PUNCHING OF HIGH STRENGTH CONCRETE FLAT SLABS – EXPERIMENTAL INVESTIGATION

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Abstract

An experimental research was conducted to investigate the punching behaviour of high strength concrete (HSC) flat slabs, presenting a compressive concrete strength of 130 MPa. The tested specimens were 1650 mm square and 125mm thick and had different longitudinal reinforcement ratios varying between 0.94% and 1.48%. The central column was simulated thru a steel plate 200 mm square. The punching capacity of slabs made of HSC was up to 43% higher than that of a reference model made with normal strength concrete (35.9 MPa). The experimental results were compared with the code provisions by EC2, ACI 318-11 and MC2010.

Keywords: High Strength Concrete (HSC), Punching, Flat Slabs

1 Introduction

High strength concrete (HSC) has continuously evolved in the last few decades and in recent years, the use of HSC in structures has increased significantly. In spite of the growing use of HSC in building construction, the information available on the structural performance of this material is reduced, and the amount of experimental tests that has been carried out regarding the study of the behaviour of HSC slab-column connections is still limited. Additionally, most of the existing experimental studies on this subject, adopted concrete compressive strengths that were under 90MPa.

In this study, an experimental research was conducted on four specimens to investigate the structural behavior of HSC slab-column connections with a concrete compressive strength of 130 MPa. The structural behavior regarding the evolution of deformations and punching capacity of HSC slabs with different reinforcement ratios (0.94 to 1.48%) is presented.

2 Experimental program

2.1 Specimens

The experimental program consisted in testing four reduced scale flat slab specimens up to failure by punching. Three of these were cast with HSC and the remaining one was cast with normal strength concrete (NSC), whose objective is to be used as a reference slab.

The specimens were named based on strength concrete class (NS for normal strength and HS for high strength) and on its longitudinal reinforcement ratio.

The specimens measured 1650x1650 mm^2 with a thickness of 125 mm. They modeled the area near a column of an interior slab panel up to zero moments line. The slab bottom flexure reinforcement consisted on a square mesh of 6 mm diameter bar spaced at 200 mm and the top reinforcement is presented in Table 1. During the specimens production the average effective depths of longitudinal reinforcement were measured which are also presented in Table 1.

2.2 Test setup and monitoring

The specimens were subjected to a central monotonic loading up to failure using a hydraulic jack with a capacity of 1000 kN positioned under the slab. The load was applied at rate of 0.25 kN/s through a square steel plate with 200 mm sides and 50 mm thickness. The slabs were fixed to the strong floor of the laboratory in eight points, using four steel tendons and spreader beams.

Loads, displacements and strains in the top longitudinal reinforcement bars were recorded by means of an electronic data acquisition system connected to a computer. Vertical deflections of test specimens were measured at eleven different points using linear variable differential transformer (LVDT's) with a displacement stroke of 100 mm (Figure 1). The vertical load applied to the specimen was measured by four load cells, one for each steel tendon, which fixed the specimen to the strong floor.

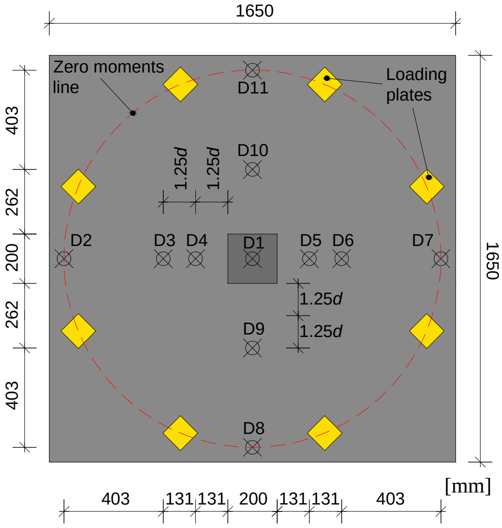

Fig. 1 LVDT's and loading plates position.

2.3 Materials

Twelve 150x300 mm^2 cylinders were casted for each specimen and used to determine the average compressive strength (f_{cm}) and the average splitting tensile strength of concrete ($f_{ctm,sp}$). The compression and splitting tests were performed in the same day of the respective slab specimen test. The average values are listed in Table 1, together with the 0.2% proof strength ($f_{0.2}$) and ultimate strength (f_t) of the longitudinal reinforcement steel.

Table 1
Characteristics of the specimens and materials properties

Specimens	ρ (%)	d (mm)	Concrete		Top Reinforcement			Bottom Reinforcement	
			f_{cm} [MPa]	$f_{ctm.sp}$ [MPa]	Mesh	$f_{0.2}$ [MPa]	f_t [MPa]	$f_{0.2}$ [MPa]	f_t [MPa]
NS	1.00	105.0	35.9	3.4	Ø10//75 mm	523.0	607.0	594.0	724.0
HS1	0.94	104.2	125.6	7.7	Ø10//80 mm	493.5	643.9	549.7	697.3
HS2	1.24	101.6	130.1	8.4	Ø12//90 mm	523.4	671.4	549.7	697.3
HS3	1.48	101.7	129.6	8.3	Ø12//75 mm	523.4	671.4	549.7	697.3

3 Tests results

3.1 Vertical displacements

Figure 2 presents the evolution of vertical displacement along the loading for all specimens, using the relative displacements computed between the mean of D8-D11 LVDT's and D1 (Figure 1).

