ANALYSIS OF CRUCIFORM CONNECTIONS USING FIBRE REINFORCED SELF-COMPACTING CONCRETE UNDER PUSH-OUT TESTS

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Abstract

Self-compacting, also known as self-consolidating concrete, (SCC), was introduced as a high performance material that could avoid the difficult and onerous process of vibration. This special behaviour was responsible for its definition: a material that is capable to flow inside a formwork, without any vibration equipment. In this paper, self-compacting concrete is used in association with precast concrete systems, since both techniques are considered suitable for the civil construction industrialization. The main purpose of this study is to develop a high strength self-consolidating concrete to be used as a filling material joining precast beams and columns to produce connections with semi-rigid behaviour. Fibres were included in the mix to increase strength and also ductility of the connection. In a first stage, shear resistance of the obtained connection was evaluated, while a next stage will investigate the flexural behaviour of the connection. Results of the first stage, where cruciform specimens were submitted to push-out tests, are reported in this paper. The main studied parameters were the type of concrete and the effect of steel fibres addition. According to the results of these preliminary tests, the developed material seems to be very efficient to provide semi-rigid behaviour.

Keywords: Self-compacting concrete, precast connections, steel fibres, push-out tests, experimental analysis

1 INTRODUCTION

Precast concrete structures are easily built and their elements have a high standard quality control. But, unlike the cast-in-situ concrete systems, their connections are not monolithic, requiring a careful design. Connections in general are always discontinuous regions subjected to high level stresses, but in precast concrete structures, depending on the design, their various components can or cannot contribute to the efforts absorption. The consequent redistribution of moments that could occur along the structure will determine its global behaviour. So, in this way, the performance of the whole system and its success depends on the behaviour of the connections.

The main idea of this research is to optimize the precast concrete system through the improvement of their connections, considering constructive and structural aspects, that means reducing assembly labour and increasing strength capacity.

The use of high strength concrete as well as the steel fibres addition can be good strategies to enhance connections behaviour, according to MIOTTO (2002). So, the design of the connection that is proposed in this study is similar to the considered there, only changing the type and strength of used concrete. The main goal is to develop a high performance concrete, which could be loaded at early ages, to be used only for the connection. The desired results include speeding construction process and improving structural behaviour.

. In the preliminary stage of study reported here, shear resistance of the proposed material was investigated. Push-out tests in cruciform models were performed aiming to understand the influence of concrete type in the observed behaviour. In the next stage of this research, a precast connection will be subjected to flexural tests.

2. CONSIDERED MATERIALS

The design of the used mix for the self-compacting concrete reinforced with steel fibres (FRSCC) was based in method developed at Polytechnic University of Catalunya (GOMES, 2002). At first, the saturation point of the paste is determined and the granular skeleton is optimized. After that, the volume of paste is chosen to get the needed fluidity. More details about the method can be found in the literature.

Table 1 shows the mixes considered in the experimental programme.

Table.1 Considered Concrete Mixes

Material	VC	SCC	FRSCC
Cement (kg)	488.3	426.8	426.8
Sand (kg)	227.0	789.8	789.8
Gravel(kg)	766.6	864.5	864.5
Water (kg)	942.4	14.,4	149.4
Superplast. (%)	0.0	2.0	2.0
Filler (kg)	0.0	85.4	85.4
Silica fume(kg)	0.0	85.4	85.4
Steel fibre 13 mm (%)	0.0	0.0	1.0

Silica fume was added to the mix in-order to increase compressive strength and Young modulus, also improving bond on steel-concrete interface. Filler was used to reduce material's porosity, increasing concrete quality. And, to evaluate the effect of using SCC and steel fibres, a connection made with usual vibrated concrete (VC) was also tested.

Table 2 shows the properties of self-compacting concrete in the fresh state.

Table.2 SCC properties in fresh state

Material	SCC	FRSCC
Temp. (^oC)	27	27
RH (%)	30	30
Slump test		
t_{50} (s)	1.0	1.0
D (cm)	68.0	78.0
V-Funnel test		
t_v (s)	4.70	7.70
L-Box test		
t_{60} (s)	2.0	1.0
Blocking ratio	0.8	1.0

3. EXPERIMENTAL PROGRAMME

Experimental programme consisted of 3 cruciform specimens for push-out tests. Vibrated concrete and self-compacting concrete of similar compressive strength were used aiming to compare the behaviour of both mixes. The target strength was 60 MPa at 28 days for vibrated concrete. Self-compacting concrete, however, was tested at 3 days with and without fibres, since one of the objectives of the study was to obtain a high performance concrete at early ages.

