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STRUCTURAL VULNERABILITY ASSESSMENT OF MASONRY BUILDINGS IN TURKEY

Kasım Armagan KORKMAZ*, Asuman Isıl CARHOGLU

Süleyman Demirel University, Civil Engineering Department, Isparta, Turkey

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Abstract: Turkey is located in an active seismic zone. Mid to high rise R/C building and low rise masonry buildings are very common construction type in Turkey. In recent earthquakes, lots of existing buildings got damage including masonry buildings. Masonry building history in Turkey goes long years back. For sure, it is an important structure type for Turkey. Therefore, earthquake behavior and structural vulnerability of masonry buildings are crucial issues for Turkey as a earthquake prone country. In the present study, masonry buildings in Turkey were evaluated. Representative masonry buildings were analytically investigated. For representative masonry buildings, dynamic analysis was carried out by Finite Element Methodology (FEM). The results of the study show that structural behavior of masonry building is critical in earthquake assessment point of view.

Keywords: Structural vulnerability assessment, masonry buildings, dynamic analysis.

* armagan@mmf.sdu.edu.tr

INTRODUCTION

Turkey is one of the earthquake prone countries. In August 1999, an earthquake struck northwestern Turkey. The earthquake occurred at the west part of the North Anatolian fault system with its epicenter about 100 km southeast of Istanbul. The area struck by the Kocaeli earthquake supported approximately 40% of Turkey's heavy industry. The Anatolian fault map is shown in Figure 1 [1].

Fig. 1. Anatoilan fault map [1]

In recent earthquakes, most of the existing buildings including masonry buildings got damage. Therefore earthquake behaviors and vulnerability of existing masonry buildings are very important for Turkey. Assessment of the masonry buildings considering seismic capacity is one of the essential steps in earthquake assessment point of view [2].

History of masonry buildings in Turkey goes years back. There are so many masonry buildings in Istanbul from Ottoman Empire. From that time, construction technology of masonry structures hasn't changed considerably considering the reinforced concrete buildings [3,4]. In some rural areas of Turkey, masonry building technology is still applied in same way, which is mainly composed of units and mortar. Bricks, blocks, adobes, ashlars, irregular stones and others are typical masonry units [5]. Wood and iron were also used for different purposes in historical masonry structures.

In the open literature, there are various research studies for masonry buildings. However, it is difficult to find studies for Turkish type of historical masonry buildings. Some researches worked on real mechanical specifications of masonry buildings via application of numerical methods. They also set up an experimental design for masonry buildings [6,7].

In the present study, masonry buildings in Turkey were evaluated. Representative masonry buildings were analytically investigated by using SAP2000 [8]. For representative masonry buildings, dynamic analysis was carried out by Finite Element Methodology (FEM) using SAP2000 [8]. It is a fact that numerical modeling of masonry structures through the FEM is very complex. Masonry structures include blocks connected by mortar joints that is geometrical complexity, and reflected in the computational effort needed. A properly homogenisated material should be characterized.

In the analyses, single- and double-story masonry buildings with different door and window openings were modeled. In total, four different models were investigated in the current research. The models were selected regarding existing Turkish masonry buildings. For the representative models, time history and mod superposition analyses were conducted for X and Y directions of the buildings. Periods of the buildings, max. base shear forces, max. displacements were determined. The graphical demonstrations are given in the result part of the study. In the analyses, Duzce earthquake was used.

Masonry Buildings in Turkey

In Turkey, typical old masonry building sample could be seen in rural areas. Most of them are single- or double-story buildings. They generally don't have any project or application profile. They have been built by owners of the buildings. In Figure 2, some of the examples of old masonry buildings are demonstrated.

Fig. 2. Some examples for Turkish old masonry buildings (Original).

In the recent Turkish earthquakes, most of them get damaged. The main reason of the damage is the poor construction. In Figure 3, some examples of failure from Elazig earthquake (Mach 8^{th}, 2010) are demonstrated. Some of the recent research works focus on the damage reasons of masonry buildings.

