

Comparison of Performances of Various Rehabilitation Approaches for a Hospital Building

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ABSTRACT

In this study, the seismic performance of the Merkez Efendi hospital building in Manisa is determined with SAP2000 computer program according to the Turkish Earthquake Code-2007. The building and its footings do not provide sufficient performance level. So the superstructure is rehabilitated by converting some of the brick infill walls to RC shear walls. The seismic performance of the building reaches to the satisfactory level. Secondly, the same infill walls are strengthened with steel profiles according to Turkish Earthquake Code-2007. Thirdly, the same infill walls are strengthened with CFRP plates to get the required seismic performance level. The seismic performances of the hospital building are compared for the four cases.

Keywords: *Strengthening, Rehabilitation, Shear Wall, CFRP, Steel Profile, Seismic Performance*

1. INTRODUCTION

Buildings are subjected earthquake, wind, fire etc. during their lifetimes. Sometimes, addition of a story and change in the purpose of using occur. For these reasons, the performances of the buildings should be investigated according to the present earthquake codes of the countries. If the performance of the building is insufficient, it has to be rehabilitated. The Turkish Earthquake Code-2007 (TEC-2007) gives alternative rehabilitation methods. One should choose the most suitable method for buildings.

Kaplan et al. [1] rehabilitated the old SSK hospital building in Denizli by strengthening the one side of the brick walls with matting steel and compared the performance levels by taking into account the effect of the infill walls. As a result, they found that the performance level of the building increased 4-6 times. Turk et al. [2] rehabilitated the reinforced concrete column-beam frame by strengthening the infill walls experimentally and found out that the lateral capacity of the frame increased considerably. Damcı et al. [3] rehabilitated the buildings of the İstanbul University according to the TEC-2007 by adding shear walls to the outside of the buildings and the new performance reached the necessary levels. Chapter 7 of TEC-2007 entitled "Assessment and Strengthening of Existing Buildings" and sets standards for assessment and rehabilitation of existing buildings [4]. Recently, there have been some studies about linear and non-linear procedures in TEC-2007 [5] and concluded that results of linear procedures are more conservative than non-linear ones [6, 7, 8].

In this study, the seismic performance level of the Merkez Efendi hospital building is found to be insufficient according to TEC-2007. The methods in the TEC-2007 are used for rehabilitation. Firstly, it is strengthened with adding RC shear walls instead of the infill walls. Secondly, the same infill walls are strengthened with steel profiles. Thirdly, the same infill

walls are strengthened with CFRP plates. The capacity curves and performance levels of the strengthened buildings are determined. Finally, the comparison of seismic behaviours of the building is made. The seismic performances of the building are investigated by using SAP2000 V14 program and the incremental static pushover analysis.

2. DESCRIPTION OF THE HOSPITAL BUILDING

The hospital building has ground floor and three stories. The height of the ground floor is 3.70 m and the heights of the other floors are 3.20 m. The building has dimensions 34.90 m by 14.70 m in plan. The building has two shear walls, columns and beams (Fig.1). The columns in the ground and first floor have dimensions 30x60 cm and 60x40 cm. The columns in second and third floor have dimensions 30x50 cm and 50x40 cm. In addition to this, in every floor, there are four columns having dimensions 60x60 cm. In every floor the shear walls have the dimension of 30x240 cm. All the floors beams have the dimensions of 30x60 cm. The building is situated in the 1.seismic zone and Z3 local site class. The standard compressive strength of the concrete of the building is determined from the samples taken from the columns as 11 MPa (Fig.2.b). Material properties are 220 MPa for the yield strength of both longitudinal and transverse reinforcements.

