BENCHMARK ANNOUNCEMENT

Simulation of slabs reinforced with conventional flexural reinforcement and fibres subjected to punching loading configuration

1. Introduction

The 3rd Blind Simulation Competition (BSC) is being organized within the scope of the *fib* Working Group WP 2.4.1 *Modelling of Fibre Reinforced Concrete Structures.*

Researchers, engineers and designers are invited to participate in order to verify the performance of the numerical models used in the simulation of the behaviour of fibre reinforced concrete (FRC) structures.

The purpose of the benchmark is to predict some important behavioural aspects of a slab made by steel fibre reinforced concrete (SFRC) and flexurally reinforced with conventional longitudinal bars (R/SFRC). This prototype aims to represent a region over a column of an elevated slab or over a pile of a slab supported on piles made by SFRC and including conventional flexural reinforcement in the alignment of columns/piles. The fibres aim to provide punching-shear reinforcement. The two twin prototypes to be tested will be subjected to punching loading configuration.

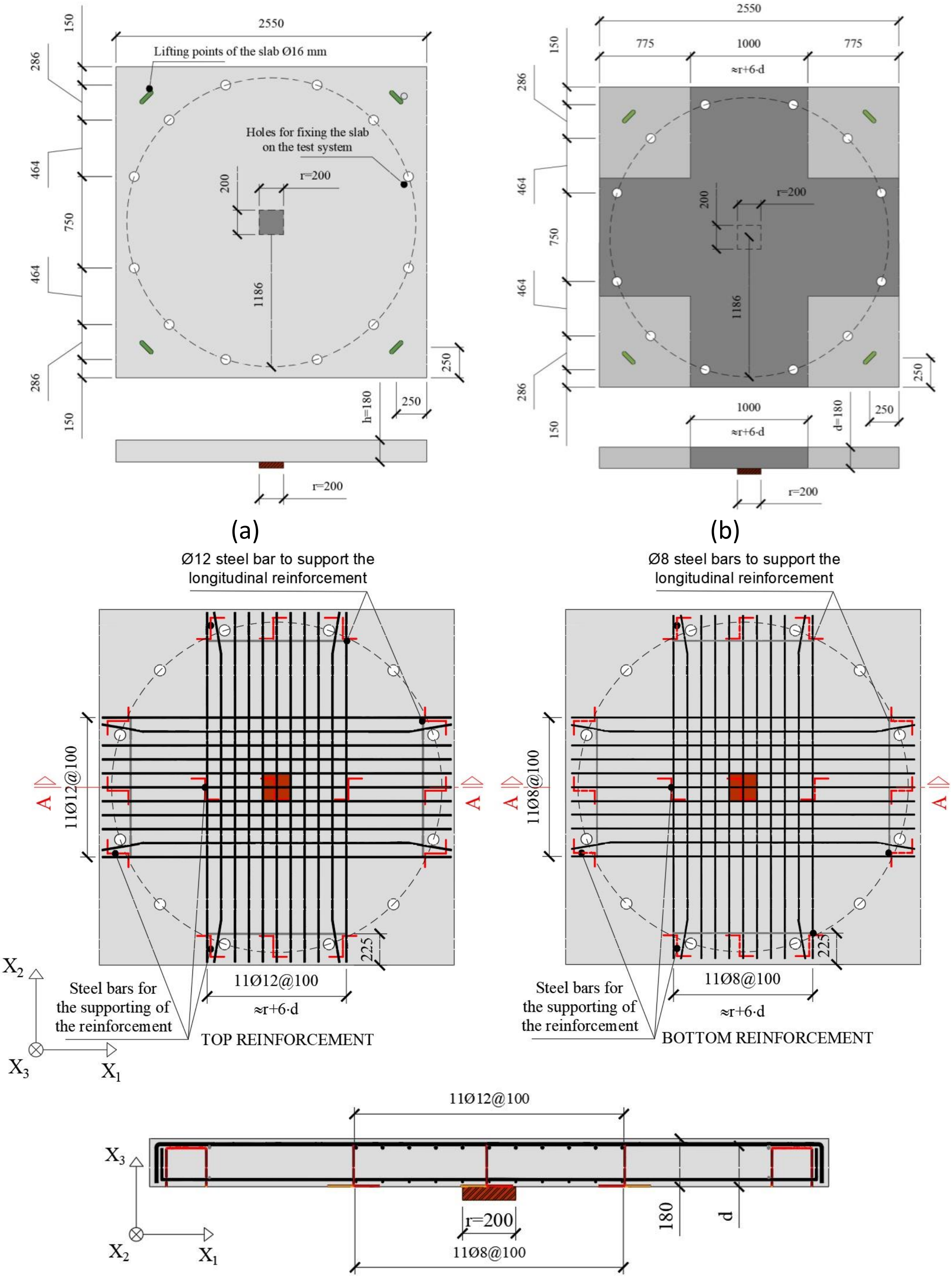
After reception of participant report's predictions, two R/SFRC slab prototypes will be tested up to their failure in the laboratory of the Structural Division of the Department of Civil Engineering of Minho University (LEST), between 19/06/2023 and 30/06/2023, in order to obtain the experimental results and compare them with the numerical predictions.

