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Research Article

DYNAMIC BEHAVIOUR OF HISTORICAL BAYBURT GRAND MOSQUE

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ABSTRACT

In this study, the locations of the damages that would occur when a historical building was exposed to different earthquakes were determined. The selected building is Bayburt Ulu Mosque located in the city center of Bayburt and it was built by the Anatolian Seljuk Sultan II. Gıyaseddin. This selected historical building is modelled according to the macro modelling technique in the SAP2000 program using the finite element method. Modules of elasticity, poisson's ratio and weight per unit of volume of Bayburt Stone which is used in the mosque are determined by the experiment. Also, the properties of the ground on which the building was built are determined. As earthquake records which recorded on similar grounds, components of DZC180 and DZC270 of 17 August 1999 Kocaeli earthquake, components BOL000 and BOL090 of 12 November 1999 Düzce earthquake and components of ERZE-EW and ERZE-NS of 13 March 1999 Erzincan earthquake are used. In the results of the dynamic analysis made, quantities and locations of the strains that can occur in the historic mosque are determined.
Keywords: Historic buildings, Bayburt stone, dynamic analysis, finite element macro modelling.

1. INTRODUCTION

Historical buildings have the characteristics of cultural heritage, which have survived from the past to the present, have been an important part of Turkish culture. In addition to cultural heritage, these structures guide us in the knowledge and construction techniques of past generations. In this respect, we need to protect this cultural heritage while preserving this historical structures.

In addition to adverse environmental conditions, physical and chemical deterioration and negative physical actions of people to these structures, natural disasters accelerate the destruction of historical buildings. In order to transfer these cultural heritages to the future safely, necessary maintenance, strengthening and repair works are required. In order to do all of this, the behaviour of the existing historical building against the earthquake should be known. In this respect, static and dynamic analyses were carried out by many researchers in historical buildings. Yılmaz [1] examined the Rahime Sultan Mosque in Sapanca and performed static analyses under own loads and response spectrum analyses with SAP2000 computer program. In the study, free vibration periods of the structure were calculated. Akdeniz [2] conducted linear and nonlinear dynamic analyses using the acceleration records of the Bingöl earthquake of 1 May 2003 in Malatya Ulu

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Mosque, which was built as a masonry structure in 1224. This historical structure was modelled with macro modelling method in ANSYS program. In this study, distribution of maximum and minimum principal stresses in the structure and damage status are given and the results are evaluated. In n onlinear analyses, it was observed that the damage caused by cracks was intensified in areas where tensile stresses were high in the mosque. Şeker et al. [3] examined the structural behavior of the historical Erzurum Lala Paşa Mosque with finite element method. Mutlu [4] modelled the numerical model of Bursa Ulu Mosque and Bursa Green Mosque and carried out modal analyses to evaluate the structural behaviour. As a result of the analysis, the most difficult sections and regions of mosques were determined. Çal [5] formed the numerical model of Ortaköy Grand Mecidiye Mosque and carried out static and dynamic analyses in order to evaluate its structural behaviour. In the study, seismic records which suitable for the ground structure of the region was used as strong earthquake ground motion. As a result of the study, the behaviour of the building was interpreted in general and made evaluations about the regions were forced. Tetik [6] performed static and dynamic analyses of Sheikh Süleyman Masjid in Istanbul. The finite element model of the historical structure was modelled in the SAP2000 program. In the results of the analysis, he identified weak sections and proposed reinforcement. Anadut [7] examined the earthquake behaviour of the Elekçi Bridge and Yozgat Clock Tower in Yozgat. These historical structures were modeled in the SAP2000 program. In the dynamic analysis, the acceleration records of the 13 March 1992 Erzincan earthquake were used. In the results of the analysis, the mode shapes of the structures, natural frequency values, the largest displacement values occurring in the structural elements, displacement time graphs, maximum pressure and tensile stress values were evaluated and the earthquake performance of the historical structures were evaluated. Dabanlı [8] examined the earthquake performance of Nur-u Osmaniye Mosque and the measures to be taken against damage were determined. In the study, the operational dynamic modal analysis of the structure was performed and the actual dynamic characteristics of the structure were determined. Material properties are determined with the samples taken from the structure. By constructing a finite element model of the historical structure, it has examined the static and dynamic analyse in detail and evaluated the results of the analysis and the earthquake performance of the structure. There is a study to determine the effect of soil-structure interaction [9].