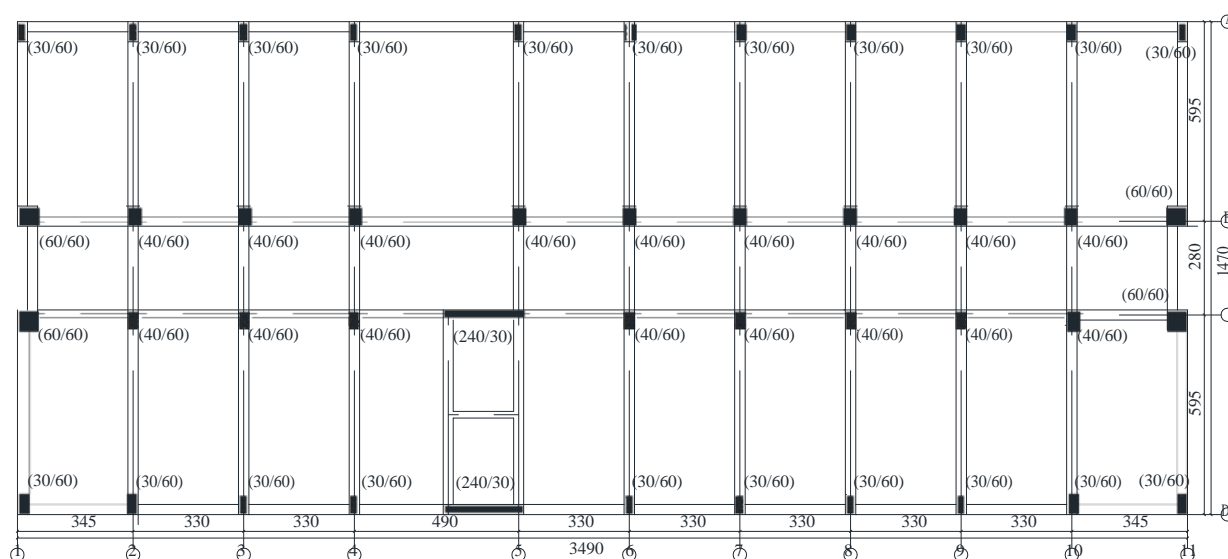


Figure 1. The plan of ground and first floor of the existing building



a) The hospital building



b) The coring

Figure 2.

The existing hospital building is rehabilitated by three methods as: removing the infill walls and putting the shear walls instead (Fig 3.b), strengthening the infill walls with steel profiles (Fig 3.c) and strengthening the infill walls with CFRP plates (Fig 3.d).

The shear walls are seen in Fig.3.b. The shear wall thicknesses are 250 mm. The strengthening with steel profiles is seen in Fig.3.c. The steel profiles are chosen as U160. The strengthening with CFRP plates is seen in Fig.3.d. The width of the CFRP plates is 100 mm and the thickness is 1.4 mm, the modulus of elasticity of CFRP is 210000 MPa. The three CFRP plates are bonded to the infill walls side by side. The performance levels of these three rehabilitations are compared with the existing building performance. The connection details of steel profiles and CFRP are shown in Fig.4.

- H-EB** = The Existing Hospital Building
- H-RCSW** = The Strengthened Hospital Building with Shear Walls
- H-SP** = The Strengthened Hospital Building with Steel Profiles
- H-CFRP** = The Strengthened Hospital Building with CFRP

