NUMERICAL INVESTIGATION FOR THE FLEXURAL BEHAVIOR OF RC BEAMS STRENGTHENED WITH TEXTILE REINFORCED CONCRETE

MSC. Nguyen Huy Cuong
Dr. Le Minh Cuong
Assoc. Prof. Dr. Ngo Dang Quang
MSC. Le Dang Dung
University of Transport and Communications

Summary: *Strengthening of reinforced concrete structures using textile reinforced concrete (TRC) has emerged as a viable technique to retrofit/repair deteriorated structures. In this study, the flexural performance of concrete beams strengthened with TRC has been investigated by means of a finite element (FE) analysis on ABAQUS software. The work reported in this paper deals with the analytical models, proposed to predict the behavior of reinforced concrete beam strengthened with externally bonded TRC layers. The results of the numerical simulations are used to validate the experimental results.*

Keywords: *flexural, strengthening, textile reinforced concrete (TRC), ABAQUS*

I. INTRODUCTION

In the middle of 19th century, reinforced concrete (RC), a composite material from concrete and reinforcing bars, was invented and greatly influenced in the development of new structures. As a result, RC became a very popular material and nowadays most constructions are made of this material. It also brings about an increasing demand in the past years for rehabilitating/strengthening existing RC structures due to deterioration of material and structures, and augmentation/increasing of load demand.

Just over a decade ago, a new concept has been developed with the idea of replacing the steel reinforcement with textile fibers resulting in a new composite material called Textile Reinforced Concrete (TRC). Since, TRC is becoming a more and more economically and technically appropriate building material which may be applied both for extraordinary designed and common structures. TRC is especially suited for concrete components that need to be repaired, strengthened or maintained with its important advantages such as high resistance to corrosion, thin and light (Curbach et al., 2002). This new construction material gradually replaces FRP – one of the most

Figure 1. *Textile reinforced concrete*

common strengthening materials for RC structures. TRC consists of two components - the textile fabric and a special fine-grained concrete (Figure 1). The first component comprises fabric meshes made of long woven, knitted or even unwoven fiber rovings in at least two (typically orthogonal) directions. For TRC, currently carbon or alkaline resistant (AR) glass fibers are used. A special fine-grained mineral cement matrix was developed to be able to apply the new composite material for concrete strengthening and repair works.

Many projects or researches studied experimentally and/or numerically on the use of textiles in the upgrading of concrete structures such as: improves the bond between concrete and cement-based textile composites; studies the RC beams strengthened with different layers of TRC; demonstrates the effectiveness of cement-based textile composites in the form of jackets to confine concrete in compression, etc (Curbach et al., 2002). In this study, the flexural performance of concrete beams strengthened with TRC layer has been investigated by means of a finite element (FE) analysis. The work reported in this paper deals with the analytical models, proposed to predict the behavior of RC beam strengthened with externally bonded TRC layer for the purpose of FE validation.

II. SUMMARY OF EXPERIMENTAL INVESTIGATION

Hussein et al. (2013) studied the flexural strengthening of RC beams using TRC with three simply supported small-scale RC beams under 4-point bending at a total span of 2.0 m and a shear span of 0.8 m. All specimens were monotonically loaded at a displacement rate of 1 mm/min till failure.

