The Impacts of Separation Distance in Reducing the Earthquake Effects Case Study: Courthouse (Divan khaneh) of Masoudieh Mansion of Tehran

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Abstract

Iran is a country that is prone to earthquake. Approximately 90% of the Iranian land locates on the seismic zone. In Iran, many valuable historical buildings and monuments face the threat of destruction and decay by the earthquake. There is a direct relationship between the type of the materials and construction technology on one hand and the level of vulnerability of the buildings against the earthquake on the other hand. Thus before any action for protecting the cultural heritage, it is necessary to analyze the seismic behavior of the buildings based on their specific nature. Through such an analysis, we would be able to identify the vulnerable points of the structure against the different magnitudes in order to investigate and find the most suitable, safe, effective and nondestructive methods of seismic reform. One of the most effective methods for reducing the scale of the vulnerability is to apply the separation distance in the historical monuments .This research attempts to study and analyze the vulnerability of one of the most valuable monuments of Tehran belonging to Qajar period of Iranian history. In this research, we use the time-history analysis in order to assess the linear vulnerability of the courthouse of Masoudieh Mansion of Tehran against a pair of different accelerograph. Then we create a separation distance and divide the building into three separate parts and apply the time history analysis with the same pair of accelerograph on one of the mentioned parts. The results of the analysis show that the scale of the stresses is reduced considerably after applying the separation distance.

Keywords: *Masoudieh Mansion, Seismic Vulnerability, Earthquake, Monuments*

Introduction

Most historical buildings and monuments of Iran are made of clay and brick. The weakness of such buildings is that almost all such traditional materials are brittle and face failure under the load imposition (Zaribafan, 2006). The seismic vulnerability of the buildings with such construction materials in the historical cores of the cities and villages is the main cause of their structural damage and destroy (Araujo, Lourenco, Oliveira, & Leite, 2012, p. 160). In Iranian traditional construction method, the transformation of all types of forces to the compressive force and the different ways of fulfilling such a transformation has been always an important issue, while this would increase the weight of the building. The overweight and rigidity of the building leads to inflexibility of it. This problem especially emerges when the building encounters destructive forces such as the earthquake. Based on the above-mentioned facts, it is necessary to pay attention to the valuable and unrepeatable historical buildings and monuments and to assess their seismic vulnerability and try to reduce the destructive effects of the earthquake on them. In this regard, ICOMOS[1] has suggested some advices for analyzing and protecting the architectural constructs. The

[1] International Council on Monuments and Sites

suggested method of ICOMOS for evaluating the historical constructs requires obtaining some data such as the geometry and the formation date of the building. The next step is to inspect the current situation of the building through the experimental test of observation; and doing the numerical modeling in order to simulate the building and consequently to evaluate the seismic behavior of the building (Araujo, Lourenco, Oliveira, & Leite, 2012, p. 160). Some actions such as investigating the vulnerability of the monuments against the seismic shock and vibration along with other damaging factors can help us try to increase the life of the building. It is difficult to determine the seismic behavior of the buildings that have been made of the available construction materials. This task depends on several factors such as the traits of the materials, geometry, foundation, wall – roof connection, wall – floor connection, hardness level of the horizontal diaphragms, and the position of the building (Mandes & Mourenco, 2014, p. 137). Considering all of these factors and assessing the current situation of the building, we can find some suitable methods for reducing the vulnerability of the building against the earthquake. The following questions have to be asked in this regard: Is this building vulnerable against the earthquake?Which points of the building would be face the most sever damages in this building?Does the application of the separation distance leads to the reduction of the damages of this building?In this research, we will conduct the needed time-history analysis to answer the above questions for the case of courthouse of Masoudieh Mansion as one of the most valuable monuments of Tehran.

