

# **EXPERIMENTAL STUDY ON THE APPLICATION OF TRC TO ENHANCE THE LOAD-BEARING CAPACITY OF REINFORCED CONCRETE SLABS**

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## **Abstract**

To enhance load-bearing capacity and prevent structural damage, reinforced concrete elements are often strengthened with additional layers of material. This study investigates the bonding performance between Textile Reinforced Concrete (TRC) and reinforced concrete slabs through four-point bending tests. The primary objective is to assess the effectiveness of surface grooving on the old concrete to improve the adhesion between the TRC layer and the slab. Experimental results demonstrate that TRC strengthening significantly improves both the load capacity and mid-span deflection of the slabs. Specifically, TRC-strengthened reinforced slabs exhibited an average 137% increase in load-bearing capacity and a 53% increase in mid-span deflection compared to unreinforced slabs. Notably, no debonding occurred, even at failure, confirming the reliability of the grooving technique in ensuring a strong bond. The study concludes that TRC is an effective method for enhancing the flexural strength of reinforced concrete slabs, while also improving safety under high loading conditions.

***Keywords:** Textile reinforced concrete; strengthened reinforced concrete slab; four-point bending test; experimental study.*

## **1. Introduction**

The application of Textile Reinforced Concrete (TRC) for enhancing the load-bearing structures of reinforced concrete constructions is an effective solution that has been extensively studied in recent years [1, 2]. TRC is a combination of fine aggregate concrete and high-strength fibers, such as carbon, glass, and other materials. This combination provides TRC with superior mechanical properties, high durability, and better abrasion resistance compared to traditional concrete. Consequently, TRC is widely used in the construction of new structures to reduce weight, as well as in the repair and restoration of existing structures.

TRC is also considered an optimal solution for improving the load-carrying capacity of reinforced concrete slabs due to its significant reinforcement capabilities, which enhance maximum load capacity, increase structural ductility, and slow down the

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DOI: 10.56651/lqdtu.jst.v7.n02.890.sce

initial cracking process. Through experimental studies and numerical simulations, TRC has proven to be highly effective in reinforcing structures subjected to bending loads [2-4]. Additionally, TRC helps mitigate the penetration of harmful environmental factors [5, 6].

A common method currently used in the practical application of bonding TRC to old concrete slabs involves roughening or grooving the surface of the existing concrete before applying the TRC layer [7, 8]. This method is effective in creating good surface friction at the bond interface. It is simple, cost-effective, and suitable for real-world construction conditions, especially in marine and island environments. However, further experimental studies are needed to validate the effectiveness of this approach in practice. In addition to research on TRC reinforcement for concrete elements subjected to special loads, Le Quy Don Technical University has also conducted extensive studies on flexural reinforcement (beams, columns, slabs) for TRC-strengthened elements. This article presents an experimental study aimed at evaluating the impact of using TRC to enhance the load-carrying capacity of reinforced concrete slabs employing a surface grooving technique. The research focuses on analyzing the initial cracking load and maximum load of the slabs to determine the effectiveness of the TRC layer, while also examining the bonding method between the reinforcement layer and the original structure, thereby providing insights before applying the TRC reinforcement method to reinforced concrete slabs in practice.

## 2. Flexural tests of TRC-reinforced concrete slabs

### 2.1. Materials for slab fabrication

The normal-weight concrete B30 is used for the reinforced concrete slab structure, while fine aggregate concrete utilizes Sikagrout 214-11, with the material characteristics presented in Table 1.

The steel used for the slab structure belongs to group AI according to TCVN 5574-2018, with the mechanical properties outlined in Table 2.

The textile fiber material, designated as Sigratex Grid 350, is assumed to have similar properties for both longitudinal and transverse orientations, as shown in Table 3.

