RESULTS OF 2ND BLIND SIMULATION COMPETITION

Simulation of two continuous spans slab strip with conventional reinforcement and fibres: service limit states assessment

1. Introduction

This document presents the results of the 2nd Blind Simulation Competition carried out within the scope of the *fib* Working Part WP 2.4.1 *Modelling of Fibre Reinforced Concrete Structures*. The object of the benchmark is to predict the behaviour of a slab strip made by steel fibre-reinforced concrete (SFRC) and reinforced with conventional longitudinal bars positioned in the bottom region and over the intermediate support.

This benchmark and the rules of the competition were announced in September 2021. Information about the properties of the materials at the age of 19 days was communicated at 17th of November 2021. A total of eighteen teams of participants submitted the results of the numerical simulations, before the 31st of December of 2021. Experiments were conducted on two twin slabs for the appraisal of the predictive performance of the submitted simulation proposals on the 26th and 28th of January 2022. The experiments were transmitted in real time through a YouTube channel (the videos can be found in the following links: https://www.youtube.com/watch?v=aD3JolKoTCQ, https://www.youtube.com/watch?v=6jnIjESyK0M). In the weeks following to that, the experimental results and those of the simulations have been analysed.

The following sections present the name of the participants, the experimental results, the numerical results and the performance of the numerical predictions.

2. Name of participants

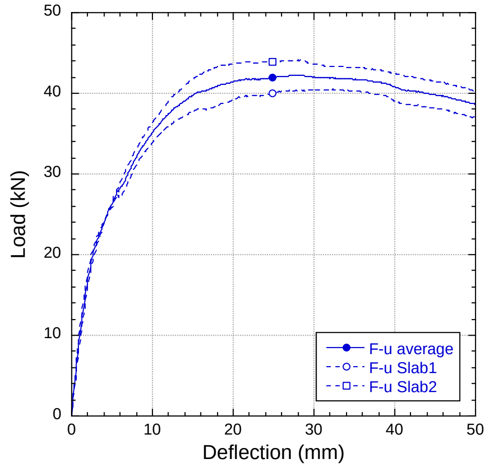
There were eighteen teams of participants with a total of 48 persons involved, nineteen institutions from fourteen different countries including Brazil, Canada, China, Finland, Germany, Hungary, Iran, Italy, Portugal, Spain, Switzerland, The Czech Republic, The Netherlands and U.K, six companies of structural design and development of software based on the finite element method, and thirteen universities. Table 1 includes a list of the participants and their affiliation, sorted by alphabetical order.

