International Journal of Advances in Engineering and Management (IJAEM)
Volume 8, Issue 1 Jan. 2026, pp: 320-326 www.ijaem.net ISSN: 2395-5252

Strengthening Of Reinforced Concrete Beams Using Fiber Reinforced Polymer (FRP) Composites

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Date of Submission: 08-01-2026 Date of Acceptance: 20-01-2026

ABSTRACT: Composite materials made from fibers and high-molecular-weight polymers, commonly known as Fiber Reinforced Polymers (FRP), have emerged as a modern alternative to traditional materials in the repair and rehabilitation of damaged structures. FRP materials are characterized by their lightweight nature, excellent corrosion resistance, and exceptionally high tensile strength. They are available in various forms, from factory-manufactured thin laminates to dry fiber fabrics, which can be wrapped around the geometry of structural elements and subsequently impregnated with polymer-based adhesives. This paper presents a method for designing the structural strengthening of reinforced concrete beams in civil engineering works using FRP sheets. The approach is applied and evaluated through a case study at the Commercial Center, Supermarket, and Product Exhibition Complex project located in Hoang Mai District, Hanoi.

KEYWORDS: Fiber Reinforced Polymer; Structural strengthening; Structural repairing; Reinforced Concrete Beam.

I. STRENGTHENING OF REINFORCED CONCRETE STRUCTURES USING FIBER MATERIALS

Fiber-Reinforced Polymer (FRP) is a composite material manufactured from high-performance fibers, among which carbon fibers (CFRP), glass fibers (GFRP), and aramid fibers (AFRP) are the most commonly used. These fibers exhibit exceptional mechanical properties, including very high tensile strength, a large elastic modulus, low density, excellent abrasion resistance, electrical insulation capability, good thermal stability, and long-term durability. In structural engineering applications, FRP materials are typically available in several forms, such as sheets, bars, cables, fabrics, and rolls. For the repair and strengthening of civil engineering structures, FRP sheets and fabrics are the most widely utilized. These may include unidirectional or multidirectional woven fabrics, single-weave or cross-weave configurations, as illustrated in Figure 1 [1].

FRP FIBER MATERIALS ARE USED FOR STRENGTHENING REINFORCED CONCRETE STRUCTURES [1].

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Carbon composite fibers are materials containing at least 90% carbon atoms, produced through a tightly controlled pyrolysis process of precursor fibers. These fibers are compatible with common polymer matrices such as epoxy and vinylester, with areal densities ranging from 100 g/m² to 1200 g/m². The major advantages of FRP strengthening, as reported in previous studies, include: extremely high tensile strength—approximately 10 to 15 times that of conventional steel reinforcement; low self-weight and versatility, making the material suitable for components of various geometries; and effectiveness in strengthening structural members subjected to flexure, shear, and compression. In addition, FRP systems offer rapid and straightforward installation, do not adversely affect the architectural appearance, exhibit long-term durability and chemical resistance, and can be easily designed and verified using manufacturer-provided software—factors that further highlight their practical benefits [2, 3, 4].

Recent studies have introduced construction and repair techniques using FRP sheets based on the fundamental principle of externally bonded FRP strengthening: FRP sheets must be installed at locations requiring increased load-carrying capacity, with fiber orientation aligned with the principal tensile stress direction to fully mobilize the tensile strength and stiffness of the fibers. It is also essential to ensure that the FRP system does not debond from the concrete substrate during service [5]. The procedures for installing FRP sheets, as summarized in [6, 7], generally consist of the following steps: (1) preparing and repairing the concrete surface; (2) applying a primer to enhance adhesion, leveling the surface if necessary, and spreading the bonding resin or adhesive; (3) placing the FRP sheet onto the resin layer, allowing the resin to cure for the prescribed duration before applying subsequent layers; and (4) applying a protective and aesthetic coating once the system has fully cured. Currently, two installation techniques are most commonly used for FRP sheets and fabrics: the dry lay-up method and the wet lay-up method [8, 9], as illustrated in the figure below.