Table 1. Material parameters for different types of concrete

Concrete types	$f'_c$ (MPa)	$f_t$ (MPa)	$E_c$ (MPa)	$\nu$	$\gamma$ (kg/m <sup>3</sup> )
Normal-weight concrete for slabs (B30)	39.5	4.1	29540	0.20	2320
Fine aggregate concrete Sikagrout 214-11	74.6	15.2	32600	0.18	2400

The reinforced concrete beams (RC beams) were made from conventional B30 concrete. The concrete mix design and material properties determined from experimental testing are shown in Table 1.

Table 2. Material parameters for steel

$f_y$ (MPa)	$E_s$ (MPa)	$\nu$	$\gamma$ (kg/m <sup>3</sup> )
280	210000	0.3	7850

Table 3. Material parameters for textile fiber

$f_{tu}$ (MPa)	$E_t$ (MPa)	$\nu$	$\gamma$ (kg/m <sup>3</sup> )
623	31940	0.22	1740

### 2.2. Sample preparation process

The specimen configuration with a size of 800 mm × 400 mm × 100 mm is illustrated in Fig. 1. The fabrication process for the unstrengthened reinforced concrete slab is illustrated in Fig. 2 while the TRC-strengthened reinforced concrete slab is depicted in Fig. 3 and Fig. 4. The properties of the test specimens prepared for the flexural test are summarized in Table 4.

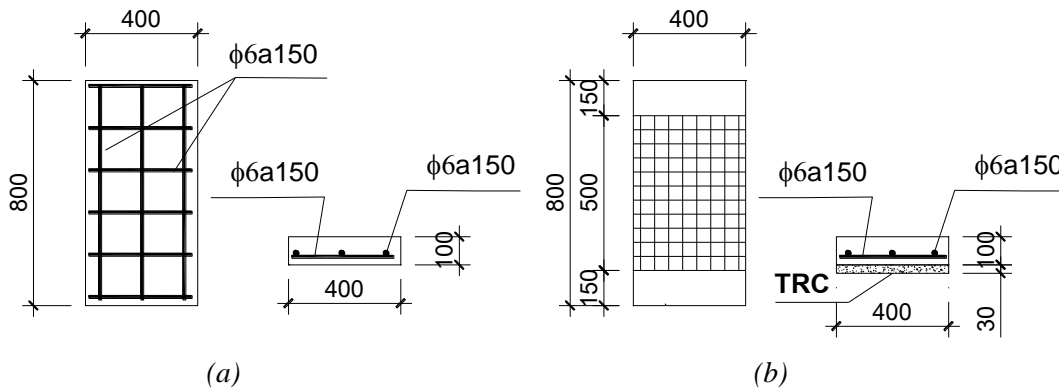


Fig. 1. Configuration of the specimen:

(a) Unstrengthened reinforced concrete slab; (b) TRC-strengthened reinforced concrete slab.

The formwork is constructed from box steel with dimensions of 100 mm × 50 mm. The formwork is cut and assembled according to specifications to ensure the correct dimensions of the slab. At the joints, welding is performed to ensure the airtightness of the formwork. After completion, the formwork is cleaned and a thin layer of oil is applied to the inner surface to facilitate the removal process.



Fig. 2. Reinforcement work, formwork, and concrete pouring of the reinforced concrete slab.

Sample fabrication process:

- Fabricate the reinforcement according to the specified design dimensions.
- Tie the reinforcement bars together to form a grid based on the design dimensions.
- Fabricate the steel formwork, clean the formwork, weld any gaps, and apply a thin layer of release oil to the formwork.
- Pour the concrete in two layers, with each layer having a height of 50 mm.
- Use a concrete vibrator to compact the concrete thoroughly.
- After pouring the concrete, finish the surface.
- Once the concrete reaches sufficient strength at 2 days of age, remove the formwork and proceed with the concrete curing process.

