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Numerical modelling of reinforced concrete beams repaired by TRC composites

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ABSTRACT

This study establishes a numerical model of reinforced concrete beams that are repaired using TRC composite materials. The resulting model, which is based on nonlinear behaviour laws for constitutive materials (concrete, steel and TRC composite), is compared on several scales with experimental results for nine reinforced concrete beams, of which five have been repaired by composite materials using several parameters, including the type of implementation (hand lay-up and gluing of plates).

The qualitative and quantitative agreement between the model and the results, as expressed in the load–deflection curves, validates the proposed model on a global scale.

At the local level (transverse and longitudinal deformation of the steel), the numerical–experimental comparison confirms the qualitative agreement, and the quantitative agreement is confirmed to a lesser extent in the case of the transverse reinforcement.

On a local scale, a comparison with the optical field measurements of the deformation of the TRC composites confirms the relevance of the proposed model in the case of in situ implementation (multi-cracking damage mechanisms) and its lack of relevance in the case of implementation by the gluing of composite plates (localisation of a macrocrack and pull-out damage).

1. Introduction

The repair of reinforced concrete structures, particularly with regard to shear force stress, comprises a rapidly growing market. The implementation of FRP composite by the use of carbon-fibre-reinforced polymer (CFRP), is a preferred solutions due to its mechanical efficiency and an implementation that is well suited to civil engineering projects.

This solution may prove the need for improvement as carbon fibres are ill-suited to the design of long-lasting structures due to their poor fire resistance and cost, which can be prohibitive. Alternative solutions, such as the use of composites that are based on a mineral matrix and textile-reinforced concrete (TRC), which are likely to provide solutions to the previously mentioned limitations, are needed.

Numerous studies have addressed the repair and/or strengthening of reinforced concrete beams by TRC [1–7] due to the potential advantages of these new generation composites.

The majority of these studies discuss experimental approaches; few studies focus on the simulation of the repair and/or strengthening of structural elements by TRC composites [8–10].

Two different approaches are employed to model TRC composite reinforcement. The first approach is a micromechanical approach in which the properties of the cement and the textile that are employed are explicitly introduced [8]. However, the introduction of a readjustment coefficient to consider the complex and heterogeneous behaviour of a TRC composite when the textile has not undergone a pre-impregnation process, which restricts the pertinence of this approach, may be required.

The second approach is a homogeneous macroscopic approach [9] in which the constitutive law of the TRC composite under traction, which is obtained by appropriate characterisation tests, is introduced without mentioning the properties of the cement and textile that in the TRC. This approach seems better suited to the specificities of TRC composite.

The main objective of this paper is to develop and validate a numerical model that requires few calculations and reproduces the global and local behaviours of reinforced concrete beams that are strengthened by TRC composites. Two distinct implementations (gluing of prefabricated TRC plates and hand lay-up) that

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are associated with different damage mechanisms are employed. A micromechanical approach was adopted for modelling the reinforced concrete beams. In the case of the TRC composite simulation, a homogeneous macroscopic approach, with interaction between the TRC composite and the concrete that is considered to be perfect, was chosen.

2. Experimental approach

2.1. Methodology

As the objective of this paper is concerned with numerical aspects, the treatment of the experimental aspects will be limited to a presentation of the main elements [6].

Nine reinforced concrete beams, which were designed to be undersized with respect to shear force, were fabricated and tested. The total length of the beams is 2.3 m with 2 m of working length. The cross-section is rectangular with dimensions of 0.15 m × 0.25 m.

The positioning of the transverse reinforcements is asymmetrical to locate the damage and failure on one side of the beam and reduce the instrumentation (Fig. 1).

A static and monotonous test—the four-point bending test—was force-controlled. The choice was made to exclusively focus on repair. The beams were damaged by the four-point bending test prior to repair. The damage was produced by loading the test bodies until one of the two transverse steel frames yielded after a strain of 2.7% was achieved.

To assess the influence of concrete strength on the contribution of the reinforcement, two sets of beams were implemented. The first set comprised five test bodies, and the second set consisted of four specimens.