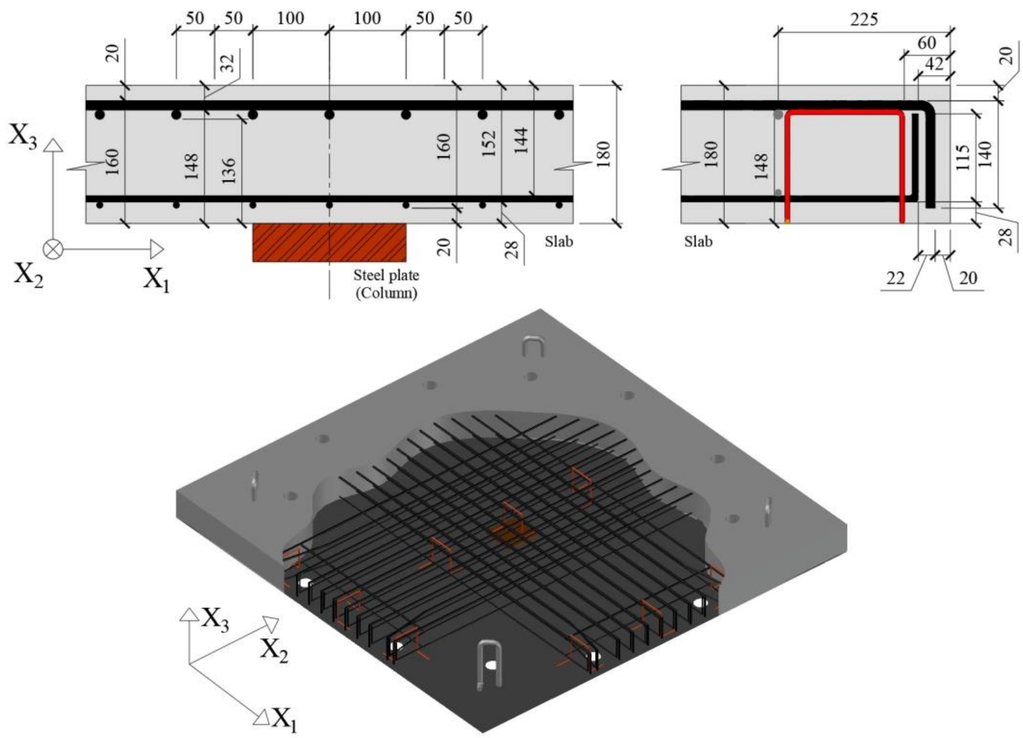
2. Objectives

The purpose of this BSC is to verify the capacity of existing FEM-based models to estimate, mainly, the force-deflection, deflection profile, and strain levels in conventional flexural reinforcement and in concrete of critical regions of R/SFRC slab under punching loading conditions. The predictive capacity in terms of crack pattern and failure mode will be also an objective.

