Column Strengthening at Commercial Ground Floor

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Introduction

The speed of increase in the number of reinforced concrete buildings within the overall building stock experienced its first peak in the early 1980's in Istanbul, Turkiye. This rapid development was basically due to the high demand of the people migrating from small villages or cities to Istanbul because of the social and economic developments. The high construction speed and the lack of enough number of qualified personnel in private and municipal bodies resulted in buildings without proper engineering services. The building contractors were rarely engineers. Usually an "experienced" worker, mainly a "formwork master", was taking the whole responsibility to apply the design project on the field, or even re-shape the building during the construction according to the demands of the building owners. At the same time the inflationary rate of 1980's was causing the prices for the construction goods and services to increase overnight. Therefore, the pressure of keeping the final budget as predicted and the errors made by the "masters" resulted in low quality buildings with smaller frame sections and definitely lesser reinforcement ratios than designed, hence resulting a building stock very sensitive to the earthquakes.

The residential building which is the topic of this case study was constructed in the very beginning of 1980's. The structural blue-prints were not available at all. The basement of the building was serving as a parking area while two restaurants were occupying the ground floor. There were three floors above for residential purposes. The location of the building is very popular and the real-estate prices are well above the city average.

Many municipal regulations related to the footprint area and the mandatory distances between the building facade and the road, similarly the neighbouring buildings, changed since 1980's. Currently, in some districts in Istanbul, the buildings can use less footprint area within the registered land as compared to the 1980's. Therefore the building owners do not prefer to reconstruct their buildings. At the same time, the legal written structure of the building ownership in Turkiye usually do not courage a consensus for the structural interventions to the buildings by the owners.

The seismic upgrading of the building was the main target. Fortunately, the two commercial spaces on the ground floor belong to the same person and he was the person who demanded the seismic upgrading of the building structure. During summer 2015 and summer 2016, the two restaurants renewed their interior decoration thoroughly allowing enough time and space for the structural intervention.

The Challenges

The building plan (*Fig.1*) clearly shows the irregularity in the shear wall layout and the irregularity in column dimensions (350x600mm; 350x650mm; 350x750mm; 350x900mm) without a symmetry. The field observations revealed that the columns experienced severe corrosion (*Fig.2, Fig.3, Fig.4*). In the shear walls and in corner columns the tie bars were simply discontinuous due to local and severe corrosion. The corner columns were not only underwent severe corrosion but also some indications of vertical load carrying deficiencies observed during the site investigation.

As a start for the intervention, all the column plasters and the cover concrete was chipped out (Fig.2; *Fig.4; Fig.5*) and longitudinal bars and tie bars were covered with an epoxy layer in order to stop or delay the corrosion (*Fig.5*). A high strength mortar was used to restore the original cross-sectional

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dimensions (*Fig.6*). It should be noted that the first layer of high strength mortar was applied onto the member surface while the corrosion repair epoxy layer was still wet. By doing so, the bond between the mortar layer and the epoxy coated surfaces were satisfied.

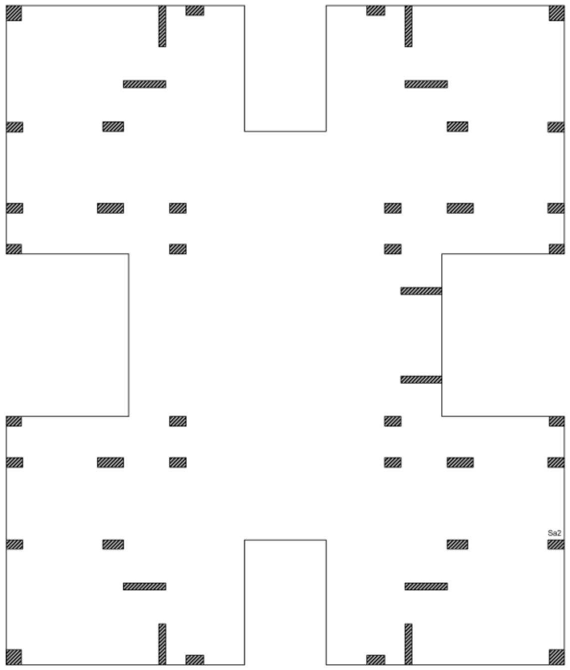


Fig.1 - Column Locations on the Ground Floor

Fig.2 - Corrosion Damage on Columns

Fig.3 – Cracks on Corner Column

Fig.4 – Cleaning on Corner Column

Fig.5 – Corrosion Repair on Shear Walls

Fig.6 – Restoring the Original Cross-Section

Fig.7 – CFRP Application on Shear Walls

Fig.8 – CFRP Application on Corner Columns

Fig.9 – Sand Cover for Better Plastering

Fig.10 – Plastering Against Fire

The member surface texture was smooth and the corners were rounded to 35mm after the application of the high strength mortar layer. The workmanship for this plaster layer should be high quality in order to be able to bond the CFRP layer to the columns. Producer specified amount of primer was applied onto the member surfaces for a better bonding of the CFRP layers with impregnation epoxy. Furthermore the amount of impregnating epoxy was in good agreement with the producer specified values (*Fig.7; Fig.8*).