Bayburt Ulu Mosque, one of the most important historical buildings located in Bayburt, has not been found in the literature. In this study, dynamic behaviour of Bayburt Ulu Mosque will be observed in possible earthquakes. Within the scope of this study, firstly, the properties of Bayburt Ulu Mosque ground and the mechanical properties of yellow Bayburt stone were examined and then, considering these results, the model was modeled with macro model in SAP2000 [10] program and it was aimed to determine the dynamic performance of the Bayburt Ulu Mosque.

2. MATERIAL AND METHOD

2.1. Wall Compressive Strength and Elasticity Module

The strength of the masonry building element depends generally on the joint behaviour of the stone and mortar combination. Historical masonry structural elements show a very wide strength value. Different approaches have been developed to determine the compressive strength and elasticity modulus of the masonry structural element. Kocak [11] stated that the modulus of elasticity of mortar used in masonry structures varies between 8000-10000 MPa. However, the compressive strength on the brick wall and the compressive strength of the brick are around 70% and 30%, respectively, when the thickness of the mortar is 2 cm and 5 cm respectively.

Dabanlı [12] proposed equation 1 for calculating the modulus of elasticity of composite structures such as masonry structures.

$$E_{composite} = \frac{(2E_{stone/brick} \times E_{mortar})}{(E_{mortar} + E_{stone/brick})} \quad (1)$$

Ulukaya and Yüzer [13] indicated that the factors affecting the modulus of elasticity of the masonry structures are primaril y the stone and the modulus of elasticity of the mortar. They used equation 2 was used proposed by Sahlin [14] and equation 3 proposed by Cheema and Klinger [15]. In addition, when the elasticity modulus results determined by flatjack method were taken into consideration in the model walls, they indicated that equation 4 should be used.

$$E_{yy} = 750 f_{c,b} \quad (2)$$

$$E_{yy} = (500 \sim 1000) f_{c,b} \quad (3)$$

$$E_{yy} = \frac{0{,}11 E_h^{1{,}35} E_b}{1{,}84 E_h + E_h} \quad (4)$$

Where E_{yy} is the modulus of elasticity of the masonry structure, $f_{c,b}$ is compressive strength of brick. E_h and E_b are the modulus of elasticity of mortar and brick. Drysdale et al. [16] proposes the equation 5 considering the properties of both the masonry unit and the mortar.

$$E_{yy} = \frac{1}{\frac{\frac{h_t}{(h_t+h_h)}}{E_t} + \frac{1-\frac{h_t}{(h_t+h_h)}}{E_h}} \quad (5)$$

Where h_t is thickness of the mortar in the brick and h_h is the horizontal joint. In this study, the physical and chemical properties of the yellow Bayburt stone used in the walls of the mosque were determined in the laboratory as shown in figure 1. The mechanical properties of the Bayburt stone determined by compression test are presented in Table 1. The chemical and physical properties of Bayburt stone determined by XRF, XRD and SEM analyses are presented in Table 2.

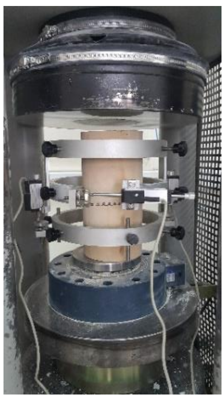

Figure 1. Test setup of mechanical properties of Bayburt stone

Table 1. Mechanical properties of Bayburt stone

Modulus of elasticity (MPa)	Compressive strength (MPa)	Poisson's ratio	Density (kg/m^3)
16649	26.97	0.12	1820

Table 2. Chemical and physical properties of Bayburt stone

Chemical Analysis	
Total SiO_2 (%)	70.26
Al_2O_3 (%)	16.91
Fe_2O_3 (%)	2.97
CaO (%)	0.37
MgO (%)	0.81
SO_3 (%)	0.05
K_2O (%)	3.29
Na_2O (%)	0.30
Loss of Glow (%)	4.25
Cl (%)	0.0280
Physical Analysis	
Over 45 μ sieve (%)	5.0
Specific weight (Mg/m^3)	2.50
Blaine (cm^2/g)	7364
Puzolanic activity	1.4

In the test results of the Bayburt yellow stone, the elasticity modulus (E) and the compressive strength (fb) are obtained 16649 MPa and 26.97 MPa respectively. E / fb ratio is obtained as 641. This value corresponds to equation 3. In the study, to determine the compressive strength of masonry wall, the approach which is the compressive strength of the masonry wall is 70% of the compressive strength of the block is used proposed by Koçak [11]. With this approach, the compressive strength of the stone wall is calculated as 18.88 MPa.

