# Shear and Flexural Upgrading of RC Beams Using CFRP Sheets and Laminates

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## Introduction

Upgrading the deficient reinforced concrete (RC) buildings in Turkey is a critical issue for the public safety. The deficiency may be either due to the aging and corrosion or due to the lack of on-site quality control and mis-interpretation of the blue-prints. Such buildings need to be strengthened especially before being hit by a catastrophic earthquake. The intervention methods for the strengthening applications supposed to be rapid, easily applicable and cost effective in terms of not only application budget but also the occupancy interruption expenditures. Strengthening of the existing buildings by using the fiber reinforced polymer (FRP) applications is one of the most effective strengthening techniques among the other intervention choices. Ease of application, relatively short time duration for the installation, limited time elapse for occupancy/operation delay, and the adaptability to almost all cases can be listed as superior advantages of FRP strengthening techniques.

In this paper, the FRP strengthening application at a RC public building, even during its construction period in 2014 in Kayseri, Turkey, is presented. The city is located in 3$^{rd}$ grade seismic zone according to Turkish Seismic Code 2007 (TSC 2007) of which seismic zone classification is similar to Eurocode. The building has a U-shaped plan (*Fig.1*) and was composed of a ground floor (h=4.0m) and four storeys above with h=3.2m. The diaphragm system was two-way solid slab with beams in the building. Typical column and peripheral beam dimensions were 500x500mm and 300x600mm, respectively. The inner beams were 300x450mm in dimensions.

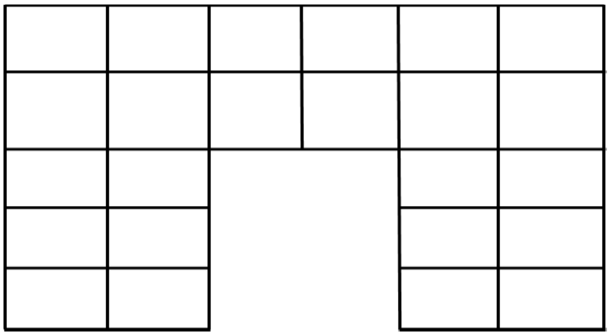

**Figure 1: Plan of the strengthened building**

The construction steps for that specific building were first to cast the columns at a specific height, and to cast the beams and the slabs afterwards. During the construction process, due to the lack of skilled onsite quality control engineers, all columns were cast at a height only 450mm shorter than the specified floor height, in order to preserve a space for the beams and the slabs. Unfortunately, the peripheral beams were 600mm in height and the flexural reinforcement for the positive moment was mis-placed resulting a reduction of 150mm in the useful depth of the beams. Moreover, the reinforcement for the negative moment at the beam ends was also less than the design specified values. In some other locations, especially for long span beams, the positive span moment and shear capacities were below the design values. In short, there were a wide spread of deficiencies in flexural moment capacity (either or both the positive and the negative sides) and shear capacities in beams of the building. The problem was concentrated on the second floor and identified well after the completion of the floors above. Strengthening of the beams was the only alternative against demolishing and reconstruction. The constructor preferred strengthening to reduce its overall budget and the owner accepted the strengthening designs offered for that specific problem.

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## The Challenges

The building to be strengthened would be used for public services and it was needed to be operational as soon as possible. Since the structural problem was related to member deficiencies and there was no need to enhance the lateral load capacity, in addition to time constraint, FRP strengthening technique was considered the best way for the intervention.

The shortage of moment capacity was not only in positive moment region but also in the negative sides of the beam supports. As it is a well-known matter about the negative moment capacity enhancement for beams, continuity of the reinforcement in beam to/through column is still a standing problem especially for the FRP strengthening. Therefore, a solution scheme for the continuity of the reinforcement should have to be adapted at the top face of the beams near the joints. Beside the moment capacity enhancement, shear strength upgrading was another issue for the beams in the building. The evaluation proses have shown that spread shear reinforcement needed along the beams. Obtaining the proper shear behaviour, it was aimed to have closed loops for the FRP wrapping instead of using U-shaped or end-anchored applications. Since the beams and slabs connected monolithically and cutting or slitting the edges excessively for the FRP wrapping would have given damage to the load flow and rigidity of the system, it was decided to just drill holes and supply the FRP continuity through the CFRP anchors bonded on the CFRP sheets.

