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Experimental assessment of the composite joints shear connector component

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ABSTRACT

One of the methods adopted for the composite semi-rigid beam to column joints characterization is the component method present in the Eurocodes 3 and 4 that considers the composite action in the model by incorporating the component contributions of the reinforcing bars, concrete and shears connectors. However, the model is based on not fully validated assumptions of the composite joints structural response mainly located in hogging moment regions. All these aspect have limited the adoption of this method for composite joints design. These issues motivated the conception and development of an experimental programme to investigate semi-rigid beam to column joints, by means of pull out tests. The present paper focus on tests that presented failure modes associated to the shear connector failure. Additionally a study was also made on the resistance of shear connector welds. This investigation was provoked to some observed shear connector weld failures in a few pull out tests. The tests results enabled a better understanding of the shear connector weld resistance and their impacts and influence over the global semi-rigid beam to column joints structural response.

1. Introduction

The composite construction development has been motivated by the observation of the optimum solution regarding the structural system concrete slab versus steel beam interaction. Extensive investigations have been carried out during last decades on steel-concrete composite joints and the associated nonlinear behaviour of the various components present in composite beam to column joints [4–11]. Piluso [4] suggested a procedure for characterizing the behaviour of some types of composite semi-rigid joints subject to positive and negative bending moments under seismic loads in the context of EC8 [3]. Liew et al. [5–7] conducted six experimental tests of steel-concrete composite joints, comparing their results with the EC3 [1] provisions indicating that some procedures could be reviewed in future versions of the code.

Kattner and Crisinel [8] proposed a finite element model for composite joints where the concrete slab and steel column were modeled as beam elements and the shear connectors, steel joint and the concrete slab to the column steel flange interaction adopted spring elements. Braconi et al. [9] studied the behaviour of composite joints under cyclic loads, proposing a model that has been compared to experiments and were complemented with a parametric study performed to illustrate the ability and the behaviour of the examined joints. Da Silva et al. [10] conducted experiments on internal and external joints under positive and negative bending moment identifying the contribution of the concrete confinement in the composite columns under symmetrical and asymmetrical loading. Pisarek [11] proposed a model based on the components method to evaluate the composite joint characteristics. Significant advances have been obtained in particular, regarding the use of mechanical models, based in the components method, which allows the prediction of the joint global moment versus rotation curve, from the knowledge of the individual components mechanical and geometric properties [4].

The EC4 [2] prescribes a procedure to characterize the behaviour of joints subjected to hogging moment. In this regions the tensile stresses generate concrete cracks in a perpendicular direction to the transverse reinforcing bars; it reduce the materials adherence and, consequently, the joint stiffness as the concrete cracks increase locally. The main aim of this paper is to present a series of pull out tests focused on determining and analyzing the shear connector component and the influence of the shear connector welds over the global composite semi rigid beam to column joint response.

2. Composite semi-rigid beam to column joints

The structural design of steel beam to column semi-rigid joints is performed through a meticulous evaluation of their response based on their mechanical and geometric characteristics. However, for the composite

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beam to column semi-rigid joints, the current design standards still do not prescribe a procedure with the required clarity and accuracy. One of the most used recommendations is the Eurocode component method [1–2]. For the composite portion, however, the reinforcing bar component is the only term incorporated to the of steel joints model.

The support regions under hogging moments is influenced by numerous elements other than the reinforcing bars, as suggested by the of the EC 4 composite joint model [2]. In addition, the influence of the reinforcing bar component is still not fully understood in relation to the effective length that should be used for determining of the composite joint initial stiffness. The most significant composite joint components are: concrete slab, reinforcing bar and shear connectors.

A fact that should be considered in the study of components is related to the study of the force transmission. The way starts at the beam flange, passes from the beam flange to the shear connector and from there to the concrete, where the interaction between two components occurs. This force path proceeds from the concrete to the reinforcing bars, where an interaction between these components also occurs. Finally, the reinforcing bar action starts. All these facts have motivated the development of an experimental program [12–15], to investigate the composite components that influence the overall response of the composite beam-column semi-rigid joints in hogging moment regions.

3. Experimental program characterization

The Taguchi method [16], or robust design method, was adopted to determine the series of experiments of the present experimental programme with a reduced amount of variables. The tests to be performed based on this methodology considered the following variables: length, diameter and number of main reinforcing bars, concrete strength, shear connectors number and spacing.