Fig. 3. Some examples of masonry failures (Original)

Damages in Recent Turkish Earthquakes

In the recent earthquakes, the majority of damaged and partially or totally collapsed buildings were of the older reinforced concrete and masonry buildings which were designed according to Turkish Design Code [9-12]. Data reported by Donmez and Pujol indicated that 50% of the buildings in Duzce incurred severe damage or collapsed as a result of the 1999 earthquakes [13]. The most common types of failures are localized, simple structural failures [13]. Figure 4 depicts typical damage following the 1999 earthquakes. These kinds of residential buildings still widely exist in most parts of Turkey.

Fig. 4. Typical building damages following the 1999 Marmara earthquake, Turkey

Modeling of Masonry Buildings

Masonry consists of mainly unit element and mortar. Most common unit elements are brick and stone. Mortar is used for connecting the units each other. Compressive strength, tensile strength, durability, shear strength, water absorption coefficient and thermal expansion affect the load bearing capacity of masonry [9].

Numerical modeling of masonry structures through the FEM is very complex. Masonry structures include blocks connected by mortar joints that is geometrical complexity, and reflected in the computational effort needed. Modelling of joints is specificly important, since the sliding at joint level often starts up the crack propagation. The mortar joints in the masonry buildings cause the masonry to be anisotropic. Two different approaches have been adopted to model such anisotropy: the ‘micro-model’, or ‘two-material approach’ and the macro-model. In both models, the discretization follows the actual geometry of both the blocks and mortar joints, adopting different constitutive models for the two components. In FEM applications, the system is meshed in finite members instead of driving equations. The meshed members are solved considering the whole system. The boundary conditions members are superposed to form the equations in the matrices for the whole system. In Figure 5, the continuous system can be seen [14].

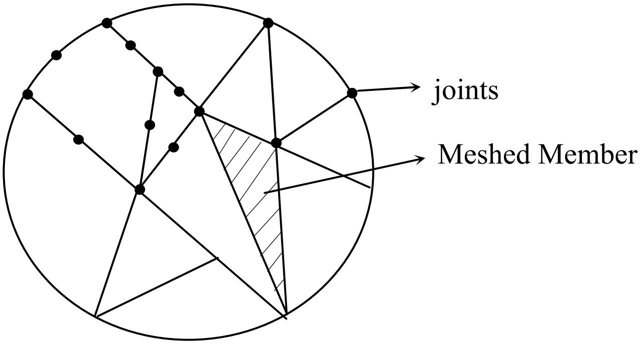


Fig. 5. Continuous System and Finite Member [14]

Structural Properties of Masonry Buildings

The masonry structure has higher compressive strength and lower tensile stress. This property of the masonry structure is very important that the structural form of masonry constructions is based on compressive forces. The masonry material is brittle. Sudden failure occurs in tension loading. Fracture energy is the absorbed energy until the failure time. It can be determined calculating the area under stress-strain diagram (Figure 6) [15].

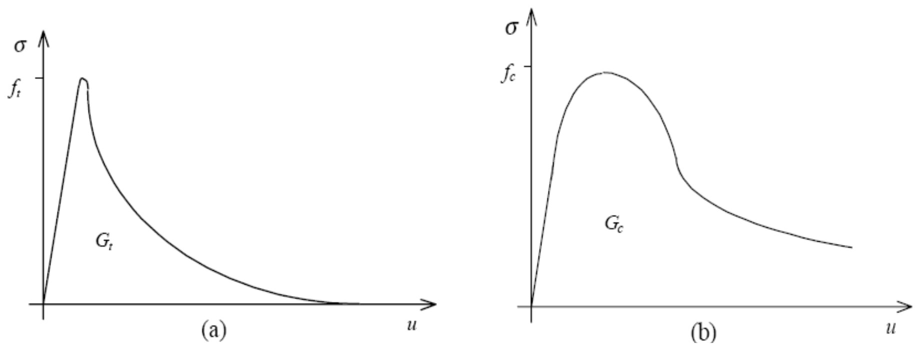


Fig. 6. Typical behavior of quasi-fragile materials under uniaxial loading and definition of the fracture energy a) tension loading b) compression loading [15]

Strength of stone masonry depends on the material properties and bond type of units. The stone is massive and stiff. Type and thickness of mortar is more effective on the compressive strength of stone masonry than stone units. The strength of stone does not much effect to stone masonry. The joint behavior of unit and mortar determines the strength of stone masonry. If the mortar strength is weaker than units, masonry strength primarily depends on the strength of mortar. The shear strength of the stone masonry is approximately 25% of the compressive strength . Different types of stone masonry are shown in Figure 7 .

