# SEISMIC STRENGTHENING OF A MID-RISE REINFORCED CONCRETE FRAME USING CFRPS: A REAL LIFE APPLICATION

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## 1 INTRODUCTION

In this study, retrofit design of an existing 9-storey deficient RC building located in Antakya, Turkey was conducted. Two different retrofit schemes, namely shear wall strengthening, and a hybrid strengthening with FRPs and reduced number of shear walls were investigated. A forced based assessment method along with the rules of mode superposition was employed for the strengthening design. FRP retrofit scheme was employed using the simplified diagonal strut model and design was conducted such that life safety performance criterion is satisfied for the design spectrum with 10% probability of exceedance in 50 years according to the Turkish Earthquake Code (TEC2007) [1]. As the recommended scheme, FRP retrofitted infills were used together with the RC shearwalls. Cost and performance comparisons of the two retrofit alternatives are presented and obtained results are critically discussed.

Building under consideration is a moment resisting frame with 8 typical storeys with one ground and a basement storey. Basement floor can be considered as a rigid floor with shear walls surrounding the exterior frame. The building has a total height of 28.8m and 9 storeys (excluding basement). Typical floor plan is given in Figure 1. According to TEC 2007, city of Antakya is located in Earthquake Zone 1, which corresponds to an effective Ground Acceleration Coefficient of 0.4 resulting in a maximum pseudo spectral acceleration of 1g. Geological and geotechnical investigations reveal that the soil beneath the structure can be classified as Z2 (stiff soil) resulting in spectrum corner periods of 0.15 and 0.4 secs. A detailed site survey has been conducted to determine the existing state of the structure. According to this survey, the concrete compressive strength was determined as 10 MPa value corresponding to mean minus one standard deviation). The reinforcement steel plain bars were found to have yield strength of 220MPa. There were incidents of corrosion initiation especially at the ground floor level. The survey results showed that the on-site reinforcement amount were in 99% compliance with the blueprints of the buildings. Typical stirrup layout in columns and beams was 8mm diameter bars with a 250 mm spacing having a clear cover of 25 mm. No confining reinforcement was observed at potential plastic hinge regions. Thus, the stirrup layout is clearly inadequate for sufficient energy dissipation and deformation capacity at critical regions.

## 2 ASSESMENT AND STRENGTHENING

### 2.1 Modeling and Analysis Procedure

Three dimensional finite element model of the building was created by using frame elements for beams and columns (Figure 2). Shear walls were also modeled by frame elements defined at wall midpoints connected by rigid links. Gravity loads from the slabs were transferred onto beams following the distribution given by the yield line theory. Rigid diaphragms were utilized at each storey level. At each beam-column intersection, rigid end-offsets were introduced. Figure 1 shows the finite element model employed for the building frame. The first three modes of the existing building were found to have natural periods of 1.12 and 0.97, 0.79 seconds. After retrofit, employing the strengthening procedures explained below these periods dropped to 0.82, 0.74, 0.66 seconds. It should be noted that first three modes' mass participation factors add up to more than 90% of the total mass contributing to inertial forces (modal mass participation factor of the first mode alone is less than 80% of the total mass, hence requiring modal analysis). Existing and FRP retrofitted infill walls were modeled using diagonal strut and tie models. For the latter case infill wall was with a compression strut whereas diagonal FRPs were modeled as tension ties. The tensile strength of the tension tie was based on a limiting tensile strain of 0.003 for the FRPs as recommended by Binici et. al. [2] and TEC 2007 [1]. TEC 2007 employs a force based assessment procedure for use along with linear elastic analysis methods. Assessment technique depends on the determination of Demand/Capacity Ratios (DCR) for each member in the structure. Reinforced concrete members are classified as "ductile" if mode of failure is flexure. They are classified as “brittle” if the failure is due to shear or axial load. At the critical sections of each beam, column and wall members, the “capacity shear” forces were calculated based on hinging of the two ends of the members. After the performance criteria were determined, the member DCR were compared with the code specified tables for the specified performance level. For the life safety performance level, the number of beams in “High Damage” region should not exceed the 30% of the total in compatible direction in any storey. For columns, the shear forces carried by “High Damage” columns should not exceed the 20% of total shear in compatible direction in any storey.

