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Seismic Evaluation of A Historical Structure In Kastamonu - Turkey

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Abstract. The Kastomonu province is a seismically active zone. the city has many historical buildings made of stone-masonry. In case of any probable future earthquakes, existing buildings may suffer substantial or heavy damages. In the present study, one of the historical traditional house located in Kastamonu were structurally investigated through probabilistic seismic risk assessment methodology. In the study, the building was modeled by using the Finite Element Modeling (FEM) software, SAP2000. Time history analyses were carried out using 10 different ground motion data on the FEM models. Displacements were interpreted, and the results were displayed graphically and discussed.

Keywords: Time history analysis, Finite element methods, cultural heritage

1. Introduction

Historical buildings are carrying the thousands of years' cultural wealth and heritage from past to present. These buildings must be preserved for the next generation. They give us historical conception about sociological, economical and political perspective from the past. Historical structures were built based on the masters` knowledge and experience without design standards or scientific studies (Ilerisoy and Soyluk, 2012). Structural performances of historical buildings are in variety with their geometry and defined material properties. Therefore, when modeling historical buildings, defining the material properties and the accurate geometrical shape of the structure are the critical steps in the procedure (Yardim and Mustafaraj, 2016). Historical structures have low ductility because of their brittle structural components. They may have severe damage during the severe earthquakes. Many historical buildings are located in high seismic zone in Turkey (Erdil ve Okuyucu, 2011).

A masonry historical building protection, repair and strengthening is really a difficult and challenging task. cultural value and the desire to preserve historical buildings for future generations, requires a high level of protection against any possible destruction under future actions, like earthquake loads. At the same time, should be avoided to damage on historical building which has survived until these days. To accomplish this duty, a precise understanding of the problems to be faced by the structure,

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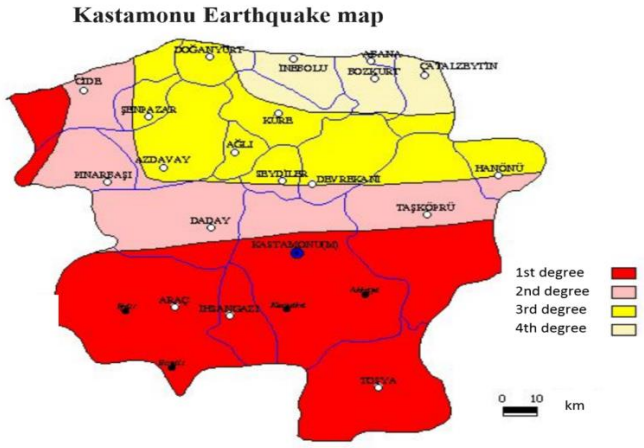
the reasons for them, as well as a sound knowledge of the effect any intervention might have on the structure are needed, so that intervention does not become the cause of future damage to the building under consideration (Asteris et al., 2005).

The many structural systems of historical buildings are masonry elements which are composed of stone, bricks and mortar. For each of the old historic structures (including the monuments) built in high seismic seismic zones, the earthquake has always been the number one enemy, as the earthquake reacted very badly (Asteris, 2008).

The task of protecting historic structures is generally the responsibility of the engineer. For the successful intervention on a monument requires a good understanding of structural behavior under with a static and dynamic (earthquake) loads. For an engineer, taking part to the restoration process of a historical structure, through the analysis of its structural system, means mainly to face the demanding task of equipping the historical structure with the capability to withstand future actions with the minimum possible amount of damage, while bearing in mind the characteristics and values which make this structure unique and worthy of special attention (Asteris, 2008).

2. The Seismicity and Earthquake Hazard of Kastamonu Province

Kastamonu is located on the North Anatolian Fault Zone and total population is 363 700. Kastamonu city center falls into the first-degree earthquake zone in the latest map of 1996 which is still in force. According to Seismic Zoning Map of Turkey, 46 percent of the surface area of Kastamonu province is in the first-degree hazard zone, 22 percent in the second-degree hazard zone, 24 percent in the third degree hazard zone and 8 percent in the fourth degree hazard zone. The city center is the first-degree danger zone but nevertheless, there are very few studies on seismic and seismic hazard for this region and region's buildings (Ozmen, 2001 and Ozmen, 2011). Kastamonu earthquake map, Distribution of earthquakes with a magnitude of $M \geq 4$ and Number of occurrences of earthquakes with $M \geq 4$, which occurred in the instrumental period are given in figure 1, figure 2 and figure 3, respectively.