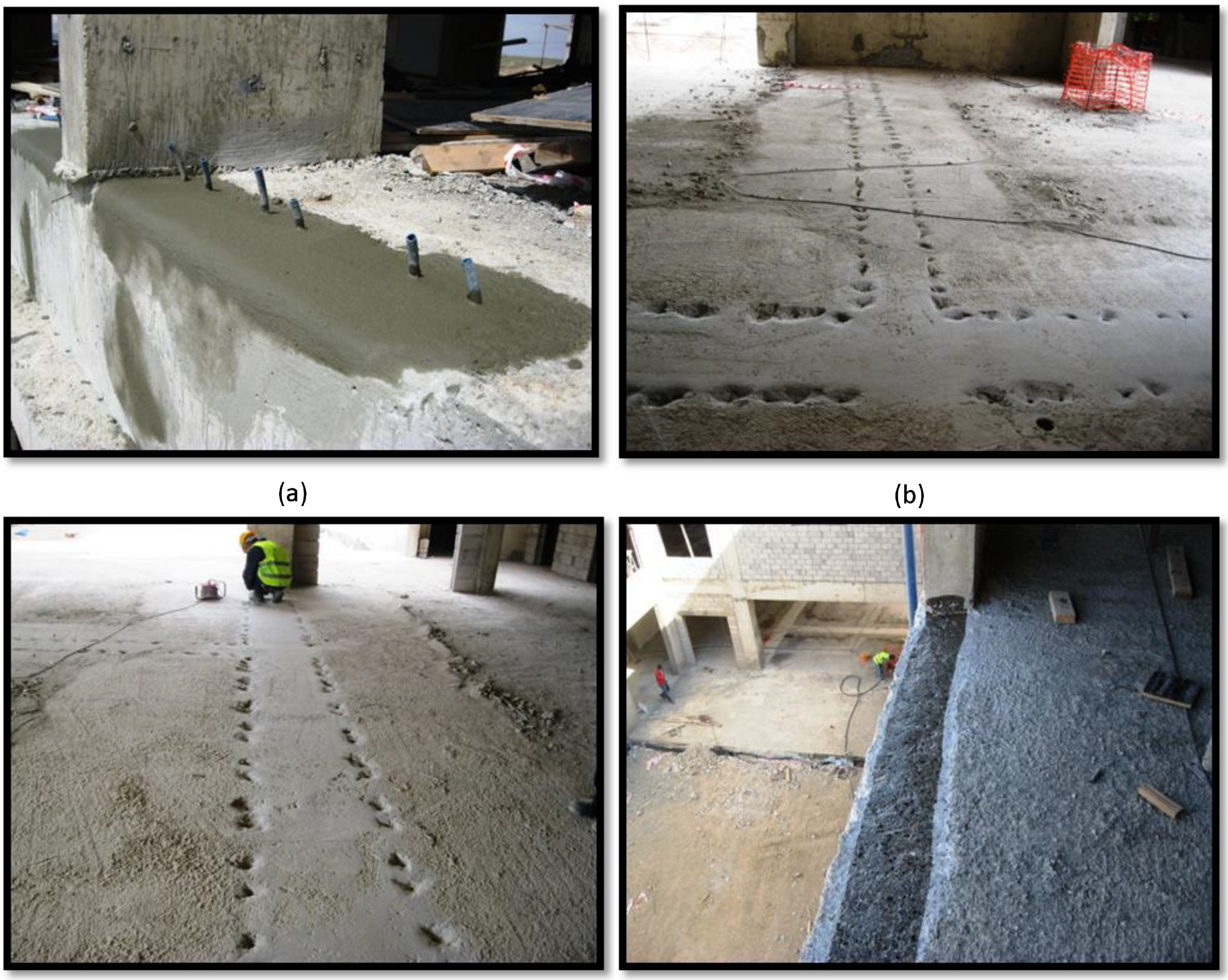
## The Solution

After the completion of the assessment and the analysis phases, the first thing on the field was the member surface preparation and the corner rounding at a 3 cm diameter. Some pictures related to the preparation process are shown in *Fig.2*. There exist certain amounts of unevenness on several beams. Prior the FRP application, such surfaces repaired with high quality cement based grout of which compressive strength is higher than 20 MPa after 1 day of pouring and tensile strength is 2 MPa after 28 days after pouring (*Fig.3 a*). The holes near the edges of the beams for shear strengthening were drilled and pressurise air was used for the cleaning (*Fig. 3 b and 3 c*). The epoxy based primer was rolled on to the concrete surfaces before the FRP application for the surface saturation (*Fig.3 d*). CFRP plates and sheets were used as FRP material for the strengthening application. The properties of CFRP materials are given in *Table 1*.