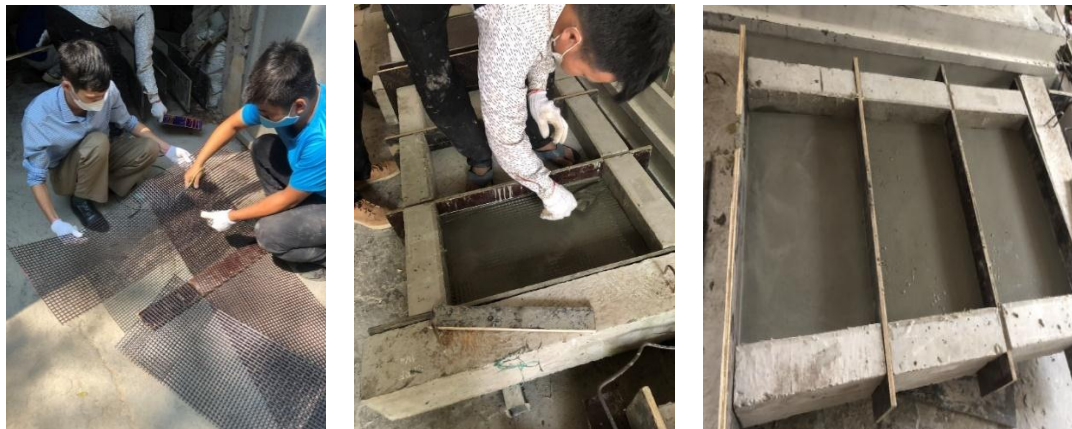
The concrete in the beams is tested for strength at 28 days, while for the strengthened slabs, the TRC reinforcement material is applied only after the concrete has reached sufficient strength beyond 28 days. Equipment includes grinding and grooving tools. The grooves are 2 - 3 mm deep and spaced 5 cm apart [7]. After the first layer of mortar matrix (1.5 mm thickness) was applied, fiber mesh was installed by pressing it into the mortar layer, which was followed immediately by installing the top mortar layer (1.5 mm thickness) [9].

Table 4. Characteristic of slab specimens

Specimen ID	Specimen dimensions (mm)	TRC strengthening dimensions (mm)	Number of TRC layers	Number of specimens
TO	800 × 400 × 100	No	1	1
TO2-1	800 × 400 × 100	Yes, 500 × 400 × 30	1	1
TO2-2	800 × 400 × 100	Yes, 500 × 400 × 30	1	1



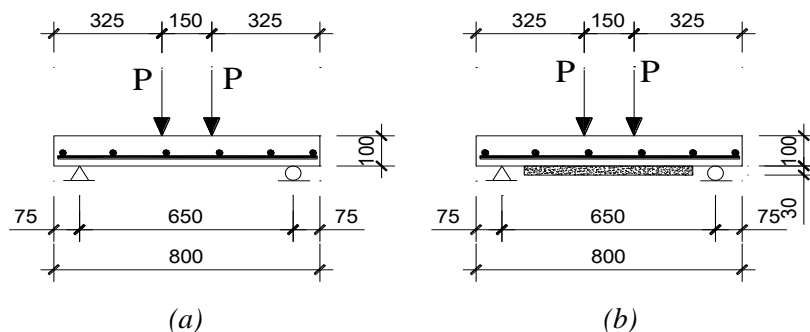
*Fig. 3. Cleaning and roughening the slab surface before applying the strengthening layer.*



*Fig. 4. Cutting textile mesh to the slab size, formwork preparation, and surface finishing of the strengthening layer.*

### **2.3. Testing procedure and equipment for bending slabs**

The testing setup for the slab follows a simple beam configuration (one fixed support and one movable support), subjected to two concentrated forces denoted as  $P$ . The locations of the applied forces and the supports are shown in Fig. 5.



*Fig. 5. Bending test setup diagram for the slab:*

*(a) Unstrengthened reinforced concrete slab; (b) TRC-strengthened reinforced concrete slab.*

The setup utilizes a hydraulic jack with a 20-ton capacity and a distribution slab to divide the load. The total concentrated force at the jack head,  $2P$ , is evenly distributed into two loads,  $P$ , which are applied to the beam (Fig. 5). The load magnitude is measured by a load cell connected to a TDS 530 Data Logger from Tokyo Sokki, Japan.

