22MPa. It can be seen that the maximum principal stress values show a decreasing trend as the damping ratio increases.

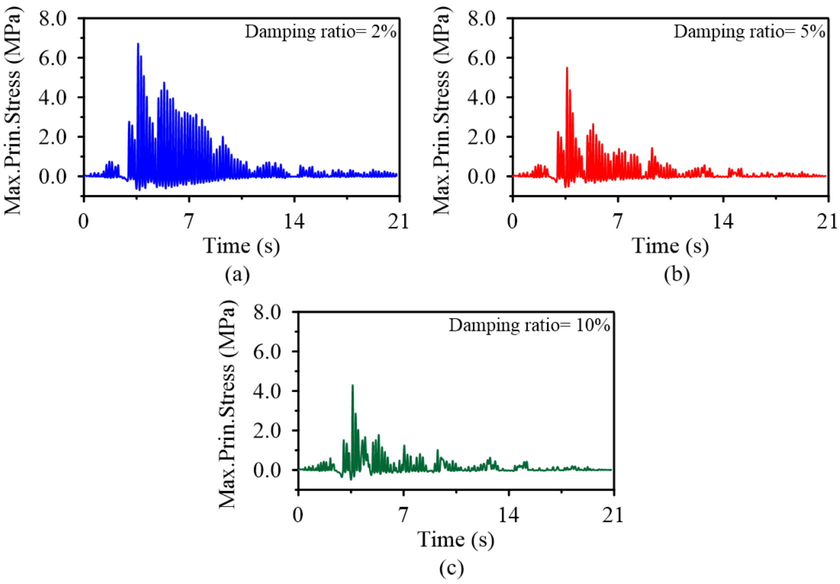

Figure 7. Max. principal stress time histories for (a) 2%, (b) 5% and (c) 10% damping ratio