3. Geometry of the specimen

Figure 1 shows the plant and cross section geometry of the prototype, reinforcement details, load and support conditions of the type of prototype to be tested. A concrete cover thickness of 20 mm is adopted for the most external reinforcement (top and bottom). The prototype consists of a slab flexurally reinforced with steel bars at the bottom and at the top, representing the flexural reinforcement in the alignment of columns/piles of R/SFRC slabs, a represented in Figure 2.


2550
Lifting points of the slab Ø16 mm
Holes for fixing the slab on the test system
r=200
200
1186
150
286
464
750
250
h=180
775
1000
≈r+6·d
d=180
(a)
(b)
Ø12 steel bar to support the longitudinal reinforcement
Ø8 steel bars to support the longitudinal reinforcement
11Ø12@100
11Ø8@100
225
A
Steel bars for the supporting of the reinforcement
TOP REINFORCEMENT
BOTTOM REINFORCEMENT
X2
X3
X1
180
d



(c)

Figure 1. (a) Geometry of the R/SFRC slab: cross-section (b) localization of the conventional reinforcement (c) details of the conventional reinforcement (dimensions in mm).

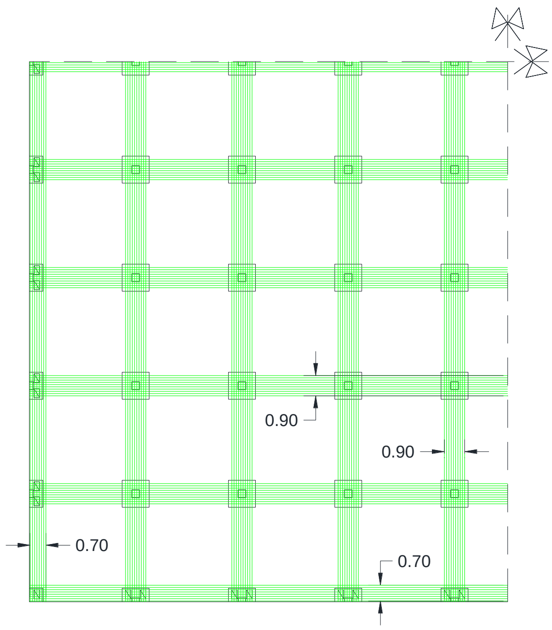
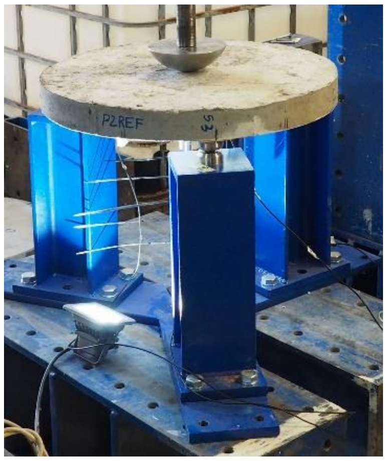


Figure 2. (a) R/SFRC slab supported on piles with the representation of the flexural reinforcement in the alignment of the piles.

4. Materials

Properties of the materials will be available to the participants up to 30/03/2023 in the webpage of *fib* organization or by request by contacting: beatriz.sanz@upm.es.

The mix composition of the SFRC will be provided (including the geometry and tensile strength of the fibres according to the supplier), as well as its slump. SFRC properties will be determined from standard tests, namely: four-cylinder specimens will be tested for the evaluation of the compressive strength and Young's modulus (EN 12390-3:2019, EN 12390-13:2014, respectively), and the average and CoV values will be provided; nine three-point notched beam bending tests (Figure 3a) will be executed according to the recommendations of EN 14651:2007 for the evaluation of the load versus the crack mouth opening displacement (CMOD) relationship, from which the residual flexural tensile strength parameters (f_{Ri}, i=1 to 4) will be determined, and the average ad CoV values will be provided; six round panel tests (RPT) will be also tested according to the ASTM C1550-05 recommendations (Figure 3b), by recording the force-deflection and the crack patterns. The tensile stress-strain relationship of the conventional reinforcements (average of five tests per each type of steel bar) will be also provided (EN ISO 6892-1:2016).



(a) (b)

Figure 3. Test set up of (a) Three-point notched beam bending test, and (b) round panel test.