The load applied to the beam and the deflection at the two supports and mid-span are recorded during the experiment. Measurement devices are arranged as follows:

- The applied load is measured using a load cell.
- The displacement is determined through three LVDT displacement sensors (amplification factor  $K = 100$ ) manufactured by TML, Japan. These sensors are placed at both supports and at the mid-span of the slab.

The data acquisition and processing system, Data Logger TDS 530, enables automatic and simultaneous recording of the measured parameters (displacement and load) during the experiment, and is connected to a computer (Fig. 6). The data is recorded automatically at a frequency of one reading per second.



*Fig. 6. Loading diagram for simply supported beam:  
 (a) Unstrengthened reinforced concrete slab; (b) TRC-strengthened reinforced concrete slab.*

During the loading process, the experimental load is divided into multiple smaller increments. The ultimate load capacity of the slab is calculated, and the experimental load levels are divided accordingly. For a slab with the cross-section shown in Fig. 6, the predicted failure load is  $P = 15$  kN. The applied load per pump stroke of the hydraulic jack is calculated using the following formula:  $a = \frac{2P_{ph}}{10}$  (kN).

- After completing the experimental setup, an initial trial load 3.0 kN is applied. This trial load aims to eliminate any errors in the setup and verify the stability of the system.
- Once the system and measurement devices are confirmed to be stable, all recorded data is reset to zero.
- The hydraulic jack applies the load to the slab at a cylinder displacement rate of 0.5 mm per minute.
- During the loading process, based on experimental calculations and the deformation graph of the tensioned concrete and reinforcing steel, the moment when cracks appear is identified.
- The load increases step by step according to the predetermined load levels.

### **3. Experimental results**

Figure 7-9 illustrate that both strengthened and unstrengthened slabs exhibited failure due to concrete crushing in the compression zone. Notably, during the experiment on the strengthened slab, no debonding occurred, even at the point of failure. This confirms the effectiveness of the reinforcement method. Furthermore, all the samples, both strengthened and unstrengthened, experienced the same failure mode (Fig. 9) and exhibited similar flexural failure patterns (Fig. 7, 8).



*Fig. 7. Unreinforced slab: (a) under flexural failure and (b) failure mode.*



*Fig. 8. TRC-strengthened reinforced concrete slabs: (a) under flexural failure and (b) failure mode.*



Fig. 9. Flexural failure in unreinforced and TRC-strengthened reinforced concrete slabs.

The experimental results indicate that the bonding performance between the old concrete and the TRC reinforcement layer is highly effective. The connection between these two layers is strong, allowing the reinforced layer and the old concrete to work together simultaneously.

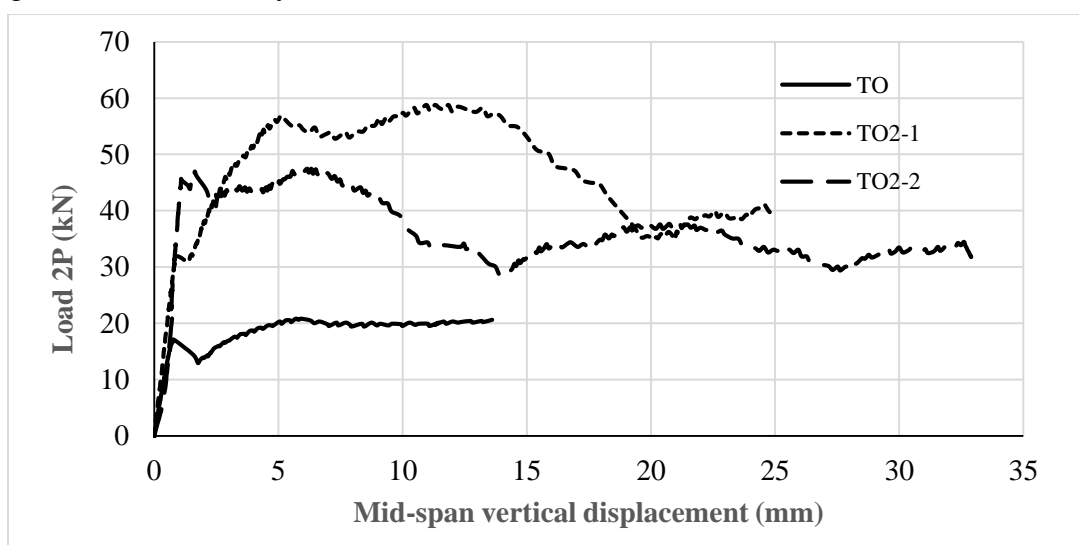


Fig. 10. Load-Displacement relationship at the midpoint of the slab (bottom surface).