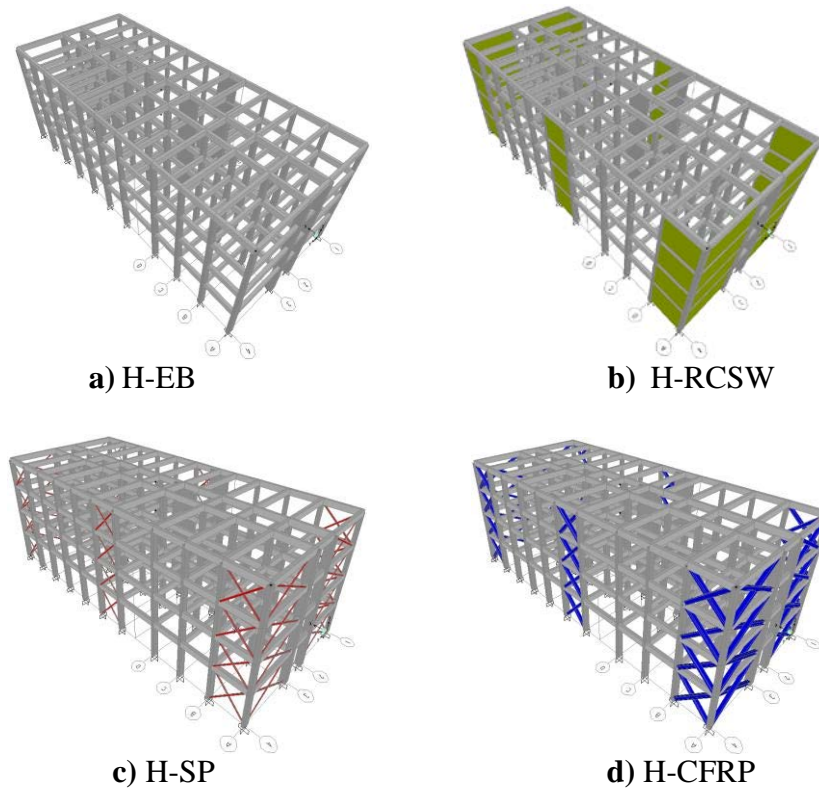


Figure 3. The strengthened hospital buildings with various methods

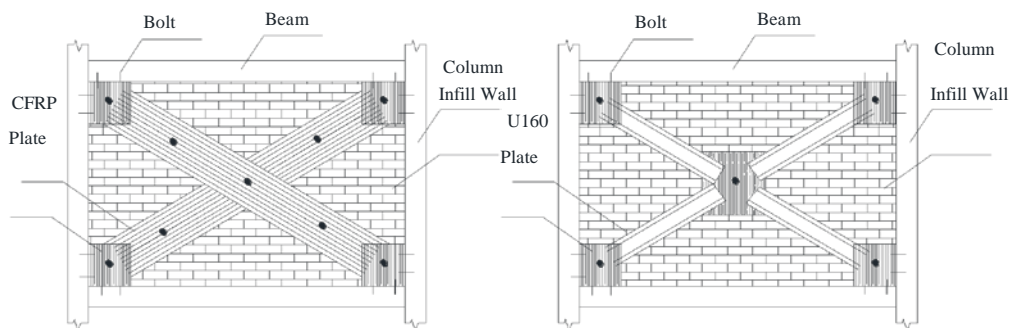


Figure 4. The connection details of steel profiles and CFRPs

3. THE METHODS

The incremental static pushover analysis was employed for the performance assessments. The incremental equivalent static lateral force analysis is limited to 8 story buildings with total height not exceeding 25 m, and not possessing torsion irregularity. Nonlinear flexural behaviour in frame members are confined to plastic hinges, where the plastic hinge length L_p is assumed as half of the section depth ($L_p = h/2$). Pre-yield linear behaviour of concrete sections is represented by cracked sections, which is $0.40EI_0$ for beams and varies between $(0.40-0.80)EI_0$ with the axial stress for columns. Strain hardening in the plastic range may be ignored, provided that the plastic deformation vector remains normal to the yield surface.

The objective is to carry out nonlinear static analysis under incrementally increasing lateral forces distributed in accordance with the dominant mode shape in the earthquake excitation direction. Lateral forces are increased until the earthquake displacement demand is reached. Internal member forces and plastic deformations are calculated at the demand level. A capacity diagram is obtained from the incremental analysis which is expressed in the “base shear force - roof displacement” plane.

The reference design spectrum in the Code has 10% probability of exceeding in 50 years. Based on Turkish strong motion data, it is estimated that the spectral ordinates for 50% probability of exceeding in 50 years are half of the reference spectrum whereas the ordinates for 2% probability of exceeding in 50 years are 1.5 times that of the reference spectrum. Accordingly, the target performance levels of buildings are summarized in Table 1.

Table 1. Target performance levels for buildings under different earthquake intensities

Type of Building use	Probability of Exceeding		
	50% in 50 years	10% in 50 years	2% in 50 years
Emergency facilities (hospital, etc.)	-	IO.	LS
Buildings with long duration occupancy (schools, etc.)	IO	-	LS
Theatres, concert halls, sport arenas, congress centers	-	LS	CP
Buildings containing toxic materials	-	IO	CP
Others (residential, commercial, etc.)	-	LS	-

Building earthquake performance level is determined after determining the member damage states. Evaluation of the investigated buildings is performed using the recently published TEC-2007. Three performance levels, immediate occupancy (IO), life safety (LS), and collapse prevention (CP) are considered as specified in this code and several other international guidelines such as ATC-40, FEMA-273, FEMA-307, FEMA-356(ASCE 2000), FEMA-440, EC-8 and NZS-2003. The rules for determining building performance in TEC-2007 are given for each performance level as shown in Table 2.