Table 3 shows mechanical properties of hardened concrete (compressive strength, tension strength and modulus of elasticity), obtained at the same day of the push-out tests (28 days for VC and 3 days for SCC and FRSCC).

Table 3 Properties in hardened state

Material	VC (28 days)	SCC (3 days)	FRSCC (3 days)
$f_{c,3}$ (MPa)	62.34	54.50 (84,49 – 28 dias)	54.95 (83,68 – 28 dias)
$f_{ct,3}$ (MPa)	3.05	3.53	3.16
$E_{c,3}$ (GPa)	33.99	36.20	35.50

Though the compressive strength used in MIOTTO (2002) was 30 MPa, the design of the column was the same, with steel reinforcement of 15.76 cm^2 (4 bars of 20 mm and 4 bars of 10 mm). Besides that, transference reinforcement was also added, which, associated to the high performance material used as filling, aimed to produce a moment resistant connection.

Figure 1 shows the design of the formwork of the studied connection and Figure 2 shows the used reinforcement.

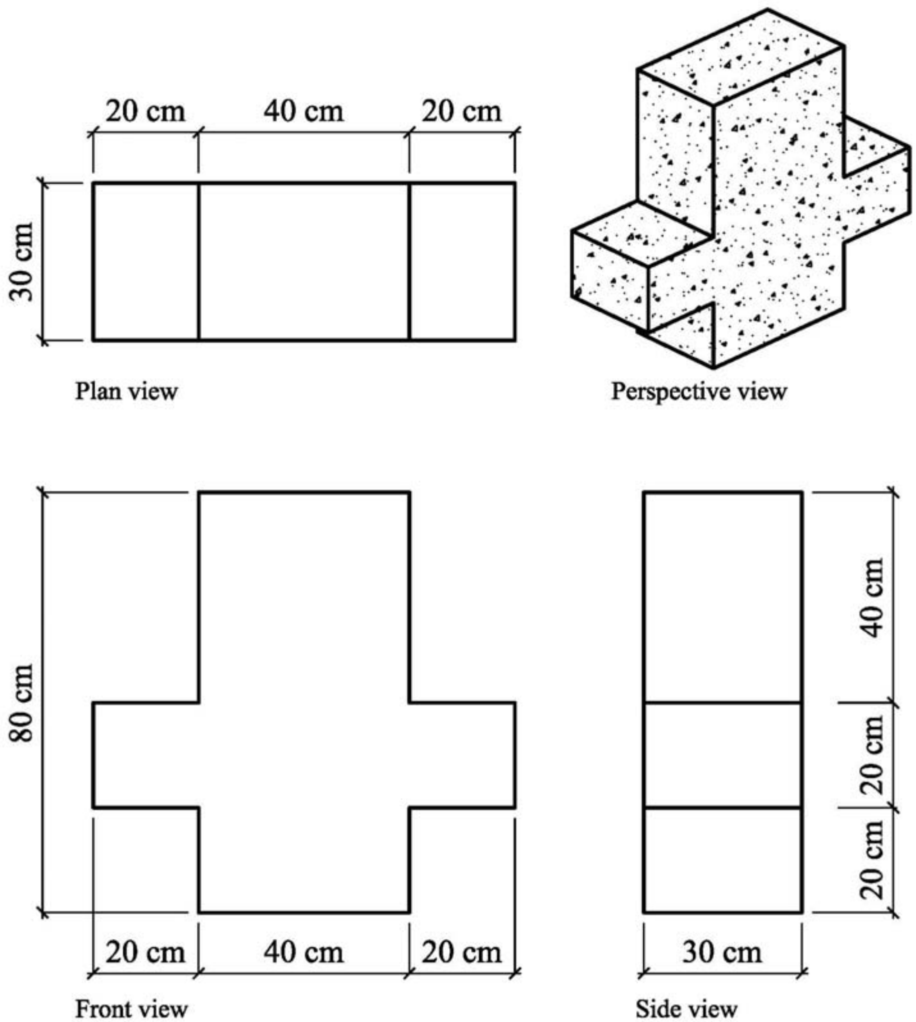

Figure 1. Formwork dimensions

Push-out tests were used to evaluate the shear resistance of the connection. Therefore, in this series the support reaction was placed about 2 cm from the column face, reducing the influence of flexure in the failure.