5. Test procedure

Two slab prototypes will be subjected to the load configuration represented in Figure 4, being the test performed under displacement control at 50μm/s in the piston of the actuator, until their failure or up to a maximum deflection of 50mm. During the tests, deflection will be measured in the points indicated in Figure 5, and strains in the flexural reinforcements and in the concrete will be recorded in electric strain gauges disposed as shown in Figure 6. The displacement transducers (LVDTs) for measuring the slab's deflection will be supported on an external system in order to exclude parasitic values from the measurements. To monitor the applied load, a load cell will be installed in the extremity of the piston of the actuator. The maximum crack width will be determined through Digital Image Correlation (DIC) technique in the region represented in Figure 5. The results to be provided are the average of the two experimental tests.

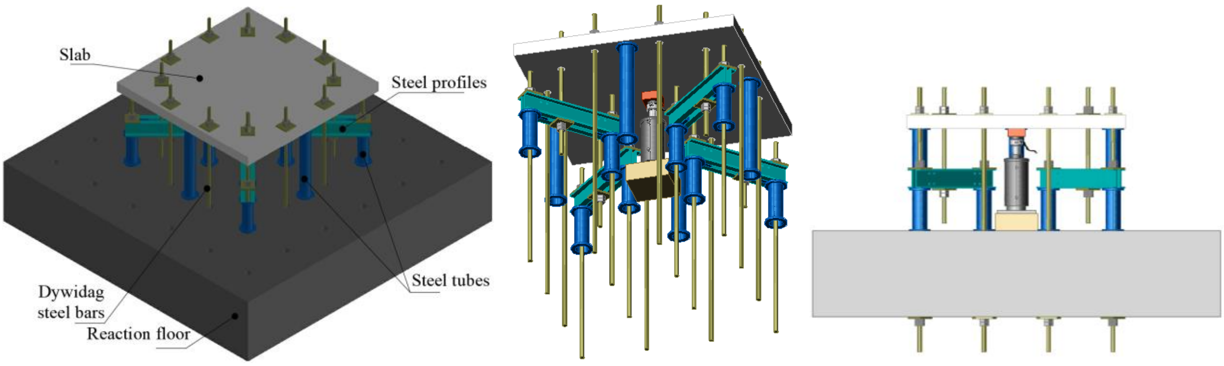


Figure 4. Test setup of the R/SFRC slab prototypes.

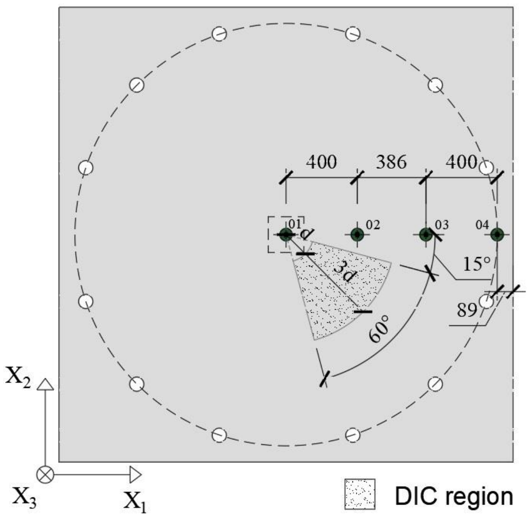
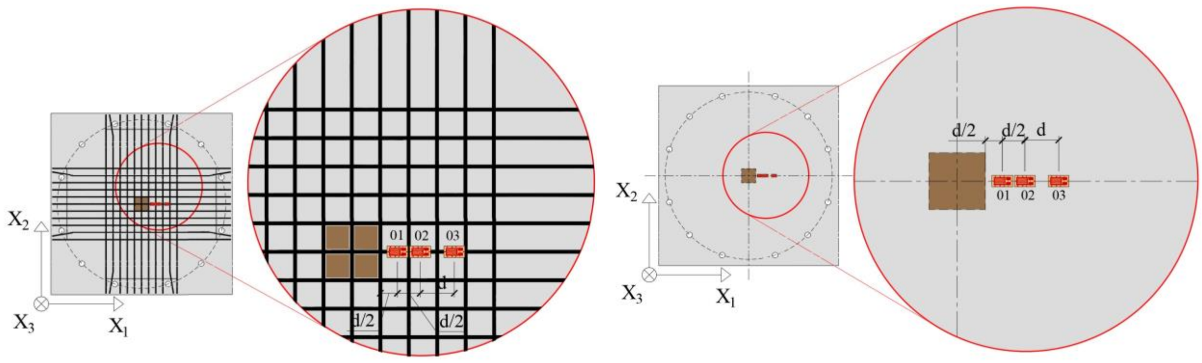