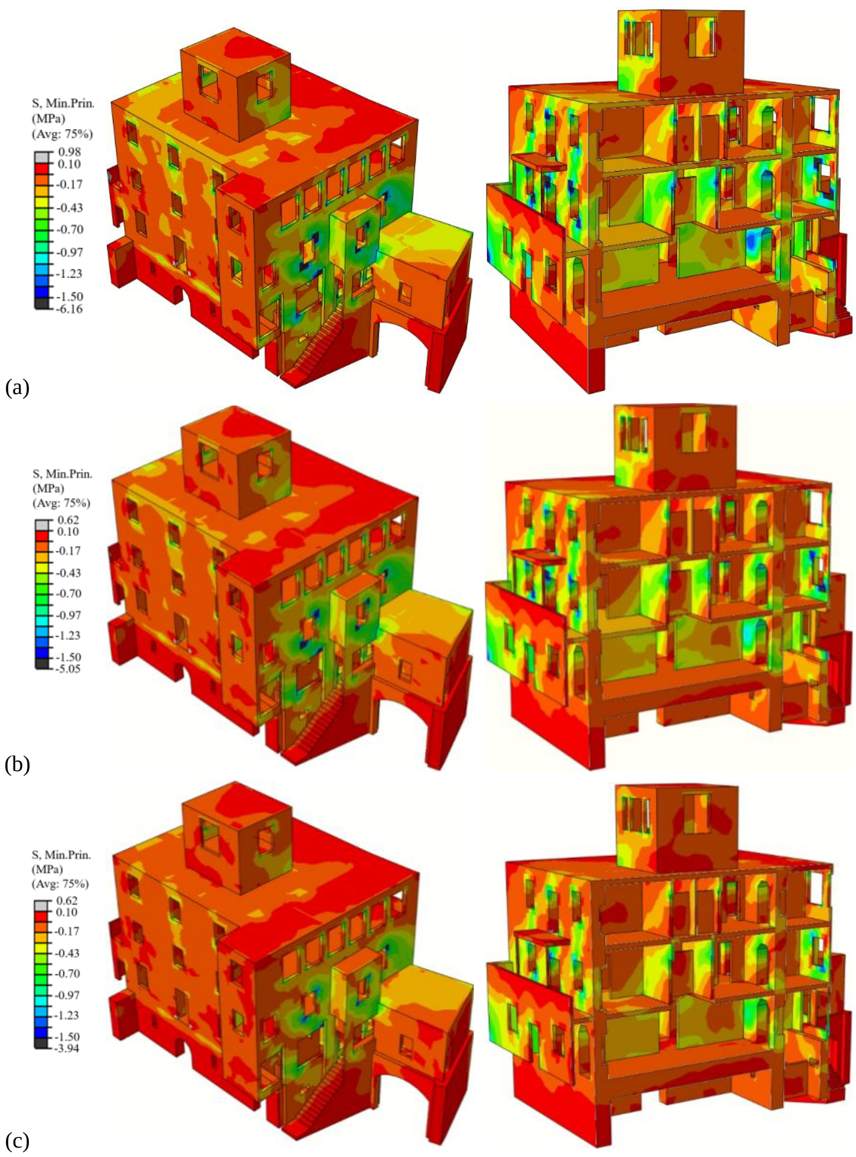

Figure 8. Min. principal stress contour diagrams for (a) 2%, (b) 5% and (c) 10% damping ratio

Similar to maximum principal stresses, minimum principal stresses occurred on local crossing point of inner masonry walls as 6.16MPa, 5.05MPa and 3.94MPa for 2%, 5% and 10% damping ratios, respectively. The minimum principal stress contour diagrams are given in Figure 8. Figure 9 also shows the minimum principal stress time histories for each damping ratios. The general stress distributions in the Guesthouse building are between 0.70MPa-1.23MPa. The increase in damping ratio caused a decrease in the minimum principal stress values. The relationship between the maximum and minimum principal stress values is given in Figure 10.

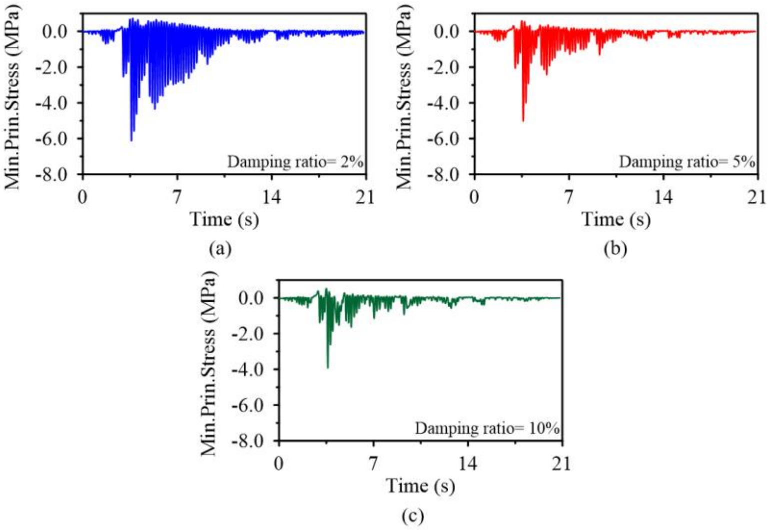

Figure 9. Min. principal stress time histories for (a) 2%, (b) 5% and (c) 10% damping ratio

The maximum and minimum principal strains occurred crossing point of inner masonry walls for each damping ratio. Figures 11 and 12 present the maximum and minimum principal strain contour diagrams. Figures 13 and 14 also shows the maximum and minimum principal strain time histories. It can be clearly seen that both the maximum and minimum principal strains decrease depending on the increase in damping ratio. The relationship between the maximum and minimum principal strain values obtained from the analyses performed by using different damping ratios is given in Figure 15.