Figure 10 illustrates the relationship between the applied load and displacement at the midpoint of both unreinforced and TRC-reinforced slabs. Although the samples were cast simultaneously, the results reveal a significant difference in load capacity and displacement for the reinforced slabs. However, the development stages of the load-displacement curves exhibit similarities, indicating three distinct phases.

Phase 1: A linear elastic stage without crack formation, corresponding to small displacements of approximately 1 - 1.2 mm.

Phase 2: The initiation of small cracks, where the load either drops slightly or plateaus within a displacement range of 1.2 - 2.2 mm.

Phase 3: A nonlinear increase in load, with significant displacement growth before total failure occurs.

Additionally, during the elastic stage, a notable reduction in deflection is observed for the reinforced slabs compared to the unreinforced ones under the same load. The key distinction between the two sample types is observed in phase 3. The unreinforced slabs demonstrate a rapid increase in load followed by a near-horizontal plateau before failure. In contrast, the reinforced slabs exhibit a cyclical pattern of load increase, decrease, and then another rise over two cycles, eventually stabilizing at around 60% of the maximum load ( $P_{max}$ ) with a larger displacement before failure.

Upon examining the failure patterns of the specimens, the following observations can be made:

Unreinforced slabs: Both the steel reinforcement and concrete are completely severed, separating into two distinct parts.

Strengthened slabs: Though the steel and concrete are also cut through, the fiber mesh remains intact, holding the two parts together. This has significant implications for safety, as it could help prevent catastrophic collapse in structures under normal loading conditions.

Table 5 summarizes the displacement and load measurements for the RC slabs strengthened with TRC. The results indicate a significant improvement in the cracking load of the reinforced specimens compared to the unreinforced specimen. Although the maximum load and displacement values of the two reinforced specimens show considerable differences, the variations at the failure stage are relatively minor. In this table, the ductility factor is defined by the formula  $\Delta_f / \Delta_y$ , where  $\Delta_f$  is the displacement at failure and  $\Delta_y$  is the yield displacement. The yield displacement is the lateral displacement at 80% of ultimate load at the ascending part of the curve while the failure displacement is lateral displacement at 80% of ultimate load at the descending part of the curve. The displacement ductility factors of the TO2-1 and TO2-2 specimens are over twice as high as that of the TO specimen. Overall, the specimens with higher ductility factors (TO2-1 and TO2-2) exhibit better performance in terms of deformation capacity and energy absorption compared to the more brittle TO specimen. The data suggests that the application of TRC reinforcement enhances the ductility of the reinforced concrete slabs.

Table 5. Results of failure test

Specimen ID	Concrete cracking (mm)		Ultimate stage (Flexural capacity)		Failure stage		Ductility factor		
	Load (kN)	Disp. (mm)	Load (kN)	Disp. (mm)	Load (kN)	Disp. (mm)	$\Delta_y$	$\Delta_f$	$\Delta_f / \Delta_y$
TO	17.09	0.78	20.79	5.70	20.79	5.70	2.94	5.70	1.94
TO2-1	31.79	1.02	58.79	10.97	47.03	16.94	3.18	16.94	5.33
TO2-2	45.88	1.49	47.48	6.33	37.98	10.04	2.39	10.04	4.20

Table 6 provides the results of the enhanced flexural capacity of TRC-reinforced concrete slabs using a single layer of carbon fiber mesh. The results show a substantial improvement, with the load capacity increasing by an average of 137%, which is consistent with previous research findings [10]. Furthermore, the mid-span displacement at failure increases by 52%.