Literature review

Up to now, several activities have being done by the researchers to understand the seismic behavior and to develop the needed methods and technics for the improvement of the seismic resistance of the buildings and preserving them for the next generations (Tomazvic, Klemence, & Welss, 2009, p. 294). In this regard, different buildings and constructs have been assessed for their seismic characteristics. In assessing the level of seismic vulnerability of the buildings and their component, the researchers such as Lourenco, Miha Tomaževič, Nuno, Mendes, Paulo, etc. have performed analyses by some softwares like the ANSYS, ABAQUS and other finite element and separate element softwares. Among such valuable historical buildings and monuments whose seismic vulnerability have been studied we can refer to *Colosseum* (Croci, Anala, & Libudi, 1995), *Lateran Obelisk* (Buffarini, Clemente, & Paciello, 200), *Basilica S. Maria di Collemaggio* (Gattulli, Antonacci, & Vestroni, 2013), etc. In Iran, Hejazi and Nasri have investigated the Monument of Gonbad Ghabous (Hejazi and Nasri, 2009) and Hejazi has studied the seismic features of Iranian domes (Hejazi, 2003). Moreover, there is some researches in the literature on seismic restoration of the buildings such as St. James building in New Zealand (Araujo, Lourenco, Oliveira, & Leite, 2012) using sand vibration separators for improving the seismic performance of the buildings (Hejazi, Etemadi and Mahdad, 2010).

Methodology

For finding a desirable answer for the above-mentioned questions, we first modeled the courthouse of Masoudieh Mansion in finite element software (ANASYS 14). Moreover, we conducted the time-history analysis linearly for detecting the vulnerable points of the building against the earthquake. Finite elements method is one of the strongest methods for the structures that are made of construction materials (Hejazi and Mirqaderi, *Seismic Analysis of Iranian Historical Domes*, 2004). In this regard, we used some accelerographs to simulate the conditions of earthquake at the site as far as possible (table 2). To choose the suitable accelerograph we studied different factors such as the soil type of the area, active faults, basic fault of the region, and magnitude of the past recorder destructive earthquake that has happened in Tehran. After performing the time-history analysis, we determined the most sensitive and vulnerable points of the building and specified the level of their vulnerability.

Modeling and time-history analysis

Modeling in finite element software of ANASYS is being done in two methods: direct method and indirect method (Jahed Motlaq, Nowban and Eshraqi, 2011). In this research, we used indirect modeling method in which the plan is drawn in Auto Cad software and then the dots are removed to obtain the final volume in ANASYS 14. In modeling the final volume in the software, we did not model the truss of the building (Fig. 1) due to the following reasons:The enlargement of the dimensions of structure in the building or the increase of the degrees of freedom, the analysis time will get longer and even it may fail to be loaded.

In the related analysis, the rigid parts are usually counted into account, while the truss is not regarded as a rigid part. The number of removed dots for drawing the final volume was approximately equal to 800 dots. The number of available elements after networking was approximately equal to 395,000. The element to be used in modeling is the SOLID65.

Needed information for time-history analysis

We have used some specific criteria for choosing the final accelerograph for doing the time-history analysis (table 1). Based on these criteria, the final accelerograph was selected (table 2) so that it has the maximum ability of simulation with regard to the current conditions of the building.

Table 1. Criteria for selecting the accelerograph

#	Basic fault	Distance from the basic fault	Soil type	Average magnitude of the recorded earthquakes
1	Rey Fault	25 km	III	7.2 Richter

Table 2. Specifications of the final accelerograph

1	SAN FERNANDO 02/09/71 14:00, LA HOLLYWOOD STOR LOT, UP (USGS STATION 135)
2	SUPERSTITION HILLS 11/24/87 13:16, PLC, 045 (USGS STATION 5052)
3	SAN FERNANDO 02/09/71 14:00, GORMAN - OSO PUMP, UP (CDWR STATION 994)

Needed data for performing the time-history analysis

For performing the analysis, the mechanical features of the materials that are used in constructing the courthouse of the building have been determined (Table 3). In order to determine the density, the load of the roof was calculated and the results was added to the primary value of density that was equal to 1460 kg/m^3. Then the level of allowable stress was determined based on the analyses previously performed on Iranian brick buildings (table 4).

