INVESTIGATION OF SEISMIC BEHAVIOR OF A MONUMENTAL BUILDING IN HISTORICAL CAPPADOCIA REGION OF TURKEY

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ABSTRACT :

This study focuses on the investigation of seismic behavior of a monumental building constructed in historical Cappadocia region of Turkey. The building is located at the town of Fertek which is two kilometers from the city of Nigde. It has been used as a worshipping temple since it was built in the year 1835. It is suggested to be representative of many similar buildings which were built as worshipping temples during the same era at the Cappadocia region. Seismic behavior of the monumental building is investigated using dynamic analysis procedures. The building is subjected to ground motion records which were obtained during the recent earthquakes in Turkey. These ground motions were recorded during Ceyhan earthquake (1998) which occured close to Nigde, Marmara earthquake (1999) and Duzce earthquake (1999). The dynamic analyses are conducted on the monumental building for the two cases of with wall and without wall which helps to consider the effect of structural walls on the seismic behavior of the building. In the light of the dynamic analyses results, expected level of damage and the structural irregularities of the monumental building are examined. It is observed that slab discontinuties on the first floor constitute a major element in the structural damage presumed. In addition, upon application of certain ground motions used, excessive levels of drift are observed which is another element for expected damage.

KEYWORDS: monumental building, Cappadocia region, dynamic analysis, drift, structural irregularity

1. INTRODUCTION

In this study seismic behavior of a monumental building constructed in historical Cappadocia region of Turkey is investigated. The building, which has been used as a worshipping temple since it was built in the year 1835, is located at the town of Fertek which is close to the city of Nigde. It is suggested to be representative of many similar buildings which were built during the same era as temples in the Cappadocia region.

Modal, response spectrum and nonlinear dynamic analysis procedures for investigation of seismic behavior of the monumental building are applied. The building is subjected to ground motion records which were obtained during the recent earthquakes in Turkey. These ground motions were recorded during Marmara earthquake (1999), Duzce earthquake (1999) and Ceyhan earthquake (1998). The analyses are conducted on the monumental building model for two cases of with wall and without wall which helps to consider the effect of structural walls on the seismic behavior of the building.

Seismic drift response of building structures at seismically active regions has been investigated (Ozturk 2003). This study will help to evaluate the seismic behavior of a historical building under different earthquake excitations from a perspective of maximum drift and the resulting damage to be observed. In addition, the importance of considering slab discontinuities in the building will be noted.

2. BUILDING DESCRIPTION

The investigated monumental building in Fertek was built as a church in 1835, in 1924 it was converted into a mosque and is still being used. It is located 2 km. from the City Center of Nigde County. It is a two storey structure with entrance floor and gallery floor.

When it was built in 1835, it was built in the form of a basilica type of church. There are three semicircular apses at its east part. There is a "U" shaped narthex at the west entrance of the building which has a circular curve outside of the building (Parman 1988). Inside the building, the gallery part is composed of columns which are connected to each other with rounded arches in the east, west, north and south directions and the main area is surrounded in "U" shape.

In all outer walls, yellow or dark gray colored straight-cut stones are used as a material. Timber is used both in the inner part at the top of the columns and at the entrance hall at the top of the narthex. The front and inside view of the building are given in Figure 1.

(a) (b)

Figure 1 Front (a) and inside (b) view

The material used in construction is named as Nigde yellowstone which is commonly used in the Cappadocia region. The stone has a density, γ value of 18 kN/m^3 , modulus of elasticity value of 18 * 10^6 kN/m^2 and Poisson's ratio, ν value of 0,3.

The diameter of inner columns is 60 cm (Ø 60) while for the outer columns it is 50 cm (Ø 50). In the east-west direction the building extends for 34.55 m while in the north-south direction the length of the building is 23.90 m. The inner walls are of 60 cm thickness while the outer walls are of 85 cm thickness. The plan of the entrance and gallery stories of the building is given in Figure 2 while its three-dimensional model is provided in Figure 3.

