EFFECT OF CFRP RETROFITTING APPLICATION ON SEISMIC BEHAVIOR OF HISTORIC MONUMENTAL BUILDINGS AT CAPPADOCIA REGION OF TURKEY

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- In this study analytical investigation of effect of retrofit application using carbon fiber (CFRP) on seismic behavior of a monumental building at historical Cappadocia region of Turkey is investigated.
- The monumental building has been used as a worshipping temple since it was built in the year 1835. It is located at the town of Fertek at Nigde province.
- It is a good model for similar temples which were built during the same era in the Cappadocia region.

- Investigation of seismic behavior of the retrofitted monumental building is conducted using the analytical approaches for modal, response spectrum and static analysis procedures.
- Ground motion records which were recorded during recent earthquakes in Turkey are used. The indicated ground motions were recorded during Ceyhan earthquake (1998), Marmara earthquake (1999) and Duzce earthquake (1999).
- The original and CFRP retrofitted models of the monumental building for two cases of with wall and without wall are analyzed considering the effect of structural walls on the seismic behavior.

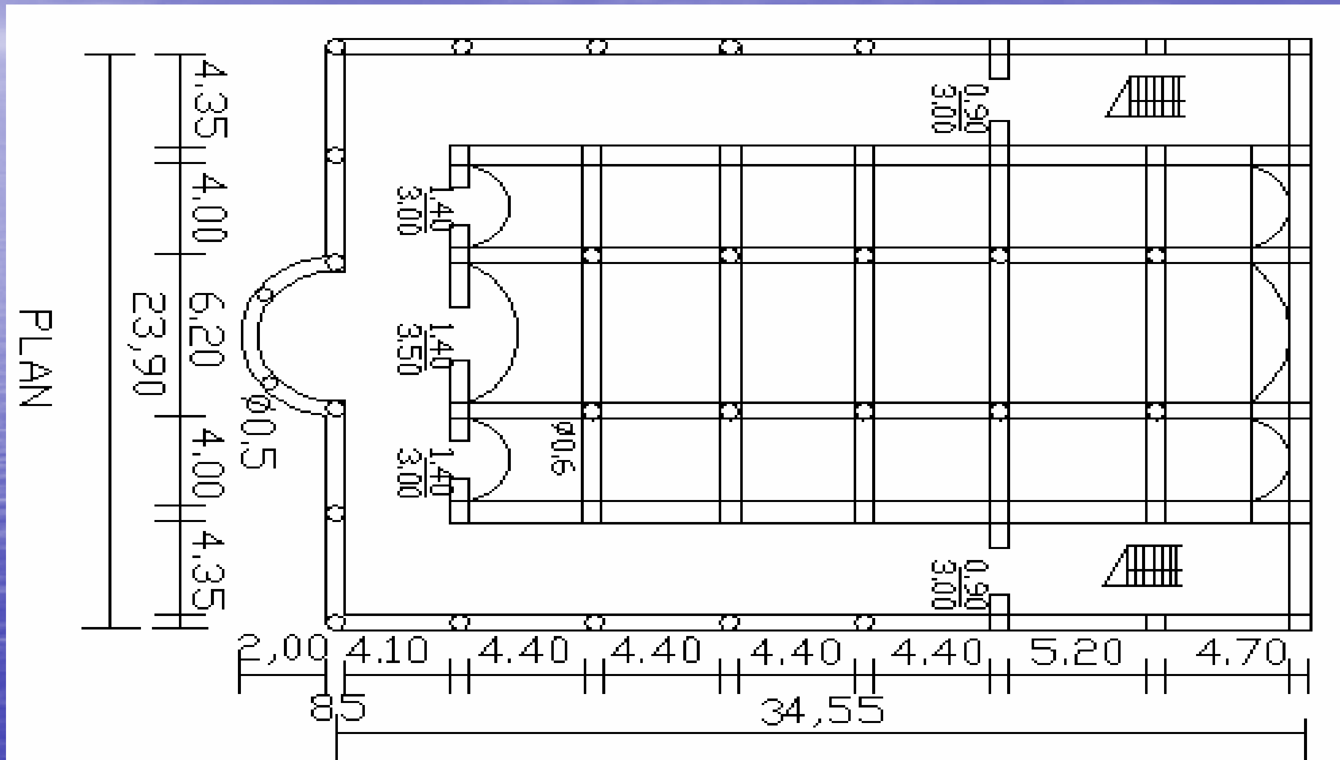
Building Description

- The monumental building was built as a church in 1835. It is located 2 km. from the city center of Nigde county. It has two storeys which are the entrance floor and the gallery floor, respectively.
- 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.
- 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. Finally, the elevation of building roof top is 11.60 m. Total weight of the building is around 9070 kN.

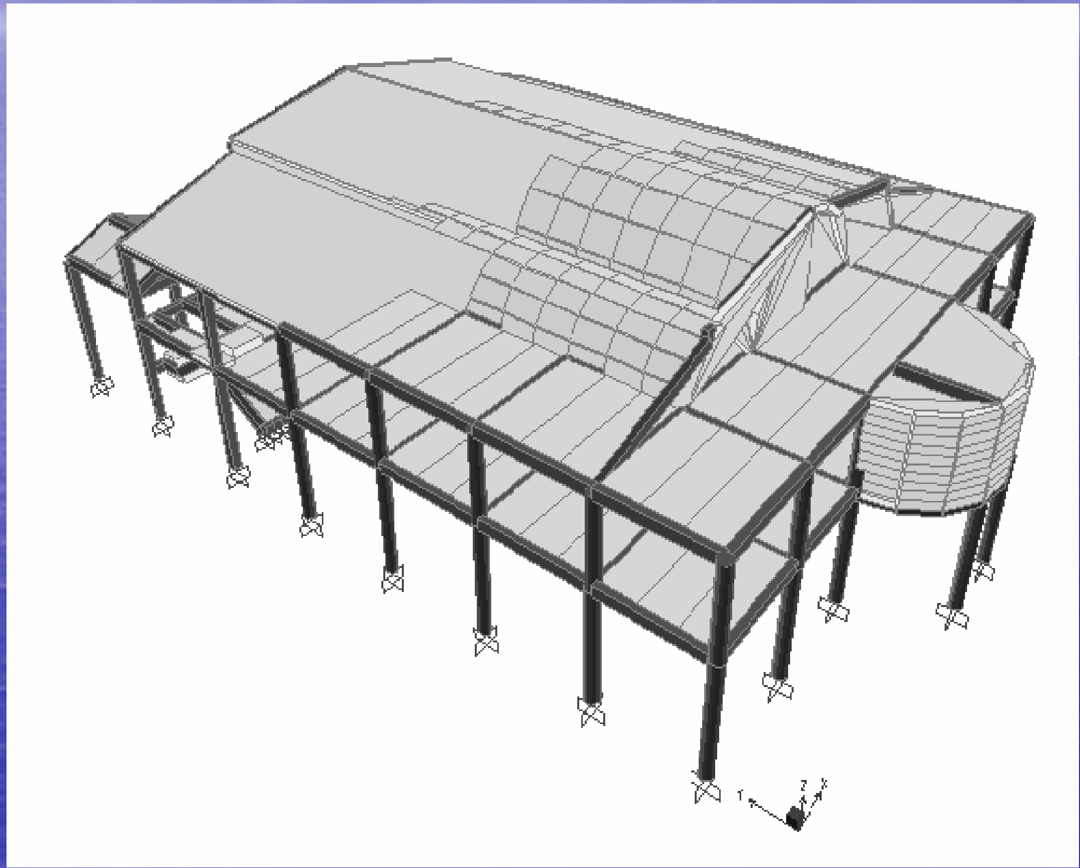
(a) (b)