Table 2. Performance levels and criteria provided in Turkish Earthquake Code (2007)

Performance Level	Performance Criteria
Immediate occupancy (IO)	1. There shall not be any column or shear walls beyond minimum damage state. Life safety (LS)

2. The ratio of beams in significant damage state shall not exceed 10% in any story.
3. There shall not be any beams beyond extreme damage state..
4. Story drift ratio shall not exceed 0.8% in any story.
 1. In any story, the shear carried by columns or shear walls in extreme damage state shall not exceed 20% of story shear.
 2. In any story, the shear carried by columns or shear walls yielded at both ends shall not exceed 30% of story shear.
 3. The ratio of beams in extreme damage state shall not exceed 20% in any story.
 4. Story drift ratio shall not exceed 2% in any story.

Collapse prevention (CP)	<ol style="list-style-type: none"> 1. In any story, the shear carried by columns or shear walls beyond in collapse state shall not exceed 20% of story shear. 2. In any story, the shear carried by columns or shear walls yielded at both ends shall not exceed 30% of story shear. 3. The ratio of beams beyond in collapse state shall not exceed 20% in any story. 4. Story drift ratio shall not exceed 3% in any story.
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Concrete compressive strains and steel tensile strain demands at the plastic regions are calculated from the moment-curvature diagrams at the plastic curvature level. Moment-curvature diagrams of the critical sections are obtained by using appropriate stress-strain rules for concrete and steel. Finally, the calculated strain demands are compared with the damage limits given in Table 3 to determine the member damage states.

Table 3. Concrete and steel strain limits at the fibres of cross section for damage state

Strain limits	Damage limits	
	Concrete strain (ϵ_{cu})	Steel strain (ϵ_{su})
Minimum damage limit (IO)	$(\epsilon_{cg})_{IO} = 0.004$	$(\epsilon_s)_{IO} = 0.010$
Safety damage limit (LS)	$(\epsilon_{cg})_{LS} = \min \left[0.004 + 0.0095 \frac{\rho_s}{\rho_{sm}} \right] \leq 0.0135$	$(\epsilon_s)_{LS} = 0.040$
Collapse damage limit (CP)	$(\epsilon_{cg})_{CP} = \min \left[0.004 + 0.013 \frac{\rho_s}{\rho_{sm}} \right] \leq 0.018$	$(\epsilon_s)_{CP} = 0.060$

In the Table 3, ϵ_{cu} is the concrete strain at the outer fibre, ϵ_{cg} is the concrete strain at the outer fibre of the confined core, ϵ_s is the steel strain and (ρ_s/ρ_{sm}) is the ratio of existing confinement reinforcement at the section to the confinement required by the TEC-2007.

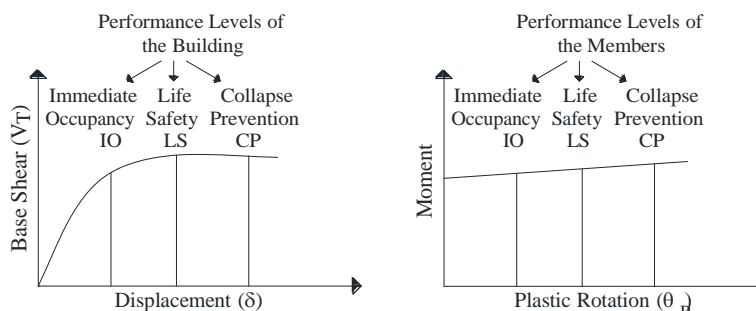


Figure 5. Performance levels for members and buildings

4. RESULTS

Modal properties of the first mode of the building are given in Table 4. The shear wall, steel profile, CFRP plate effects on dynamic properties of the building are shown in Table 4.

Table 4. Dynamic characteristics of the hospital building

Mode No	1	
Type of Building	X direction	Y direction
H-EB	0.566	0.555
H-RCSW	0.319	0.229
H-SP	0.447	0.438
H-CFRP	0.528	0.520

The capacity curves (base shear-displacement) of the buildings are obtained for x and y directions with incremental static pushover analysis and shown in Figure 6.

