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Experimental assessment of connections for precast concrete frames using ultra high performance fibre reinforced concrete

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HIGHLIGHTS

- Study of connections using ultra high performance fibre reinforced concrete.
- Experimental assessment of short reinforcement splices.
- Beam–column connection proposal for precast concrete frames.
- Experimental assessment of beam–column connection.

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ABSTRACT

Interest in precast construction system has been growing due to the emphasis on improving work zone safety, reducing construction time and environmental impact, while maintaining quality. This experimental study aimed to develop a method to connect precast elements avoiding the use of complex reinforcing details and inefficient construction processes. For that purpose, the outstanding properties of ultra high performance fibre reinforced concretes (UHPFRC) were used to develop continuity connections between precast elements. A two-stage experimental program was defined to study the behaviour of precast elements connected using short reinforcement splice lengths. In the first experimental stage, flexural beam tests were carried out to assess the use of short reinforcement splice lengths in continuity connections. In the second experimental stage, an alternative beam–column connection for precast construction using UHPFRC was proposed and tested. The configuration proposed avoids the interference between longitudinal and transversal reinforcement, reduces the *in situ* work and makes it possible to define an efficient and safe construction process.

1. Introduction

Precast construction is regarded as an appealing alternative to be considered in a wide range of construction projects. It is thanks, among other factors, to the advantages related to the reduction in construction times, work force and *in situ* labour, as well as more favourable cost-benefit relations, less environmental impact, and greater control and final quality of the elements. However, the use of precast construction is sometimes limited by the inappropriate assessment of several typical singularities of these construction systems. Finding a practical and economical method of connecting precast elements has been recognised as a critical factor and one of those important singularities [1]. Besides, the connections are the construction process stage developed *in situ* in which common problems in the structure assemblage have to be faced. Among the different mechanisms to connect precast elements, reinforcement splices are widely used in practice. However, the large splice lengths are usually regarded as a disadvantage that makes transport and erection difficult.

The splice of the beam longitudinal reinforcement at the beam–column connections is usually employed to construct moment-resisting frames for *in situ* and precast systems. Research studies conducted in recent years have allowed a better understanding of the behaviour of beam–column connections, improving the general knowledge of the internal resisting mechanism and detailing requirements. In this type of connection, the joint and the elements are subjected to large flexural, shear and bond demands when the frame is under the action of lateral forces. In particular, bond conditions in beam and column longitudinal bars are regarded as an important factor due to the change in the sign of the moments at the joint faces. In that sense, this research was focused on the behaviour of frames under the action of alternative loads that sub-

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Nomenclature

A_j	effective cross-sectional area within a joint in a plane parallel to plane of reinforcement
A_s	area of tensile reinforcement
d	effective depth of the cross section
d_b	diameter of the longitudinal reinforcement
f_c	average compressive strength of concrete (measured in cylinders)
$f_{cc,UHPFRC}$	average compressive strength of UHPFRC (measured in cubic specimens)
$f_{cf,UHPFRC}$	average flexural strength of UHPFRC
f_s	stress of reinforcing bars
f_y	yield strength of reinforcement
h_b	depth of the beam section
$h_{f,c}$	crack depth
H_c	column height
w_{cf}	crack width
w_{lim}	crack limit width
l_b	free span of the beam
L_b	distance between beam supports
L_{base}	base length of extensometer measurements
L_{splice}	splice length
$M_{b,n}$	nominal flexural strength of beam elements
$M_{b,max}$	maximum experimental strength of beam elements
s	transverse reinforcement spacing
v_{jh}	joint shear stress
$V_{c,max}$	measured maximum force
$V_{u,est}$	estimated ultimate force
λ	joint distortion
δ	midspan deflection
$\delta_{b,t}$	deformation at the top face of the beam
$\delta_{b,c}$	deformation at the bottom face of the beam
Δ_c	horizontal drift
$\Delta_{c,w}$	horizontal drift due to the crack opening
$\theta_{b,av}$	average rotation
λ	overstrength factor for steel
λ_0	overstrength factor
$u_{sp,av}$	average bonding stress
ϕ	curvature

ject the beam–column connection to lateral loads, such as wind, water and earth pressure, accidental actions, and settlements. The setup and experimental process were intended to test critical bond conditions in connections under the action of alternative loads.

The development of new materials is an opportunity to innovate. In that direction, the development of the ultra high performance fibre reinforced concretes (UHPFRC) has defined a dynamic line of research, which is currently focused on identifying applications that take advantage of the outstanding material properties and give alternatives to common practical problems. Structural or architectural requirements can make the use of UHPFRC in whole elements viable; particularly applications in slender elements such as sections of footbridges and shell roofs [2–4]. However, an optimal use of these materials aims at local applications in high demanded regions where the material cost and the benefits associated whit its use seem economically more adequate.

Besides the outstanding compressive and tensile behaviours, the positive effect of UHPFRC on the bond conditions of bar reinforcement is notable [5–8]. Several studies have been carried out to assess the viability of using UHPFRC in short reinforcement splices for concrete structures. However, most part of those studies has been focused on connections between precast slabs or bridge decks and the information available about connection of larger flexural elements is scarce. Splice lengths as short as seven times the bar diameter have been successfully assessed for an alternative bridge deck connection in order to avoid the use of loop connections [9–12]. The use of Fibre Reinforced Concrete (FRC) to improve the behaviour of beam–column connections has been studied during the last decades and a moderate effect on shear and flexural capacity has been reported [13–17]. Vasconez et al. [18] studied the use of cast in place high performance fibre reinforced concrete elements in external beam–column connections and more recently different proposals to incorporate UHPFRC in beam column-connections have been successfully tested for precast and monolithic structures [19,20].

2. Research program

This paper describes an experimental research project carried out to assess the use of UHPFRC in short reinforcement splices, which can encourage the use of continuity connections between precast elements. Moreover, this paper deepens on the study of beam–column connections as a practical application of continuity connections. Finally, an alternative proposal for moment-resisting frames in precast construction is presented. As part of the research project, a two stage experimental study was carried out in collaboration with the Technical Department of PRAINSA and the Structural Laboratory of the Instituto de Ciencias de la Construccion Eduardo Torroja. During the initial stage, four beam flexural tests were performed to experimentally assess the behaviour of short reinforcement splices in simple flexural elements. In the second stage, an alternative interior beam–column connection for moment resisting frames was proposed and tested. A detailed description of the test program is presented in Maya, 2011 [21].

3. Flexural test

As part of a first experimental program, four beam elements were fabricated and tested. According to their sectional dimensions and reinforcement layouts the elements were classified in two different types; VT-1 and VT-2. Fig. 1 presents the dimensions of the elements. The main parameter considered was the reinforcement splice length.

3.1. Details of the test units

The elements tested were composed of two precast concrete beam elements connected in a central region made of UHPFRC poured *in situ*. Design details of the tested elements are presented in Fig. 1. The cross section of elements VT-1 was 200 mm wide and 300 mm deep, while element VT-2 was 380 mm wide and 400 mm deep. Top and bottom longitudinal reinforcement consisted of two 20 mm diameter bars for elements VT1 and three 20 mm diameter bars for element VT-2. The transverse reinforcement for all the precast beam elements was 10 mm diameter closed stirrups at 100 mm spacing. The spacing was reduced to 50 mm in the end supported region of the beam elements to avoid shear failures. In the splice region, instead of closed stirrups, only straight bars without vertical ties were tied over and under the longitudinal reinforcement at spacing of 100 mm. Although these bars were located at top and bottom splices, they were mainly intended to