In the literature, tensile strength of stone is on average 10% of compressive strength [17-18]. However, Şeker et al. [3] reported this rate as between 14.8% -15.3%. In this study, tensile strength of the wall is chosen as 12% of compressive strength. Accordingly, the tensile strength of the stone wall is calculated as 2.18 MPa.

2.2. Determination of Soil Parameters

In this study, geotechnical properties of ground of mosque are investigated. In this context, sieve analysis and shear box tests were performed to determine the soil type and shear strength parameters. As a result of the test performed in accordance with ASTM D 2487, the soil class is determined as well-graded sand (SW) according to the Unified Soil Classification System [19]. The granulometry curve of the natural soil is given in Figure 2.

After determining the soil class of the medium dense sand, shear strength parameters of the ground compact sand are determined by using the shear box test. As a result of the experiment, the internal friction angle and the cohesion are calculated as 42^0 and 0,000105 MPa respectively. The study area is on the banks of the Çoruh River and groundwater is less than 15 m deep. In the light of these data, local soil is determined as Z2 and the coefficient of soil reaction is calculated as 25 MPa.

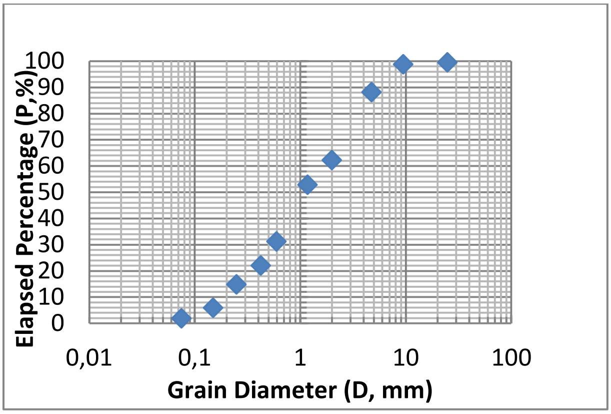

Figure 2. Granulometry curve of natural soil

2.3. Dynamic Analysis

In the soil analysis of the historical structure, it is determined that the ground group was class C. Therefore, earthquake records in type of this soil class are selected. These records are DZC180 and DZC270 components of 17 August 1999 Kocaeli earthquake, BOL000 and BOL090 components of 12 November 1999 Düzce earthquake and ERZE-EW and ERZE-NS components of Erzincan earthquake of 13 March 1999 (Figure 3-5).