Front (a) and inside (b) view

Entrance Storey Plan



Three Dimensional Structural View



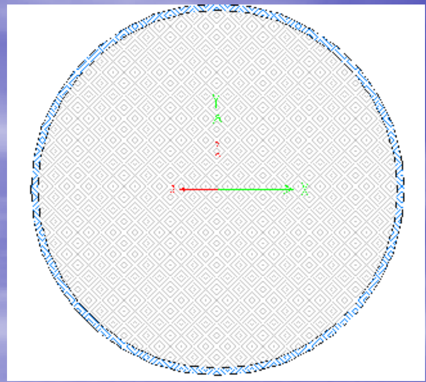
Retrofitting Material CFRP and Its Application Procedure

- Carbon fiber (CFRP) is used for retrofitting of the monumental building. The material properties of CFRP are given below.

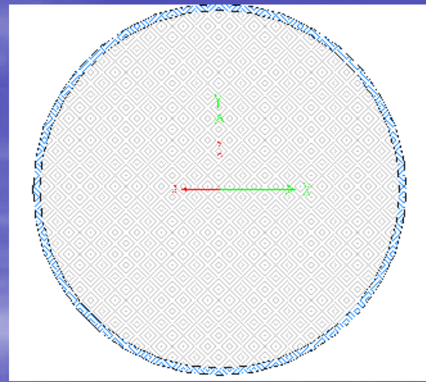
Material properties of carbon fiber (CFRP)

Strength in tension (MPa)	4'100
Elastic modulus (MPa)	231'000
Ultimate elongation (%)	1.7
Ultimate tension force (kN)	44
Density (g/m^3)	$1.78*10^6$

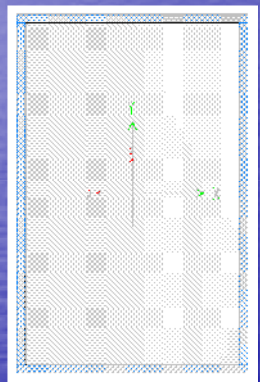
- For beams, CFRP is applied at bottom surfaces in order to withstand tension stresses. For columns, CFRP is applied at the surface area of columns in order to withstand tension stresses.
- No retrofitting is applied at structural walls, arches and domes of the building.
- For analytical investigation of effect of CFRP application on beams and columns, the thickness of CFRP is taken as 0.5 cm and 1.0 cm, respectively.
- The application of CFRP on beam and column elements are shown below.



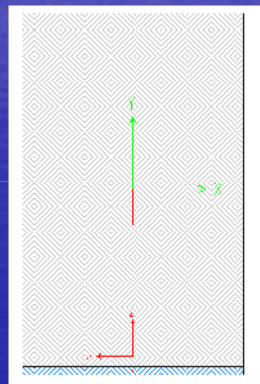
(a)



(b)



(c)



(d)

Retrofitting application on column and beam elements
(a) circular column with 50 cm diameter,
(b) circular column with 60 cm diameter,
(c) rectangular column with 25 by 40 cm dimensions,
(d) beam element with 25 by 40 cm dimensions

Analysis of the Monumental Building

- 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. Periods of the first three modes of the original building and its retrofitted versions are obtained as a result of modal analyses

Periods of first three modes of the Original Building

Modes	**Periods of building with walls (sec)**	**Periods of building without walls (sec)**
1^{st}	0.31	0.63
2^{nd}	0.28	0.46
3^{rd}	0.27	0.44