Region	Area (km²)	%	Population (1997)	%
1st Grade	**6.007**	**46**	**156.391**	**43**
2nd Grade	**2.919**	**22**	**87.288**	**24**
3rd Grade	**3.130**	**24**	**72.740**	**20**
4th Grade	**1.080**	**8**	**47.281**	**13**
Total	**13136**		**363.700**	

Figure 1. Earthquake zoning map of Kastamonu province

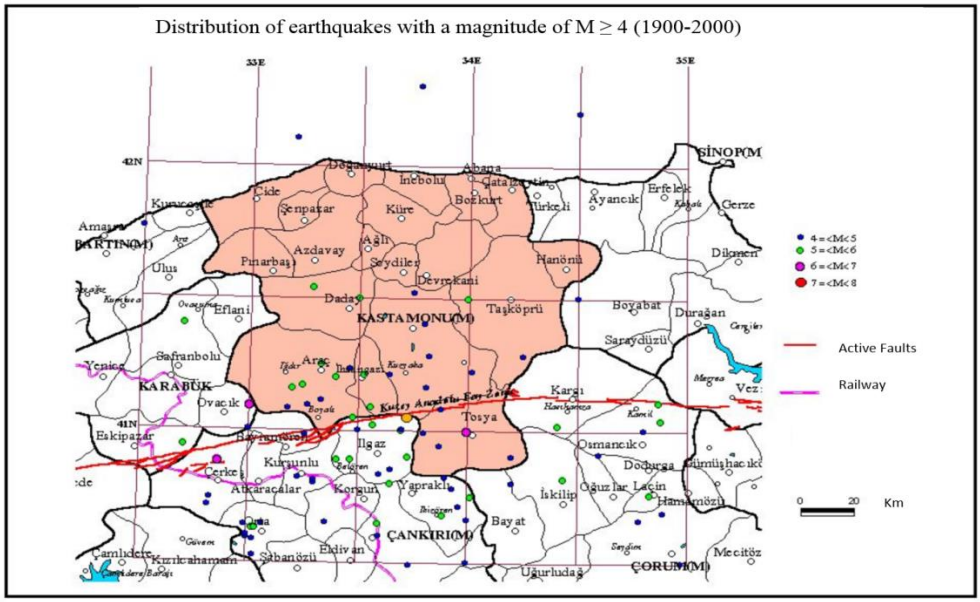


Figure 2. Distribution of earthquakes with a magnitude of M ≥ 4

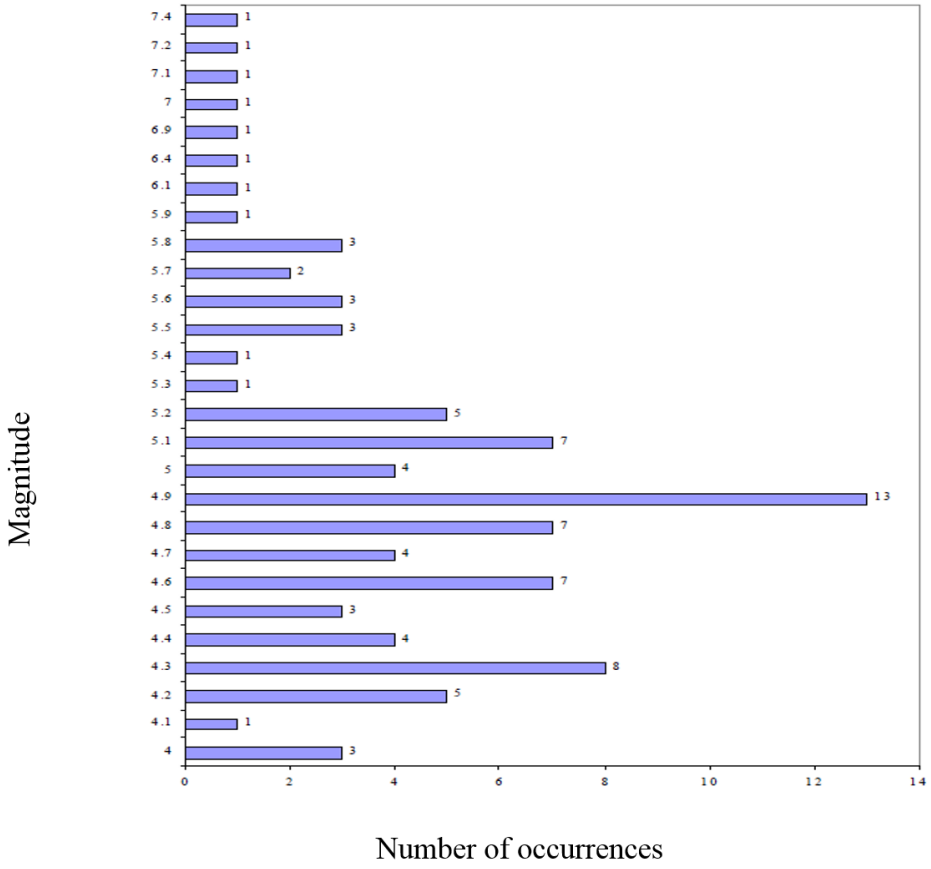


Figure 3. Number of occurrences of earthquakes with M ≥ 4, which occurred in the instrumental period

Earthquakes which have occurred in historical period (B.C.2100 – 1900) in Kastamonu province is given in Table 1.

Table 1. Earthquakes which have occurred in historical period (B.C.2100 – 1900).

History	Latitude	Longitude	Intensity	Explanation
03.09.968	41.15	34.75	IX	The earthquake that took place at 2 o'clock in Kastamonu, Çorum and Amasya it was caused by damage.
1075	40.60	34.95	VIII	The earthquake that took place in the morning hours was around Çorum caused damage.
1509	40.55	35.00	VIII	It caused damage in Çorum.
10.07.1668	41.30	33.80	VII	It caused damage in Kastamonu and Bolu
18.08.1668	41.20	33.80	VII	
12.05.1844	40.98	34.80	VIII	It caused damage in Osmancık, Çorum and Ankara. 200 people have lost their lives Due to the earthquake.