Figure 5. Points for measuring the deflections and zone for registering the average crack width (dimensions in mm).



(a) (b)

Figure 6. Locations for measuring the strains in the (a) conventional reinforcements (top layer), and (b) in the R/SFRC slab's bottom surface.

6. Report from participants

Participants should provide the following information:

a) A document limited to four pages describing the relevant characteristics of the used model, namely: type of constitutive model for simulating the nonlinear behaviour of the constituent materials; values of the model parameters; type of finite elements and mesh refinement; integration rules; other information the participants assume important for the description of the adopted model. References can be added, where detailed information about the model is provided. Text should be written in Times New Roman, size 11, with external margins of 2.5cm and single-spaced lines.

b) A .xls file with the following information (respecting the template available for this purpose): 1st to 4th columns: displacements in the points 1 to 4 (upward displacement is considered positive, u_{1-4}); 5th column: applied load (F); 6th column: average strain in the flexural reinforcement (average of the values recorded in the three locations where the strain gauges are applied, $\bar{\varepsilon}_s$); 7th column: strain in the SFRC (average of the values recorded in the three locations where the strain gauges are applied, $\bar{\varepsilon}_c$); 8th column: maximum crack width in the slab's top surface in the region indicated in Figure 5 ($w_{\max}$). This column organization should be observed in order to facilitate the processing of the results. Files that do not fulfil this requirement may be excluded from the analysis. Load, deflections, average strains in reinforcement and SFRC, and maximum crack width obtained every 0.1mm of central displacement (point 1) must be provided. Thus, the first column, corresponding to the displacement in point 1, will contain an arithmetic progression with a difference of 0.1mm between the terms. The results should be provided only up to peak load; the data after the maximum numerical load will not be processed.

c) An image file (jpeg or pdf) of the crack pattern in the top surface obtained at peak load.

This information should be sent up to 23h:59 (Spain time) of 16/06/2023 to the following e-mail address: beatriz.sanz@upm.es

7. Criteria for selecting the best model

From the data contained in an xls file, the following curves will be analysed: 1) the applied load versus the displacement in points 1 to 4 (F - u_{1-4}); 2) average tensile strain in the flexural reinforcement versus displacement in point 1 ($\bar{\varepsilon}_s$ - u_1); 3) average compressive strain in the SFRC versus displacement in point 1 ($\bar{\varepsilon}_c$ - u_1); 4) maximum crack width versus displacement in point 1 ($w_{\max}$ - u_1).

The normalized root mean square of the numerical curves with respect to those of experiments (average registered in the two slab prototypes) will be evaluated according to the following formula:

$$NRMS_P = \frac{1}{P_{exp}^{max}} \sqrt{\frac{\sum_{\kappa}(P_{exp}^{\kappa} - P_{num}^{\kappa})^2}{n}}$$

where *P* is the considered measure (load, average tensile strain, average compressive strain or maximum crack width), κ corresponds to the records, P_{exp}^{κ} is the experimental value of the record κ, P_{num}^{κ} the numerical value of the record κ, *n* is the number of scan readings, and P_{exp}^{max} is the maximum of the experimental record. Note that the numerical curves should include only results up to the numerical peak load; if additional data is included after the peak, it will be ignored, and the last record will be considered that corresponding to the displacement of the maximum numerical load, u_{num}^{Fmax}. By defining the displacement corresponding to the experimental peak load as u_{exp}^{Fmax}, the following cases will be considered, as illustrated in Figure 7: a) if the final displacement of the numerical curve is smaller than u_{exp}^{Fmax}, the numerical curve will be completed with zero values from u_{num}^{Fmax} up to u_{exp}^{Fmax} and compared to the experimental curve up to u_{exp}^{Fmax}; (b) if the final displacement of the numerical curve u_{num}^{Fmax} is greater than u_{exp}^{Fmax}, the experimental curve will be completed with zero values from u_{exp}^{Fmax} up to u_{num}^{Fmax} and compared to the numerical curve up to u_{num}^{Fmax}.