(a) (b)

**Figure 2: Concrete surface preparation and corner rounding proses**

There was positive and negative moment capacity deficiencies in beams, therefore, both the lower side at the mid-span and the upper side-regions near the joints of the beams were strengthened where needed. For the positive moment strengthening of the beams, CFRP plates were applied until and 150mm beyond the contra flexure points supplying an anchorage length (*Fig.4 e, 4 f*). On the other hand, for the negative moment strengthening of the beams, it was more complicated than the previous one since the continuity of the introduced CFRP material was crucial at the beam to column joint region for proper improvement. By doing so, CFRP plates ends at the joint region were bonded to a custom made L-shaped steel anchorage pre-placed to the interrelated corner of the beam to column joint (*Fig.4*). Initially, after the surface preparation, holes were drilled on the column ends and anchorage steel bars were placed by using a high strength epoxy based grout (bond strength is higher than 3 MPa). The next step after the curing of the epoxy based grout, L-shaped steel anchorage apparatus bonded to CFRP plates were fastened to the bars, CFRP plates also glued to the concrete surface at the same time. CFRP wraps passing over this region which were applied originally for the shear reinforcement following the flexural strengthening, were clamped the L-shaped anchorage and supplied a secure supplementary measure for the application. It was calculated and designed that the weakest point of this negative moment intervention was the anchorage bars embedded into the columns. It was aimed that any possible failure for the assemblage would be occurred by yielding of the anchored bars to result in a limited ductility.



(a) (b) (c) (d)

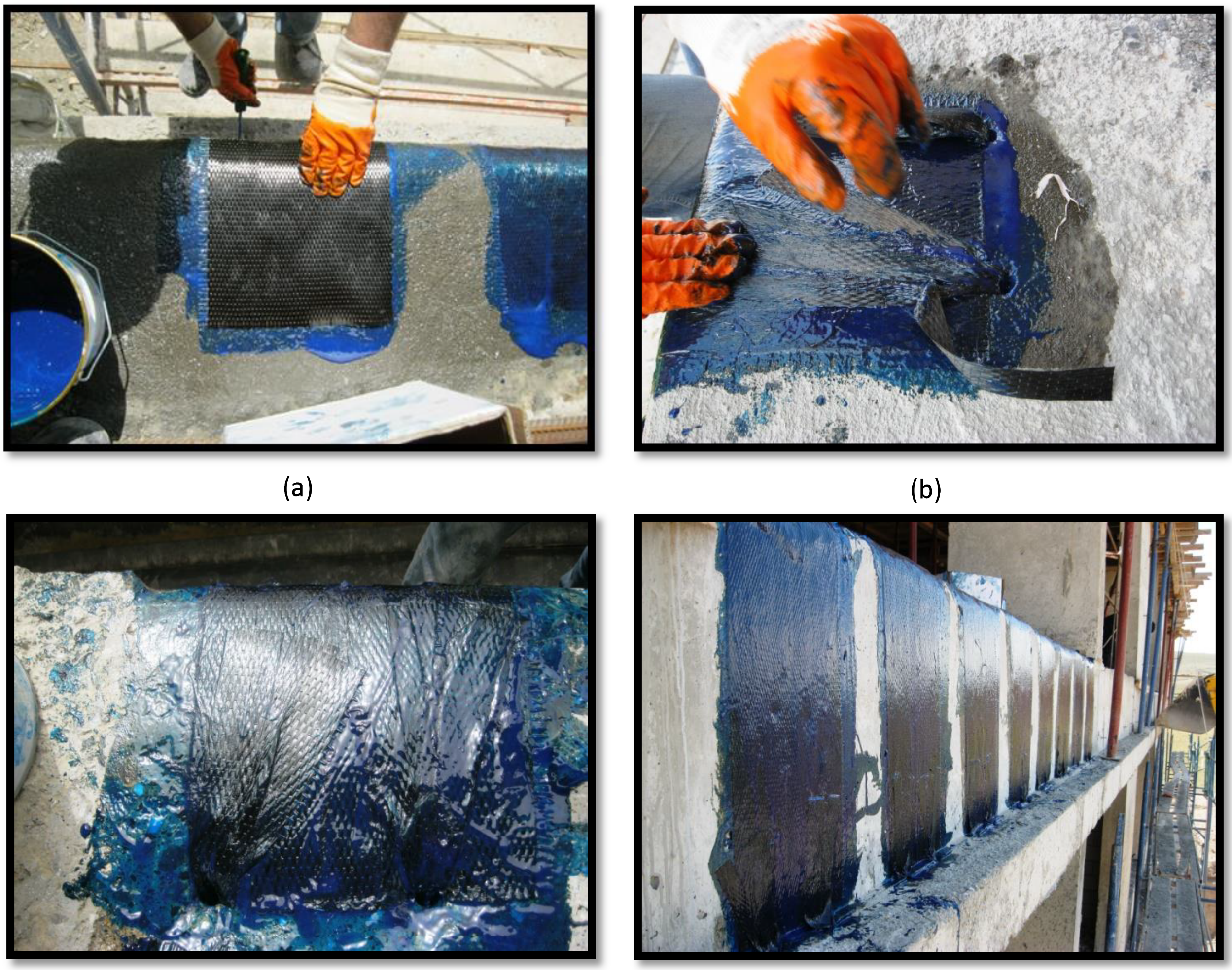
**Figure 3: Repairing the unevenness on the surface and drilling holes**