Table 1. List of participants and affiliation, sorted by alphabetical order

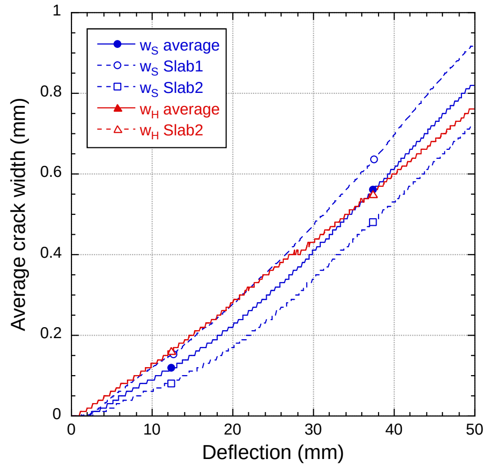
Name of the participants	Affiliation(s)
Ab van den Bos[1], Saurabh Dhanmeher[1]	[1]DIANA FEA / Consulting, Delft, The Netherlands
Alexander Kagermanov[1]	[1]Eastern University of Applied Science (OST), Switzerland
Carlos Alberto Benedetty Torres[1], Ingrid Rocío Irreño Palomo[1], Pablo Augusto Krahl[1], Luiz Carlos de Almeida[1], Leandro Mouta Trautwein[1]	[1]Structural Modeling and Monitoring Laboratory (LabMEM), University of Campinas, São Paulo, Brazil
Carlos Azua-Gonzalez[1,2], Rosen Tenchev[1], Mohammad Asghar[1], Ahad Kolahi[1], Paul Lyons[1], Louis Barber[2], Iulia Mihai[2], Tony Jefferson[2]	[1]Finite Element Analysis Ltd, London, UK [2]Cardiff University, Wales, UK
Chandan Gowda[1], Chris Hendy[1], Wong Pak-Long[1]	[1]Atkins, Woodcote Grove Office, Epsom, U.K.
Dan-Dan Wang[1,2], Xiao-Fan Yu[1,2], Shao-Bo Kang[1]	[1]Key Laboratory of New Technology for Construction of Cities in Mountain Area, Chongqing University, Ministry of Education, China [2]School of Civil Engineering, Chongqing University, China
Dawei Gu[1], Shozab Mustafa[1], Mladena Luković[1], Erik Schlangen[1]	[1]Delft University of Technology, The Netherlands
Erfan Shafei[1]	[1]Urmia University of Technology, Urmia, Iran
Frank J. Vecchio[1]	[1]Department of Civil & Mineral Engineering, University of Toronto, Canada
Gerrit E. Neu[1], Vladislav Gudžulić[1], Günther Meschke[1]	[1]Ruhr University of Bochum, Germany
Jaime Planas[1], Beatriz Sanz[1], José M. Sancho[2]	[1]Dep. de Ciencia de Materiales, E.T.S. de Ingenieros de Caminos, Canales y Puertos, Universidad Politécnica de Madrid, Madrid, Spain [2]Dep. de Estructuras de Edificación, E.T.S. de Arquitectura, Universidad Politécnica de Madrid, Madrid, Spain
José Joaquín Ortega[1], Rena C. Yu[2], Elisa Poveda[2]	[1]Universidad Politécnica de Madrid, Spain [2]Universidad de Castilla-La Mancha, Spain
Kryštof Toman[1]	[1]Faculty of Civil Engineering, Czech Technical University in Prague, The Czech Republic
Marcílio M. A. Filho[1]	[1]Department of Civil Engineering, University of Minho, Portugal
Nino Spinella[1]	[1]Department of Civil Engineering and Architecture, University of Catania, Italy
Pavel Ostrovsky[1]	[1]Ramboll Finland
Peter K. Juhasz[1], Peter Schaul[1]	[1]JKP Static Ltd., Budapest, Hungary
Tiago Valente[1], Inês Costa[1], Lúcio Lourenço[1], Christoph de Sousa[1], Cristina Frazão[1]	[1]CiviTest-Pesquisa de Novos Materiais para a Engenharia Civil, Lda., Vila Nova de Famalicão, Portugal

3. Experimental results

Two slabs were subjected to bending under a configuration with two loaded sections and three vertical supports. Figure 1 displays the experimental results. Unfortunately, the record of crack width of the first slab was lost.



(a)



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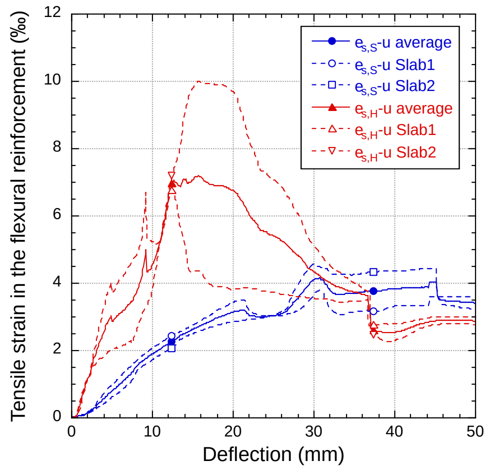

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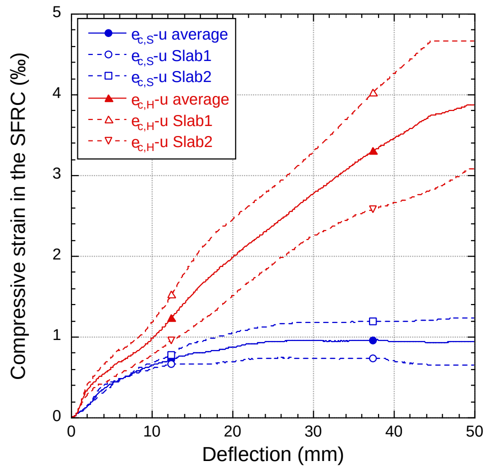