The building has seven spans in east-west direction four of which have a length of 4.40 m while the remaining three have lengths of 5.20 m, 4.70 m and 4.10 m, respectively. In the north-south direction there are five spans: two of them have a length of 4.00 m, two of them 4.35 m and one of them 6.20 m.

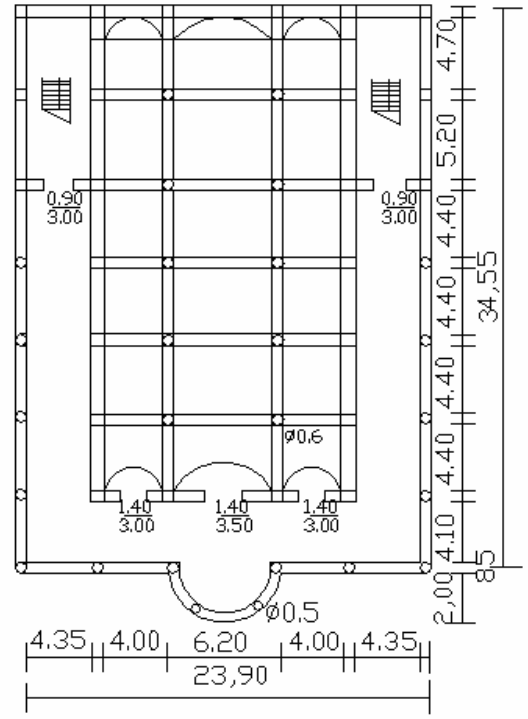

Figure 2 Building plan (Celik and Sadak 2007)
(All dimensions in m)

Building roof top elevation is 11.60 m. The top of the gallery storey elevation is 8.00 m such that while the entrance storey has a height of 4.50 m, the gallery storey has a height of 3.50 m. Total weight of the building is calculated to be around 9070 kN.

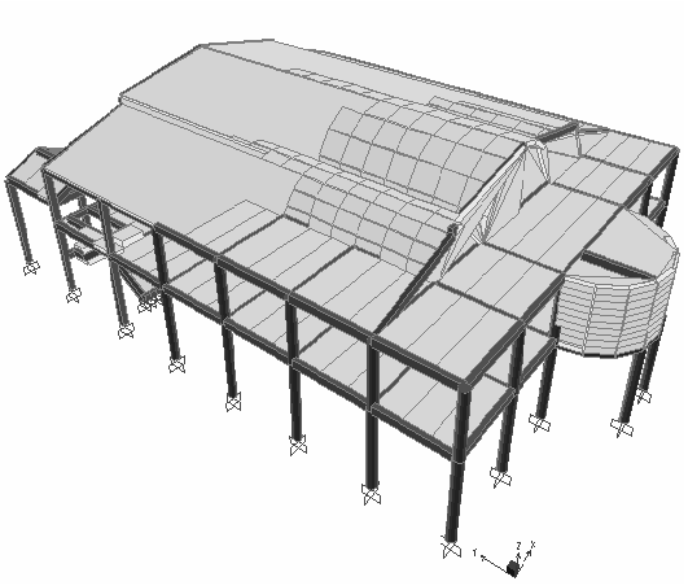

Figure 3 Three-dimensional model (Celik and Sadak 2007)

3. MODAL AND RESPONSE SPECTRUM ANALYSIS OF THE BUILDING

For the analysis of the structure, SAP2000 Program (2000) is used. First three structural periods obtained as a result of modal analyses both for the building with walls and the building without walls are provided in Table 1. For the building with walls the first three periods are 0.31 sec, 0.28 sec and 0.27 sec, respectively while for the building without walls the first three modes are 0.63 sec, 0.46 sec and 0.44 sec, respectively. There are 1881 nodes defined in the structural system of the building with walls while there are 814 nodes defined for the building without walls. In the analyses, a damping ratio of 5 % is considered.

