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Plastic fibres as the only reinforcement for flat suspended slabs: Parametric study and design considerations

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HIGHLIGHTS

- The influence of the parameters from the constitutive equations on the structural behaviour of the slabs is analysed.
- The existence of a network effect was identified.
- Two geometric coefficients were defined to adapt the σ–ε curve suggested by the EHE.
- The first of them (ψ) considers the favourable orientation of the fibres in slab-type elements.
- The second (ζ) considers the overestimation in the response of the slabs provided by the current σ–ε diagrams.

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ABSTRACT

The use of constitutive equations from the standards to model flat suspended slabs reinforced only with plastic fibres leads to an overestimation of the experimental response of these elements. To address such problem, a parametric study is conducted. In this study, the influence of the parameters from the constitutive equations on the structural behaviour of the slabs is analysed and the ones that provide the best fit with the experimental results are found through a non-linear regression. Based on this analysis, the existence of a network effect was identified and a design philosophy for suspended slabs reinforced only with plastic fibres is proposed. Thereby, this paper represents a meaningful contribution to provide a step towards the development of a rational and design-oriented constitutive model for real-scale hyperstatic slabs-type elements.

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1. Introduction

Fibre Reinforced Concrete (FRC) has proven to be a competitive material in many types of structures [1,2]. In several of them, fibres are used with structural responsibility substituting partially or completely the conventional reinforcement [3–9]. Despite the efforts to understand the material and its structural behaviour, different authors have reported the need to adjust the constitutive equations that are currently being used to design FRC to better reproduce the FRC slab-type elements [9–13].

In this sense [10–12] identified a size effect in the flexural behaviour of slab-type elements in their studies on steel fibre reinforced concrete (SFRC), in which less residual strength was obtained in the post-cracking stage as the size of the element increased. The reduction in the fracture energy observed shows the need to consider this effect in the design process of slab-type elements. Likewise, [13] identified the existence of a network effect in SFRC slabs, showing a more favourable orientation of the fibres with regards to the slabs cracking pattern that resulted in higher residual strength. According to [10–13] geometric factors should be included in the design in order to consider different orientations of the steel fibres depending on the edge height and width of the slabs. However, little research has been conducted on this effect in plastic fibre reinforced concrete (PFRC) elements.

In order to gain insight, [9] performed a full-scale experimental program on different hyperstatic slabs reinforced only with macro-plastic fibres. The slabs tested showed a ductile behaviour with great capacity to redistribute stresses, even for high load levels after cracking. However, [9] also demonstrated that the numerical simulations with the tri-linear and multi-linear constitutive equations proposed by [14] and [15] clearly overestimate the

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experimental results, and suggested the need to adjust the values that define the constitutive equations for PFRC in tension and to consider the effect of the slab width.

For this reason, in this paper the experimental and numerical results reported in [9] will be used to analyse the possible existence of a network effect for PFRC slabs and propose a design philosophy to take it into account. With this aim a parametric study will be conducted in order to determine the sensibility of the values defining the constitutive equations and its influence on the structural response of slabs, as well as the values that lead to the best fit of the experimental results. Based on this study two geometric factors to adjust the constitutive equations from the guidelines and recommendations will be proposed.

2. Background

In this paper, the results of a full-scale experimental program on different point loaded flat suspended slabs reinforced only with structural plastic macro-fibres (presented in [9]) will be used. The length of the slabs (b_{long}) and height (h) were fixed at 3.00 m and 0.20 m, respectively and three different widths (b_{short}) were tested 1.5 m, 2.0 m and 3.0 m. The slabs were supported only along the central part of each edge (the central 2/4) simulating a hyperstatic support configuration that should allow a redistribution of moments and the contribution of fibres in more than one direction.