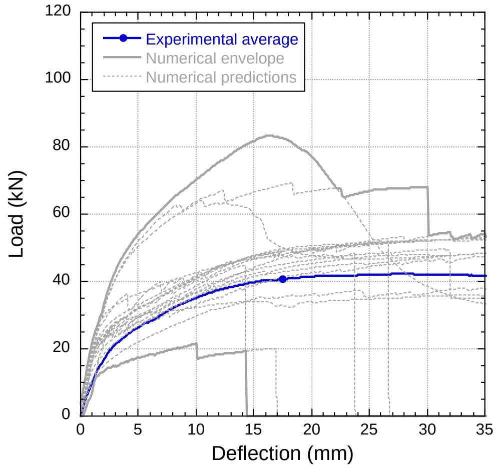
(d)

Figure 1. Experimental results and average curves of load versus deflection (a), crack width versus deflection in the sagging region w_S and in the hogging region w_H (b), tensile strain in the flexural reinforcement versus deflection at the loaded section $\varepsilon_{s,S}$ and over the intermediate support $\varepsilon_{s,H}$ (c), and compressive strain in the SFRC versus deflection at the loaded section $\varepsilon_{c,S}$ and over the intermediate support $\varepsilon_{c,H}$ (d)

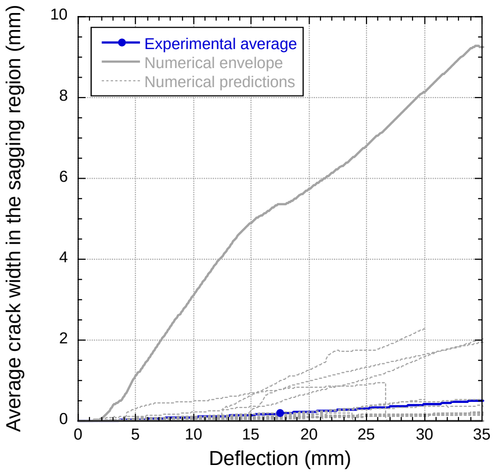
4. Results of the simulations

Figure 2 and Figure 3 show the experimental average, numerical envelope and numerical predictions of all participants. Figure 2 includes the curves of load versus deflection, and average crack width in the hogging region and in the sagging region versus deflection. Figure 3 includes the curves of tensile strain in the flexural reinforcement at the loaded section and over the intermediate support versus deflection, and compressive strain in the SFRC at the loaded section and over the intermediate support versus deflection.

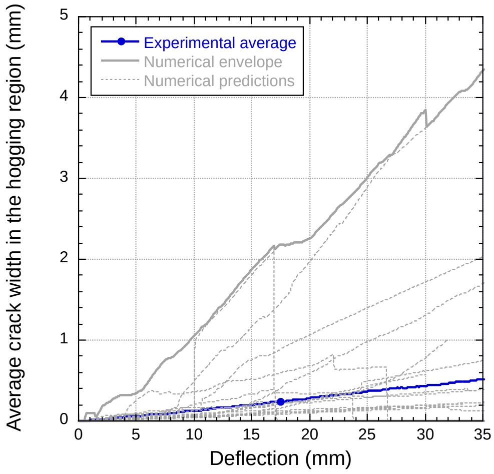
The results are displayed up to the deflection corresponding to the end of the experiments.



(a)



(b)



(c)

Figure 2. Experimental results, numerical envelope and numerical predictions of all participants regarding the: load versus deflection (a), average crack width in the sagging region versus deflection (b) and average crack width in the hogging region versus deflection (c)