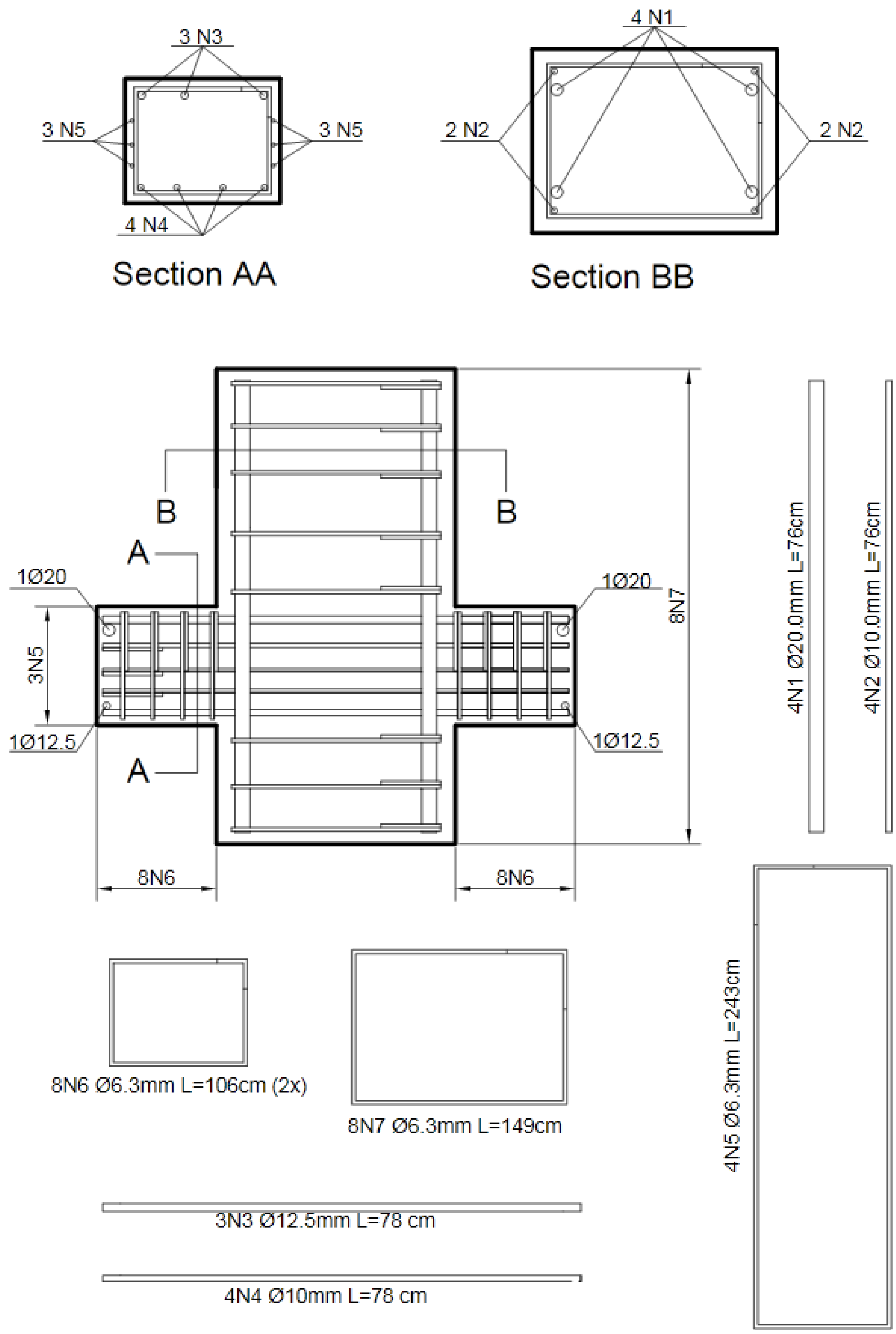

Figure 2. Details of reinforment

Displacement transducers were used to measure the vertical displacement of the connection and also the horizontal displacements in the upper and lower parts of the corbels. Figure 3 shows the test set-up and the used instrumentation.