**Table 1. Properties of used CFRP materials**

| | Carbon Fiber Sheet | Carbon Fiber Laminate |
|---|---|---|
| Modulus of Elasticity (MPa) | 230,000 | 165,000 |
| Tensile Strength (MPa) | 4,900 | 2,500 |
| Thickness (mm) | 0.166 | 1.2 |
| Width (mm) | 500 | 50 |
| Elongation at Break (%) | - | 1.5 |
| Total Fabric Weight (gr/m$^2$) | 300 | - |


**Figure 4: Flexural strengthening of beams a, b, c, d negative moment strengthening application, e, f positive moment strengthening application (f is also represents the shear strengthening application)**

After the completion of the flexural strengthening, shear strengthening was carried out. Since the spread shear strengthening needed along the beams, it was decided to use full wrapping using CFRP sheets instead of using U-shaped or end-anchored application. On the other hand, it was obvious that the cutting or slitting the beam to slab edges excessively for the fully wrapping were harmful for the global behaviour and also time consuming effort. For overcoming this constraint, it was decided to drill holes with a constant space along the beam to slab edges and supplied the CFRP sheets continuity through them. Accordingly, after the flexural strengthening phase completed, CFRP wraps were applied at each ends of the material were passed through the pre-drilled holes. The props of the CFRP sheets coming out through the holes were spliced 200 mm for obtaining sufficient anchorage. Further step, before the epoxy was not totally cured, was sand blasted by hand to roughen the surface of the beams for good bonding for the following plaster application.



(a) (b) (c) (d)

**Figure 5: Shear strengthening of beams and fan type lap splice of FRP ends**

**Project details**

| | |
|---|---|
| **City, Country** | Kayseri, Turkey |
| **Owner** | Public Affairs |
| **Contractor** | Privately owned company |
| **Designer** | Sevket Ozden |
| **Completion Date** | October 2014 |
| **Images** | Courtesy of ACIBADEM Restorasyon Ltd.Sti. |

## Key references

Turkish Seismic Code 2007 (TSC 2007)

BASF Material Property Data Sheets

COST Action TU1207

# Next Generation Design Guidelines for Composites in Construction

# STATE-OF-THE-ART

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## About COST

Founded in 1971, COST – European Cooperation in Science and Technology – is the first and widest European framework for the transnational coordination of nationally funded research activities. It is based on an inter-governmental agreement between 35 European countries.
COST enables break-through scientific developments leading to new concepts and products and thereby contributes to strengthen Europe's research and innovation capacities.
It is a unique means for European researchers to jointly develop their own ideas and new initiatives across all scientific disciplines through trans-European networking of nationally funded research activities.
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- providing networking opportunities for early career investigators
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Through its inclusiveness, COST supports integration of research communities, leverages national research investments and addresses issues of global relevance.
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- Biomedicine and Molecular Biosciences
- Food and Agriculture
- Forests, their Products and Services
- Materials, Physics and Nanosciences
- Chemistry and Molecular Sciences and Technologies
- Earth System Science and Environmental Management
- Information and Communication Technologies
- Transport and Urban Development
- Individuals, Societies, Cultures and Health

In addition, Trans-Domain Proposals allow for broad, multidisciplinary proposals to strike across the nine scientific domains.
COST is funded through the EU RTD Framework Programmes.