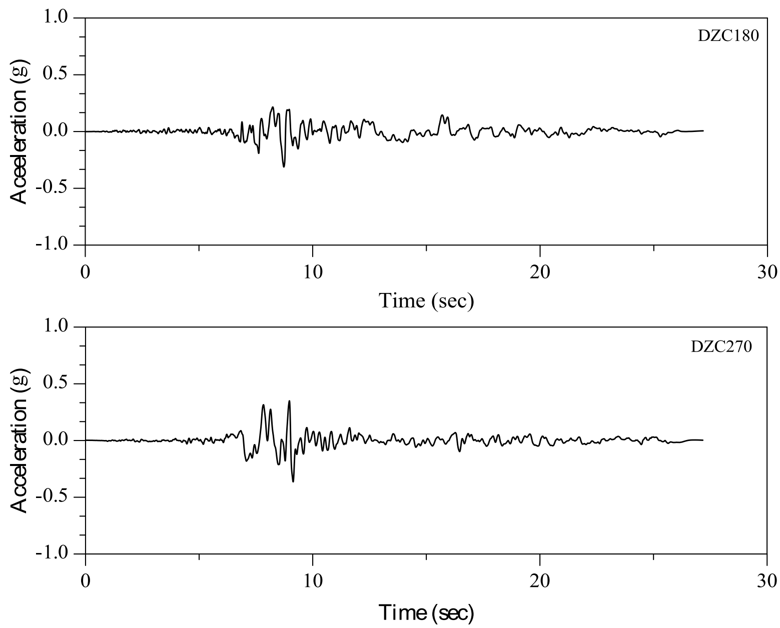

Figure 3. DZC180 and DZC270 components of 17 August 1999 Kocaeli earthquake

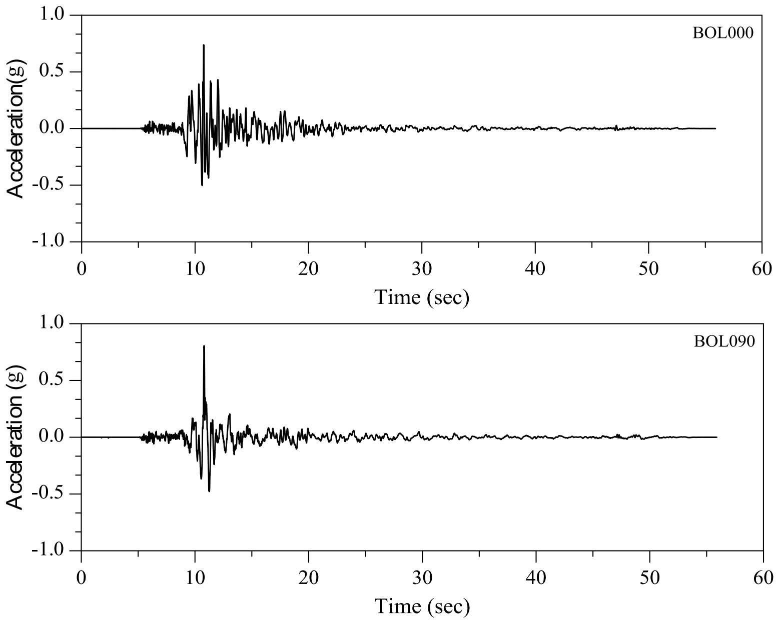

Figure 4. BOL000 and BOL090 components of 12 November 1999 Düzce earthquake

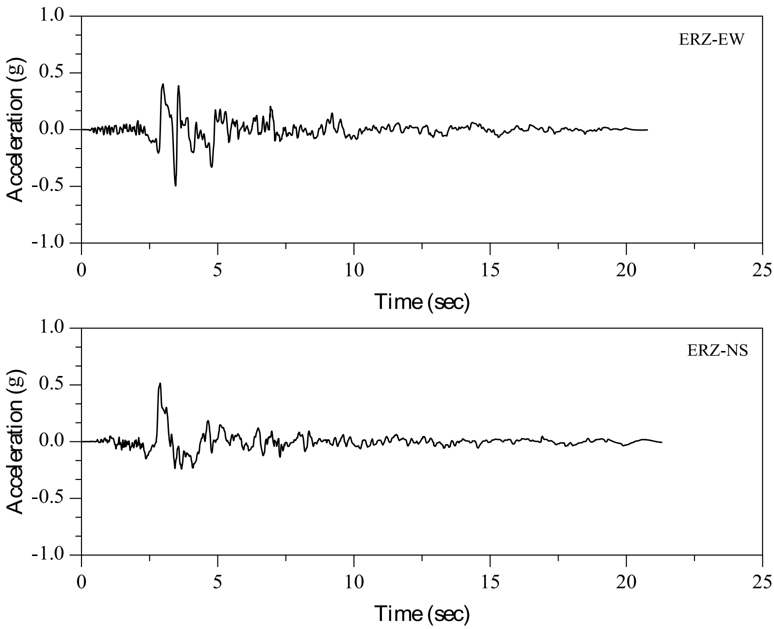

Figure 5. ERZE-EW and ERZE-NS components of Erzincan earthquake of 13 March 1999

3. RESULTS

As a numerical application, Bayburt Ulu Mosque in the city center of Bayburt is chosen. The Mosque was built in 1282 by Seljuk Sultan II. Gıyaseddin (Figure 6-7).

Figure 6. Bayburt Ulu Mosque

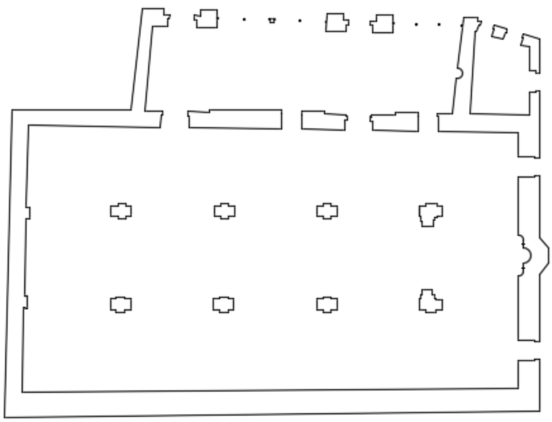

Figure 7. Plan of Bayburt Grand Mosque

The finite element model of the mosque is created in the SAP2000 program (Figure 8). The historical mosque is modelled with 2956 joints and 13051 solid elements.