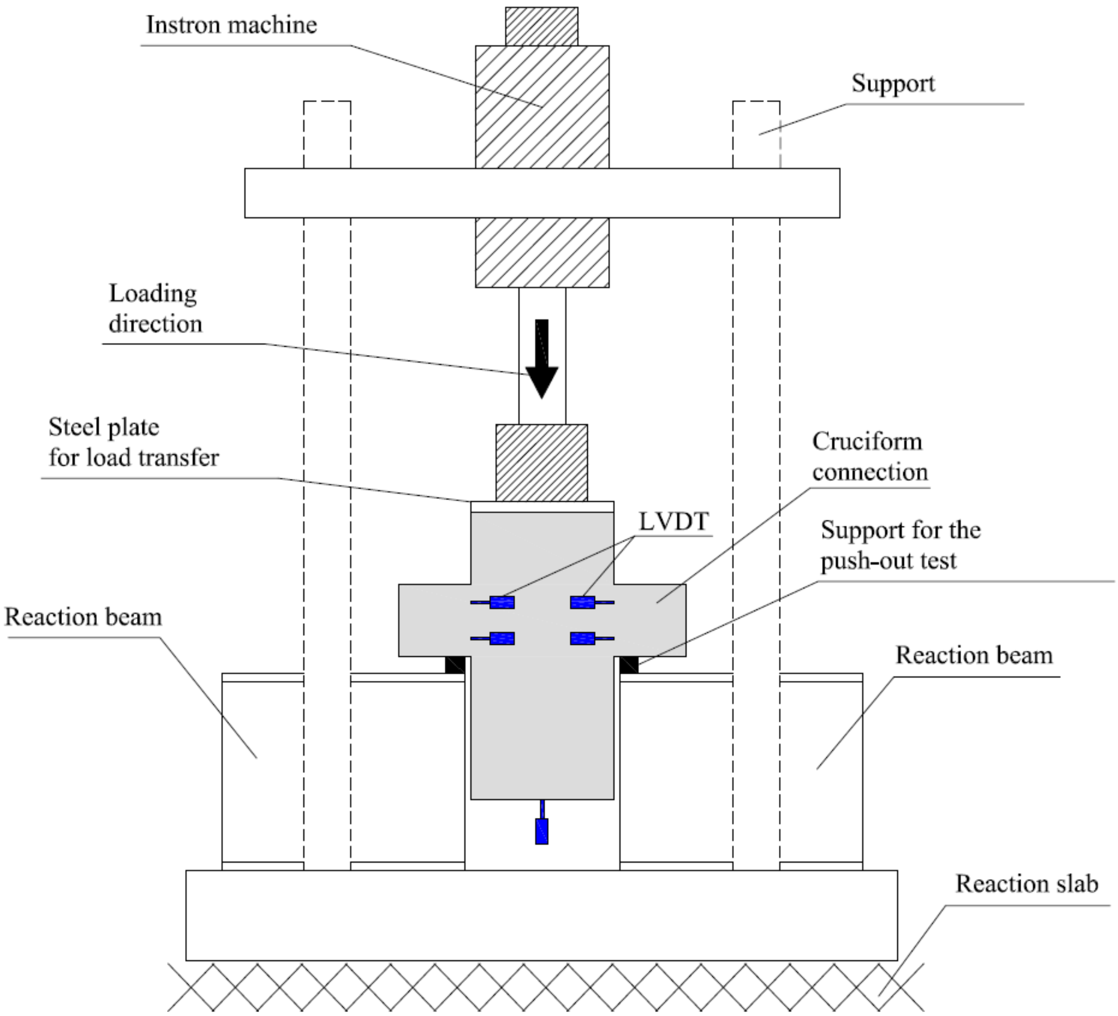

Figure 3. Test set-up

Table 4 presents the characteristics of the considered connections.

Table.4 Tested connections

Specimen	Concrete type	Steel fibres
PO-01	VC	0
PO-02	SCC	0
PO-03	FRSCC	1%

Since the performed push-out tests were exploratory tests, the load was limited to 1300 kN, avoiding the risks of a splitting failure with possible damage of the equipments.

4. ANALYSIS OF RESULTS

The connections were tested till similar load level and their aspect after test is presented in Figure 4. Wider concentrated cracks in the connection with vibrated concrete PO-01, spread cracking in the connection with self-consolidating concrete PO-02 and more cracks of small openings in connection with fibre-reinforced self-consolidating concrete PO-03 are in accordance with was expected for the different used materials.

PO-01 PO-02 PO-03

Figure 4 Cracking map after tests

The behaviour of the 3 connections can be compared through the average of readings from the upper transducers showing the corbels displacements in Figure 5. It can be seen that PO-02 behaves better than PO-01, and that PO-03 with fibres addition behaved even better.