Once the CFRP layer was bonded to the surface of the column, satisfying that the impregnation epoxy was still wet, a layer of sand was blasted by hand to roughen the surface (*Fig.9*) for further bonding of the fire protection layer (*Fig.10*). Finally fire protection layer was plastered and the intervention was stopped.

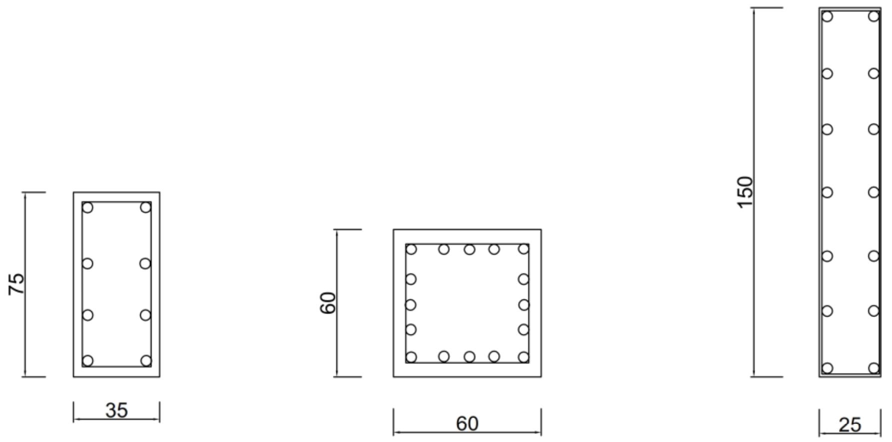
The above procedure for the intervention with carbon fiber seems easy to apply, however a stringent field investigation and a very detailed capacity calculations are to be accompanied.

Since there was no chance to intervene the overall building but the ground floor, a capacity check was made for the ground floor columns and any possibility of shear failure was discarded by wrapping the columns and shear walls with carbon fiber. Turkish Seismic Code of 2007 (TSC 2007) was used for all the calculations. However, the vertical cracks on the column surface and the flaking type of concrete failures observed when the cover concrete was chipped out on the corner columns reminded the possibility of failure under compressive forces. Although the axial load level on the corner columns was below the balance point, there might be a local defect in concrete that causes such flaking under compression.

The 600x600mm columns with a corner radius of 35mm, were confined by 300gr/m^2 CFRP by 6 layers. The lateral confining pressure was calculated as 1.9 MPa, resulting a confined concrete compressive strength of 14.6 MPa. The confined concrete strength which is approximately 46% higher than the existing in-situ value, was considered to be acceptable for the upgrading of the ground floor columns.

The reinforcement layout of the columns (Table.1), flexural capacities under vertical service loads (Table.2) and the shear strength after CFRP application (Table.3) are summarised in the following tables. It should be noted that the design shear values are calculated with the assumption that the hinging will take place on both end of the columns. In other words, the design shear force is calculated from capacity moments. However, for the 600x600mmm corner columns, the number of layers was not calculated by the shear demand, but by the confinement demand for strength enhancement.

Table 1 – Dimensions and Reinforcement Layout



Inner Columns:	Corner Columns:	Shear Walls:
350x750 mm	600x600 mm	250x1500 mm
8 bars D=18mm (ρ_L=0.008)	16 bars D=18mm (ρ_L=0.011)	14 bars D=14mm (ρ_L=0.006)
Tie bars : D=8mm, s=25cm	Tie bars : D=8mm, s=25cm	Tie bars : D=8mm, s=25cm
f_{yk}= f_{ywk}= 220MPa	f_{yk}= f_{ywk}= 220MPa	f_{yk}= f_{ywk}= 220MPa
(diameter of tie bars reduced to 4mm due to corrosion)	(rupture in some tie bars due to corrosion)	(rupture in some tie bars due to corrosion)