In the HSC specimens the beginning of development of flexural cracking occurs for a load around 130 kN while in the NSC specimen occurs for a load around 50 kN. This behaviour is related to the greater tensile strength of HSC. As expected, all specimens exhibited a decrease of stiffness when the flexure cracks starts to form and develop. Furthermore, before cracking, the stiffness of the HSC specimens was slightly higher than of the NSC specimen.

The tests results also showed a displacements decrease at failure with the increase of the longitudinal reinforcement ratio, while stiffness increased slightly.

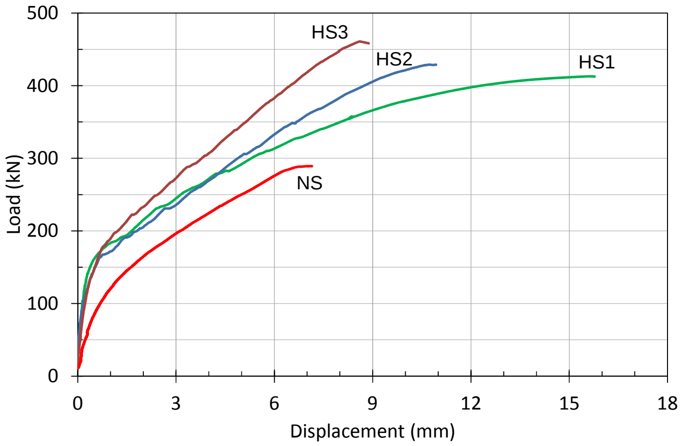

Fig. 2 Load-displacement evolution for all specimens.

3.2 Punching capacity

Table 2 presents the experimental failure loads (V_{exp}) including self-weight. All tested specimens failed by punching. From the results obtained, and for this set of tests, it is possible to conclude that the use of HSC instead of NSC led to an increase up to 43% of the punching capacity. The increase of reinforcement ratio from 0.94% to 1.48% led to an increase of punching capacity of 12%.

Table 2
Experimental loads

Specimen	**NS**	**HS1**	**HS2**	**HS3**
V_{Exp} (kN)	289.2	412.9	429.0	460.9

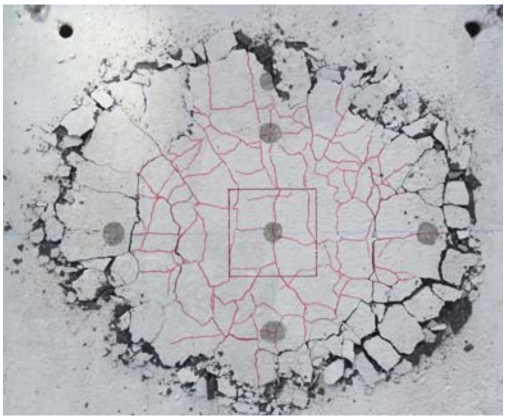

Fig. 3 Top view of the tested specimen HS3.

4 Comparison between experimental failure loads and code provisions

In this section the experimental punching forces obtained are compared with the predictions of (EC2, 2004), (ACI 318-11, 2011) and (MC2010, 2012). In the quantification of the punching resistance the mean values for the properties of materials were used and the partial safety coefficients were not considered. Table 3 presents the average and the coefficient of variation (CoV) for the ratio V_{Exp}/V_{Rm}, considering all specimens (left values) and when only HSC specimens are considered (right values).

When considering only the specimens cast with HSC, it may be concluded that both, (ACI 318-11, 2011) and (MC2010, 2012) leads to a good prediction of punching capacity, for this set of experimental tests, but (ACI 318-11) presents higher values for CoV. The predicted values using (EC2, 2004) are slightly against safety. Additionally (ACI 318-11, 2011) shows a trend of higher ratios of V_{Exp}/V_{Rm} as the ratio of longitudinal reinforcement increases, because its formulation does not take into account the amount of longitudinal reinforcement, contrary to the provisions from (EC2, 2004) and (MC2010, 2012).

Table 3
Resumed results of the obtained relations V_{Exp}/V_{Rm}[a]

Code	**EC2**	**ACI 318-11**	**MC2010 (III)**
Average	0.91 / 0.89	1.09 / 1.00	0.97 / 0.96
CoV	0.04 / 0.01	0.19 / 0.10	0.04 / 0.03

[a] All specimens / only HSC specimens

5 Conclusions

This paper presents an experimental investigation conducted to analyze the punching behaviour of HSC flat slabs. The tests results showed that the punching capacity of flat slabs is substantially increased with the use of HSC, but the rupture is also more brittle when comparing with NSC slabs. The use of HSC led to an increase up to 43% of the punching capacity, when compared with the NSC specimen. The increase of reinforcement ratio led to a slight increase of the punching capacity.

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