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SFRC flat slabs punching behaviour – Experimental research

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ABSTRACT

The use of randomly distributed steel fibres in the concrete mix improves its mechanical properties. In the particular case of a flat slab-column connection, this solution can provide slabs with an increased load capacity and deformation capacity, allowing a potential reduction of reinforcement. This work presents the experimental study of the behaviour of SFRC flat slabs up to failure under a concentrated loading, accompanied by the study of the mechanical properties of the SFRC, which consisted in three-point loading notched beams, compression and splitting tests. In this study, the hooked end steel fibre dosages varied between 0% and 1.25% by volume. Test results showed that the inclusion of steel fibres influences both slab stiffness and its load capacity. Increments of load capacity up to 64% were obtained in slabs with SFRC compared with the reference slab without fibres. The experimental results were compared with the predictions provided by several existing models.

1. Introduction

In the last years, there has been a growing interest in FRC due to its higher efficiency in enhancing the tensile behaviour of concrete, converting its brittleness into deformation capacity. There are now various types of steel fibres, including straight, crimped, hooked and twisted that can be used, each type with their advantages and disadvantages [1]. Because they are usually small, the fibres may be easily and sparsely added to a concrete matrix in a fresh state. In the hardened state, the fibres have the function of bridging the cracks that appear in concrete and thereby prevent them from growing by transferring the tension across the cracks.

The presence of steel fibres in reinforced concrete (SFRC) allows the composite toughness to increase as the fibres enable the crack to be bridged, following the cracking of the matrix. The significance of this study is related to the fact that although several experimental researchers [2–9] have studied the punching capacity of steel fibre reinforced concrete (SFRC) slabs, in most cases, the concrete is only characterized by its compression strength. Moreover, in previous works [10,11] it was shown that the compressive strength and the fracture (post-crack) behaviour of concrete are of great importance in the capacity of slab/column connections.

To increase the knowledge on the behaviour of SFRC slabs subjected to a monotonic concentrated load and further increase the database of existing research works [12–16], in this work is presented an experimental study on SFRC slabs, which mainly focuses in the effect of varying the fibres volume ratio and also the effect of introducing a plasticizer into the concrete mixtures.

This work intends to contribute with additional results regarding the tests of SFRC slabs under punching, accompanied by flexural tests that allow the determination of the tensile behaviour of the used SFRC's. The obtained results are compared with several existing models, showing the adequacy of its applicability, taking into account the measured mechanical proprieties of the used SFRC. This information is scarce and thus it is of interest for the engineering and scientific community.

2. Experimental tests

2.1. SFRC mixes

The concrete composition was the same for all mixes, except for the amount of steel fibres and the use of a plasticizer. The concrete was produced using 450 kg/m^3 of Portland cement CEM II/B-L 32.5 N, 185 kg/m^3 of sand 0/2 mm, 545 kg/m^3 of sand 2/4 mm, 882 kg/m^3 of course aggregate (crushed limestone) 4/12.5 mm and 216 l/m^3 of water (w_a/ce = 0.48). The steel fibres used were hooked end type, Bekaert's Dramix® RC 65/35 BN, with a length of 35 mm, a diameter of 0.55 mm and a nominal tensile strength of 1150 MPa.