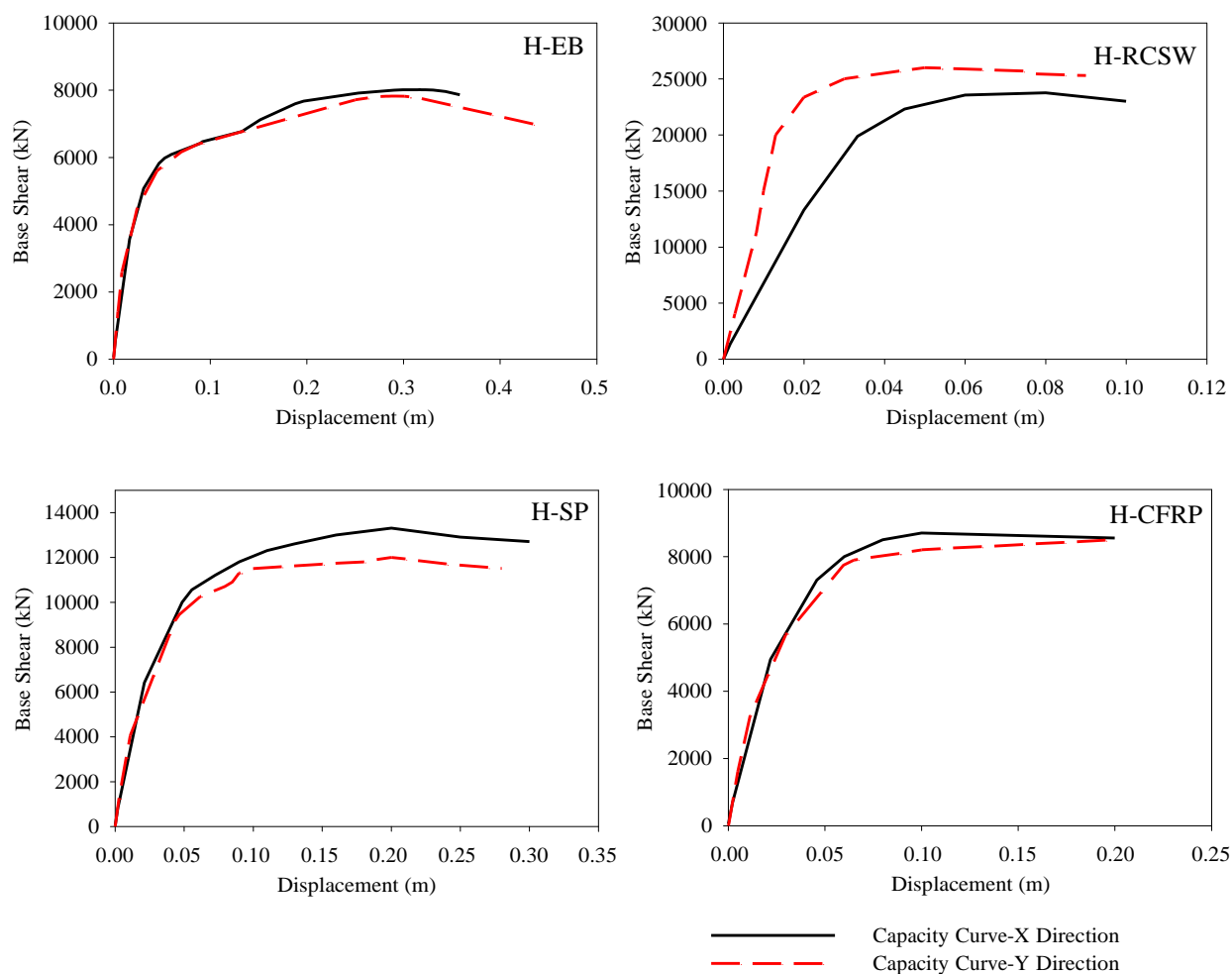


Figure 6. The capacity curves of the building

According to TEC-2007, the seismic performance points of the hospital building are obtained with incremental static pushover analysis and shown in Table 5. While the base shears of the strengthened building increase compared to the existing building, the displacements are decreased. The maximum increase is observed in H-RCSW building due to the most rigid shear walls.

Table 5. Performance points for incremental static pushover analysis

	H-EB		H-RCSW		H-SP		H-CFRP	
	X	Y	X	Y	X	Y	X	Y
Base Shear (kN)	6233	5703	20647	23812	10650	9534	8182	7470
Displacement (m)	0.073	0.050	0.038	0.028	0.058	0.048	0.070	0.050

According to TEC-2007, the member damage states are determined and shown in Table 6-9. Since the existing building does not provide life safety level, it is strengthened with shear walls, steel profiles, CFRP plates. The seismic evaluations of the building are calculated for each state due to the TEC-2007.