1845	40.60	33.60	V	It has been effective around Çankırı.
28.03.1880	42.00	35.20	VIII	
28.09.1881	40.60	33.60	VIII	It has been effective around Çankırı. It was stated that the magnitude of the earthquake was 6.1 and 12 people lost their lives.
1882	41.00	34.00	VI	It caused damage in Tosya, Kastamonu, İskilip and Çankırı
1883	41.00	33.70	VI	It caused damage in Kastamonu and Çankırı.
1885	41.30	34.30	VI	It caused damage in Sinop, İnebolu, Taşköprü, Tosya, Çankırı and İskilip.
1890	41.30	33.80	VI	It caused damage in Kastamonu and around.

3. Analizing and Modeling of Structure

After determining of measured drawing of structure and creation of axes, structure has beenmodeled with method of finite element. The three-dimensional analysis model was developed by using SAP2000 structural analysis software (Wilson and Habibullah 1992).

By using Sap2000 finite element program. Shell and solid elements have been used for modeling of structure.8500elements had been used in model such as; 6054-unit solid element, 2446 unit covering element. Numbers of Total crucial point is 14853. All elements have been improved and defined with prismatic elements accordance with characteristic of equipment and behave. Finite element modeling of historical masonry building of Kastamonu is given in Figure 4.