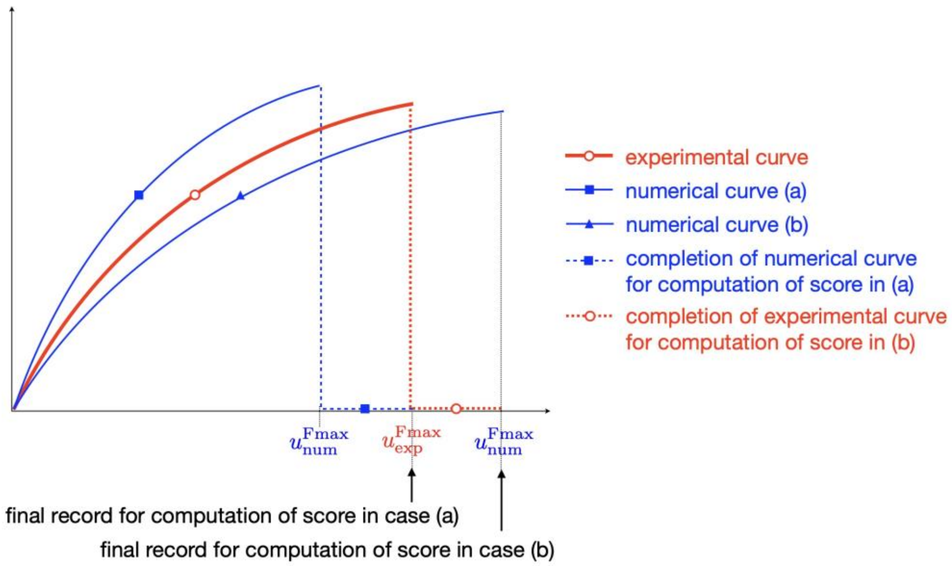


Figure 7. Example of a numerical curve with a displacement corresponding to peak load u_{num}^{Fmax} (a) smaller and (b) greater than that of the experimental curve u_{exp}^{Fmax}, and completion of the curves for the computation of score.

This will be assessed in order to determine the best model in reproducing the experimental results according to the following percentage: 40% for the F - u_{1-4} , 20% for the $\bar{\varepsilon}_s$ - u_1 , 20% for the $\bar{\varepsilon}_c$ - u_1 , 20% for the $w_{\max}$ - u_1 .

Note that the crack pattern will not be considered in the evaluation of the models, but the quality of the crack pattern prediction will be considered in case of tied participants.

8. Deadlines

1) Information about the material properties will be provided up to 30/03/2023.
2) Participant must submit their report up to 23h:59 of 16/06/2023 (Spain time).
3) Experiments will be conducted from 19/06/2023 to 30/06/2023.
4) Conclusions about processing of results will be communicated by the end of 31/07/2023.

9. References

ASTM C1550-05. Standard test method for flexural toughness of fiber reinforced concrete (using centrally loaded round panel), West Conshohocken, PA, USA, ASTM International, 2005.
EN 12390–3:2019. Testing hardened concrete-Part 3: Compressive strength of test specimens, 2019.
EN 12390–13:2014. Testing hardened concrete-Part 13: Determination of secant modulus of elasticity in compression, 2014.
EN ISO 6892-1:2016. Metallic materials-Tensile testing - Part 1: Method of test at room temperature, 2016.

JOAQUIM ANTÓNIO OLIVEIRA DE BARROS
Assinado de forma digital por JOAQUIM ANTÓNIO OLIVEIRA DE BARROS

Joaquim Barros (Convener)

SANZ MERINO BEATRIZ - 50123689L
Firmado digitalmente por SANZ MERINO BEATRIZ - 50123689L
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Beatriz Sanz (Deputy convener)