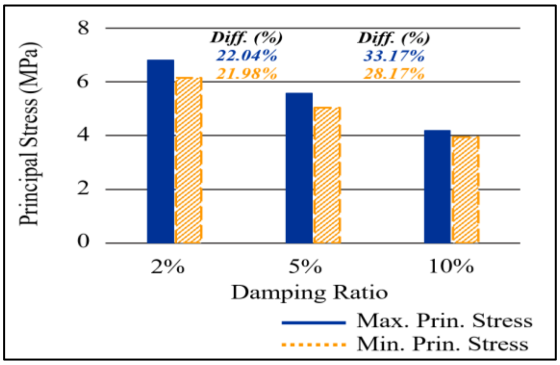

Figure 10. Comparison of the principal stresses

The maximum displacement, maximum and minimum principal stress and strain values obtained from analyses performed by using 2%, 5% and 10% damping ratios are given in Table 2 as comparatively. Table 2 shows that the effect of damping ratio on the seismic response of the structures is significant.

5. Conclusion

This study presents the seismic response of a historical masonry Guesthouse Building belong to the Church of Santa Maria located in the city of Trabzon, Turkey based on different damping ratios. The following conclusions have been drawn as a result of the study:

- The first three natural frequencies were obtained as 5.21Hz, 6.16Hz and 7.49Hz respectively. Mode shapes of these frequencies are translation modes and torsional mode.
- Maximum drift ratios were calculated as 0.13%, 0.11% and 0.08% for 2%, 5% and 10% damping ratio, respectively.