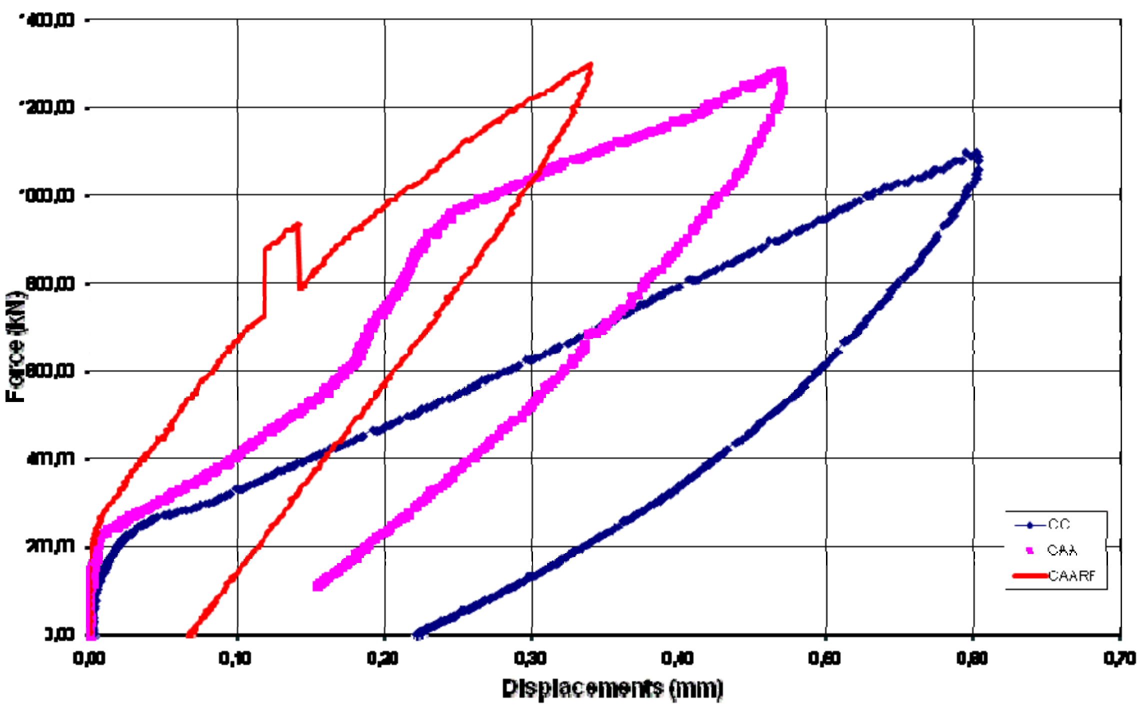

Figure 5 Load x displacement curves

According to EL DEBS (2000), the corbel's capacity can be estimated considering concrete strength (Equation 1) or reinforcement cross section $A_{s,tir}$ (Equation 2):

$$\tau_{wd} = \frac{V_d}{b \cdot d} = \frac{0{,}18 \cdot f_{cd}}{\sqrt{(0{,}9)^2 + (a/d)^2}} \rightarrow V_d = \frac{b \cdot d \cdot 0{,}18 \cdot f_{cd}}{\sqrt{(0{,}9)^2 + (a/d)^2}} \qquad \text{(Eq. 1)}$$

$$A_{s,tir} = \frac{1}{f_{yd}} \cdot \frac{V_d \cdot a}{0{,}9 \cdot d} \rightarrow V_d = \frac{A_{s,tir} \cdot f_{yd} \cdot 0{,}9 \cdot d}{a} \qquad \text{(Eq. 2)}$$

where V_d is the corbel's capacity, *b*, *d* and *a* are the corbel's dimensions, f_{cd} is concrete compressive strength and f_{yd} is the yielding stress of steel.

Table 4 compares theoretical and experimental values.

Table 4 Comparison among results

Model	f_c (MPa)	$V_{k,\,Eq.1}$ (kN)	$V_{k,\,Eq.2}$ (kN)	$V_{k,exp}$ (kN)	$V_{k,exp.}/V_{k,Eq.1}$
PO-01	62.34	900.79*	796,50**	1100.00	1.22
PO-02	54.50	787.51*		1284.10	1.63
PO-03	54.95	794.00*		1301.50	1.64

* Value resisted by 2 corbels, according tested model.

**f_{yk} = yielding stress of steel= 590 MPa

As it can be observed, experimental behaviour was always superior to the calculated one, with connections PO-02 and PO-03, of self-consolidating concrete without and with fibres, presenting additional shear capacity.

5. CONCLUSIONS

Based on the previous study, some conclusions can be drawn:

- Self-consolidating concrete produced a better result than vibrated concrete, though for safety reasons the failure was not achieved in both tests.
- Connection PO-01, with vibrated concrete, presented the most opened cracks, producing high stresses in the corbel's reinforcement.
- Connection PO-03, with the developed fibre reinforced self consolidating concrete, presented the less opened cracks due to the use of the steel fibres.
- The developed material was very easy to be placed, and produced good behaviour related to shear transfer.
- Next stage, where flexural behaviour will be studied, can show the adequacy of the proposed connection for precast concrete systems.

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