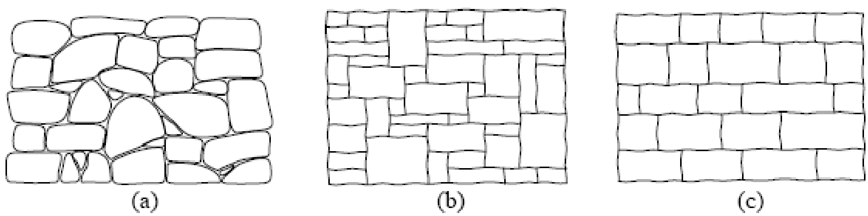


Fig. 7. Different kinds of stone masonry: (a) rubble masonry, (b) ashlar masonry; c) coursed ashlar masonry [15]

Time History Analyses

Nonlinear dynamic time history analyses have been employed to the representative masonry buildings. An extraordinarily important step for application of time history analysis is the selection of a representative earthquake. Here, Duzce earthquake data was selected for the analysis. The properties of the earthquake are given in Figure 8. The results of nonlinear time history analysis for representative buildings are presented in analyses results part in figures and tables.

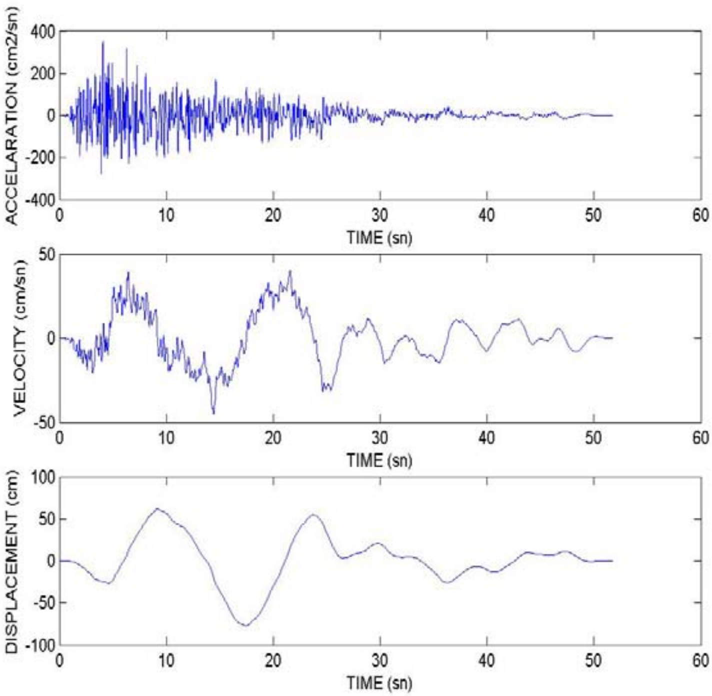
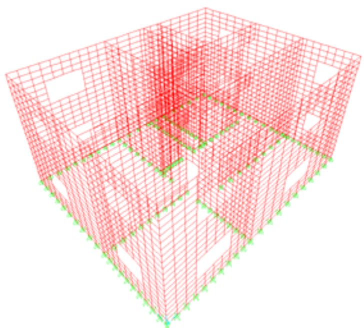


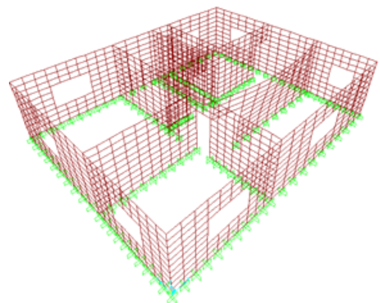
Fig. 8. Duzce (DZC-UP) Earthquake Data.