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Nomenclature

α_e	fibre engagement parameter according Variable Engagement Model (VEM)
α_f	fibres slenderness (l_f/d_f)
β_c	ratio of long and short side of column
λ_s	size effect factor that depends on the slab depth ξ distance (vertical) of a point with respect to the soffit of the slab
ρ	average flexural reinforcement ratio
ρ_f	fibre volume content
ρ_l	reinforcement ratio
σ_{tf}	SFRC tensile strength
$\sigma_{tf,MC}$	SFRC tensile strength according to MC2010 Eq. (28)
$\sigma_{tf,VEM}$	SFRC tensile strength according to VEM Eq. (31)
τ	average fibre-matrix interfacial bond stress
ψ	slab rotation
b	notched beam width
c	dimensions of column section
ce	cement
d	distance between the bottom compressed face and the centroid of the top longitudinal reinforcement bars
d_f	fibre diameter
d_g	maximum aggregate size
d_{g0}	is a reference size of aggregate which is 16 mm
f_{ccm}	mean value of concrete compression strength on 150 mm sided cubes
f_{cm}	mean value of concrete compression strength on 150 × 300 mm cylinders
$f_{ctm,sp}$	concrete tensile splitting strength
$f_{R,j}$	flexural tensile strength beam corresponding to CMOD$_j$
f_t	ultimate strength of steel reinforcement
f_y	yield strength of steel reinforcement
h_{sp}	distance between the notch tip and the top of the specimens.
l	span length of notched beam
l_f	fibre length
m_R	average flexural strength per unit width in the support strip
m_s	moment per unit width for calculation of the flexural reinforcement in the support strip
r_s	distance between the column axis and the position where the radial bending moment is zero
u	length of the control perimeter
u_p	is perimeter of loading pad or column
w	crack opening
w_a	water
A_p	horizontally projected area of the punching shear failure surface
E_s	modulus of elasticity of the longitudinal reinforcement
F	load applied to the notched beam
F_f	fibre factor
F_j	load in notched beam corresponding to CMOD$_j$
K	non-dimensional constant value ($K = 0.32$)
L_l	theoretical span of slab
V	load applied to the slab
V_{exp}	experimental failure load
$V_{exp,ND0}$	experimental failure load in the model ND0
V_{flex}	flexural capacity of the slab
V_R	predicted punching capacity
$V_{R,c\ CSCT}$	mean value of contribution of the concrete to the punching capacity according to CSCT
$V_{R,f\ CSCT}$	mean value of contribution of the fibres to the punching capacity according to CSCT
$V_{R,\ MC}$	characteristic value of the punching capacity according to MC2010
$V_{R,c\ MC}$	characteristic value of the contribution of the concrete to the punching capacity according to MC2010
$V_{R,f\ MC}$	characteristic value of the contribution of the fibres to the punching capacity according to MC2010

Six mixes were produced (M0 to M5). A reference mix was used (M0) without steel fibres. The other five contained the following dosages of steel fibres: 0.5% vol. (M1), 0.75% vol. (M2 and M3), 1.0% vol. (M4) and 1.25% vol. (M5). In mixes M3 to M5 a plasticizer was used in a dosage of 3.0 kg/m^3, to allow proper mixing of the concrete constituents. The plasticizer used in these mixtures was *Pozzolith 540*®. The specimens used to characterize the material were produced alongside the slabs specimens and afterwards tested at the same time. All mixes were made using a vertical axis mixer.

The fibre content was chosen taking into account its most common use (between 0.5 and 0.75%) and higher values were also studied in order to ascertain (1% and 1.25%) its executability and behaviour.

In order to assess the workability of the concretes, the slump test was carried out for each cast, allowing a comparison between mixes. The obtained slumps were of 170, 98, 83, 105, 95 and 80 mm for the mixtures M0, M1, M2, M3, M4 and M5, respectively. As expected, slumps decreased with increasing fibre content, being that mix M0 presented the highest slump value. The addition of plasticizer in the mixtures promoted a better workability, as can be observed by comparing mixes M2 and M3.

2.2. SFRC mechanical properties

2.2.1. Compression and splitting tests

Compression tests of 150 mm cubes (f_{ccm}) were carried out on the same day as the test of the corresponding slab. The average results are given in Table 1, along with the cylinder compression strengths (f_{cm}) taken as 0.80 of cube compression strengths. The concrete splitting tensile strength was determined by testing cylinders 300 mm long and 150 mm in diameter. The results are also presented in Table 1. Six cubes and six cylinders of each mix were cast and tested.

The results show that there is a tendency for compressive strength to decrease slightly with the increase of the fibre content. Also, the introduction of a plasticizer (mixtures M3 to M5) led to an increase in concrete compressive strength compared with mixes without plasticizer (M0 to M2). The splitting test results ($f_{ctm,sp}$) show that as the fibre content rises, so does the splitting tensile strength. In mixes containing fibre contents of 0.5% and of 0.75% the splitting tensile strength of concrete did not increase significantly since the concrete workability was impaired by its introduction. Nevertheless, in mixes where a plasticizer was introduced the same did not happen, as workability was not so affected. As with the compression test results, when a plasticizer is added to mixtures M3 to M5 the splitting tensile strength increases considerably. The increase of tensile strength with the higher fibre content is more pronounced in these mixtures than in mixtures M0 to M2. The improved strengths, both in compression and in tension, when the plasticizer was introduced may be ascribed to a better hydration of the cement particles, leading to a better concrete compaction and therefore to a denser concrete. These improved properties lead therefore to an improved bond between the steel fibres and the concrete matrix, allowing the fibres to