Examination of parameters impacting flexural and shear strengthening of RC beams

Name Surname1, Name Surname2\*, Name Surname2

1 Istanbul University-Cerrahpasa, Institute of Graduate Studies in Science and Engineering, Istanbul, Türkiye

2 Istanbul University-Cerrahpasa, Department of Civil Engineering, Istanbul, Türkiye

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| Abstract |
| **Purpose:** This is where you explain “why” you undertook this study. If you are presenting new or novel research, explain the problem that you have solved. If you are building upon previous research, briefly explain why you felt it was important to do so. This is your opportunity to let readers know why you chose to study this topic or problem and its relevance. Let them know what your key argument or main finding is.  **Study design/methodology/approach:** This is “how” you did it. Let readers know exactly what you did to reach your results. For example, did you undertake interviews? Did you carry out an experiment in the lab? What tools, methods, protocols, or datasets did you use?  **Findings:** Here you can explain “what” you found during your study, whether it answers the problem you set out to explore, and whether your hypothesis was confirmed. You need to be very clear and direct and give exact figures, rather than generalize. It’s important not to exaggerate or create an expectation that your paper won’t fulfill.  **Originality/value:** This is your opportunity to provide readers with an analysis of the value of your results. It’s a good idea to ask colleagues whether your analysis is balanced and fair and again, it’s important not to exaggerate. You can also conjecture what future research steps could be.  The following three items should be included, if relevant to your paper or required by the journal you are submitting to:   * Research limitations/implications * Practical implications * Social implications   Follow the chronology of the paper, using headlines as guidelines if necessary. Make sure there is a consistent flow of information.  **Keywords:** Your submission should include up to five appropriate and short keywords that capture the principal topics of the paper. Please separate keywords by column. |

# Introduction

Improving the seismic performance of a reinforced concrete structure can be done by reducing seismic requirements or increasing the capacity of structural members. Traditional and non-conventional techniques are used in retrofitting applications performed with this purpose. Conventional retrofitting methods are implemented to improve the seismic capacities of existing structures by diminishing the negative effects of structural design or members. The other approach, non-conventional methods, are also used for structural retrofitting practices (Fardis, 2018). The use of fiber-reinforced polymer (FRP) materials can be implemented as an alternative to conventional strengthening practices for RC structural components which mostly applied by mounting steel plates, increasing sectional areas, and external post-tensioning. In FRP strengthening applications, FRP composite materials are used as EBR (externally-bonded reinforcement) or NSM (near-surface-mounted strengthening material). FRP materials yield several benefits such as being lightweight, easy mounting, and corrosion resistance. Due to the unique properties of FRP materials and the different structural behaviors displayed by FRP-strengthened members, an appropriate guidance is required for the use of these materials (Chen, 2006). Three types of materials (carbon, glass, aramid) are used in FRP strengthening.

FRP structural strengthening is mostly preferred to enhance the shear, flexural, or seismic performance of structural members. In general, EBR (Externally bonded reinforcement) and NSM-FRP techniques are used for beams strengthened with FRP (Pampanin et al., 2007; TS 500, 2003; Park and Mosallam, 2009). Ali et al. (2020) examined the impact of CFRP mechanical anchorages on the flexural capacity of RC beams externally strengthened using both CFRP sheets and plates. The authors also measured the ductility and load-bearing capacity of the beams. Hawileh et al. (2021) investigated the effect of longitudinal CFRP that externally bonded to beams using epoxy adhesives on the shear strength.

Karzad et al. (2017) examined the shear performance of full-scale CFRP-wrapped RC beams. Sabol and Priganc (2013) carried out a study on shear strengthening of RC structures with NSM technique. Mhanna et al. (2015) examined the shear performance increase in RC beams using U-wrapped and completely wrapped CFRP sheets. In their study, the authors performed three-point bending tests on their beam samples and they plotted the mid-span load displacement response graphs. Salama et al. (2020) measured the flexural performance of RC beams externally strengthened by CFRP sheets. They used side-bonded CFRP sheets with epoxy-based adhesives. The authors compared the obtained performance improvement in the flexural performance of CFRP-sheet strengthened RC beams with those traditionally bottom-bonded strengthened beams. On the other hand, NSM and EBR methods used to increase the flexural performance of RC beams were examined in terms of performance and effectiveness by Khalifa (2000). In that study, RC beams strengthened by various CFRP schemes were examined.

# Methodology

The calculations in the proposed approach will refer to ACI 440.2R. The calculations for the design process were coded in the Matlab software. Matlab is a well-known programming language used in engineering applications. Matlab combines numerical calculations with a high-order programming language that can perform sophisticated calculations and create advanced graphs.

The RC beam examined in this study was exposed to a comparably higher load since the building’s purpose has changed. Sectional elevation and cross-section of the RC beam are shown in Fig. 1. We determined that the beam failed under higher loads. Therefore, CFRP material was used to strengthen the RC beam against flexural and shear loading. The material features of the RC beam is given in Tables 1.

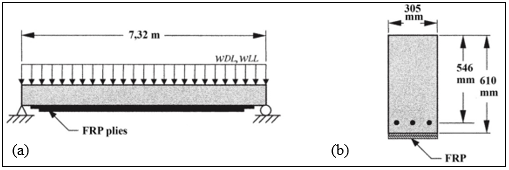


Fig. 1.The examined RC beam (a) Sectional elevation, (b) Cross-section

Table 1. The material features for the RC beam

|  |  |  |
| --- | --- | --- |
| Parameter | Definition | Value |
|  | width of beam | 305 mm |
| h | height of beam | 610 mm |
|  | effective depth | 546 mm |
|  | diameter of reinforcement | 28 mm |
|  | stirrup diameter | 10 mm |
|  | compressive strength of concrete | 34.5 MPa |
|  | yield strength of steel | 414 MPa |
|  | modulus of elasticity of steel | 2.105 MPa |
|  | length of beam | 7.32 m |
| s | reinforcement range | 200 mm |
|  | dead loads | 14.6 N/mm |
|  | live load | 17.5 N/mm |

## Design stages for flexural strengthening

In this stage, the ultimate flexural capacity Mu of the beam should be checked to determine whether the lowest limit value (Munstrengthened,limit) given in the ACI 440.2R is exceeded. If the current flexural capacity does not exceed the limit value, FRP strengthening is now allowed. This is because FRP’s strengthening role will be limited in this scenario. The moment values were calculated using the Eqs. 1-4 given below.

|  |  |
| --- | --- |
|  | (1) |
|  | (2) |
|  | (3) |
|  | (4) |

### Limit value control

To avoid collapse due to debonding, should be equal or less than 0.9 times the deformation at the break time (Eq.11).

|  |  |
| --- | --- |
|  | (11) |

According to the ACI 440.2R, neutral axis depth *c* can be defined 0.2 times the effective height as a presupposition (Eq.12):

|  |  |
| --- | --- |
|  | (12) |

# Declaration of conflicting interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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