INSTALLATION OF FRP SHEETS FOR STRENGTHENING REINFORCED CONCRETE STRUCTURES [8, 9].

II. DESIGN OF REINFORCED CONCRETE STRUCTURES STRENGTHENED WITH FRP MATERIALS

2.1. Design Principles for FRP Strengthening
The authors in [10, 11] established the fundamental basis for calculating the strengthening of reinforced concrete (RC) structures using carbon fiber materials. They indicated that the design process adheres to the principles commonly applied in RC structural analysis. Specifically, the following assumptions are employed:

1. A strain-compatibility hypothesis between the steel reinforcement and the FRP sheets bonded to the RC member;
2. No slip occurs between the FRP sheet/plate and the concrete substrate; and
3. The tensile contribution of the adhesive layer and the concrete cover is neglected.

2.2. Flexural Strengthening of RC Beams According to ACI 318–85 [12]

a) Preliminary calculation for selecting the required number of FRP layers

The flexural capacity of the existing reinforced concrete beam is determined as follows:

$$\phi.M_n = \phi.A_s.f_y.\left(d - \frac{a}{2}\right) \text{ with } a = \frac{A_s f_y}{0{,}85 f_c^{'} b}$$

and $\phi = 0.9$

IF $\phi.M_n \geq M_u$ then no strengthening intervention is necessary.

IF $\phi.M_n < M_u$ then strengthening intervention is required.

Required FRP plate area for strengthening

$$A_f = \frac{T}{\phi 0{,}85 f_{fu}} \text{ with } T = \frac{M_u - \phi M_n}{0{,}9d}$$

The required number of FRP layers is selected as (n_f is an integer):

$$n_f = \frac{A_f}{w_f t_f};$$

with the FRP sheet dimensions of $w_f\ t_f$

b) Calculation of the initial strain at the beam soffit at the time of FRP sheet installation

The working condition of the concrete at the time of bonding the FRP sheet is considered *cracked* when , and *uncracked* when .

The cracking moment of the reinforced concrete beam is determined as follows:

$$M_{cr} = f_r.S_m \text{ with } f_r = 7{,}5.\sqrt{f_c^{'}}$$

Initial concrete strain at the beam soffit in the cracked state:

$$\varepsilon_{bi} = \frac{M_{ip}(h - h_d)}{l_{cr} E_c}$$

with

$$k_d = \frac{\sqrt{\left((E\ /E_c)A\right)^2 + 2b(E_s/E_c)A_s d} - (E_s/E_c)A_s}{b}$$

and $I_{cr} = b.\frac{(k_d)^2}{12} + b.k_d\left(\frac{k_d}{2}\right)^3 + \frac{E_s}{E_c}.A_s.(d - k_d)^2$

Initial concrete strain of the reinforced concrete beam in the uncracked state:

$$E_{bi} = \frac{M_{ip} C_b}{l_g E_c} - \frac{P_e}{A_c \mathrm{E_c}}\left(1 + \frac{ec_b}{r_g^2}\right)$$

c) Flexural capacity of the beam after strengthening with FRP laminates

$$M_n = A_s.f_s\left(d - \frac{\beta_1 c}{2}\right) + 0{,}85.A_s.f_s\left(h - \frac{\beta_1 c}{2}\right)$$

with $\beta_1 = 1{,}05 - 0{,}05\frac{f_c^{'}}{1000}$ and $c \approx 0{,}02.d$

The load-carrying capacity of the strengthened beam is given by $\phi.M_n$ is required to be larger than the design bending moment, considering the load factor. The corresponding value is determined as follows:

$$\phi = \begin{cases} 0{,}90 Khi \varepsilon_s \geq 2\varepsilon_{sy} \\ 0{,}50 + 0{,}20\frac{\varepsilon_s}{\varepsilon_{sy}} Khi \varepsilon_{sy} < \varepsilon_s < 2\varepsilon_{sy} \\ 0{,}70 Khi \varepsilon\ \leq \varepsilon\ y \end{cases}$$