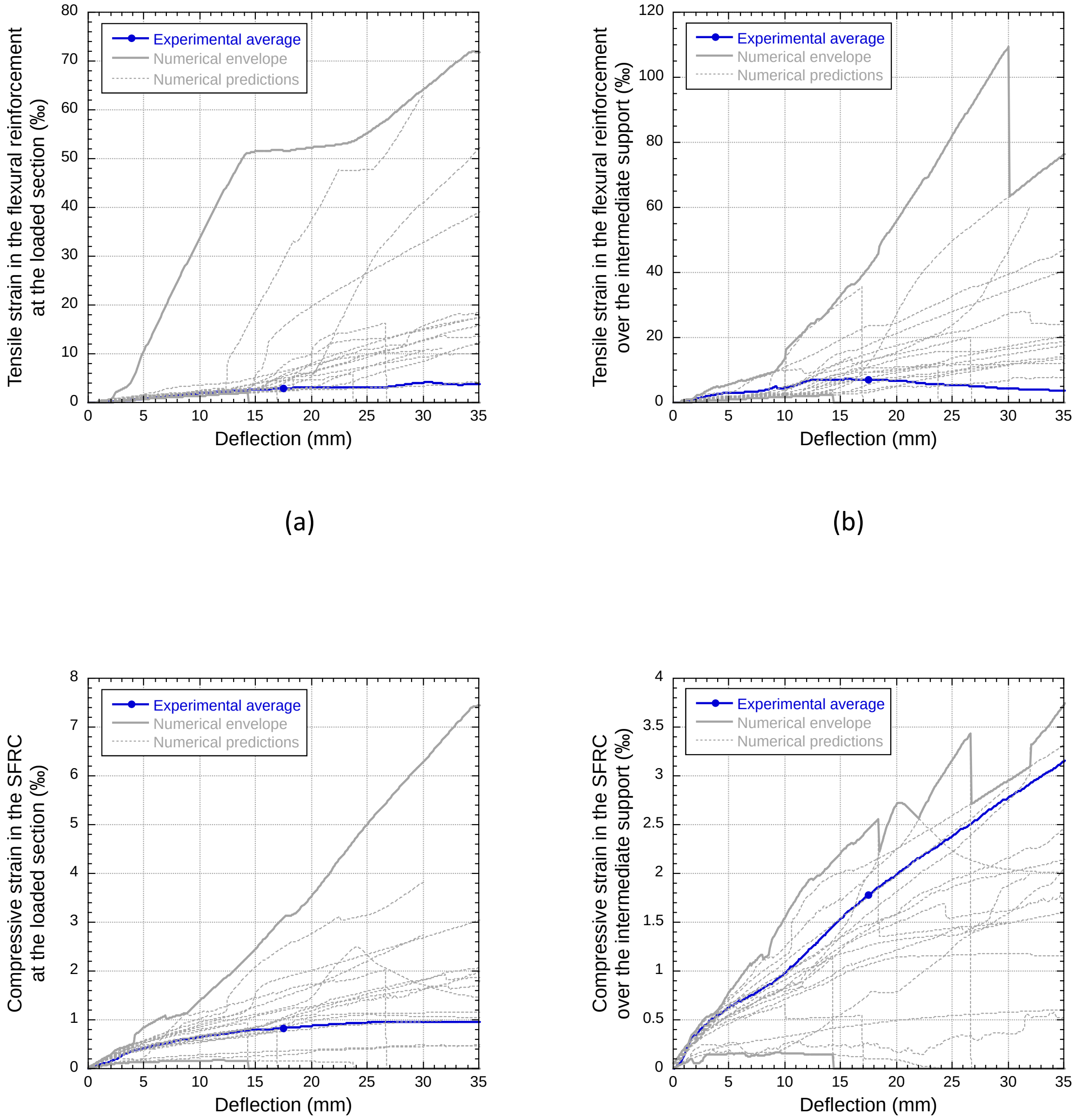


Figure 3. Experimental results, numerical envelope and numerical predictions of all participants regarding the: tensile strain in the flexural reinforcement at the loaded section versus deflection (a), tensile strain in the flexural reinforcement over the intermediate support versus deflection (b), compressive strain in the SFRC at the loaded section versus deflection (c) and compressive strain in the SFRC over the intermediate support versus deflection (d)

5. Predictive performance of the simulations

For each participant, the predictive performance of the numerical simulation was computed after performing the tests, according to the following:

1. The experimental average was computed from the results of the two slabs.

2. The numerical results of each participant were compared with the experimental average, up to the experimental peak load.

3. The normalised root mean square root $NRMS_F$ of the numerical prediction of load was calculated as:

$$NRMS_F = \frac{1}{F_{exp}^{max}} \sqrt{\frac{\sum_\kappa (F_{exp}^\kappa - F_{num}^\kappa)^2}{n}} \quad (1)$$

where κ corresponds to the records, F_{exp}^κ is the experimental value of load of the record κ, F_{num}^κ the numerical value of the record κ, n is the number of scan readings, and F_{exp}^{max} is the maximum of the experimental load. Equivalent equations are used to compute the *NRMS* of the tensile strain in the flexural reinforcement at the loaded section $NRMS\varepsilon_{s,S}$, compressive strain in the SFRC at the loaded section $NRMS\varepsilon_{c,S}$, tensile strain in the flexural reinforcement over the intermediate support $NRMS\varepsilon_{s,H}$, compressive strain in the SFRC over the intermediate support $NRMS\varepsilon_{c,H}$, average crack width in the sagging region $NRMSw_S$, and average crack width in the hogging region $NRMSw_H$.