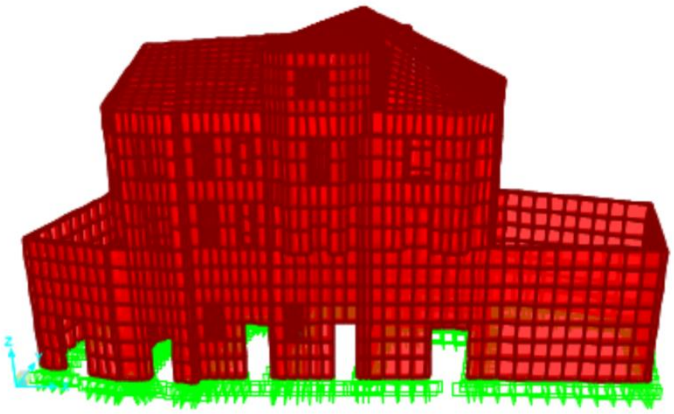


Figure 4. Finite element modeling of historical masonry building of Kastamonu

To determine the structural behavior of masonry building, time history analyses were carried out by using 10 different ground motion records on the masonry building's Finite Element models. Time history analyses are most reliable analysis type in the structural assessment approaches. For time history analyses, ground motion data were taken from Pacific Earthquake Engineering Research Center (PEER) (Yon et all., 2015). Selected ground motion records from Soils used for the dynamic analysis of the historical buildings are given in Tables 2 and 3, respectively.

The building was assumed to be made of a stone material and coverage material. Material values, which are used in model, are given in table 2. These values were determined by literature survey.

Table 2. Characteristics of equipments that used in model

Material Properties **(ton - m)**					
Equipment	Type	Mass	Weight	E	Poisson
Falez stone	Isotrope	0.25	2.50	204000.00	0.20
Brick	Isotrope	0.1835	1.8355	40788.65	0.2

Table 3. Ground motion records of A Soil Class

No	**Earthquake**	**Date**	**Moment Magnitude (Mw)**	**Record**	**Ground Velocity (cm/s)**	**Ground Acceleration (g)**	**Epicenter distance (km)**	**Type**
1	Anza (Horse Cany)	25/02/1980	4.9	AZF315	2.6	0.066	12.1	lateral slip
2	Morgan Hill	24/04/1984	6.2	G01320	2.9	0.098	16.2	lateral slip
3	Coyote Lake	06/08/1979	5.7	G01320	8.3	0.132	9.3	lateral slip
4	Landers	28/06/1992	7.3	GRN180	14.1	0.041	141.6	lateral slip
5	Landers	28/06/1992	7.3	ABY090	20	0.146	69.2	lateral slip
6	Landers	28/06/1992	7.3	SIL000	3.8	0.05	51.7	lateral slip
7	Landers	28/06/1992	7.3	29P000	3.7	0.08	42.2	lateral slip
9	Loma Prieta	18/10/1989	6.9	SGI360	8.4	0.06	30.6	Oblique

10	Loma Prieta	18/10/1989	6.9	MCH000	3.5	0.073	44.8	Oblique
11	Loma Prieta	18/10/1989	6.9	PTB297	12.9	0.072	78.3	Oblique

4. Structural Analyses

SAP 2000 software was used for time history analyses to determine the structural behavior of the historical building. 12 mode values were considered in the dynamic time history analyses. Displacements values were interpreted, and the results were displayed graphically and discussed. The values of the displacement obtained from historical masonry building is given in Figures 5, and 6 respectively. In Figures displacements values obtained for earthquakes are seen in the X and Y directions.

