CICE2025 STUDENT BENCHMARK COMPETITION

Prediction of the behaviour at SLS and ULS of RC beams flexurally strengthened with NSM-CFRP laminates

Universidade do Minho

1. INTRODUCTION

A blind simulation competition (BSC) is being organized within the scope of the 12th International Conference on FRP Composites in Civil Engineering (CICE 2025).

Students are invited to participate for verifying the performance of the models used in the prediction of the behaviour at serviceability and ultimate limit state design conditions (SLS and ULS, respectively) of reinforced concrete (RC) beams flexurally strengthened with Carbon Fibre Reinforced Polymer (CFRP) laminates applied according to the Near Surface Mounted (NSM) technique. The predictions can be based on numerical simulations or analytical formulations (new or existing ones, such as design guidelines).

After reception of participant predictions, two twin RC beams flexurally strengthened with CFRP laminates will be tested up to their failure under a four-point loading configuration. The experimental tests will be carried out in the laboratory of Minho University on 23 of June 2025, in order to obtain the experimental response and to compare it with the results of the predictions.

The bases of the benchmark are detailed in the following sections.

2. OBJECTIVE

The objective of the benchmark is to verify the performance of numerical/analytical approaches for the design of RC beams flexurally strengthened with CFRP laminates applied according to the NSM technique, including the SLS and ULS verifications. For that purpose, the response up to failure of twin T cross-section beams subjected to bending will be tested.

For the beam's deflection at mid-span section corresponding to SLS conditions ($u^{SLS} = L/250 = 18\ mm$, where $L = 4500$ mm is the distance between supports), the objective is to estimate the load level, and predict the tensile strain in the CFRP and longitudinal tensile steel reinforcement, and the concrete compressive strain (top surface of the cross section). Another objective is the evaluation of the maximum crack width and the average crack spacing in the region between the applied load. Regarding the ULS verifications, the objective is to estimate the beam's load carrying capacity, and the corresponding deflection and strain in the CFRP at the beams' mid-span section.

3. GEOMETRY OF THE BEAMS

Figure 1 shows a sketch of the geometry of the beams under evaluation. It consists of a T cross-section beam reinforced with 2 longitudinal bars of 20 mm diameter in the bottom of the web, and 6 longitudinal bars of 10 mm diameter in the flange (4 in the top and 2 in the bottom). Shear stirrups of 8 mm diameter will be disposed in a percentage capable of avoiding shear failure in the beam flexurally strengthened with 3 CFRP laminates with 1.4 mm x 20 mm of cross section, as represented in Figure 1. The flexural and shear steel reinforcements are composed of bars of ribbed surface. A concrete cover thickness of 25 mm is adopted. Four-point bending is applied, as indicated in Figure 1.