Table 3. Mechanical characteristics of the construction materials

Elasticity module	Poisson's ratio	Density
$0.5 * 10^8$ Pa	0.17	1646 kg/m^3

Table 4. Mechanical characteristics of the construction materials

Stress	Abbreviation	Scale	Values
Allowable compressive stress	(f_t)	N/m^2	$5*10^4$
Allowable tensile stress	(f_c)	N/m^2	$5*10^5$

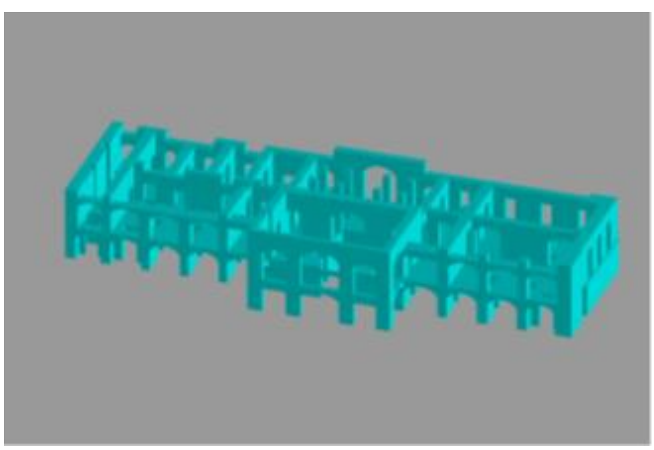

Fig. 1. Final volume of the courthouse building after modeling

Results of linear static analysis under the gravity effect

The results of static analysis under the weight load shows that the building undertakes stress under the effect of its weight (Table 4, Fig. 2). This issue can be found by observing the building in site. The highest level of tensile stress after loading the weight is observed in the loading archs.Considering the maximum allowable compressive and tensile stresses of the building (tables 5 and 6) we can find out that the building is prone to damage for intolerance of the weight (Fig. 2).

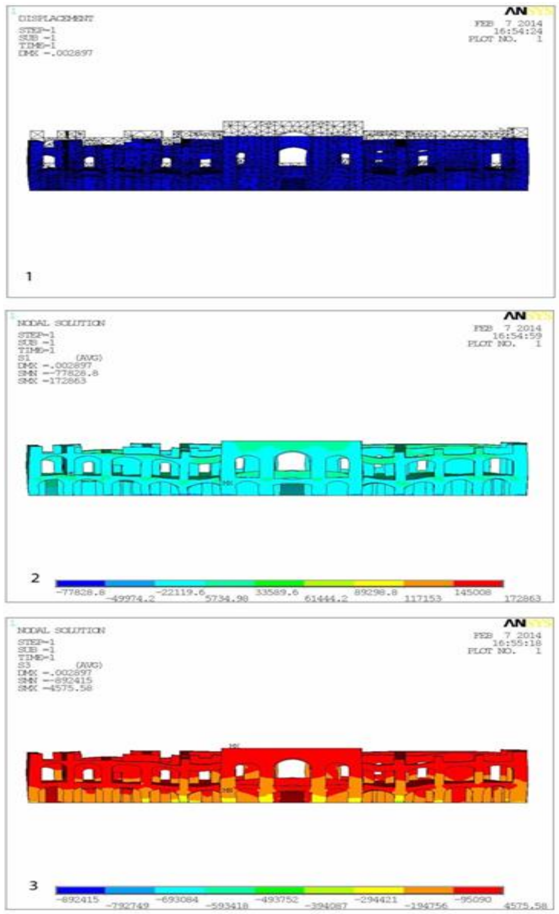

Fig. 2 Displacement of the building after imposing the weight load Tensile stress after imposing the weight load compressive stress after imposing the weight load

Table 5. Comparing the effective stresses with the allowable values in static analysis under the weight load