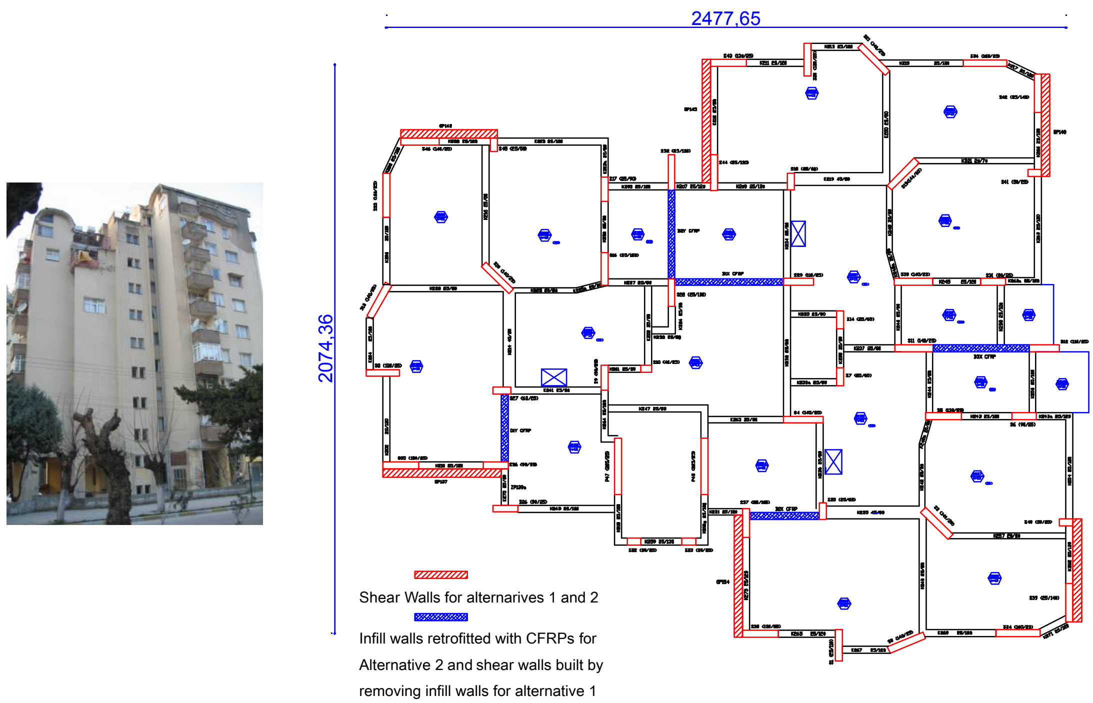
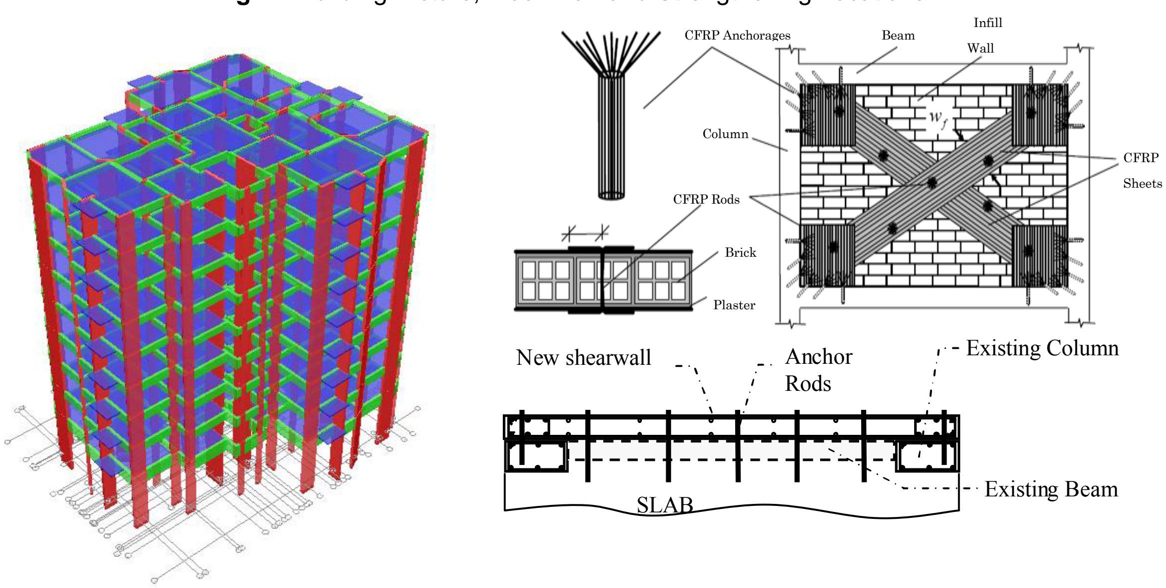