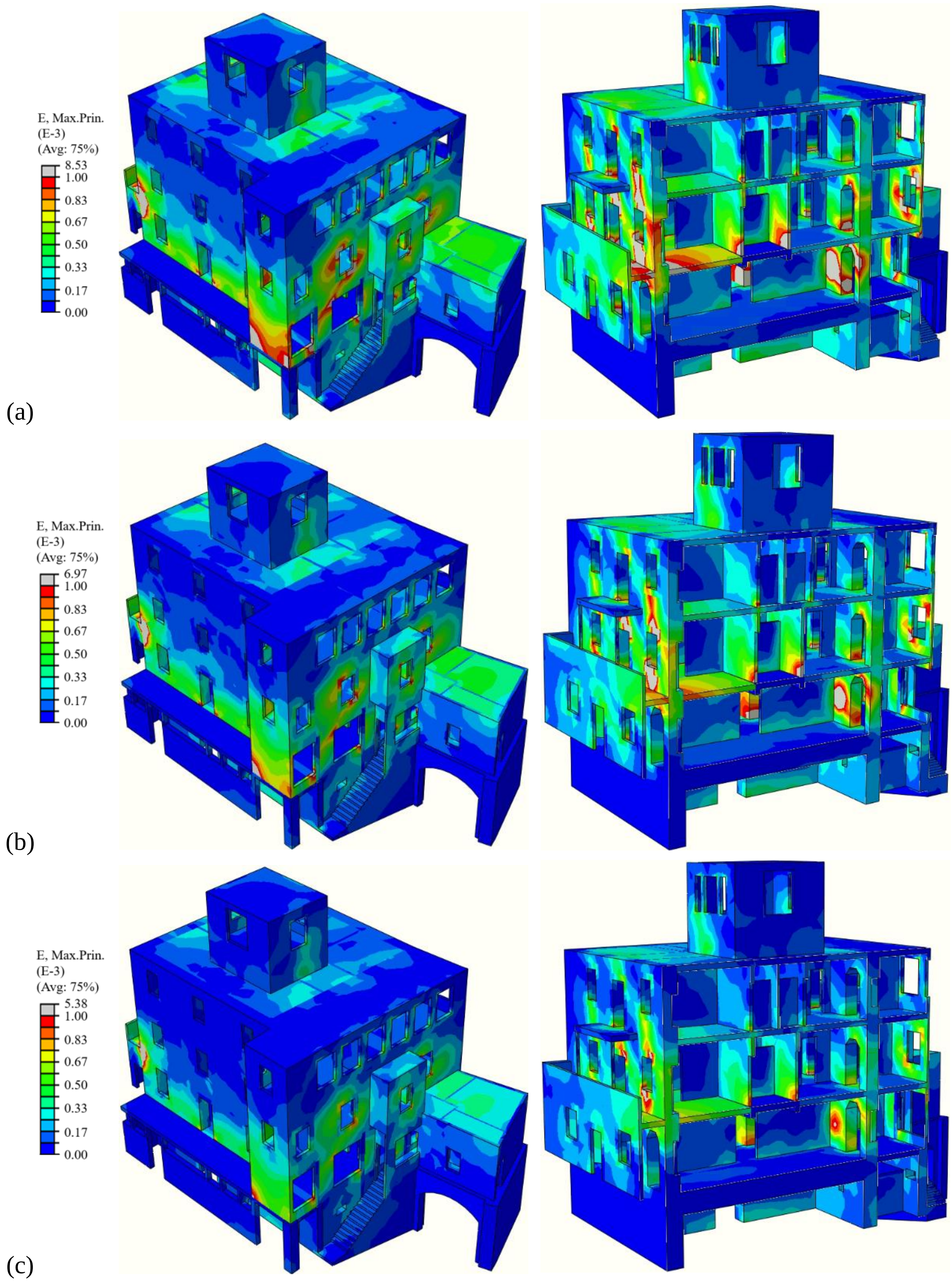

Figure 11. Max. principal strain contour diagrams for a) 2%, b)5% and c)10% damping ratio