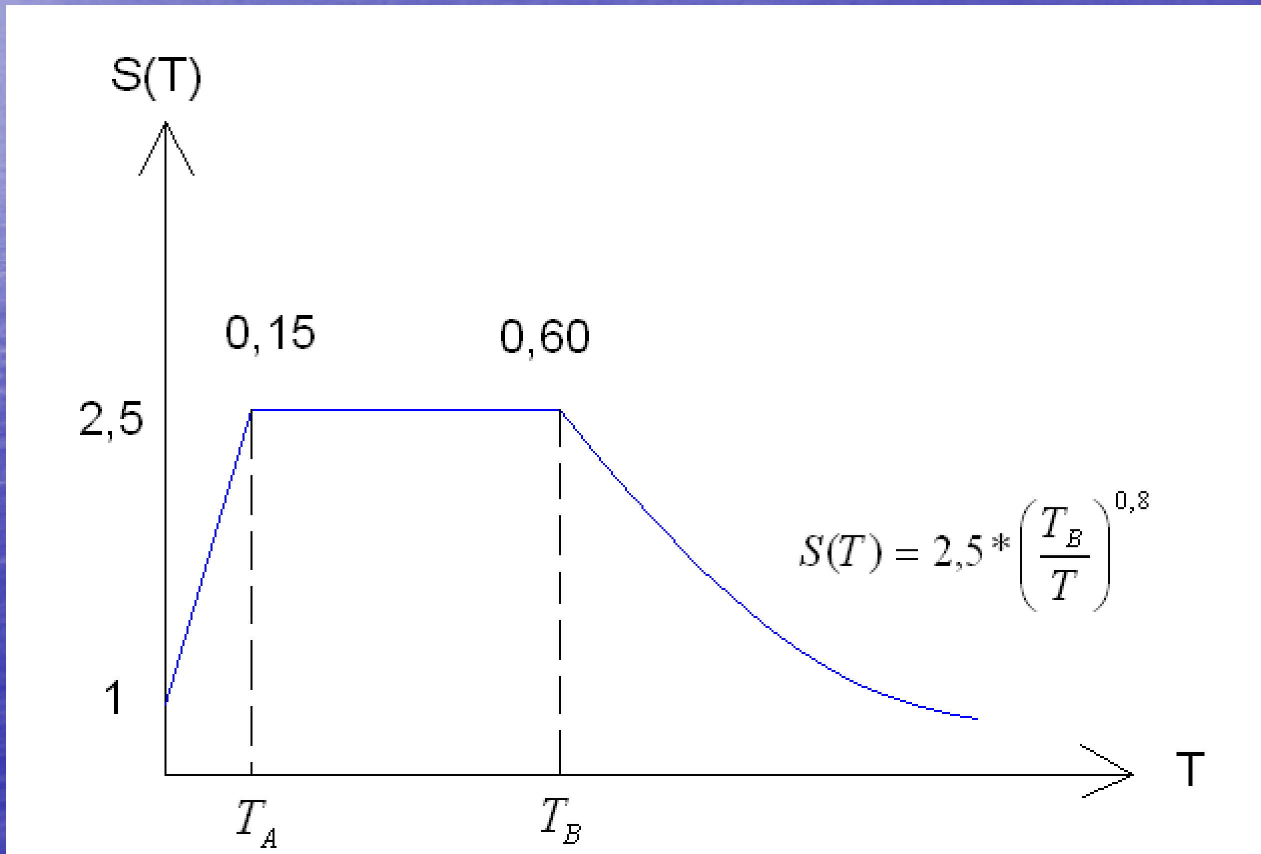
Periods of first three modes of the Retrofitted Building (CFRP thickness is 0.5 cm)

Modes	Periods of building with walls (sec)	Periods of building without walls (sec)
1st	0.27	0.33
2nd	0.22	0.27
3rd	0.17	0.22

Periods of first three modes of the Retrofitted Building (CFRP thickness is 1.0 cm)

Modes	Periods of building with walls (sec)	Periods of building without walls (sec)
1st	0.26	0.31
2nd	0.21	0.27
3rd	0.17	0.21

- 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 below.



- Effective ground acceleration constant, A_O value is 0.1.

- The building importance constant, I value is 1.0.

- Ductility constant, R value is taken as 1 regarding the brittleness of the material.

- Spectrum constant, K is evaluated as 0.98 m/sec^2 .