Representative Masonry Buildings

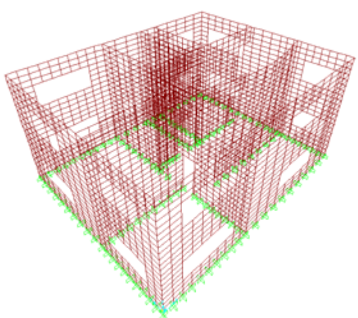
Four different types of buildings were used in the analyses. The representative buildings are shown in Figure 9. The openings and number of story are changed in every model.



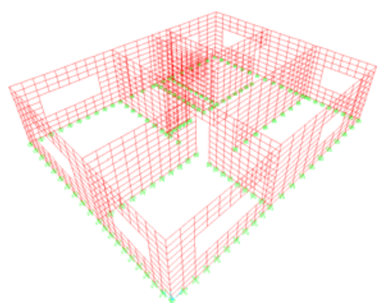
Model 1. Two-Story-less openings



Model 2. One Story-less openings



Model 3. Two-Story-More Openings

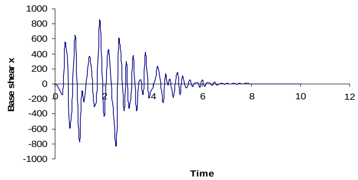


Model 4. One-story-more opening

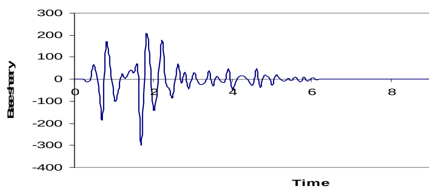
Fig. 9. Representative buildings for the analysis.

Analysis Results

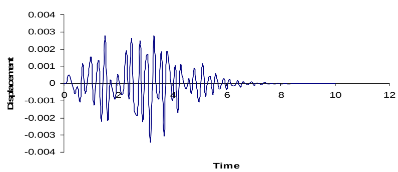
In this section of the study, the analyses results are given for four type of sample buildings. The models are analyzed by using time history analysis with Duzce earthquake data. In Figure 10, base shear, displacements and response spectrums are given for Model 1. In Table 1, force vs. displacements are listed.



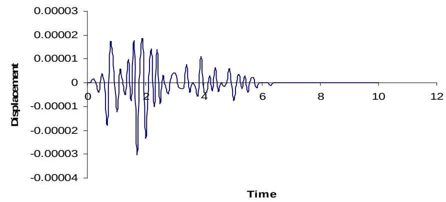
Model 1. Base Shear X



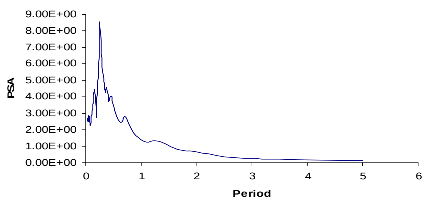
Model 1. Base Shear Y



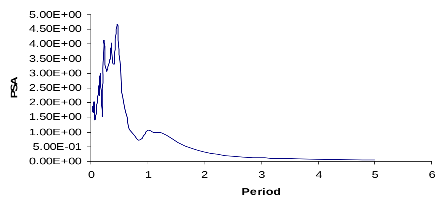
Model 1. Displacement X



Model 1. Displacement Y



Response Spectrum x



Response sectrum Y

Fig. 10. Time History Analyses Results for Model 1.