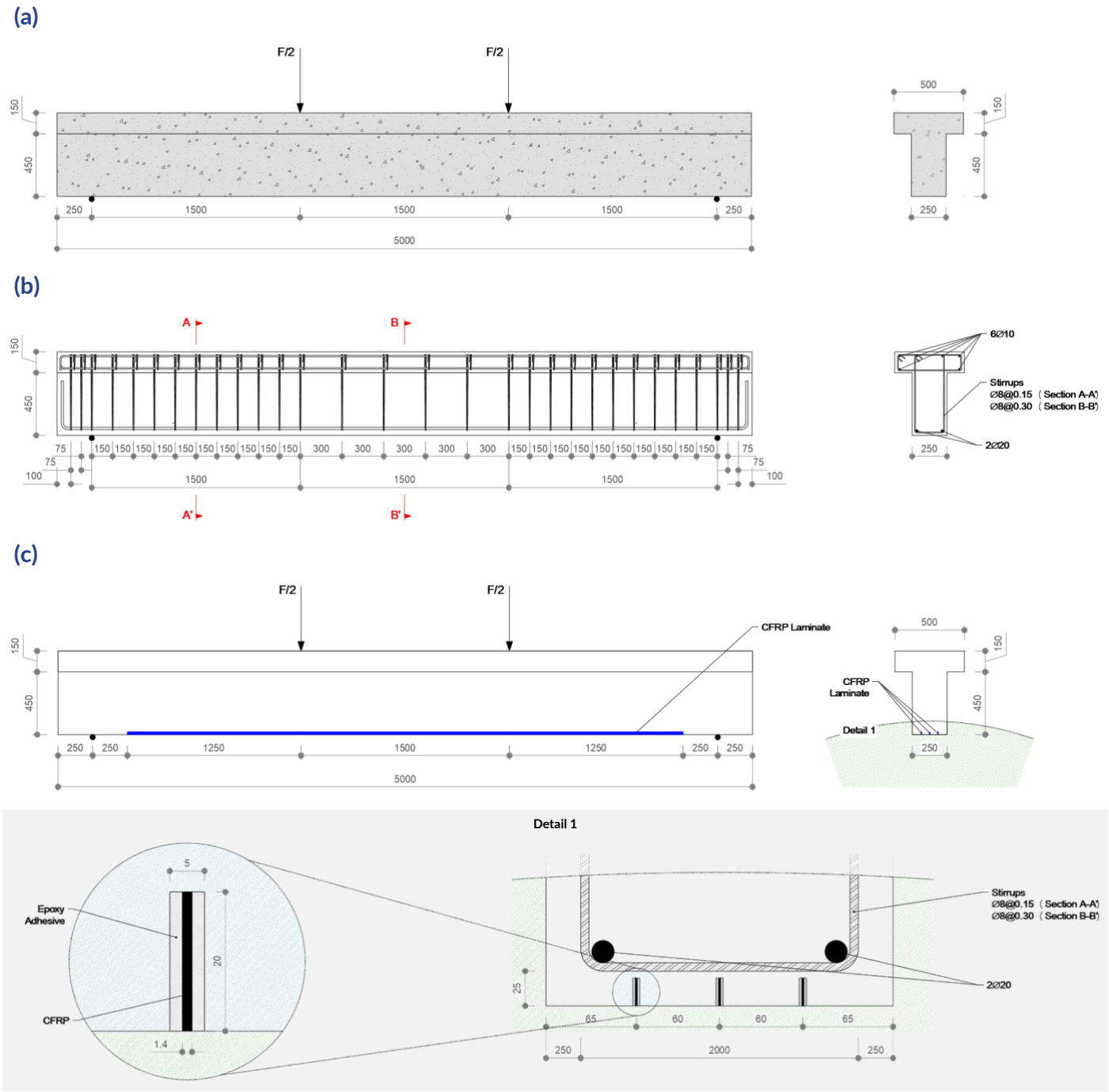

Figure 1. (a) Lateral view and cross section; (b) Longitudinal and transversal steel reinforcements; (c) Flexural strengthening with 3 NSM CFRP laminates (dimensions in mm).

4. MATERIALS

Properties of the materials will be available to the participants up to 31 January 2025 in the webpage of CICE 2025 (https://cice2025.org); by requesting from the secretariat of CICE 2025 (cice@cice2025.org).

Concrete, steel reinforcements, CFRP and epoxy adhesive properties will be determined from standard tests. The average values and COV will be provided.

5. TEST PROCEDURE

Two twin beams will be subjected to four-point loading under displacement control of $50\ \mu m/s$ at the midspan section, until failure. During the tests, the total applied load (F_t) will be measured with a load cell attached to the actuator, the beam's deflection will be recorded in the loaded sections and in the beam's mid span ($u_i, i = 1\ to\ 3$) using displacement transducers (LVDTs), and the strains in the CFRP (ε_f), longitudinal tensile steel reinforcement (ε_s) and concrete top surface (ε_c) in the beam's mid span will be registered using electric strain gauges (Figure 2). The LVDTs will be supported on a Japanese yoke system to exclude parasitic values from the displacements recorded by the LVDTs that measure the deflections. By using the Digital Image Correlation (DIC) technique, the maximum crack width (w_{max}) and the average crack spacing ($\bar{s}_{cr}$) will be determined at the level of the longitudinal tensile steel reinforcement, in the region between applied loads. The load level, strains, maximum crack width and average crack spacing will be determined at the deflection corresponding to SLS ($u^{SLS} = 18\ mm$): F_t^{SLS}, ε_f^{SLS}, ε_s^{SLS}, ε_c^{SLS}, w_{max}^{SLS} and $\bar{s}_{cr}^{SLS}$. The maximum load (F_t^{ULS}), corresponding deflection (u^{ULS}) and strain in the CFRP laminates (ε_f^{ULS}) at the beam's midspan will also be determined.

The results to be provided are the average of the two experimental tests.

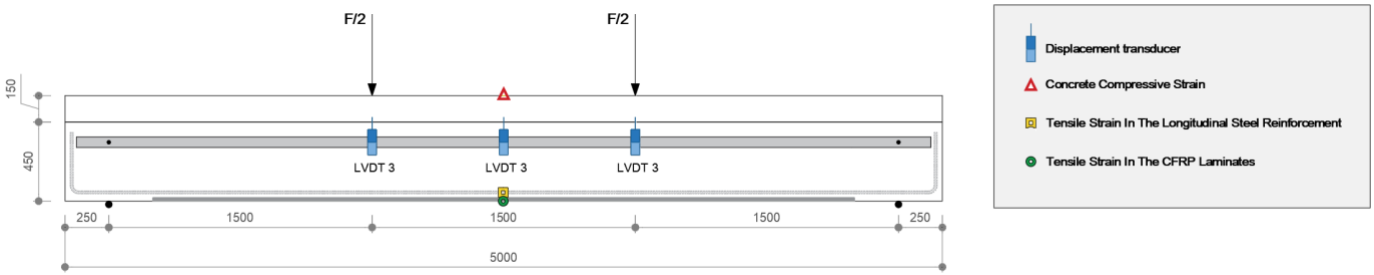

Figure 2. Sketch of the measurements of deflection and strain of the beam (dimensions in mm).