**Fig. 1** Building Picture, Floor Plan and Strengthening Locations.

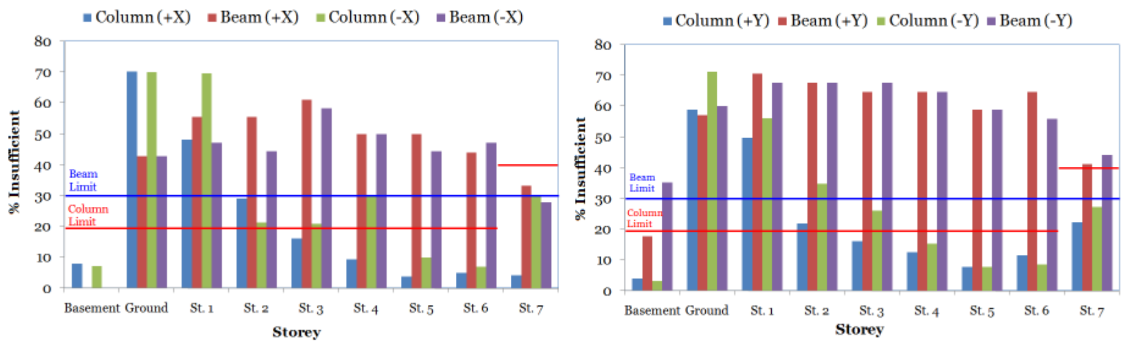



(a) Mathematical Model b) Strengthening Schemes

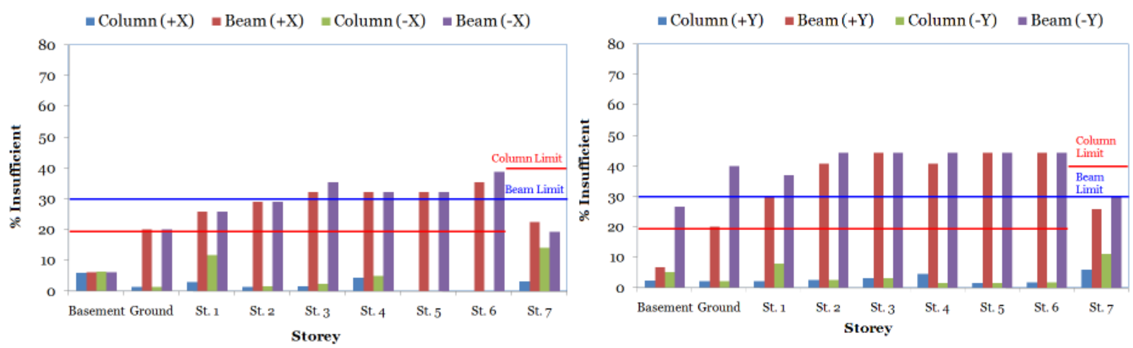
**Fig. 2** Building Model and Strengthening Schemes.