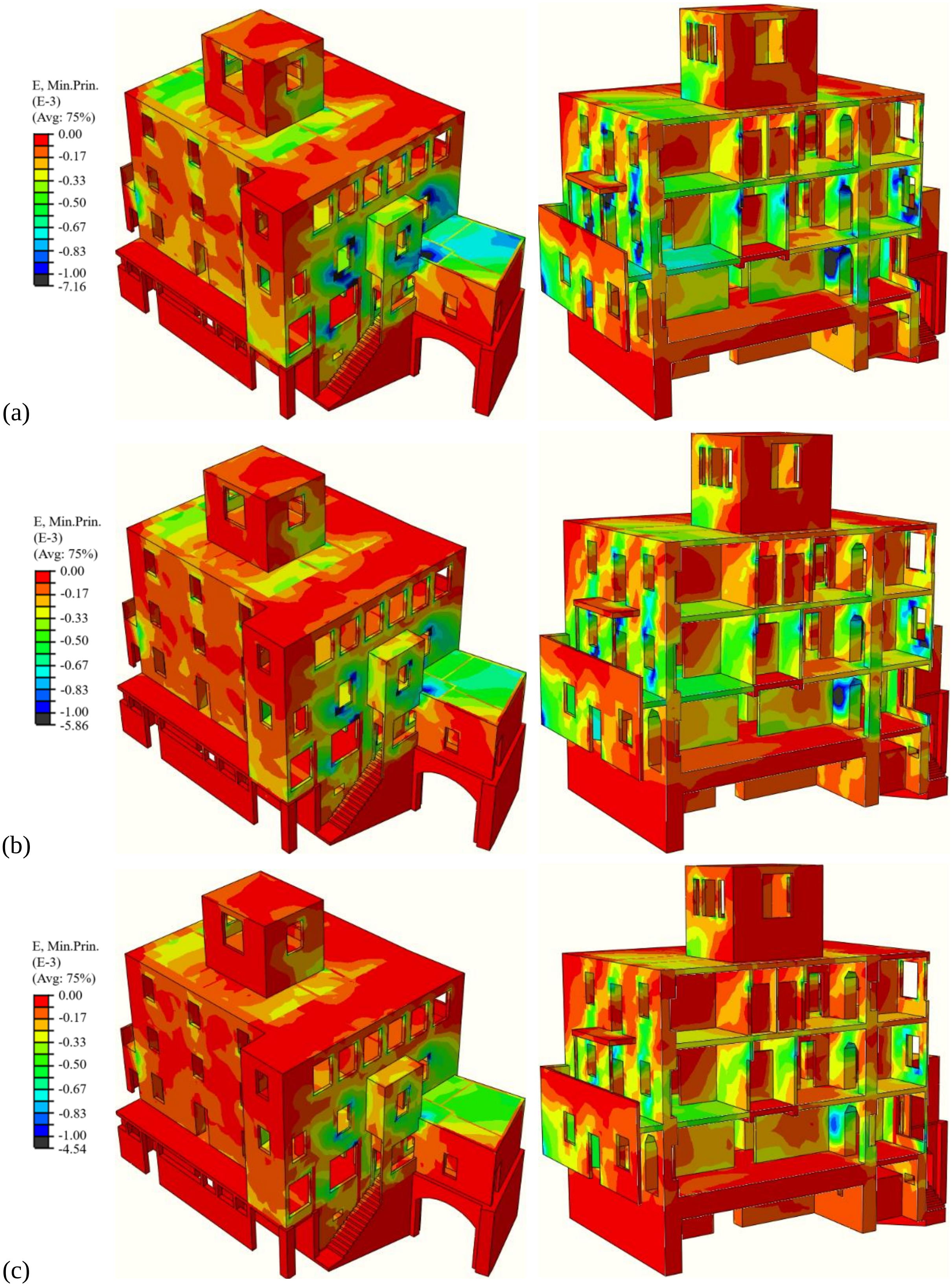

Figure 12. Min. principal strain contour diagrams for a) 2%, b)5% and c)10% damping ratio