#	Stress	SMAX	Allowable values	results
1	S1	172863	50000	Upper the allowable value
2	S3	4575.58	500000	Below the allowable value

Table 6. Maximum and minimum stress under the gravity effect

#	Stress	DMAX	SMAX	SMIN
1	S1	0.002897	172863	-77828.8
2	S2	0.002897	43070.1	-119079
3	S3	0.002897	4575.58	-892415

Results of time-history analyses
First accelerograph pair

Table 7. Critical times in first time-history analysis (accelerograph 1) in terms of tensile and compressive stresses

#	Time	STEP	S1MAX	S3MAX	DMX
1	0.100E-04	1	0.379E+07	459898	0.152811
2	0.02	2	0.373E+07	456412	0.151845
3	0.04	3	0.349E+07	431507	0.147854
4	0.06	4	0.303E+07	370653	0.139114
5	0.08	5	0.262E+07	301876	0.124444
6	0.28	15	0.211E+07	274793	0.076944
7	0.3	16	0.219E+07	294361	0.082538
8	0.32	17	0.216E+07	283766	0.086378
9	0.48	25	0.106E+07	146125	0.029217
10	0.66	34	0.110E+07	145776	0.047938

At the initial times of the first analysis, the distribution of the tensile stress in the whole structure was equal and only in the bases we faced the higher tensile stress. The highest level of stress (in all steps of the analysis) is observed at the junction of the first floor columns. After the increase of time by 0.14 seconds upward, the tensile stress is no longer equal but it is observed dispersedly in the piers and walls of the trusses in the ground and first floor. The highest level of tensile stress was observed in the loading trusses.

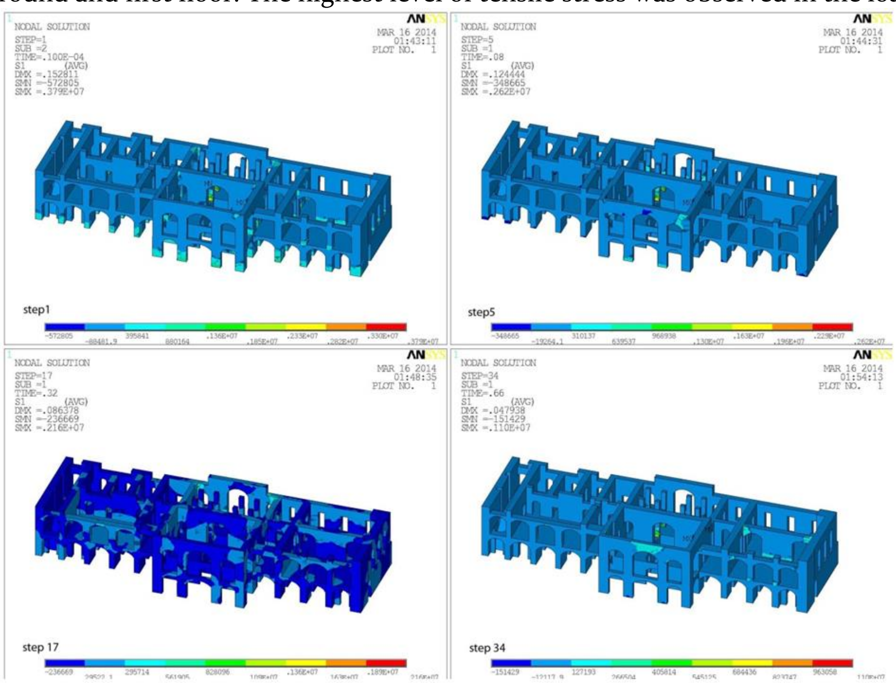

Fig. 3. The building under the effect of tensile stress in 1st analysis

Applying the separation distance in the building

As it is obvious in the results of the time-history analysis (table 7), the level of the stresses is higher than the allowable tensile stress. Due to the length of the building, we suggest to apply the separation distance in specific distances with regard to the conditions of the building (Fig. 4 and 5). Accordingly, we divided the building in three separate parts to apply the separation distance in the ground and first plans.