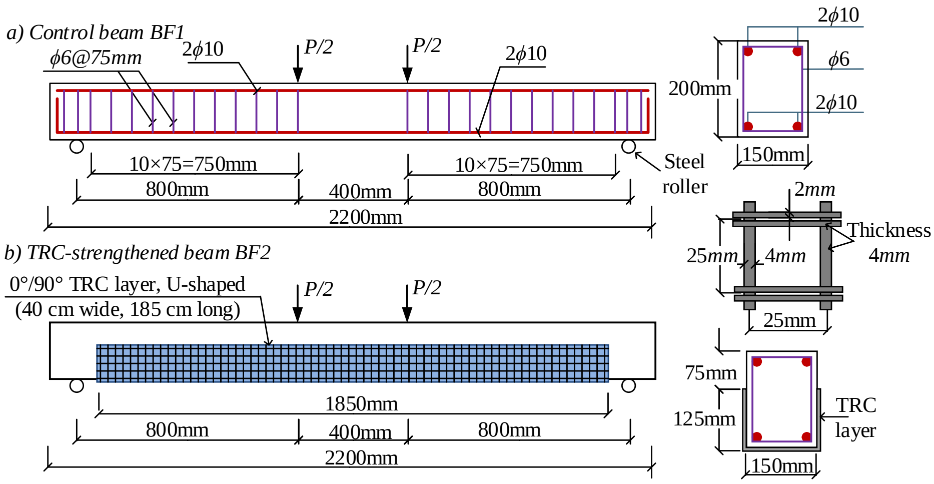


Figure 2. *Details of beam specimens [2]*

The beams were reinforced with 2∏10 longitudinal steel bars on each side (top and bottom), at a cover of 25mm. The shear reinforcement comprised of ∏6 steel bar stirrups at a small spacing of 75mm, to ensure that failure would be controlled by flexural yielding. Two beams (named BF1) were used as control specimens, which were intentionally designed to be under-reinforced with low reinforcement ratio so as to reveal the effectiveness of TRC in enhancing the flexural capacity. A RC beam (named BF2) was externally strengthened by TRC layer using fine-grained concrete and 10 strengthening layers of textile. The external layer is U-shape with 40cm wide and 185 cm long. Details of test beams are displayed in Figure 2.

III. FINITE ELEMENT MODEL

3.1. General

An appropriate three-dimensional (3D) model was formulated and implemented using the commercial FE program ABAQUS 6.10-1 for the purpose of FE validation. Due to symmetry of geometry and loading conditions, only one half of the strengthened beam is modeled as shown in Figure 3. The numerical analysis was performed to predict not only the ultimate capacity, but also the mechanical behavior of the structure.

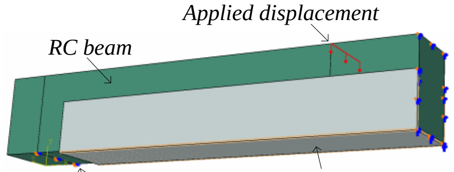


Figure 3. *FE model of RC beam strengthened with TRC layer*

3.2. Finite element type and mesh

The element type used for the numerical discretization in the 3D concrete parts, investigated in this work, is the C3D8R element from the Abaqus 6.10-1 library (Simulia et al., 2009). The C3D8R-element is an 8-node linear, reduced integration, 3D solid element with hour-glass enhanced.

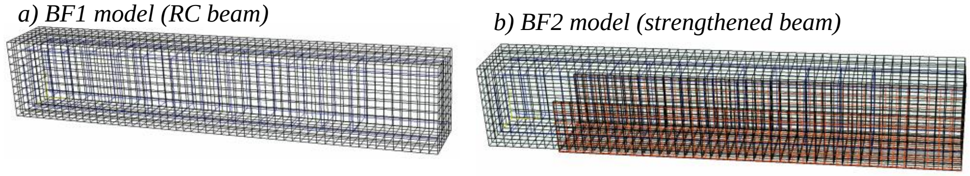


Figure 4. *Mesh for ABAQUS models*

The reinforcement bars and textile can be modeled using solid, beam or truss elements. The use of solid elements is computationally expensive and therefore not chosen. Because the reinforcing bars and the textile do not provide a very high bending stiffness, the T3D2 (3-noded quadratic 2-D) truss elements are used. The reinforcement is modeled with the wire-option in Abaqus. The wire is embedded into the solid concrete parts using the constraints-option, which its contact with the concrete is assumed to be perfectly bonded. The wires only add stiffness to the host elements in which they are located. The thickness of the wire is not geometrically modeled; however a cross-sectional area is specified as input.

The mesh was subsequently generated for the model, as can be seen in Figure 4. In order to achieve the reliable results, the fine mesh was generally used. The overall mesh size was 20 mm while the smallest was about 10mm. Reasonable convergence was achieved with such a mesh size, and refinement of the mesh was studied only up to the point where the change in the mesh size did not have an impact on the results.

3.3. Material

3.3.1 Steel

As regards the steel bars, a 'simple' elasto-plastic law was occupied, as shown in Figure 5-a. The curve is fully defined by the Young's modulus $E_s = 200Gpa$, which is a rather standard value for reinforcement steel, and the tensile yield strength of f_y. No limit on the value of the total strain is specified. The model for both compression and tension is assumed to be identical.