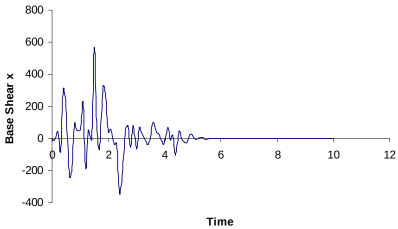
Table 1. Maximum Forces versus Maximum Displacements

	Base-x (kN)	Base-y (kN)	Base-z (kN)	U1(μm)	U2(μm)	U3(μm)
Timehistory x	851.102	197.314	1.031	27.81	7.9	0.78
Timehistory y	197.347	1345.852	0.513	10.62	44.91	0.71
Spectrum x	216.439	44.46	0.206	13.66	2.4	0.22
Spectrum y	44.47	265.961	0.147	2.64	40.	0.15

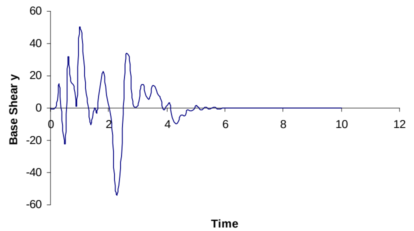
In Figure 11, base shear, displacements and response spectrums are given for Model 2. In Table 2, force vs. displacements are given.

Table 2. Maximum Forces versus Maximum Displacements

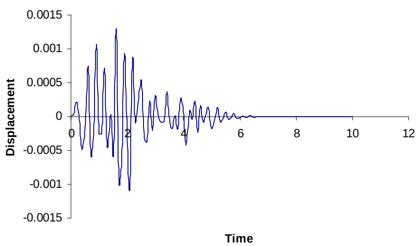
	Base-x (kN)	Base-y (kN)	Base-z (kN)	U1(μm)	U2(μm)	U3(μm)
Timehistory x	566.761	49.902	0.141	13.03	2.55	0.23
Timehistory y	49.89	455.409	0.301	3.02	21.58	0.15
Spectrum x	65.788	11.664	0.025	2.55	0.73	0.0434
Spectrum y	11.665	76.705	0.048	0.61	6.74	0.026



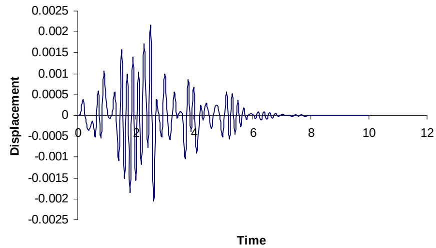
Base Shear X



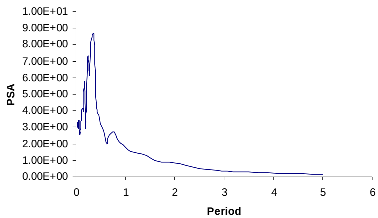
Base Shear Y



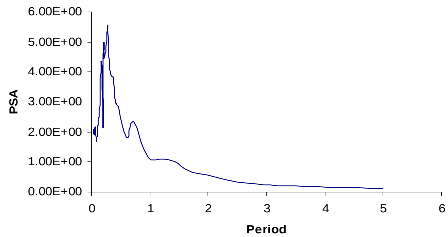
Displacement X



Displacement Y

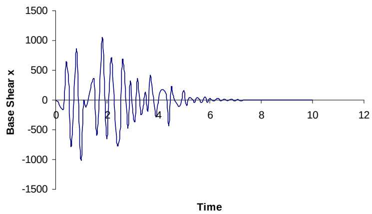


Response Spectrum X

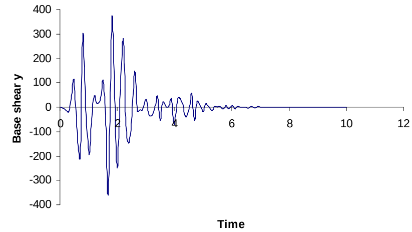


Response sectrum Y

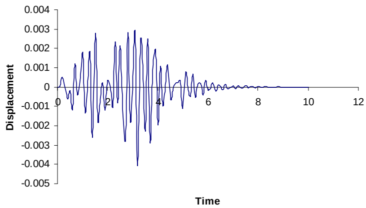
Fig. 11. Time History Analyses Results for Model 2.