## About Transport and Urban Development (TUD)

TUD fosters research coordination in the fields of transport and the built environment, which play a strategic role in the modern society and economy.
The Domain is by definition cross-sectoral and multidisciplinary, encompassing a wide range of scientific expertise within the transport and land use planning, design, and management activities with a special emphasis on the strong interrelationships among the relevant policy fields as well on all aspects related to sustainable development.
The domain activities should be innovative and complementary to other European programmes in the relevant fields. The aim is to cover both basic and applied research activities including technical and technological developments and their changeovers that are relevant to policy and decision making processes.
A significant concern is devoted to activities exploring new research needs and developments.

## About COST Action TU 1207

Construction is rapidly becoming the leading outlet for FRP composites. Although the use of composite materials in construction started in the 1980s, civil engineers only recently started gaining confidence in this technology for use in primary structural applications. Despite the considerable technological developments in this field, there are still key scientific and logistical issues that need to be addressed for the widespread acceptance in construction. For example, existing design recommendations are largely based on work carried out more than fifteen years ago on first generation reinforcing products and their conservativeness is hindering the development of innovative and more efficient products and design solutions.

This Action aims to:

- coordinate European research in the field
- develop and maintain a critical mass of researchers
- offer a link between academia and industry
- develop a new generation of design guidelines based on European Standards

This will facilitate the adoption of European products not only in Europe but also internationally and help Europe stay one step ahead of International competitors.

### General information

Start of Action: 12/04/2013
End of Action: 11/04/2017

Chair of the Action: Dr Maurizio GUADAGNINI (UK)
Vice Chair of the Action: Prof Stijn MATTHYS (BE)

Domain website: http://www.cost.eu/tud
Action website: http://www.tu1207.eu

Scientific Officer: Dr Mickael PERO
Administrative Officer: Ms Carmencita MALIMBAN

# Action TU1207 Working Groups

### WG1 Material Development and Characterisation
Chair: Renata KOTYNIA (PL)
Co-Chair: Sandor SOLYOM (HU)

- Assessing the different tests so as to select candidates for standardisation
- Bond behaviour of FRPs to concrete, steel, timber and masonry
- Behaviour of FRPs at elevated temperatures
- Accelerated tests and development of models to assess durability of FRPs in typical environments, including embedment in cement mortars and concrete

### WG2 New Reinforced Concrete (RC) Structures
Chair: Lluis TORRES (ES)
Co-Chair: Kypros PILAKOUTAS (UK)

- Serviceability requirements
- New products and prefabricated solutions
- Long-term behaviour
- Behaviour of FRP RC elements exposed to fire or elevated temperatures

### WG3 Strengthening Applications
Chair: Thanasis TRIANTAFILLOU (EL)
Co-Chair: Francesca CERONI (IT)

- Behaviour of confined concrete using different types of fibres and bonding systems
- Behaviour of strengthened reinforced concrete, masonry, steel and timber elements, in flexure, shear and punching shear
- Models and techniques for the prestressing of strengthening systems to enhance the utilisation of composites at service conditions
- Novel seismic strengthening and rehabilitation solutions and development of design models to avoid shear, anchorage, splice and buckling failures

### WG4 Whole-life-costing and life cycle assessments
Chair: Matthias PAHN (DE)
Co-Chair: Jose SENA CRUZ (PT)

- Whole-life cost assessment of new FRP reinforced concrete structures
- Whole-life cost assessment of rehabilitated structures
- Recycling and reuse of composite materials
- Innovative structural solutions using existing and future materials

### WG5 Knowledge Transfer
Chair: Joaquim BARROS (PT)
Co-Chair: Christoph CZADERSKI (CH)

WG5 will coordinate and promote inter-sectorial collaboration and outreach activities, including the maintenance and management of the Action website, organisation of industry seminars, training schools, Short-Term Scientific Mission (STSMs), maintenance of online databases, preparation and dissemination of reports and publications.