6. REPORT FROM PARTICIPANTS

Participants should provide the following information:

a) A document limited to four pages, in .pdf format, in which the relevant characteristics of the used model are described, namely, the FEM-based model (in case of FEM-based numerical simulations) or the formulation for SLS and ULS design verifications (in case of analytical formulations). References can be added where detailed information about the formulation are provided. The document should be written using Times New Roman font, size 11, with external margins of 2.5 cm and single-spaced lines.

b) The last page of the report must include the predictions of the following parameters: F_t^{SLS} (kN), ε_f^{SLS} (‰), ε_s^{SLS} (‰), ε_c^{SLS} (‰), w_{max}^{SLS} (mm), $\bar{s}_{cr}^{SLS}$ (mm), F_t^{ULS} (kN), u^{ULS} (mm), and ε_f^{ULS} (‰).

This information should be sent up to 23h:59 (CET time) of 15th June 2025 to the following e-mail address: cice@cice2025.org.

7. CRITERIA FOR SELECTING THE BEST PREDICTION

The error for each considered variable is determined as:

$$err_V = \frac{|V_{exp} - V_{the}|}{V_{exp}} \quad (1)$$

where V_{exp} and V_{the} are the values of the variable registered experimentally and predicted with the theoretical model, respectively. An equation of type (1) will be considered for the variables: F_t^{SLS}, ε_f^{SLS} , ε_s^{SLS}, ε_c^{SLS}, w_{max}^{SLS}, $\bar{s}_{cr}^{SLS}$, F_t^{ULS}, u^{ULS}, and ε_f^{ULS}.

The score of each participant will be calculated according to the following expression:

$$Score = 0.1 \cdot err_{F_t^{SLS}} + 0.1 \cdot err_{\varepsilon_f^{SLS}} + 0.1 \cdot err_{\varepsilon_s^{SLS}} + 0.1 \cdot err_{\varepsilon_c^{SLS}} + 0.1 \cdot err_{w_{max}^{SLS}} + 0.1 \cdot err_{\bar{s}_{cr}^{SLS}} + 0.1 \cdot err_{F_t^{ULS}} + 0.1 \cdot err_{u^{ULS}} + 0.2 \cdot err_{\varepsilon_f^{ULS}} \quad (2)$$

The smaller the score the better is the prediction. The quality of the report, evaluated by a jury nominated by the CICE2025 organization, will be considered in case of tied participants.

8. TEAMS

A participant team must include, at least, one PhD student registered in a Civil Engineering program (a proof of this registration should be provided with the report), and a tutor (registered in the CICE2025). More PhD students and/or MSc students can also participate in the team, but the maximum number of members per team is 4 (four), excluding the tutor. The members of a team can have different affiliations.

9. PRIZES AND AWARDS

The competition results, winners and a summary of the proposals submitted will be published in the Newsletter of IIFC. This publication will give visibility and emphasize the most creative and innovative aspects of the models proposed by the participating teams to predict the response of the beams, as well as the analysis of the models adopted.

The proposals of the participants will be grouped in two sets: 1) one where the simulations were performed with FEM-based approaches; 2) the other where analytical formulations (existing or new ones) or guidelines (available in code standards) were utilized.

The team with the best score in each of these two groups will win 750 EUR. This will include a two-year IIFC membership fee for each team member.

Honourable mention certificates will be granted by the Organizing Committee to the participating teams that, although not winning, are selected for having submitted outstanding proposals considering the main evaluation parameters referred earlier.

10. DEADLINES

1) Submission of the registration form by email (cice@cice2025.org) up to 24 January 2025.

2) Information about the material properties will be provided up to 31 January 2025.

3) Participants must submit their report up to 23h:59 of 15 June 2025 CET time.

4) Experiments will be conducted on the 23 June 2025.

5) Conclusions about processing of results will be communicated in the closing ceremony of the CICE 2025.

11. JURY

The Jury will be composed by the following members:

+ **Joaquim Barros**, University of Minho, *Portugal*
+ **Emmanuel Ferrier**, Université Lyon I, *France*
+ **Kent Harries**, University of Pittsburgh, *USA*
+ **Scott T. Smith**, University of Adelaide, *Australia*

30 October 2024

Joaquim A. O. Barros

REGISTRATION FORM

Team:

Name of the team:

Acronym (10 characters max.):

Tutor (PhD member registered in the CICE2025)

Name:

Affiliation:

e-mail:

Participants

1st member: Name / Affiliation / Type of Student (MSc or PhD) / E-mail 1

2nd member: Name / Affiliation / Type of Student (MSc or PhD) / E-mail 2

3rd member: Name / Affiliation / Type of Student (MSc or PhD) / E-mail 3

4th member: Name / Affiliation / Type of Student (MSc or PhD) / E-mail 4