Table 1 Periods of first three modes of the building

Modes	**Periods of Building withWalls (sec)**	**Periods of Building without Walls (sec)**
1st Mode	0.31	0.63
2nd Mode	0.28	0.46
3rd Mode	0.27	0.44

The building is located on a soil type of Z3 with T_A=0.15 sec and T_B=0.6 sec, respectively. The corresponding spectrum function is given in Figure 4 and spectrum constant, K is evaluated using Equation 1. In the analysis, effective ground acceleration constant, A_O value is 0.1, building importance constant, I value is 1.0. The building ductility constant, R value is taken as 1 regarding the brittleness of the material. K value is evaluated as 0.98 m/sec^2, accordingly.

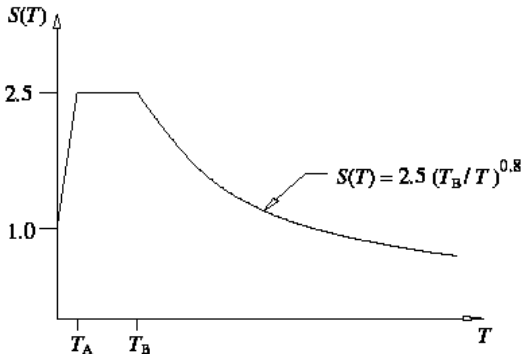

Figure 4 Spectrum function

$$K = \frac{A_O \cdot I \cdot g}{R} \tag{1}$$

Using Equation 2, spectrum constant, *S(T)* is calculated to be 4.24 for the building with walls and 2.40 for the building without walls.

$$S(T) = 2.5\left(\frac{T_B}{T}\right)^{0.8} \tag{2}$$

4. NONLINEAR ANALYSIS OF THE STRUCTURE

The nonlinear analyses are conducted both in X and Y directions for the ground motion records provided in Table 2. The building, soil and seismic region properties of the structure explained above are used for the nonlinear analyses.

The ground motion records are Ceyhan EW and Ceyhan NS records which were recorded during 1998 Adana Ceyhan earthquake, Izmit EW and Izmit NS records which were recorded during 1999 Marmara earthquake and, Bolu EW and Bolu NS records which were recorded during 1999 Duzce earthquake. For the given earthquake data maximum ground acceleration values (PGA) are given in Table 2.

Table 2 Ground motion records and maximum ground acceleration (PGA) values

Ground Motion Record	**Maximum Ground Acceleration (PGA)**
Ceyhan EW (Ceyhan1998)	0.23 g
Ceyhan NS (Ceyhan1998)	0.28 g
Izmit EW (Marmara 1999)	0.23 g
Izmit NS (Marmara 1999)	0.17 g
Bolu EW (Duzce 1999)	0.82 g
Bolu NS (Duzce 1999)	0.75 g

The building is analyzed considering both with walls and without walls in order to consider that it may be exposed to several earthquakes during its lifetime and; the walls may be destructed and may not function structurally.

The results of dynamic analyses revealed that Bolu-EW and Bolu-NS are the most demanding ground motions in means of maximum displacement response of the building. Accordingly, only the nonlinear

displacement-time histories for Bolu-EW and Bolu-NS are provided (Figures 5-12) while the maximum displacements for all of the six ground motions applied are tabulated in Tables 3 & 4. In addition, it is observed that slab discontinuities on the gallery floor constitute a major element in the structural damage expected.

Maximum displacement response values are observed at nodes located at the roof top. Nonlinear displacement time-histories for the corresponding nodes are provided in Figures 5 – 12. The maximum displacement response values are tabulated in Tables 3 & 4.