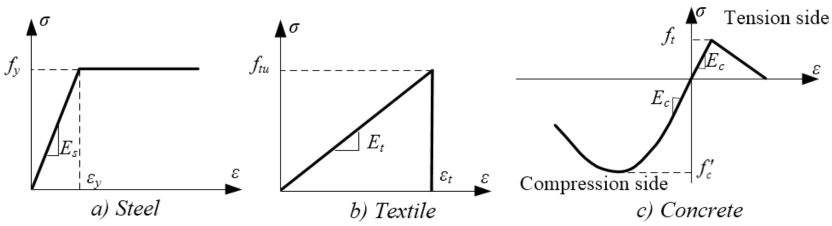


Figure 5. *The stress-strain relationship for the steel, textile, and concrete materials*

3.3.2 Textile

The material behaviour of single textile fiber can be appropriately described with a linear elastic material. Tensile failure of textile in the fiber direction is controlled by the fiber strength. As can be seen from Figure 5-b, the textile model was captured the response of elastic-brittle materials and it showed that there is no appreciable plastic deformation before failure. The stress is linear up to the tensile strength, and do not exhibit the yielding behavior. After reaching the tensile strength, the stress drops sharply to zero, representing the fracture of textile.

Table 1. *Steel and textile parameters [2]*

Steel				Textile			
E_s	υ_s	f_y	ε_y	E_t	υ_t	f_{tu}	ε_t
200 GPa	0.3	578 Mpa	0,00289	31940 MPa	0,22	623 Mpa	0,0195

3.3.3 Concrete

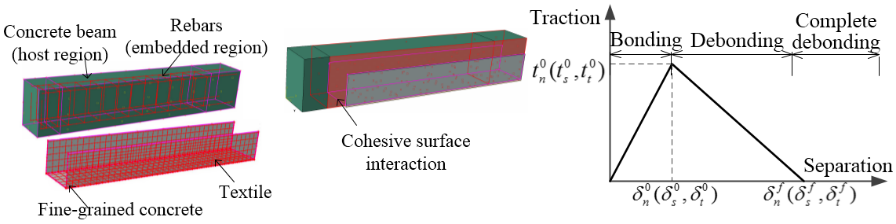
The Concrete Damaged Plasticity material model, abbreviated CDP, was adopted to model the inelastic stress-strain relation in the compressive and tensile regions of the normal concrete and fine-grained concrete (Figure 5-c). The parameters that define the concrete model are concrete compressive strength (f'_c), concrete tensile strength (f_t), elastic modulus (E_c), and poisson ratio (λ). In the CDP model, five parameters control the evolution and the shape of the yield surface and the flow potential. The default values of these papameters are taken as recommendation of CDP model in ABAQUS user's manual [3]. These material properties have been assigned in CDP model are summarized in Table 2.

Table 2. *The values of the parameters used in CDP model for concrete*

Concrete type	f'_c (Mpa)	f_t (Mpa)	E_c (Mpa)	υ	K_c	ϵ	$\frac{\sigma_{b0}}{\sigma_{c0}}$	ψ	μ
Normal	20	2.23	21150	0.2	2/3	0.1	1.16	30°	1E-5
Fine-grained	23.9	2.44	23120	0.2					

3.4 Interaction and constraint conditions

The strengthened beam was assembled to make the complete specimen model with the appropriate interaction and constraint between components. The steel bars and textile are embedded into the concrete by an embedded constraints, which implies infinite bond strength at the interface between the concrete and the reinforcement.



a) Embedded constraints *b) Surface interaction* *c) Cohesive behavior*

Figure 6. *Constraints and interaction*

Cohesive behavior is defined as part of the surface interaction properties in ABAQUS to model the interfacial behavior between concrete surface and TRC layer, including bonding and debonding phenomenon. The surface-base cohesive behavior feature models the delamination at interfaces directly in terms of traction versus separation, assumes initially linear elastic behavior followed by the initiation and evolution of damage, as can be seen in Figure 6. The elastic behavior of the element is written in terms of elastic constitutive matrix that relates the nominal stress to the nominal strain. The uncouple traction type as presented in Eq. (1) was used.

$$t = \begin{Bmatrix} t_n \\ t_s \\ t_t \end{Bmatrix} = \begin{bmatrix} K_{nn} & 0 & 0 \\ 0 & K_{ss} & 0 \\ 0 & 0 & K_{tt} \end{bmatrix} \begin{Bmatrix} \varepsilon_n \\ \varepsilon_s \\ \varepsilon_t \end{Bmatrix} \quad (1)$$

Where t - nominal stress vector; K - elastic constitutive stiffness matrix; ε - nominal strain vector [3].