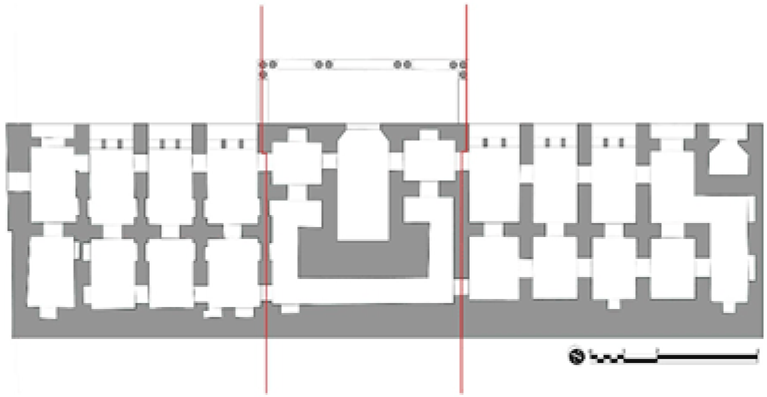

Fig. 4. The placement of the separation distance in the ground floor

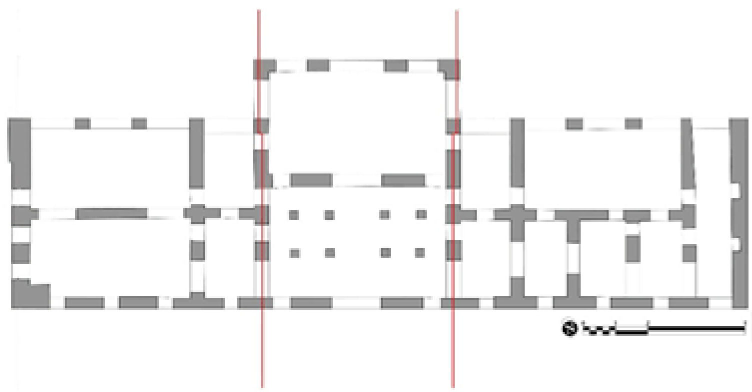

Fig. 5. The placement of the separation distance in the first floor

Time-history analysis on a specific part of the building

Then we assess a part of the building (that has been separated by the separation distance from the other parts of the building) with the same accelerograph with the same mechanical characteristic in order to determine the level of the effective stresses and the amount of the displacement.

Table 7. Critical times in the time-history analysis in terms of tensile and compressive stresses after the application of the separation distance

#	Time	STEP	S1MAX	S3MAX	DMX
1	0.100E-04	2	0.003108	0.25172	0.025172
2	0.4	3	0.002454	0.021064	0.021064
3	0.1	6	0.002843	0.015953	0.015953
4	0.12	7	0.003173	0.023726	0.023726
5	0.4	21	0.936E-03	0.007788	0.007788
6	0.42	22	0.892E-03	0.00442	0.00442
7	0.6	31	0.921E-03	0.009045	0.009045
8	0.7	36	0.593E-04	0.008015	0.008015
9	0.96	49	0.732E-04	0.0514E-03	0.514E-03
10	1.08	55	0.732E-04	0.490E-03	0.490E-03

After applying the separation distance and conducting the time-history analysis, we find that the loading trusses are still most vulnerable part of the building (Fig. 6). Moreover, the floor bases at the northern wing of the building are vulnerable as well. The tensile stress changes in a sinusoidal form so that the amount of the stress is low at the beginning seconds but it increases gradually.