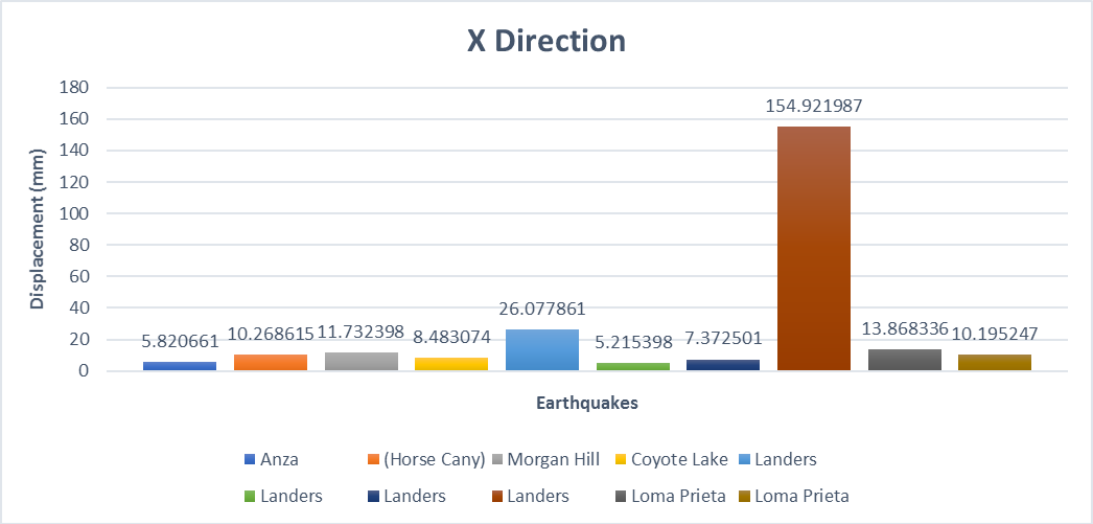


Figure 5. X-direction displacement of masonry building

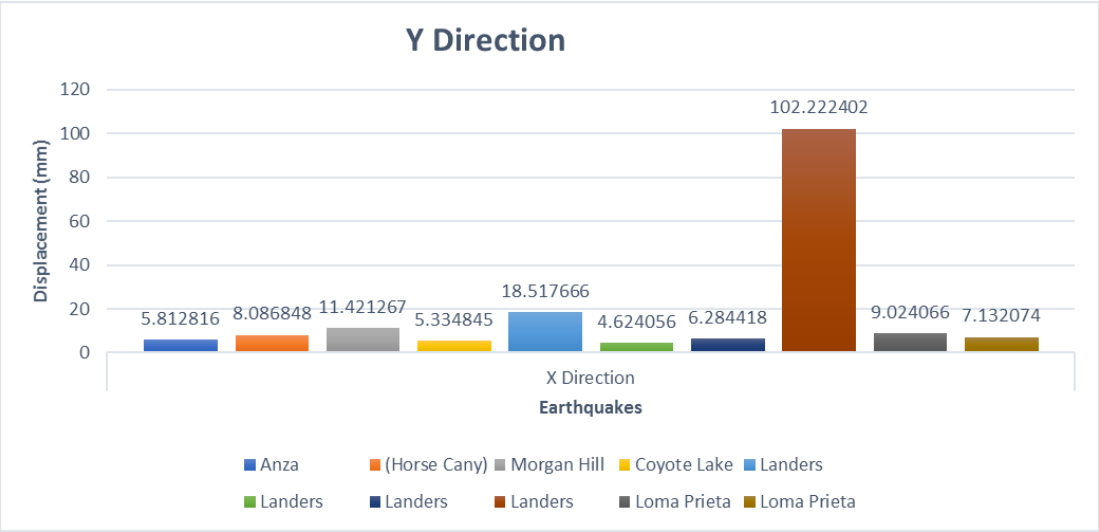


Figure 6. Y-direction displacement of masonry building

5. Result

In this study, structural assessment of masonry building in Kastamonu was discussed with detailed structural assessment approach. The historical building was modelled and analyzed through time history

analyses under 10 different ground motion data using SAP2000 Finite Element Analysis software. The dynamic analyses were performed with - 10 ground motion data with soil classes A to the historical building.

When comparing the results of the soil A according to X and Y direction, the highest displacement values for X directionoccurred at Landers (eighth Earthquake in earthquake table)Earthquake. The lowest displacement values for X direction were occurred at Landers (Sixth Earthquake in earthquake table) Earthquake. The highest displacement values for Y direction occurred at Landers (eighth Earthquake in earthquake table) Earthquake. The lowest displacement values for Y direction were occurred at Landers (sixth Earthquake in earthquake table) Earthquake.

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