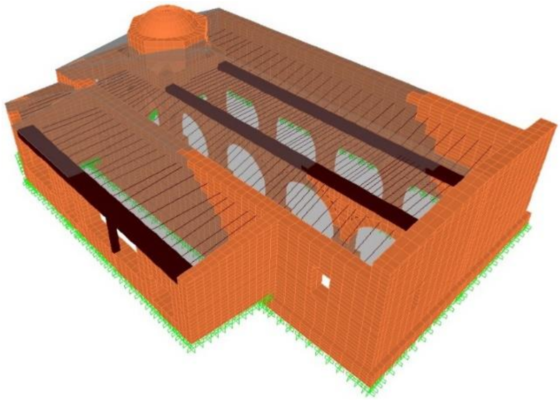

Figure 8. Finite Element Model of Bayburt Ulu Mosque

The tensile and compressive values of the mosque and the strength capacity of the wall are given in Table 3. Figure 9-11 shows the biggest regressions of the mosque which was subjected to the 17 August 1999 Kocaeli, 12 November 1999 Düzce and 13 March 1999 Erzincan earthquakes. Figure 12 shows the highest pressure stress in all three earthquakes.

Table 3. Maximum tensile values and capacity strength in the mosque

		Dead load + Erzincan	Dead load + Kocaeli	Dead load + Düzce	Strength capacity %
S11	Tensile (MPa)	0.457	0.552	**0.884**	**41**
	Compressive (MPa)	0.909	0.553	**1.102**	**6**
S22	Tensile (MPa)	0.717	0.557	**1.038**	**48**
	Compressive (MPa)	0.966	0.672	**1.312**	**7**
S33	Tensile (MPa)	2.604	1.857	**3.344**	**154**
	Compressive (MPa)	3.163	2.246	**3.923**	**22**

As it can be seen from Table 3, the highest pressure and tensile stress values occur in Düzce earthquake. The strength capacity is calculated using the values obtained from this earthquake. It is thought that damage will not occur because the compressive stresses do not exceed the compressive stress of the masonry structure in all earthquakes. It is thought that the damage will occur because S33 tensile stress is 2.18 MPa exceeds the tensile stress of the masonry structure subjected to Düzce and Erzincan earthquake. It should be noted that the tensile strength capacity of the masonry structure increases up to 85% in case of Kocaeli earthquake. This percentage shows that the stone is close to the tensile strength capacity. As shown in Figure 9-11, the greatest tensile stress occurs in the third of the left-hand arch feet in the Qibla direction in the structure subjected to three earthquakes. The maximum pressure stress occurs at the same location (Figure 12).

Figure 9. Maximum S33 tensile stresses of the mosque subject to Erzincan earthquake

Figure 10. Maximum S33 tensile stresses of the mosque subject to Kocaeli earthquake

Figure 11. Maximum S33 tensile stresses of the mosque subject to Düzce earthquake

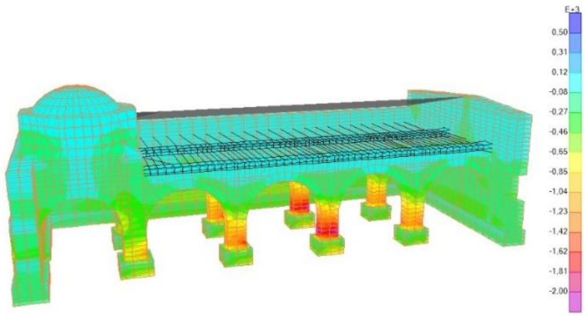

Figure 12. The largest pressure stress occurring in the mosque

4. CONCLUSION

In this study, the dynamic performance of Bayburt Ulu Mosque built in Bayburt province in 11th century is examined. As earthquake ground motions, three different earthquake records are cosidered. Also in this study, the physical and chemical properties of the yellow Bayburt stone used in the construction of the mosque are examined.
The following observations arise from the research:

- The greatest stress values in the historical mosque are obtained when the building is subjected to the 12 November 1999 Düzce earthquake.
- Since the compressive stresses are not greater than the compressive stresses of the masonry structure, it is considered that the mosque will not be damaged due to compressive.
- The greatest tensile stress occurred on the third belt leg, which is believed to cause damage. These damages are thought to be solved by FRP covering and bracing processes.

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