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Numerical assessment of slab-interaction effects on the behaviour of steel-concrete composite joints

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ABSTRACT

In current design practice for seismic resistant steel braced frames, general rules and standard provisions are aimed to ensure a structural behaviour for beam-to-column joints of non-braced spans as close as possible to perfect hinges. This is done to prevent any kind of interaction with the bracing systems, in particular under horizontal loads. However, the global performance of composite joints is markedly affected by the structural interaction between the concrete slab and the steel components and - especially during seismic events - struts can occur in the slab at the beam-to-column intersection.

In this paper, the possibility of realizing a composite joint that behaves as moment-resisting under gravitational loads and essentially as hinged under horizontal loads is investigated. Aiming to assess the actual slab-interaction effects on the overall response, a full 3D Finite Element (FE) model representative of a beam-to-column composite joint taking part of a braced frame is described in ABAQUS and validated towards past full-scale experiments. A parametric study is hence proposed, by accounting for three geometrical configurations, being characterized by (i) isolated slab with absence of rebar continuity (i.e. fully disconnected slab and steel joint only), (ii) presence of slab with partial column interaction (i.e. isolated slab and continuity of rebar), (iii) presence of fully interacting slab. It is shown that, if properly detailed, a joint with isolated slab and continuous rebars can be used in non-braced spans of composite braced frames without affecting the behaviour of the bracing system (i.e. as in presence of a hinge). Nonetheless, the composite beam can be designed as continuous on multiple supports under vertical loads, hence leading to a reduction of the steel cross-sectional size.

1. Introduction

The seismic behaviour of steel-concrete composite joints is highly affected by the structural interaction occurring between the concrete slab and the steel components at the beam-to-column intersection. This aspect has specific relevance for the design of braced frames, where the overall performance of the joints placed in non-braced spans should be as close as possible to perfect hinges, hence preventing any kind of interaction with the bracing systems [1,2]. During a seismic event, compression forces can typically arise in the concrete slab in the vicinity of the column, leading to the occurrence of struts in contact with the steel flanges. In this regard, it is thus necessary to fully understand the influence of possible interaction effects among the joint components, in order to properly assess their global response.

To this aim, the structural behaviour of composite joints attracted a multitude of research studies, over the past decades, see for example [3–16]. Most of past experimental and numerical outcomes currently represent the reference background for design procedures in use for steel-concrete composite structures. In [8–9], careful consideration was given to the detection of concrete confinement effects in composite columns, including an assessment of strength and stiffness degradation phenomena.

Several experimental tests have been carried out on various joint typologies, aiming to explore their stiffness, strength, ductility and energy dissipation capacity.

Finite-Element (FE) numerical models developed to further investigate past experimental tests have been also proposed during last years, aiming to predict the inelastic response of exterior and interior beam-to-column joints, both under monotonic or cyclic loads (see for example [17–20]). Despite the large number of research contributions, however, most of the past FE investigations have been mainly focused on the prediction of the global behaviour only of various joint typologies.

In [20], differing from existing research projects, a full 3D refined FE numerical study was proposed, aiming to assess both the global and local behaviour of steel-concrete composite joints. Taking advantage of accurate FE numerical models developed in the ABAQUS computer software [21] and validated towards full-scale experimental test results available in the literature for a welded composite joint, it was shown that the actual geometrical and mechanical properties of a given joint and its components details, as well as their reciprocal interactions, can be properly taken into account, hence resulting in rather accurate

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simulation of even complex mechanical phenomena. Critical discussion of FE results suggested in fact the use of refined FE predictions as a valid support and/or alternative to costly and time consuming full-scale experimental tests, since allowing extensive parametric investigations of composite joints - including a wide set of geometrical and mechanical configurations for steel-concrete structural systems - with careful consideration for both global and local effects.

2. Objectives

In this paper, following [21], a further Finite Element (FE) numerical investigation is proposed for beam-to-column steel-concrete composite joints. As a reference joint typology, the full-scale experimental study reported in [23] is taken into account and explored. At a preliminary stage of the ongoing research study, the experimental specimen presented in [23] is first numerically reproduced (see Section 3), so to validate all the mechanical and geometrical assumptions for the reference FE model. The so implemented model is then used to numerically assess and emphasize the actual effects of slab-to-column interactions on the overall performance of the examined steel-concrete composite joint, when subjected to various loading conditions. To avoid the interaction between the slab and the column, the Eurocode 8 [2] suggests in fact a 'total disconnection' of the slab components near the column. In this paper, conversely, the possibility to take advantage of the continuity of the longitudinal rebar is investigated.

In particular, through a set of parametric FE analyses, three different geometrical configurations are considered for the reference full-scale specimen, being aimed to characterize the actual load bearing performance of (i) the steel joint alone (i.e. isolated slab with absence of rebar continuity), (ii) the isolated slab with continuity of longitudinal rebar, and (iii) an almost fully interacting slab (even with a small gap, on one side of the column only).