Table 6. Performance level of H-EB for incremental static pushover analysis

Story	<IO		IO		LS		CP	
	Beams	Columns	Beams	Columns	Beams	Columns	Beams	Columns
1	0(%0)	0(%0)	10(%29)	19(%43)	18(%53)	12(%27)	6(%18)	13(%30)
2	0(%0)	44(%100)	1(%3)	0(%0)	14(%41)	0(%0)	19(%56)	0(%0)
3	0(%0)	44(%100)	3(%9)	0(%0)	20(%59)	0(%0)	11(%32)	0(%0)
4	0(%0)	44(%100)	20(%59)	0(%0)	14(%41)	0(%0)	0(%0)	0(%0)
Evaluation	Life Safety Level X							

Global performance level of the building is given for incremental static pushover analysis in Table 6. In first story, in the direction of the applied earthquake loads, 29% of the beams and 43% of the columns are in the immediate occupancy states. 53% of the beams and 27% the columns are life safety states in this story. 18% of the beams and 30% the columns are collapse prevention states in this story. In this situation, the building performance does not satisfy life safety (LS) level.

Table 7. Performance level of H-RCSW for incremental static pushover analysis

Story	<IO		IO		LS		CP	
	Beams	Columns	Beams	Columns	Beams	Columns	Beams	Columns
1	34(%100)	44(%100)	0(%0)	0(%0)	0(%0)	0(%0)	0(%0)	0(%0)
2	34(%100)	44(%100)	0(%0)	0(%0)	0(%0)	0(%0)	0(%0)	0(%0)
3	34(%100)	44(%100)	0(%0)	0(%0)	0(%0)	0(%0)	0(%0)	0(%0)
4	34(%100)	44(%100)	0(%0)	0(%0)	0(%0)	0(%0)	0(%0)	0(%0)
Evaluation	Life Safety Level √							

Table 8. Performance level of H-SP for incremental static pushover analysis

Story	<IO		IO		LS		CP	
	Beams	Columns	Beams	Columns	Beams	Columns	Beams	Columns
1	24(%70)	36(%82)	6(%18)	5(%11)	4(%12)	3(%7)	0(%0)	0(%0)
2	28(%82)	44(%100)	4(%12)	0(%0)	2(%6)	0(%0)	0(%0)	0(%0)
3	34(%100)	44(%100)	0(%0)	0(%0)	0(%0)	0(%0)	0(%0)	0(%0)
4	34(%100)	44(%100)	0(%0)	0(%0)	0(%0)	0(%0)	0(%0)	0(%0)
Evaluation	Life Safety Level √							

Table 9. Performance level of H-CFRP for incremental static pushover analysis

Story	<IO		IO		LS		CP	
	Beams	Columns	Beams	Columns	Beams	Columns	Beams	Columns
1	27(%79)	39(%89)	5(%15)	3(%7)	2(%6)	2(%4)	0(%0)	0(%0)
2	29(%85)	44(%100)	3(%9)	0(%0)	2(%6)	0(%0)	0(%0)	0(%0)
3	34(%100)	44(%100)	0(%0)	0(%0)	0(%0)	0(%0)	0(%0)	0(%0)
4	34(%100)	44(%100)	0(%0)	0(%0)	0(%0)	0(%0)	0(%0)	0(%0)
Evaluation	Life Safety Level √							

5. CONCLUSIONS

In this study, the seismic performances of the Merkez Efendi Hospital building are determined according to the conditions of TEC-2007. Since the seismic performance of the building is insufficient, the three strengthening methods are used for the rehabilitation and the results are compared.

As a result of the performance analyses:

- The existing hospital building does not satisfy the life safety level for the earthquake that may happen 2% probability of exceeding in 50 years.
- The building is strengthened with shear walls, steel profiles and CFRP plates. For each method, the performance of the building is found. The strengthening members are designed according to the minimum standards of the TEC-2007.
- The lateral load carrying capacities increase for the rehabilitated buildings and the horizontal displacements at the roof for the buildings decrease.
- The shear walls are put on the outer axes of the building and the lateral load capacity of the building increases 3-4 times. But the displacement of the roof decreases. As a result the ductility of the building is decreased.
- As the member damage conditions are investigated, the performances of the strengthening methods according to the conditions of TEC-2007 are satisfactory.

As a result of this work:

All the strengthening members influence the seismic performance of the building in different proportion. RC shear wall application is more difficult than the other methods of strengthening. Opposed to this, the application of CFRP and steel profile should be detailed very good and applied very well. As a result, it can be said that the rehabilitation methods recommended in the TEC-2007 can be applied with confidence.

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