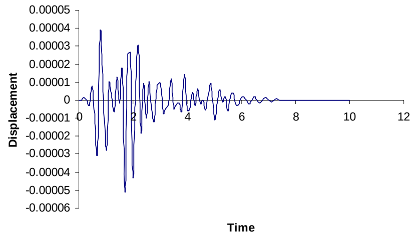
Base Shear X



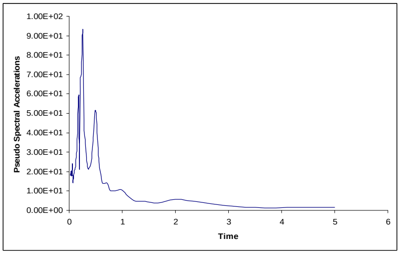
Base Shear Y



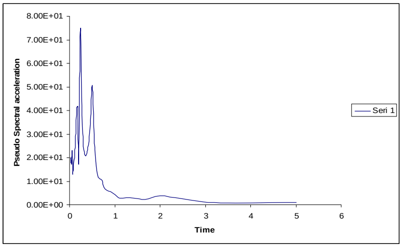
Displacement X



Displacement Y



Response Spectrum X



Response sectrum Y

Fig. 12. Time History Analyses Results for Model 3.

In Figure 12, base shear, displacements and response spectrums are given for Model 3. In Table 3, force vs. displacements are given.

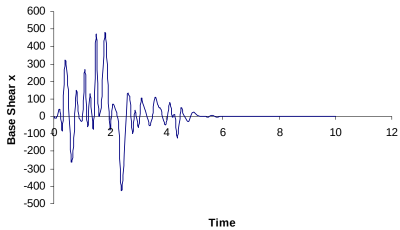
Table 3. Maximum Forces versus Maximum Displacements.

	Base-x (kN)	Base-y (kN)	Base-z (kN)	U1 (μm)	U2 (μm)	U3 (μm)
Timehistory x	1057.433	360.381	1.975	28.41	8.36	1.02
Timehistory y	360.37	1355.096	0.762	12.13	45.79	0.94
Spectrum x	248.229	60.863	0.368	15.81	2.48	0.33
Spectrum y	60.86	290.529	0.158	3.07	40.62	0.21

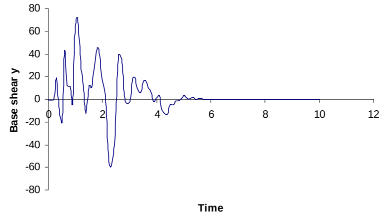
In Figure 13, base shear, displacements and response spectrums are given for Model 4. In Table 4, force vs. displacements are given.

Table 4. Maximum Forces versus Maximum Displacements.

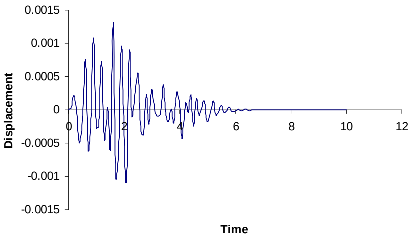
	Base-x (kN)	Base-y (kN)	Base-z (kN)	U1 (μm)	U2 (μm)	U3 (μm)
Timehistory x	477.413	72.077	0.374	13.15	2.81	0.34
Timehistory Y	72.142	392.459	0.632	3.08	21.66	0.17
Spectrum x	63.976	14.392	0.048	2.6	0.76	0.0557
Spectrum y	14.392	79.117	0.112	0.61	6.78	0.0337



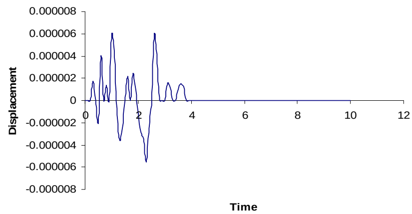
Base Shear X



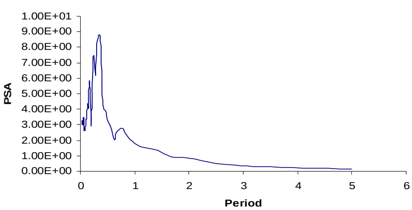
Base Shear Y



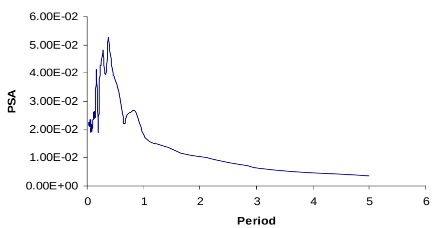
Displacement X



Displacement Y



Response Spectrum X



Response Spectrum Y

Fig. 13. Time History Analyses Results for Model 4.