4. The score of each participant was calculated according to the following expression:

Score = $0.2NRMS_F + 0.1NRMS\varepsilon_{s,S} + 0.1NRMS\varepsilon_{c,S} + 0.1NRMS\varepsilon_{s,H} + 0.1NRMS\varepsilon_{c,H} + 0.2NRMSw_S + 0.2NRMSw_H$ (2)

Table 2 includes the predictive performance of the simulations of the 18 teams of participants. Note that the order of participants is random and does not coincide with that of Table 1, for the sake of confidentiality.

Table 2. Predictive performance of the results presented by the participants, shown in random order.

Partici-pant no.	*NRMS* F	*NRMS* $\varepsilon_{s,S}$	*NRMS* $\varepsilon_{c,S}$	*NRMS* $\varepsilon_{s,H}$	*NRMS* $\varepsilon_{c,H}$	*NRMS* w_S	*NRMS* w_H	Score	Classif.
1	0.1353	11.02	2.454	3.364	0.3407	12.16	4.239	5.0251	18
2	0.08916	1.051	0.05903	2.287	0.2308	0.2492	0.1254	0.45560	7
3	0.1784	1.273	0.4234	0.7711	0.4540	0.3144	0.3270	0.45611	8
4	0.6774	0.5423	0.6032	2.264	0.5541	0.4752	1.880	1.0028	14
5	0.4199	3.620	0.9105	2.669	0.1093	1.575	1.564	1.4427	16
6	0.4383	0.4651	0.6536	0.6607	0.5802	0.3703	0.4199	0.48164	9
7	0.1643	1.510	0.3628	0.9187	0.1279	0.2663	0.3092	0.43994	6
8	0.1082	0.9299	0.3211	1.913	0.05496	0.3506	0.3718	0.48800	10
9	0.3110	1.542	0.7101	1.347	0.2734	1.248	0.7387	0.84690	13
10	0.5999	7.351	1.488	9.073	0.2416	2.292	3.635	3.1208	17
11	0.1185	1.079	0.2538	0.7273	0.1719	0.1003	0.1600	0.29897	3
12	0.05703	0.09195	0.4665	0.4957	0.5266	0.3088	0.3393	0.29909	4
13	0.7167	3.255	0.7095	4.758	0.1012	0.4440	0.5358	1.2217	15
14	0.1860	0.3257	0.1008	0.6195	0.2759	1.133	0.8065	0.55724	11
15	0.1405	0.5736	0.7578	0.6601	0.02057	0.1184	0.1350	0.27996	2
16	0.1871	0.6467	0.3484	0.5112	0.1054	0.05203	0.09747	0.22850	1
17	0.05243	0.8974	0.1184	1.191	0.2192	0.3294	0.1271	0.34443	5
18	0.6913	0.5865	0.6582	0.9727	0.5605	0.5127	0.5762	0.63382	12

Figure 4 shows the score of participants versus the raking obtained in the competition.

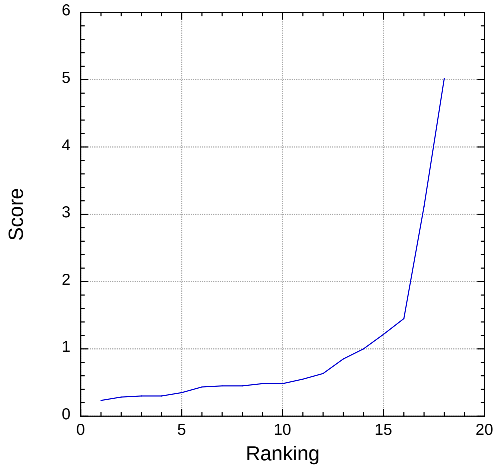


Figure 4. Score of participants

The best score, i.e., the minimum, is 0.2285, which corresponds to Participant 16, Gerrit E. Neu, Vladislav Gudžulić and Günther Meschke, from the Ruhr University of Bochum, Germany. Since the organization of this competition did not obtain explicit permission to publicly disclose the classification of now-winner participants by identifying their name (or the name of team's members) and corresponding affiliation, this has not been included in this document. The classification of the remaining participants will be communicated individually by e-mail to the corresponding author.

16 March 2022

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