The stiffness K_{nn} was taken as $0.1E_{cm}$, K_{ss} and K_{tt} were taken as $0.1G_{cm}$, where E_{cm} and G_{cm} are the elastic modulus and shear modulus of concrete. In this study, different values of the critical strains at failure were tried to obtain the values that gave the best agreement between the analysis and experiment results.

IV. VERIFICAION OF THE FE MODEL

In order to verify the FE model, the analysis results were compared with the experiment ones obtained by Hussein (et al. 2013). As shown in Figure 7, the comparison between FE results and experimental data show a good correlation for the deflection at maximum load and the softening curves for both the RC beam and the strengthened beam. The percentage difference of load bearing values between the numerical and experimental result is in the range from 1.3% to 1.6%. Load bearing increases up to 86% in comparison to the un-strengthened reference beams.

Table 3. *Load bearing of control beam and the strengthened beam*

Beam	Experimental	Numerical	Percentage Difference
Control beam BF1	42.82 kN	42.14 kN	1.6%
Strengthened beam BF2	77.45 kN	78.46 kN	1.3%

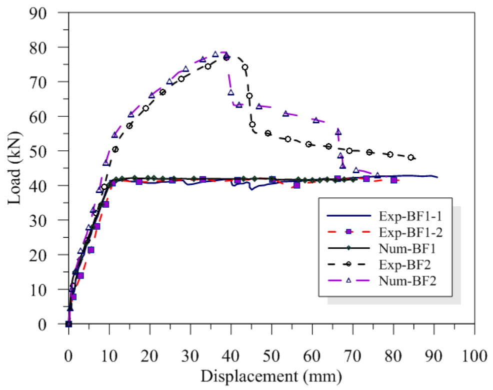


Figure 7. *Load-displacement curves of BF1 and BF2 beams*

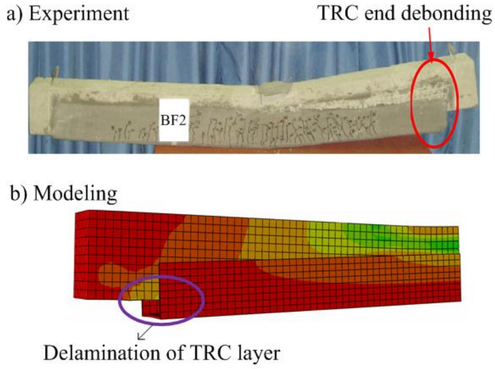


Figure 8. *Failure mode of strengthened beam BF2*

The failure mode of RC beam strengthened with TRC layer is brittle because of the delamination of the TRC layer from the concrete substrate, as can be seen in Figure 8. It shows the well agreement in failure mode to the experiment results. The debonding of the TRC layer led to a sudden drop in load with the response of the BF2 beam.

V. CONCLUSION

In this study, the reliable and efficient FE models for the analysis of flexural behavior of strengthened RC beam have been developed. It has been shown that the proposed model is capable of accurately predicting the load-carrying capacities and load-deflection relationships for the RC beam and the RC beam strengthened with TRC layer. The results are clearly demonstrated the accepted beneficial effects of TRC. Both the stiffness and strength of the strengthened beam can be substantially increased.

While the objectives of this research study are achieved, much more work is still needed to fully characterize the behavior of TRC strengthening RC beam. The main concern regarding flexural application is preventing the debonding from the composite to concrete. Future experimental research should concentrate on the bonding mechanisms.

Acknowledgement

This work was supported by the Vietnamese Ministry of Education and Training, under CTB 2014-04-03 and CTB 2014-04-04 projects.

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