CONCLUSION

In the present study, masonry buildings were investigated considering earthquake effect. Earthquake effect was considered by nonlinear time history analysis. For the analysis, Duzce earthquake data was selected. Four different types of masonry buildings were modeled and analyzed. These models have differences such as story numbers and openings. All analyses results are given in analysis result section. As a result of the analyses, base shear, displacements and response spectrums are given in figures. In tables, base shear versus displacements are given and compared. As a result, it was observed that, base shear was increasing with wall opening and story number. Model 4 has the best earthquake response through the all models. Model 2 is following Model 4. Model 3 has better results than Model 1. For Model 1 and Model 3, base shears are greater than Model 2 and Model 4. It is a conclusion that, it is critical to determine the structural behavior of masonry buildings with considering structural components and placements. Wall opening has a crucial importance for earthquake behavior on masonry buildings.

REFERENCES

[1] MTA (Turkish Mineral Research and Exploration Foundation) http://www.mta.gov.tr/english/index.php accessed in 2008.

[2] Celep, Z.: "General Considerations for Determining Resistance of Existing Buildings", Symposium for Retrofit and Rehabilitation of Existing Buildings, İstanbul, Turkey (In Turkish) **(2001)** 125-168.

[3] Bayülke, N.: Masonry buildings 2nd Ed., Ankara, Turkey (In Turkish) **(1992)**.

[4] Bayülke, N.: Earthquake Resistant Masonry Building Design, Chamber of Civil Engineers, Izmir No:27, 2nd Ed. İzmir (In Turkish) **(1998)** 245.

[5] Altin, S.; Kuran F.; Kara, M. E. and ANIL, Ö.: "A new method for rehabilitation of masonry buildings", YDGA-2005, Workshop for Increasing Earthquake Resistance of masonry Buildings (In Turkish) **(2005)**.

[6] Kanıt, R. and Isik, N. S.: “Experimental Study and Computer Modelling for Brick”, *Gazi Unv. Eng Journal*, 22(1) **(2007)** 13–20.
[7] Kanıt, R.: “Analytical and experimental Investigation of Masonry Buildings Out the Axial”, *Gazi Unv. Eng Journal*, 22(2) **(2007)** 441–449.
[8] Wilson E. and Habibullah A.: “Sap 2000 Integrated Finite Element Analysis and Design of Structures Basic Analysis Refence Manual”, Berkeley **(1998)**.
[9] Özcebe, G.: “Structural damages and reasons observed in 3 February 2002 Afyon-Sultandağı earthquake”, Civil Engineering Dept., Middle East Technical Univ., Structural Engineering Research Unit **(2002)**.
[10] Ozcebe, G.; Ramirez, J.; Wasti, S. T.; and Aykut, A.: “1 May 2003 Bingöl earthquake engineering report”, Rep. No. 2004/1, TÜBİTAK SERU Structural Engineering Research Unit, Ankara, Turkey **(2004)**.
[11] Sucuoglu, H.: “The 1999 Kocaeli and Düzce-Turkey earthquakes”, METU **(2000)**.
[12] Sucuoglu, H. and Yazgan, U.: “Seismic risk assessment survey of urban buildings”, The role of local governments in reducing the risk of disasters, World Bank Institute, Istanbul **(2003)** 127–147.
[13] Donmez, C. and Pujol, S.: “Spatial distribution of damage caused by the 1999 earthquakes in Turkey”, Earthquake Spectra 21 (1) **(2005)** 53–69.
[14] Bathe, K.: “The finite element method Publisher", Journal of the University of Cape Town Engineering Society **(1967)** 57-61.
[15] Mendes, N.; Lourenço, P. B. and Campos-Costa, A.: “Seismic Vulnerability Assessment of Ancient Masonry Building: An Experimental Method”, Advanced Materials Research, 133 **(2010)** 635-640.