Based on the FE comparative results partly summarized in this paper, it is shown that the isolation of the slab is typically associated to important effects on the structural performance of the joint. As far as the slab is properly isolated from the column - even with a small gap - any kind of over-strengthening effect on the given joint response is in fact fully avoided, hence allowing to better control the overall seismic response of the braced frame it belongs. In particular, under the action of lateral loads (e.g. earthquakes or wind), as also in line with current design regulations [1,2], the joint can be described as perfectly hinged, and the lateral loads are directly transferred to the bracing system (even in presence of continuous longitudinal rebar). Under the action of gravitational loads, in contrary, the continuity of the longitudinal rebar is typically associated to a mostly clamped performance of the joint, hence with an overall response of the steel-concrete composite beams which is close to continuity on multiple supports.

3. Finite element numerical investigation

3.1. Reference experimental specimen and past test results

As a reference geometrical configuration, the steel-concrete composite joint experimentally investigated in [23] was taken into account, see Fig. 1. The reference specimen, based on [23], consisted of Italian IPE300 type steel beams, with 2.1 m the nominal length, and an HEB260 type column, with 2.77 m the total height. The steel beams were used to support a concrete slab, 120 mm in thickness and 1 m in width (see also the transversal cross-section given in Fig. 2). In it, the longitudinal rebar was given by 8ϕ14 and 8ϕ6 bars, lying on the top and bottom slab layers respectively. Steel shear studs, 19 mm in diameter and 75 mm in total height, were then used to provide a fully rigid mechanical connection between the slab and the steel beams. Those shear connectors were 75 mm and 150 mm spaced along the transversal and longitudinal beams axis, respectively.

In terms of slab-to-column connection, at the time of past experimental tests, a 25 mm wide gap was realized on the left side of the specimen, being representative of the key aspect for the full assembly procedure and investigation, see Fig. 2(b). Such a design choice was in fact aimed to explore the occurrence and propagation of specific failure mechanisms in the specimen, due to slab-to-column mechanical interactions. Four M20 bolts (8.8 their resistant class) were finally used to

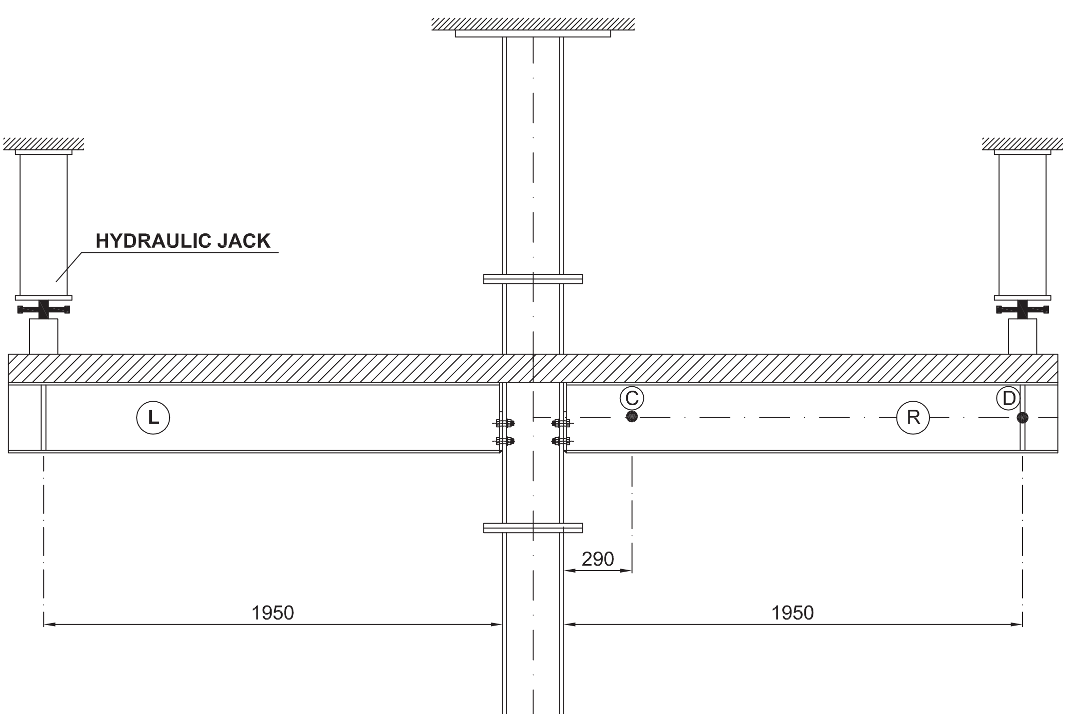

Fig. 1. Reference full-scale specimen object of investigation, in accordance with [23]. Front view (nominal dimensions given in mm).