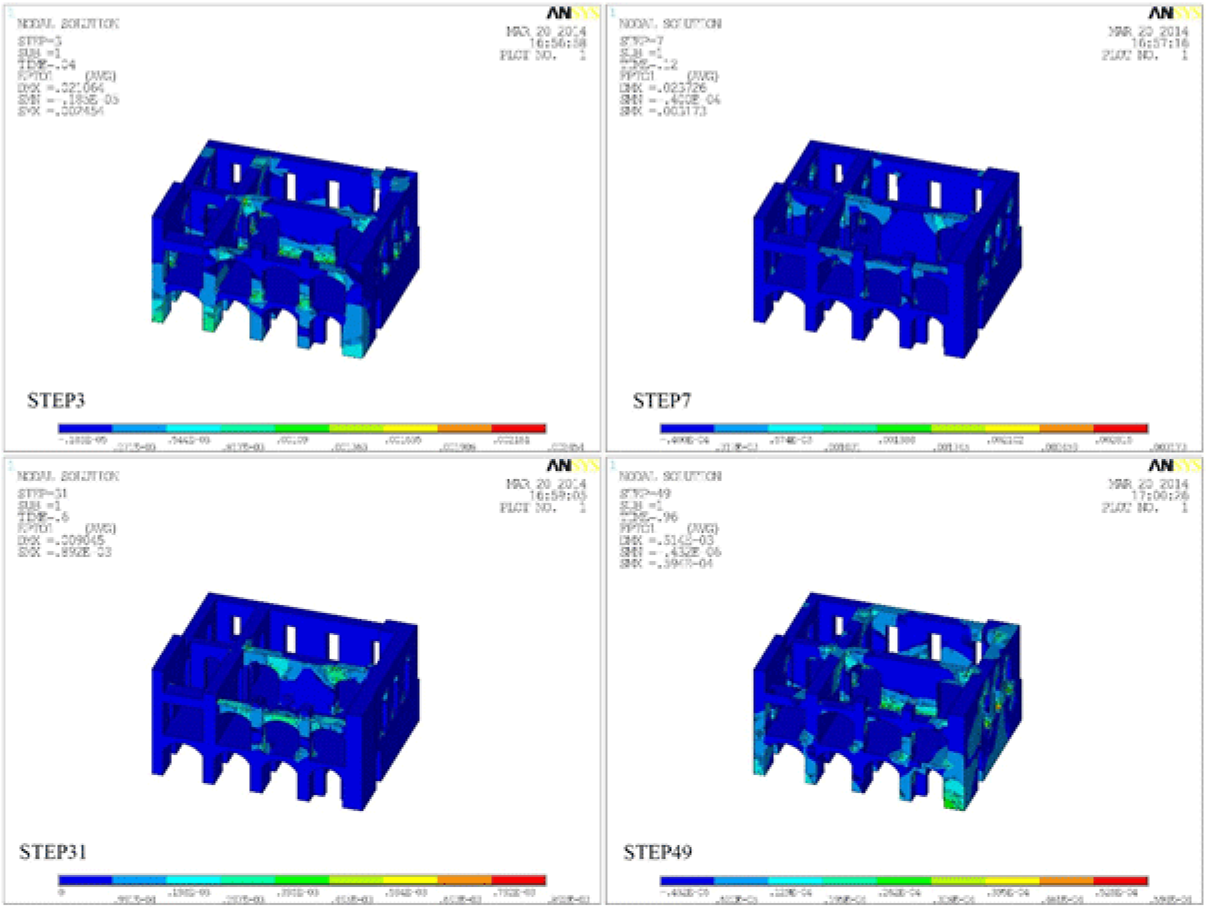

Fig. 6. One-third of the building after applying the separation distance under the tensile stress in the time-history analysis

Obtained results of the first time-history analysis

Based on the results of time-history analyses the studied building is highly vulnerable against the tensile forces. The difference between the level of tensile stresses and the allowable level of the tensile stresses was obvious in the analysis.Due to the high length of the building and the effect of the period and the procedure of the increase and decrease of the tensile stress, the building will face severe problems. Apart from the bases of the columns of first floor, the highest level of tensile stress is imposed on the loaded trusses and roof arches of the first floor. (Fig. 3).In general, the building is very vulnerable against the subsidiary forces of the earthquake.