III. STRENGTHENING OF REINFORCED CONCRETE BEAMS AT HANOI COMMERCIAL CENTER PROJECT

3.1.Design Calculations for Strengthening

The project involves a commercial center, supermarket, and product exhibition hall at CDA Tam Trinh, Hoang Mai, Hanoi, developed by Thanh Cong Group. During its operation, the owner modified the functional use of the facility, resulting in a significant increase in the imposed floor loads. Subsequent structural assessments indicated that, under the new service loads, the existing beams and floor slabs at certain locations did not satisfy the required load-carrying capacity. The proposed solution was to design strengthening measures for the beams and slabs using externally bonded FRP materials.

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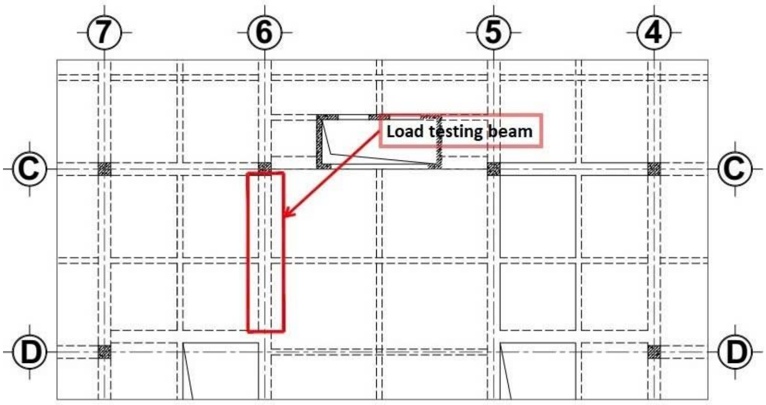
And $S_m = \dfrac{l_g}{h/2}$

INSTALLATION STEPS OF FRP SHEETS AT THE PROJECT SITE



LOCATIONS OF BEAMS FOR STRENGTHENING DESIGN CALCULATIONS AND LOAD TESTING

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3.2.Load testing to validate the computed structural capacity

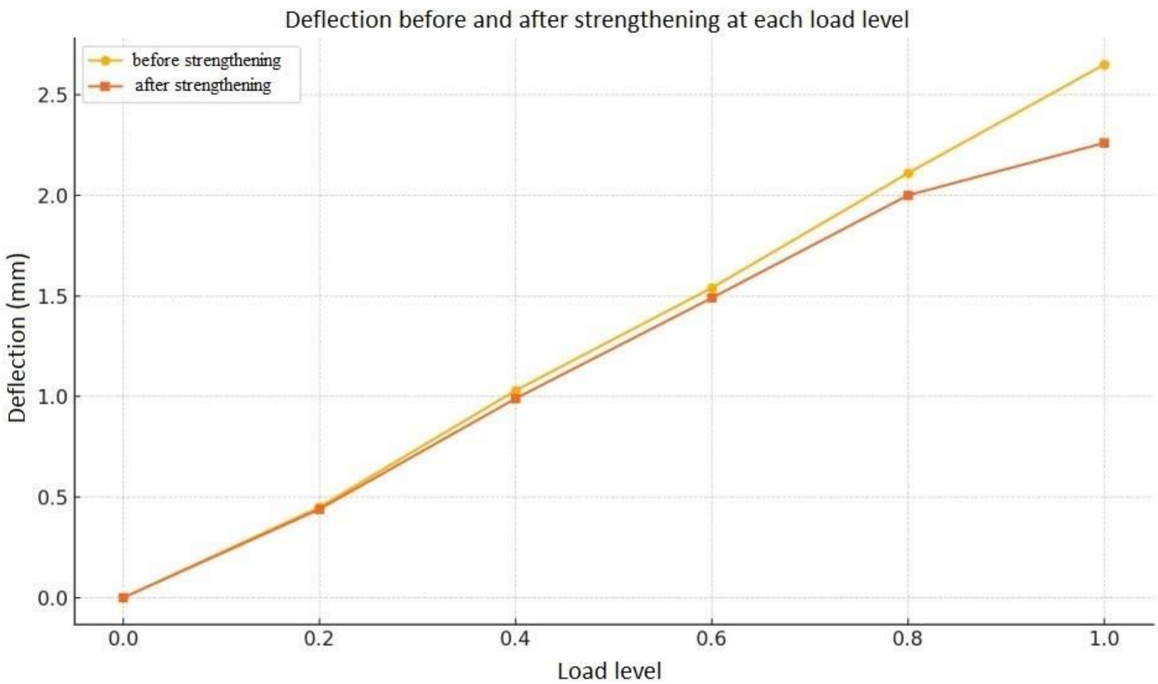
Testing and Evaluation Procedure: The procedure follows TCVN 9344, aiming to conduct load tests before and after strengthening the beams with FRP materials in order to:

1. Compare parameters reflecting the structural behavior of the beams before and after strengthening;
2. Provide a preliminary assessment of the load-carrying condition of the strengthened beams.

Based on the collected data, analyses and processing are performed to evaluate the effectiveness of the FRP strengthening in enhancing the moment capacity of the reinforced concrete members.

A comparison was made between the theoretical calculations and the actual experimental results to assess whether the design and installation of the FRP materials met the specified requirements. The beam selected for testing was beam 1C22 on basement level B1, which was strengthened with a single layer of SCH41 fibers, bonded along a length of 7.8 m and a width of 0.5 m.

Deflection Measurement Results of the Beam:



RELATIONSHIP BETWEEN DEFLECTION AND LOAD LEVELS BEFORE AND AFTER STRENGTHENING

The results indicate that the strengthening of the reinforced concrete structure—beams and slabs—has a minor effect on the overall stiffness of the structure. Depending on the load level, beam deflections were reduced by 2.2–15.6%, and the structural members remained within the elastic range. The effectiveness of the strengthening is evident at all load levels: the deflection curves after strengthening consistently lie below those measured prior to strengthening, with the differences becoming more pronounced at higher loads. Specifically, at the 1.0 load level, the deflection decreased from 2.65 mm to 2.26 mm.

. Moreover, the deflection reduction ratio varied significantly, with effectiveness ranging from approximately 85% to 98%, demonstrating that both the quality of workmanship and the FRP materials play a crucial role in the strengthening performance.

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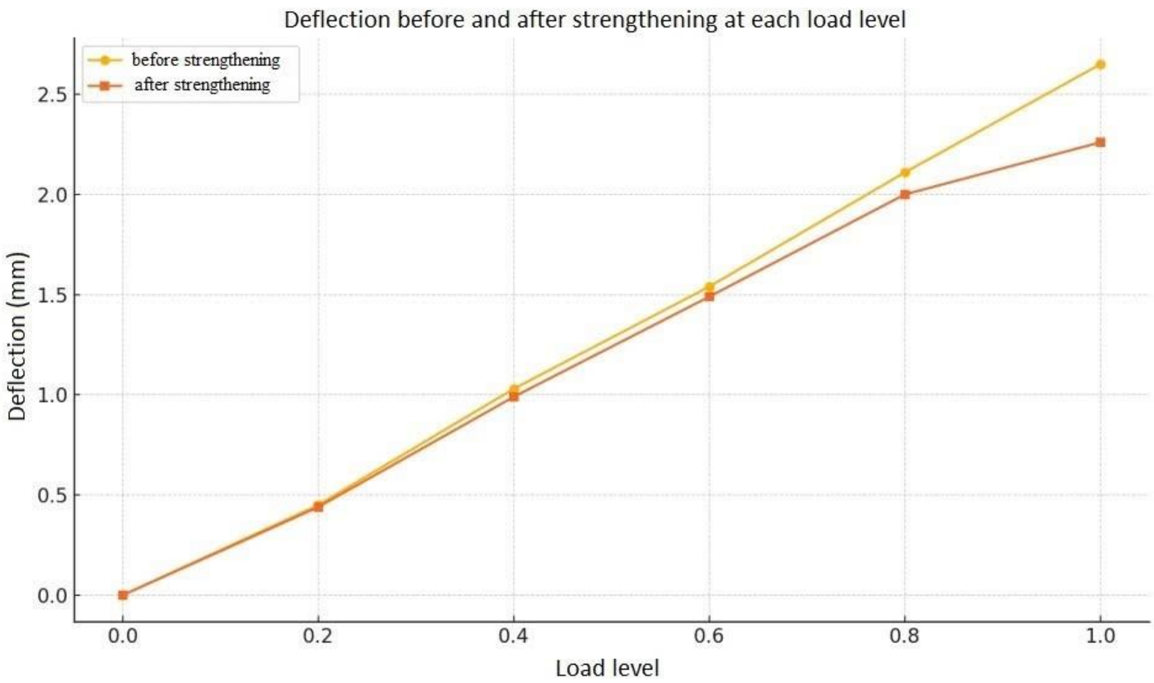
Measured strain and stress results of the beam:



RELATIONSHIP BETWEEN DEFLECTION AND LOAD LEVELS BEFORE AND AFTER STRENGTHENING

The results indicate that the stress and strain values of both the concrete and the reinforcing FRP materials remain within the allowable limits. After strengthening, the FRP materials effectively enhanced the structural performance: at each load level, strains were reduced by 8–14% (excluding very low-load cases). The strains of the FRP sheets and the concrete are similar, demonstrating that both materials work together and contribute simultaneously to the load-bearing process, confirming adequate bonding between the FRP sheets and the concrete.

Concrete strains decreased at all load levels after strengthening; the post-strengthening strains were consistently lower than those measured before, indicating effective load transfer to the FRP. The FRP strains increased progressively with the applied load, and the FRP strain curves are nearly parallel to those of the concrete, showing that the FRP participated concurrently in load resistance, thereby reducing stress in the concrete. The comparison ratio of concrete strain (before/after strengthening) was relatively high, ranging from 82% to 92%, demonstrating that the FRP sheets not only enhance performance at high loads but also improve structural behavior at lower load levels.

CONCLUSION

The FRP strengthening approach significantly improves the load-carrying capacity of beam structures under increased service loads, making it particularly suitable for buildings requiring functional renovation or upgrading. FRP materials, with their outstanding properties such as high tensile strength, low weight, corrosion resistance, ease of installation, and minimal impact on the original structural geometry, effectively satisfy both technical and aesthetic requirements during the repair and strengthening process. Verification calculations indicate that the strengthened structures achieve safe and durable performance, fully complying with current design standards.

REFERENCES

[1]. Trinh Quang Minh, Kieu Minh The, Vu Dinh Phung (2013). Using carbon fiber composite bars to enhance the shear capacity of reinforced concrete beams. *Vietnam Journal of Science and Technology*.
[2]. Nguyen Trung Hieu (2015). Study on flexural strengthening effectiveness of reinforced concrete beams using carbon fiber sheets. *Journal of Construction Science and Technology*, 1/2015.
[3]. Nguyen Trung Hieu, Ly Tran Cuong (2019). Experimental study on strengthening cracked concrete beams using CFRP sheets. *Vietnam Journal of Science and Technology*..
[4]. Ha Manh Hung, Nguyen Trung Hieu (2021). Shear strengthening effectiveness of reinforced concrete beams using carbon fiber sheets. *Journal of Construction Science and Technology*.
[5]. Nguyen Vinh Sang, Nguyen Anh Dung, Nguyen Ngoc Thang (2025). Study on the effect of amplification factor on the pure torsion behavior of reinforced concrete box beams. *Journal of Construction Science and Technology*, Hanoi University of Civil Engineering, 19(1V), 79–93.
[6]. TCCS 15:2016/TCDBVN (2016). Repairing and strengthening reinforced concrete bridge members using externally bonded FRP – Design standard..