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

Ground motion records and their 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 results of the analyses for the retrofitted building models are compared with the results of the original building model which were evaluated previously (Celik and Sadak 2007).

- The retrofitted building models are analyzed covering the cases of both with walls and without walls in order to consider that they may be exposed to several severe earthquakes during their lifetimes so that the walls may be destructed and may not function structurally (Senturk, Yilmaz and Yildirim 2008).

- Load combinations proposed in the Turkish Code (TS500 2000) are used for the determination of vertical loads and lateral earthquake loads applied on the model buildings. Results of static analyses for different load combinations given in the Turkish Code (TS500 2000) are provided in the following three Tables both for the original structure and its retrofitted models.

Results of analyses for the Original Structure

Original (with walls)			
Load combination	Structural height (m)	Δ_{imax} (m)	Δ_{imax}/H (%)
1.4G + 1.6Q	11.6	0,0039	0,03
G + Q + Ex	11.6	0,0085	0,07
G + Q - Ex	11.6	0,0086	0,07
G + Q + Ey	11.6	0,0038	0,03
G + Q - Ey	11.6	0,0052	0,05
Original (without walls)			
Load combination	Structural height (m)	Δ_{imax} (m)	Δ_{imax}/H (%)
1.4G + 1.6Q	11.6	0,0094	0,08
G + Q + Ex	11.6	0,0303	0,26
G + Q - Ex	11.6	0,0309	0,27
G + Q + Ey	11.6	0,0180	0,16
G + Q - Ey	11.6	0,0170	0,15

Results of analyses for the Retrofitted Structure (0.5 cm CFRP thickness)

Retrofitted (with walls)			
Load combination	Structural height (m)	Δ_{imax} (m)	Δ_{imax}/H (%)
1.4G + 1.6Q	11.6	0,0026	0,03
G + Q + Ex	11.6	0,0081	0,07
G + Q - Ex	11.6	0,0082	0,07
G + Q + Ey	11.6	0,0038	0,03
G + Q - Ey	11.6	0,0046	0,04
Retrofitted (without walls)			
Load combination	Structural height (m)	Δ_{imax} (m)	Δ_{imax}/H (%)
1.4G + 1.6Q	11.6	0,0073	0,07
G + Q + Ex	11.6	0,0069	0,06
G + Q - Ex	11.6	0,0070	0,06
G + Q + Ey	11.6	0,0035	0,03
G + Q - Ey	11.6	0,0032	0,03

Results of analyses for the Retrofitted Structure (1.0 cm CFRP thickness)

Retrofitted (with walls)			
Load combination	Structural height (m)	Δ_{imax} (m)	Δ_{imax}/H (%)
1.4G + 1.6Q	11.6	0,0021	0,02
G + Q + Ex	11.6	0,0063	0,05
G + Q - Ex	11.6	0,0064	0,06
G + Q + Ey	11.6	0,0033	0,03
G + Q - Ey	11.6	0,0031	0,03
Retrofitted (without walls)			
Load combination	Structural height (m)	Δ_{imax} (m)	Δ_{imax}/H (%)
1.4G + 1.6Q	11.6	0,0051	0,05
G + Q + Ex	11.6	0,0043	0,04
G + Q - Ex	11.6	0,0044	0,04
G + Q + Ey	11.6	0,0033	0,03
G + Q - Ey	11.6	0,0028	0,03

Conclusions

- The presented study focuses on analytical investigation of effect of retrofit application using carbon fiber (CFRP) on 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 modal, response spectrum and linear static analysis for different load combinations are applied.

- 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.
- As carbon fiber (CFRP) retrofitting is applied, a stable drop is observed at the period values of the first three modes of the building both for the building models with walls and the building models without walls.
- In addition, the results of static analyses show that there is a stable decrease in maximum lateral drift demand, Δ_{imax} and corresponding drift percentage, Δ_{imax} /H (%) upon application of CFRP retrofitting on the original building model.