Obtained results of first time-history analysis after applying the separation distance

Tensile and compressive stresses are reduced considerably (table 8)

The level of displacement in the building is reduced considerably (table 8).

Shortening of the building length by applying the separation distance leads to the reduction of the stresses and consequently to the reduction of the vulnerability of the building.

Conclusion and discussion

The conducted analysis showed that the wall of the courthouse is very vulnerable against the earthquake. This building has been constructed to tolerate weaker vibrations so it would be face sever damages of the analyses. Of course the increasing-decreasing sine wave of the stresses is considerably effective due to the length of the building. Placement of the separation distance in specified distances (Fig. 3 and 4) and the analysis of a part of the building after applying the separation distance showed that the stresses have reduced significantly and the level of vulnerability has decreased considerably. Considering the mentioned facts and the results of the analyses, it seems that the application of the separation distance can lead to the increase of the age of building. In this regard, we can take effective steps for preserving and protecting this valuable historical building with least level of intervention by applying the separation distances.

References

1. Araujo, A., Lourenco, P., Oliveira, D., & Leite, J. (2012). Post-earthquake numerical assessment and. *15 WCEE*.
2. Buffarini, G., Clemente, P. & Paciello, A. (2008). *Vibration Analysis Of The Lateran Obelisk*- The 14th World Conference on Earthquake Engineering. Beijing, China.
3. Croci, G., D, Anala, D. & Libudi, R. (1995). "History, observation and mathematical models in the seismic analysis of the Valadier abutment area in the Colosseum". *ANNALI DI GEOFISICA*, VOL, XXXVIII, N 5-6.
4. Gattulli, V., Antonacci, E. & Vestroni, F. (2013). "Field observations and failure analysis of the Basilica S. Maria di Collemaggio after the 2009 L'Aquila earthquake". *Engineering Failure Analysis*, Volume 34, 715-734.
5. Hejazi, M. (2003). "Seismic Vulnerability of Iranian Historical Domes", *Proceedings of the Fourth International Conference on Earthquake*, (pp. 65-157). Ancona, Italy.
6. Mandes, N. & Lourenco, B. (2014). "Sensitivity analysis of the seismic performance of existing masonry buildings". *Engineering* Structures, 80, 137-146.
7. S. Araujo, A., B. Lourenco, P., V. Oliveira, D. & Leite, J. (2012). "Seismic Assessment of St James Church by Means of Pushover Analysis – Before and After the New Zealand Earthquake", *The Open Civil Engineering Journal*, 6 (Suppl 1-M5), 160-172.
8. Tomazvic, M., Klemence, I. & Welss, P. (2009). "Seismic upgrading of old masonry buildings by seismicisolation and CFRP laminates: a shaking-table studyof reduced scale models". *Bull Earthquake Eng7*, 293-321.
9. Jahed Motlaq, H., Noban, N & Eshraqi, M. (2011), *ANASYS Finite Elements*, Tehran: Tehran University Press [in Persian].
10. Hejazi, M. & Mirqaderi, R. (2004), "Seismic Analysis of Iranian Historical Domes", *Quarterly of the Technical Faculty*, Tehran University Press, No. 38, pp. 747-757 [in Persian].
11. Hejazi, M. & Nasri, A. (2009), "Constructional Analysis of Gonbad Qabous", *Proceedings of the 8th Conference of Civil Engineering*, Shiraz: University of Shiraz [in Persian].
12. Zaribafan, A. (2006), *Solutions for Protecting the Monuments against the Earthquake*, Regional Scientific Conference of the Desert Architecture, Ardestan: Islamic Azad University [in Persian].
13. Hejazi, M., Etemadi, M & Mahdad, H. (2010), "The effects of column separation by sand vibration separators in improving the seismic performance of the buildings", *Proceedings of the fifth Iranian National Conference of the Engineering*, Mashhad: Ferdowsi University of Mashhad.
14. http://peer.berkeley.edu/nga/search.html