Table 2 – Column Flexural Capacities

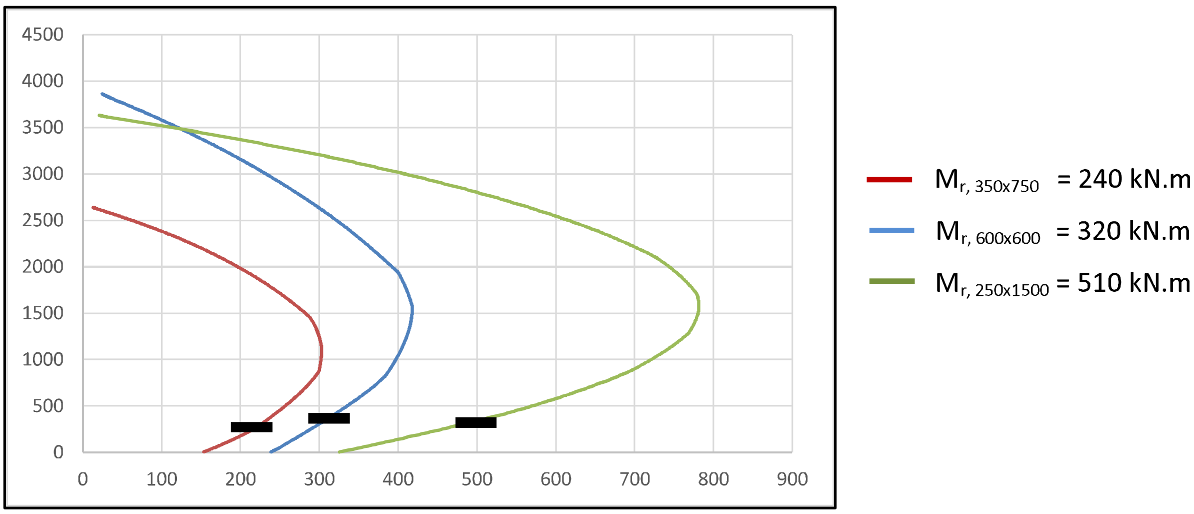


Table 3 – Shear Capacities of Columns

b	h	f_{cm} (*)	D tiebar	V_c	V_s	V_r	V_{max} (**)	M_r	h column	V_d (***)	$\Delta V=V_F$	n CFRP	$V_{f,R}$	$V_r+V_{f,R}$	$V_d / (V_r+V_{f,R})$
(mm)	*(mm)*	*(MPa)*	*(mm)*	*(N)*	*(N)*	*(kN)*	*(kN)*	*(kN.m)*	*(m)*	*(m)*	*(kN)*	*(Layers)*	*(kN)*	*(kN)*	
600	600	10	0	258,991	0	207	509	320	1.5	427	219	3	475	682	0.63
350	750	10	4	188,847	9,883	161	375	240	2.7	178	17	1	198	359	0.50
250	1500	10	0	269,782	0	216	549	510	2.7	378	162	2	792	1,008	0.37

(*) : Existing Concrete Compressive Strength
(**) : Diagonal Shear Compression Failure Capacity
(***) : Design Shear Strength when Column Hinges
NOTE : The cabon fiber is unidirectional, 300gr/m2, Ef=200,000 Mpa.; Turkish Earthquake Code is used for Design

The Solution

There were two problems with building. One was the corrosion and the loss of shear capacity of the columns due to the loss in tie-bars, the second was the vertical cracking and flaking type of concrete failure on the corner columns. The ground floor of the building was used by two restaurants, and the upper floors were not even naming an overall structural intervention against a possible seismic event in the region. And these were the basic constraint for the strengthening interventions.

The intervention methodology must be simple, quick and must not violate the continuity of the commercial areas. The use of reinforced concrete jacketing or steel bracing was not even on the table while the intervention types were discussed with the owner and with the business holders of the two restaurants. In this project, all the benefits of use of carbon fiber were named and satisfied.

The columns and shear walls were wrapped with CFRP against shear, while the corner columns were wrapped for confinement. It should be noted that the column dimensions after this intervention was not altered.

The weakest point for the carbon fiber applications was the epoxy against fire. A final layer of fire proof plaster was applied for all the CFRP wrapped columns.

Authors believe that the composites will have a wider market-space in Turkiye in the future, especially for commercial, educational and health buildings where the space can not be sacrificed for any upgrading of the structure.

Project details

City, Country	Yesilkoy, Istanbul TURKIYE
Owner	Seven owners in total
Contractor	ACIBADEM Restorasyon Ltd.Sti.
Designer	Sevket Ozden
Completion Date	June 2016
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

COST is supported by
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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.

COST key features are:

- building capacity by connecting high-quality scientific communities throughout Europe and worldwide;
- providing networking opportunities for early career investigators
- increasing the impact of research on policy makers, regulatory bodies and national decision makers as well as the private sector.

Through its inclusiveness, COST supports integration of research communities, leverages national research investments and addresses issues of global relevance.

As a precursor of advanced multidisciplinary research, COST plays a very important role in building a European Research Area (ERA). It anticipates and complements the activities of the EU Framework Programmes, constituting a "bridge" towards the scientific communities of emerging countries. It also increases the mobility of researchers across Europe and fosters the establishment of scientific excellence in the nine key domains:

- 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)

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

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

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.