4.1.Nonlinear Displacement-Time Histories of Joints with Maximum Drift in Building with Walls

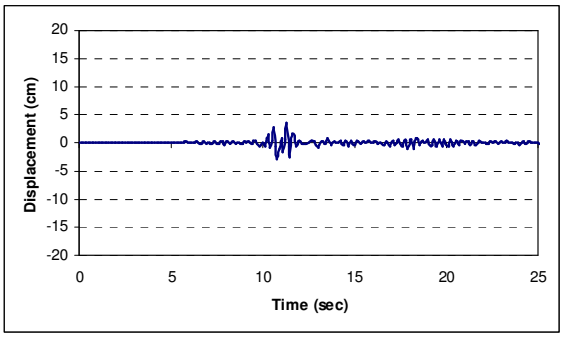

Figure 5 Roof Drift in X direction (Bolu-EW)

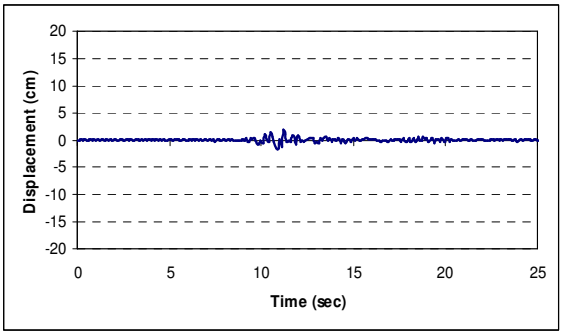

Figure 6 Roof Drift in Y direction (Bolu-EW)

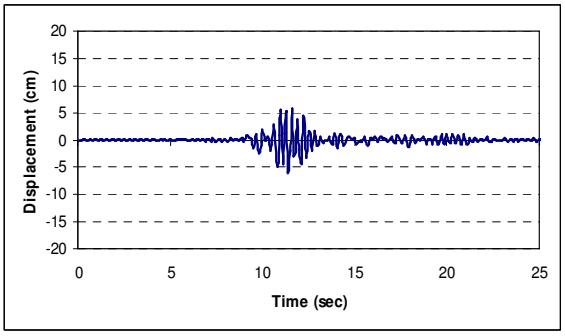

Figure 7 Roof Drift in X direction (Bolu-NS)

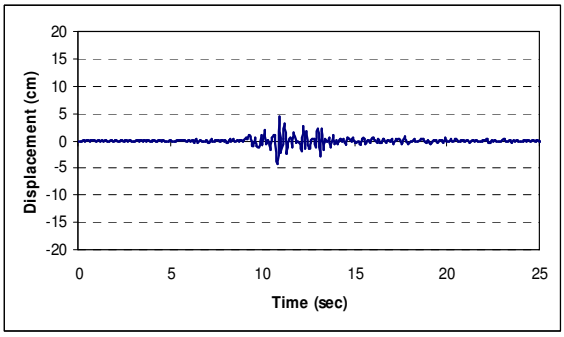

Figure 8 Roof Drift in Y direction (Bolu-NS)

Table 3 Maximum Displacements for Building with Walls

Ground Motion	X direction (m)	Mean Drift in X direction (%)	Y direction (m)	Mean Drift in Y direction (%)
Ceyhan – EW	0.02	0.2	0.01	0.1
Ceyhan – NS	0.02	0.2	0.01	0.1
Izmit – EW	0.03	0.3	0.02	0.2
Izmit – NS	0.02	0.2	0.01	0.1
Bolu – EW	0.04	0.3	0.02	0.2
Bolu - NS	0.06	0.5	0.05	0.4

4.2. Nonlinear Displacement-Time Histories of Joints with Maximum Drift in Building without Walls

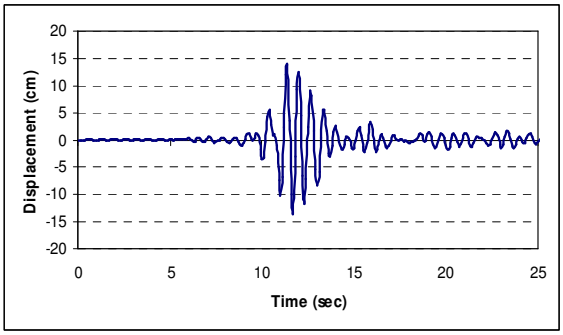

Figure 9 Roof Drift in X direction (Bolu-EW)