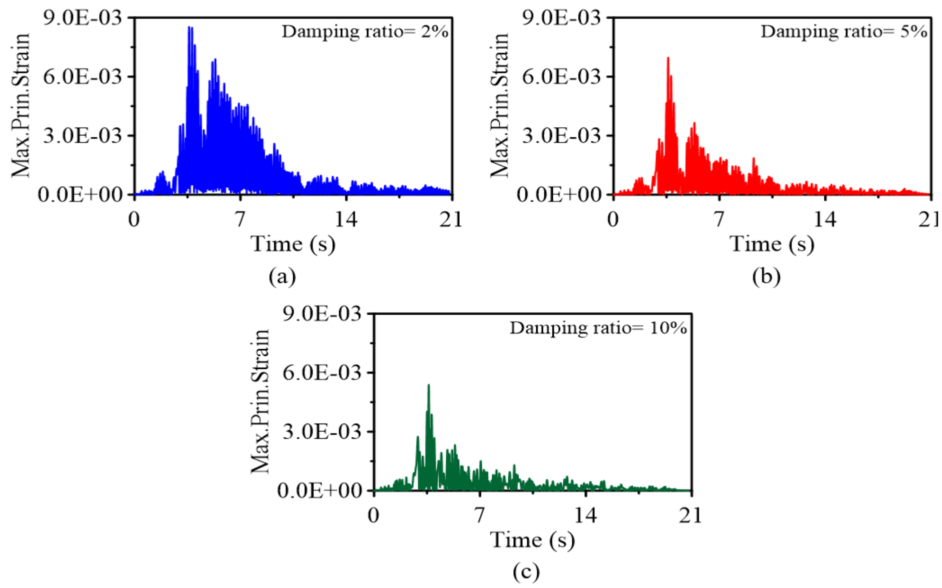

Figure 13. Max. principal strain time histories

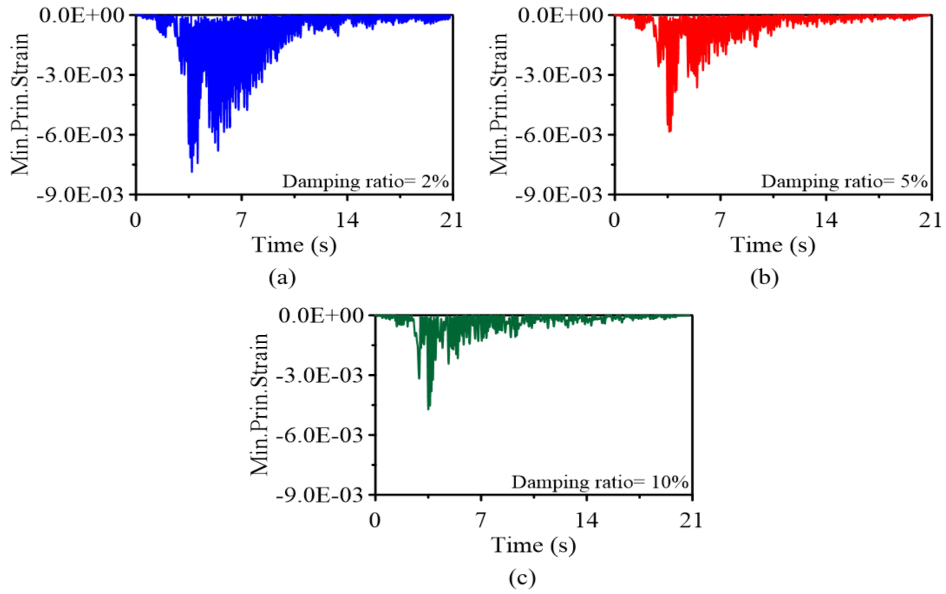

Figure 14. Min. principal strain time histories

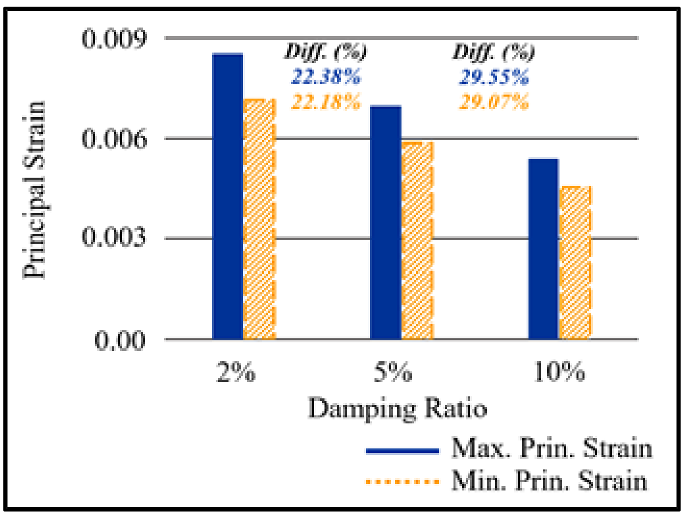

Figure 15. Comparison of the principal strains

Table 2. The comparison of the analysis results

	2%	Diff. (%)	5%	Diff. (%)	10%
Drift ratio (%)	0.13	18.18	0.11	37.50	0.08
Max. Prin. Stress (MPa)	6.81	22.04	5.58	33.17	4.19
Min. Prin. Stress (MPa)	6.16	21.98	5.05	28.17	3.94
Max. Prin. Strain (E-3)	8.53	22.38	6.97	29.55	5.38
Min. Prin. Strain	7.16	22.18	5.86	29.07	4.54

- Maximum and minimum principal stresses occurred on crossing point of inner masonry walls.
- While the maximum principal stresses were obtained as 6.81MPa, 5.58MPa and 4.19MPa, the minimum principal stresses were obtained as 6.16MPa, 5.05MPa and 3.94MPa for 2%, 5% and 10% damping ratios, respectively.
- Similar to principal stresses, principal strains occurred on crossing point of inner masonry walls.

Consequently, damping ratio is the important parameter for the evaluation of seismic response of structure such as historical masonry structures which are weak to external effect especially earthquake. Therefore, before the numerical studies the damping ratios should be obtained with experimental tests.

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