Two TRC implementation modes were considered: the first mode is known as “hand lay-up in situ”, and the second mode involves of gluing prefabricated plates.

2.2. Implemented materials

2.2.1. Reinforced concrete beams

2.2.1.1. Concrete. A series of eleven beams have been tested. The specified concrete strengths at 28 days were 30 MPa (“R30” beams) and 40 MPa (“R40” beams).

The series of R30 beams were created in two different mixes. The first batch comprised three test bodies (including a reference beam), and the second batch consisted of four specimens (including a reference beam) for which the compressive resistance of the two batches of concrete at 28 days were 30.8 ± 2.5 MPa and 31.3 ± 3 MPa. The four beams, which were composed of R40 concrete (including two reference beams), were obtained from the same batch, which had a compressive strength of 42.4 ± 3 MPa at 28 days. The compressive strength of the concrete was evaluated in accordance with NF EN 12390-3, based on six test bodies per mix.

2.2.1.2. Steel. All reinforcements are composed of S500 high adhesion steel. The average yield stress of the steel, as indicated by ten direct tensile tests, is 570 ± 13 MPa, with a Young’s modulus of 210,000 ± 5750 MPa and a yield strain of 2.7 ± 0.04%.

2.2.2. Repair composites

2.2.2.1. Textile-reinforced concrete (TRC). A textile mortar composite that is specifically developed for this application was implemented. The composite consists of a matrix with a particle size less than 1 mm that is combined with warp-knitted reinforcement meshes; the weft is composed of AR glass fibre and the warp is composed of polyester (Fig. 2).

Three “average” thicknesses of reinforcement that are compatible with TRC upgrading (1.7 mm, 5 mm, and 10 mm) were utilised (thicknesses that are guaranteed to be regular as the process involves gluing prefabricated plates). These three thicknesses are associated with the same reinforcement ratio (4.36%), which only refers to the glass fibre and does not include the thickness of the polyester, whose primary role is to provide geometrical stability. We applied the constitutive law (10 mm thickness), which is obtained by a direct tensile test, as shown in Fig. 2.

2.3. Repair configurations of the damaged beams and implementation methods

Two different repair strategies were employed. The first strategy was the hand lay-up in situ method, in which the TRC composite is directly cast onto the substrate of the beam, which has been previously sandblasted. The second implementation method involves gluing sandblasted prefabricated TRC plates, which were constructed with the required dimensions, onto the sandblasted

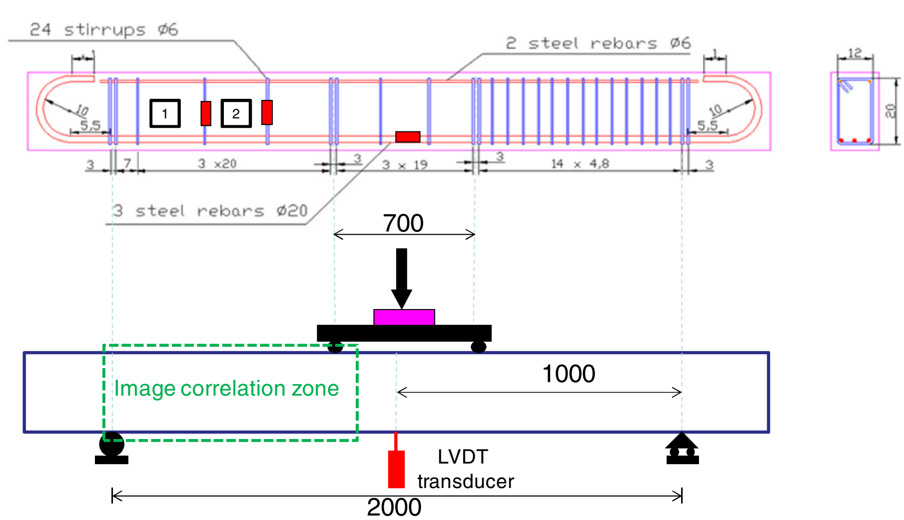

Fig. 1. Characteristics of the analyzed beams with the setup and sensors.