Table 6. Comparison of reinforcement effectiveness

Flexural capacity	Unreinforced TO1	Reinforced TO2-1	Reinforced TO2-2	Average of TO2-1 and TO2-2	Estimated effectiveness
Load capacity (KN)	20.79	58.79	47.48	53.14	237%
Mid-span displacement (mm)	5.70	10.97	6.33	8.65	152%

#### 4. Results and discussion

The experimental study evaluated the behavior of reinforced concrete slabs strengthened with a TRC layer containing carbon fiber mesh, compared to unreinforced slabs, under four-point bending conditions. The results demonstrated that TRC reinforcement significantly enhances both the load-bearing capacity and deformation capacity of RC slabs. Specifically, the reinforced samples exhibited an average increase of 137% in load capacity compared to unreinforced samples, while mid-span displacement increased by 53% before failure. This confirms the effectiveness of TRC in improving the flexural performance of reinforced concrete structures.

Although the simplest construction method of applying TRC to the RC slabs by surface grooving was used, both reinforced and unreinforced samples exhibited the same failure mode, with concrete and steel breaking at the mid-span. Notably, the reinforced

slabs did not experience any debonding issues, even upon failure, indicating that the bond between the TRC layer and the old concrete was robust, and the TRC application technique was reliable. Furthermore, in the reinforced samples, when failure occurred, the TRC fiber mesh maintained the connection between the two sections of the slab, offering enhanced safety in the event of structural failure due to heavy loads. This feature provides critical advantages in terms of warning against potential hazards and ensuring the safety of people and property in case of an incident.

The results suggest that TRC reinforcement offers significant potential for practical application, particularly in structures that require high load-bearing capacity and post-failure safety. However, further research is needed to evaluate the effectiveness of TRC reinforcement in slabs under extreme conditions such as explosions or impacts, which will be the focus of future studies.

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## NGHIÊN CỨU THỰC NGHIỆM VỀ VIỆC ÁP DỤNG TRC ĐỂ TĂNG CƯỜNG KHẢ NĂNG CHỊU LỰC CỦA TẦM BÊ TÔNG CỐT THÉP

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**Tóm tắt:** Để nâng cao khả năng chịu lực và ngăn ngừa hư hỏng, kết cấu bê tông cốt thép thường được gia cường thêm một lớp vật liệu. Nghiên cứu này tập trung vào việc đánh giá khả năng dính bám giữa lớp bê tông cốt lưới dệt (*Textile Reinforced Concrete - TRC*) và tấm bê tông cốt thép, thông qua thí nghiệm uốn bốn điểm. Mục tiêu chính là kiểm tra hiệu quả của kỹ thuật tạo rãnh trên bề mặt bê tông cũ nhằm cải thiện độ kết dính giữa lớp TRC và tấm bê tông. Kết quả thực nghiệm cho thấy việc gia cường bằng TRC đã cải thiện đáng kể khả năng chịu lực và chuyển vị tại giữa nhịp của tấm. Cụ thể, tấm được gia cường bằng TRC có khả năng chịu lực tăng trung bình 137% và chuyển vị giữa nhịp tăng 53% so với tấm không gia cường. Đáng chú ý, không xảy ra hiện tượng bong tách lớp vật liệu gia cường ngay cả khi kết cấu bị phá hoại, điều này cho thấy độ tin cậy của kỹ thuật tạo rãnh trong việc đảm bảo độ dính bám chắc chắn. Nghiên cứu khẳng định gia cường TRC là một giải pháp hiệu quả trong việc tăng cường khả năng chịu lực của kết cấu tấm bê tông cốt thép, đồng thời cải thiện độ an toàn khi kết cấu chịu tải trọng lớn.

**Từ khóa:** *Bê tông cốt lưới dệt; tấm bê tông cốt thép gia cường; thí nghiệm uốn bốn điểm; nghiên cứu thực nghiệm.*

Received: 03/10/2024; Revised: 23/12/2024; Accepted for publication: 27/12/2024