**2.2 Strengthening Schemes**

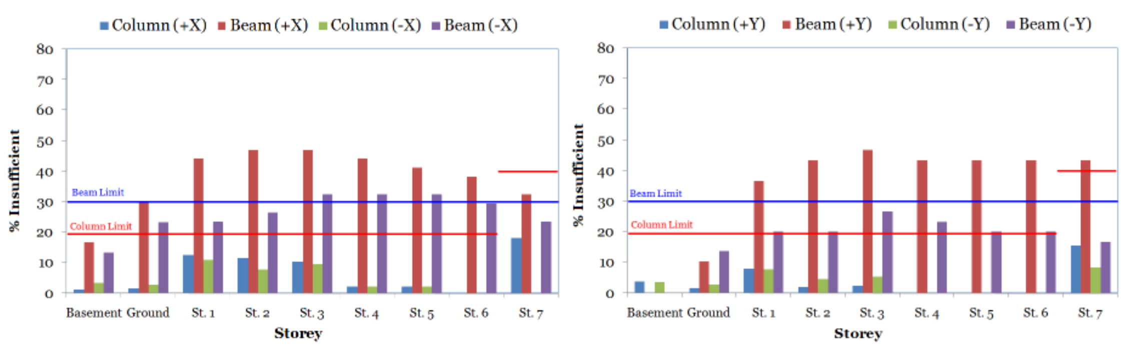
Typical storey plan after retrofitting schemes is presented in Figure 1 and the employed retrofit scheme details are presented in Figure 2. For the first alternative, all available frames were implemented with 40 cm thick reinforced concrete shearwalls. Concrete and steel grade used in shearwalls is C25 (25 MPa uniaxial compressive strength) and S420 (420 MPa yield strength), respectively. Utilizing CFRP infill walls instead of in-plane RC shearwalls speeds up the construction and decreases the construction work needed. After a number of trial and error studies, it was found that the outer walls are needed to satisfy the desired performance level. Hence a hybrid strengthening scheme was employed for the second alternative. In order to isolate the construction work totally outside the building with a comparably priced alternative, it was decided to use eccentric RC walls anchored to the existing frame and slab system from outside of the building. For this alternative, 30 cm thick reinforced concrete shearwalls were installed outside the building and CFRP strengthening on the infill walls were employed inside the building. Assessment summary results for the existing structure and two alternative retrofit schemes are presented in the form of bar charts in Figure 3. It can be observed that prior to retrofit, all the beams and columns in the first three stories exceed the tolerable damage levels, hence the structure requires upgrading. After retrofit with the proposed alternatives, all the columns were within allowable damage levels. Although slight distress were observed for the beams pushing them into the moderate to high damage zone, it was decided that this can be tolerated noting the safety of the columns.




(a) Existing Building




(b) Retrofitted with Shear walls




(c) Retrofitted with CFRPs and Eccentric Shear walls

**Fig. 2** Summary of Assessment Strengthening Studies

### 2.3 Cost Comparisons and Application Schedule

The most important concern in the selection of a retrofit scheme is generally decided based on the cost effectiveness of the alternatives. From a performance point of view both alternatives were found satisfactory, hence the next step was the evaluation of the cost of retrofit. The estimated cost of the shear wall alternative (scheme 1) was found to be about 12% of the building cost. On the other hand, the hybrid retrofit scheme had a cost of about 13% of the rebuilt cost. Hence, both alternatives approximately had a similar retrofit cost, leaving the decision based on retrofit time and disturbance given to the occupants. Based on these non-cost related comparisons, it was decided to proceed forward with the hybrid alternative (Alternative 2), since it avoids any concrete casting inside the building and does not require complete evacuation of the building. The application of the retrofit scheme started in September 30, 2008. The infill wall strengthening using CFRPs has been completed as of November 25 (Figure 3), and the work has moved on to the installation of the eccentric shear walls. This phase of the work is expected to be finished in January 2009.

**Fig. 3** Retrofit of infill walls in Progress

## 3 CONCLUSIONS

This study presented here is a real life approach to a seismic retrofit problem. Two alternatives were investigated and a hybrid solution (i.e. Alternative 2 with eccentric shear walls and CFRP retrofitted infill walls) was selected to mitigate the seismic hazard for the building under consideration. Most important advantages of the hybrid approach were: a) the reduced mass of the retrofitted structure as a result of using less RC walls, b) rapid retrofit time and less disturbance to the occupants since no construction work and concrete casting are conducted inside the building, c) eliminating the out of plane collapse of the infill walls by using CFRPs in the wall plane direction and creating a safer environment for the inhabitants during an earthquake. The study summarized above clearly shows that one single approach cannot be the solution for seismic strengthening and hybrid approaches where a number of different schemes employed together usually yield the most feasible solution.

## ACKNOWLEDGEMENTS

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