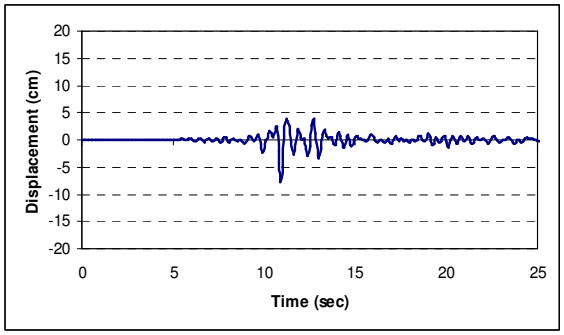

Figure 10 Roof Drift in Y direction (Bolu-EW)

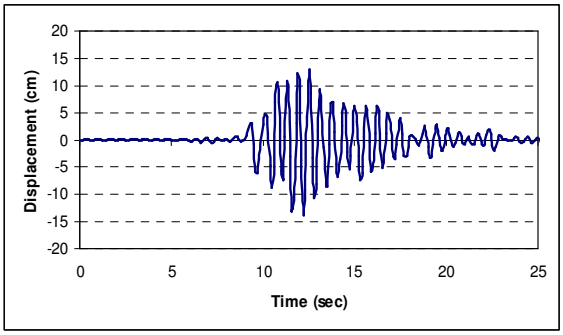

Figure 11 Roof Drift in X direction (Bolu-NS)

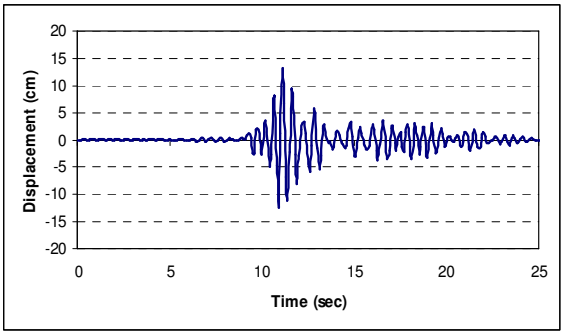

Figure 12 Roof Drift in Y direction (Bolu-NS)

Table 4 Maximum Displacements for Building without Walls

Ground Motion	X direction (m)	Mean Drift in X direction (%)	Y direction (m)	Mean Drift in Y direction (%)
Ceyhan – EW	0.12	1.0	0.06	0.5
Ceyhan – NS	0.08	0.7	0.06	0.5
Izmit – EW	0.05	0.4	0.03	0.3
Izmit – NS	0.04	0.3	0.03	0.3
Bolu – EW	0.14	1.2	0.08	0.7
Bolu - NS	0.14	1.2	0.13	1.1

5. RESULTS

The presented study focuses on the investigation of seismic behavior of a monumental building located at the town of Fertek which is in historical Cappadocia region of Turkey. The building is suggested to be representative of many similar buildings which were built as worshipping temples during the same era at the Cappadocia region.

As parts of the investigation nonlinear dynamic analyses are applied and; expected level of damage and the structural irregularities of the monumental building are examined in the light of the analyses results. The ground motion records used are Ceyhan EW and Ceyhan NS records which were recorded during 1998 Adana Ceyhan earthquake, Izmit EW and Izmit NS records which were recorded during 1999 Marmara earthquake and, Bolu EW and Bolu NS records which were recorded during 1999 Duzce earthquake. The building is analyzed for both with walls and without walls cases in order to consider that it may be exposed to several earthquakes during its lifetime and; the walls may be destructed and may not function structurally.

Considering the ground motion set applied, the building model with walls may be exposed to a mean drift value up to 0.5 % while for the building without walls the mean drift may exceed 1.0 % which is in the range of comparable damage to the structure. It has to be noted that excessive levels of drift mainly occur upon application of certain demanding ground motions (Bolu-EW and Bolu-NS). In addition, it is observed that slab discontinuities on the gallery floor constitute a major element in the structural damage expected.

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