Thus the experimental program consisted of two test groups: the first, related to the pull out tests, was developed in two series (S2010 series, denoted by the letter r, and S2014 series). The purpose of these series was to study the influence of the components present in the composite portion, by simulating the hogging moment area in the pull out test layout. A second test configuration was also investigated to determine the strength of the shear connectors welds. This was motivated by the occurrence of this failure mode in tests series, a failure mode that was not predicted in the design stage. This paper will be focused in the tests where this shear connector weld rupture occurred and a subsequent group of test performed to investigate the influence of the shear connector weld leg over this component strength. The second part of this experimental program focusing on other two failure modes, the reinforcing bars tensile rupture and anchorage capacity, is presented in an accompanying paper.

3.1. Preliminary tests

Two preliminary tests, PO0.1 and PO0.2, were performed to evaluate the pull out system assembly and check the developed load application system. A steel beam system was created to fix the test to the laboratory reaction slab, referred as auxiliary structure. The system was conceived to induce axial tension forces in the reinforcing bars by the application of the hydraulic jack load, Fig. 1. The way in which the load was introduced in the tests provide for the possibility that this load could be applied by the hydraulic jack over the whole extension of the steel web profile, it transmitted to the shear connectors and from them to the concrete slab., it continues to the main reinforcing bars that are anchored to the laboratory reaction slab.

The PO0.1 aimed to calibrate the applied loads and the reinforcing bar collapse mode, as well as check the resistance of the auxiliary structures, that it were again verified with test PO0.2.

Three different reinforcing bar sets were used. The first composed of 5 mm diameter bar utilized to acquire the concrete strains close to the shear connectors. The second set was composed of 10 mm diameter stirrups, as prescribed by EC 4 [2], positioned in longitudinal and transverse directions, along the slab length. Finally the main reinforcing bars, with 16 mm diameter, located at one third of the slab width, adopted two bars per slab, 650 mm anchoring length and a 1150 mm full length.

The preliminary tests beam was made of a ASTM A-572 Gr.50, W410 × 46.1 steel profile with steel with a 1000 mm length. The pull out load application structure used ASTM A-36, U 6 × 12.5 and I 3 × 10 rolled steel profiles in the longitudinal and transverse directions, respectively. The first and second level bracing structure was fixed to the laboratory reaction slab with circular dywidag bars.

Stud shear connectors with a 19 mm diameter and 100 mm length were welded to the steel profile flange (three connectors in PO0.1 and two in PO0.2 tests). The stud's shear connectors of the preliminary tests were initially shop welded with the standard equipment. However they were longer than the concrete slab thickness requiring of their removal, shortening and subsequent weld to the profile flange by a manual welding process, thus meeting the planned specification. The failure modes achieved in the preliminary tests confirmed the required strength capacities of the adopted stud shear connectors.

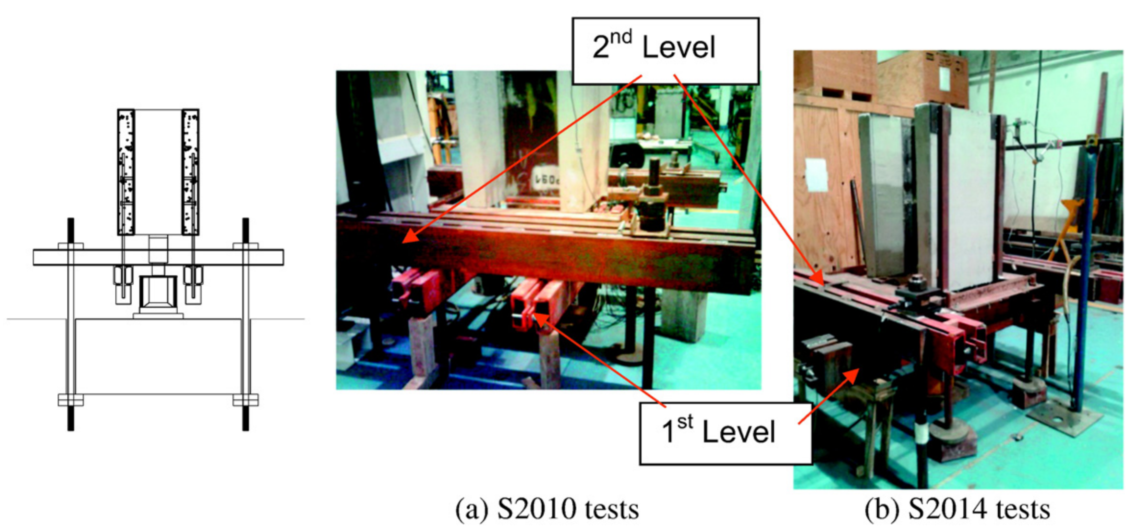

Fig. 1. Pull-out test layout and bracing system details.