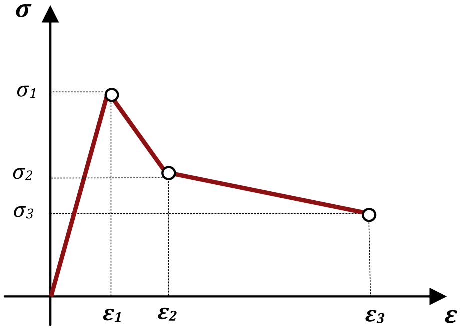

Fig. 1. Scheme of the σ–ε diagram proposed to model the uniaxial behaviour of PFRC.

Following the nomenclature presented in [9] the codes L, M and S will be used for slabs with dimensions of 3.0 m × 3.0 m, 2.0 m × 3.0 m and 1.5 m × 3.0 m, respectively. Further detail on experimental and numerical procedure and results can be found in [9].

3. Parametric study

3.1. Study cases

The $\sigma - \varepsilon$ diagram to model the uniaxial behaviour of PFRC proposed by [14] and [15] is defined by means of six values: σ_1, ε_1, σ_2, ε_2, σ_3 and ε_3 (see trilinear diagram of Fig. 1). The first point of the diagram $(\sigma_1, \varepsilon_1)$ basically depends on the concrete matrix, its estimation has been widely studied and can be considered as the end of the elastic region [16]. Additionally, [13] reported a significant effect of the parameters σ_2, σ_3 and ε_2 and to a lesser extent of ε_3 on the structural behaviour of the slabs. For these reasons, fixed values of σ_1, ε_1 and ε_3 were used in the analysis. The fixed values used correspond to the multi-linear diagram formulated by the EHE-08, which propose logical values in accordance with other international codes [17].

The same extreme values of σ_2, ε_2 and σ_3 were defined for each of the three sizes of the tested slabs (L, M and S). Each interval was divided into seven distinct values for σ_2 and five distinct values for ε_2 and σ_3. To avoid unreasonable values, variable σ_2 is defined as a function of $\sigma_{1,}$ and σ_3 is defined as a function of σ_2. The values adopted for the simulation of the three slabs are summarised in Table 1. In total, 175 cases were analysed for each slab, which leads to a parametric study with 525 simulations. Further information on the material choice and the model developed for the simulation of the three slabs can be found in [9].

3.2. Global effect of the variables σ_2, ε_2 and σ_3

Figs. 2–4 present the F–δ curves for the six studied values of σ_2 for the S, M and L slabs, respectively. To facilitate the visualization of the results and given the fact that the tendencies are similar, only the curves corresponding to the extreme values of σ_3 ($\sigma_3 = 0.5\sigma_2$ and $\sigma_3 = 1.2\sigma_2$) and ε_2 ($\varepsilon_2 = 0.1‰$ and $\varepsilon_2 = 0.5‰$) are herein presented.

Table 1
Parameters defining the constitutive models.

MODEL		MATERIAL PROPERTIES		
Model used for the complete parametric study	neoprene	Average modulus of elasticity	[MPa]	35.00
		Poisson's coefficient	[-]	0.30
	interface	Normal stiffness	[MN/m3]	$2.0 \cdot 10^8$
		Tangential stiffness	[MN/m3]	$2.0 \cdot 10^8$
		Cohesion	[MPa]	1.000
		Friction coefficient		0.10
		Traction cut-off	[MPa]	0.30
	PFRC	Average compressive strength	[MPa]	50.54
		Average modulus of elasticity	[GPa]	29.90
		Poisson's coefficient	[-]	0.20
		Tension σ_1	[MPa]	3.03
		Average residual tension σ_2	[MPa]	$[0.1\sigma_1{:}0.1\sigma_1{:}0.6\sigma_1]$
		Average residual tension σ_3	[MPa]	$[0.5\sigma_2{:}0.175\sigma_2{:}1.2\sigma_2]$
		Average deformation ε_1	[‰]	0.10
		Average deformation ε_2	[‰]	[0.1:0.1:0.5]
		Average deformation ε_3	[‰]	20.00
		Characteristic size	[m]	0.0625

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