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Analytical model for composite joints under sagging moment

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ABSTRACT

Nowadays, modern codes and standards such as the (Eurocode 4, 2004) deal with the characterisation of steel–concrete composite joints in building structures, mainly under hogging bending moments in the beam. However, in sway composite frames or when the composite structure is subjected to an accidental/exceptional event such as earthquake or column loss, the beam-to-column joint may be subjected to sagging bending moment, a loading situation which is not yet covered by the codes. This paper deals with the behaviour of composite beam-to-column external joints under sagging bending moments, mainly focusing on the specific joint component "concrete slab in compression". Indeed, if reference is made to Eurocodes, the method recommended to characterise structural joints is the component method and the "concrete slab in compression" component has been identified as the missing component to be able to apply this method to composite joints subjected to sagging bending moment. In this article, the finite element method is used to model the slab using VecTor 2 software. Through the performed numerical simulations, the behaviour of the slab is studied in detail and an analytical model is proposed. With the proposed model, it is possible to characterise the concrete slab in compression component and so, to apply the component method to predict the mechanical properties of composite joints subjected to sagging bending moment.

1. Introduction

The use of a concrete slab connected to a steel beam in buildings is widely spread. This assembly of steel and concrete components has demonstrated many advantages in comparison to steel beams working alone in terms of stiffness and resistance [2–4]. One of the key elements when using such composite members are the joints between the composite beam and steel columns which must transfer bending moments and shear forces with an appropriate stiffness (Fig. 1).

For composite beams, one of the key parameters for their characterisation is the effective width of the concrete slab. The effective width can be defined as the width of the slab which, when subjected to a constant stress equal to the compression capacity of the concrete, produces the same slab resistance associated to the actual stress distribution affected by shear lag effects. On this basis, the effective width b_{eff} is given by the following formula in which F_{ult} is the ultimate slab resistance, f_c is the compressive strength of the concrete, and d_{eff} is the slab thickness:

$$b_{eff} = F_{ult}/f_c \cdot d_{eff}. \tag{1}$$

Due to the difficulty of estimating F_{ult} in practice, many studies have been conducted to propose methods to easily predict the effective width of a composite beam or of a composite joint.

du Plessis and Hartley [5] carried out sixteen experimental tests; they were mainly dedicated to the investigation of the behaviour of composite joints subjected to positive (sagging) moments (slab in compression). The objective of the conducted investigation was to determine the effect of seven test variables, amongst which the shrinkage of the slab concrete and the concrete strength. The authors concluded that assuming the value of the maximum concrete stress equal to 1.3 times the characteristic strength f_c acting over a width equal to the column flange width represents a good lower bound to assess the maximum strength of concrete slab in compression in composite beam-to-column joints.

Tagawa et al. [6] conducted tests on a full-scale six-storey frame with composite beams under horizontal loads. They estimated the concrete maximum stress at 1.8 f_c. On this basis, an analytical formula was proposed to determine the effective width at the joint level.

Liu and Abolhassan [2] investigated sixteen full-scale cyclic tests on shear connections. Focusing on the resistance and the contribution of the slab, they suggested an effective width equal to two times the width of the column flange.

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Civjan et al. [7] tested six specimens under reversed cyclic loading, three of which were composite slab specimens. The main conclusion was that the slab compressive zone at the column flange was wider than the column face, and distributed at approximately 15° to 30° from the column considering the crack patterns. It was shown that the concrete stresses did not reach the value of 1.3 f_c proposed in [5].

Combined analytical and experimental tests were performed by Liew et al. [8] on seven composite joints and one steel joint (used as reference). A value of effective width equal to the column flange width is adopted to assess the positive moment resistance at the joint.

Castro et al. [9] focused on effective widths of composite beams for elastic and elastoplastic stages of behaviour. Based on results from finite element analyses, the authors proposed analytical formulae to assess the effective width at the elastic stage estimated as higher than 80% of slab width. They concluded that the effective width is influenced by a large number of parameters. The concrete stress reached 1.2 f_c due to the confining effects.

Four composite beam tests were conducted by Amadio et al. [3] in order to provide an experimental reference for previously conducted investigations, which involved numerical simulations using ABAQUS software [4]. Through the conducted studies, they proposed to keep the values provided by EC4 for composite beams under sagging bending moments.

Niea et al. [10] studied the effective width by using both finite element method and experimental tests on composite beams. They found that the effective width is closer to the whole slab width of the tested specimens at the ultimate stage.

Niea and Tao [11] made evaluation of the effective width of composite joints through analytical investigations which involved also finite element simulations using ANSYS. They found that the main parameters were the column flange width and the steel beam height. Authors provided an analytical formula to estimate the effective width at the joint.

Most codes and standards define the effective width on the basis of an elastic stage hypothesis.

Eurocode 4 [1] proposes rules for the determination of effective widths for continuous beams in buildings to perform elastic analysis. The effective widths for composite beams in buildings are defined as equal to $b_{e1} + b_{e2}$ in which b_{ei} is the minimum of Le/8, L_e being the distance between the zero moment's points, and of $b_i/2$, b_i being the distance between two adjacent beams. In the Chinese code [12], the proposed value for the effective width is equal to $L_e/6$ on each side of the considered composite beam.

Ahn et al. [13] compared different codes from USA, Canada, UK, Europe, and Japan. Through a numerical example of a simply supported beam, the authors found that under some limits of length span to slab width ratio, EC4 and British code give the largest value for the effective width.

For composite joints under sagging moments, the effective width differs from that of composite beam because of a local phenomenon: the concrete slab bears against the column over the steel flanges. This phenomenon significantly influences the distribution of stresses within the concrete slab at the joint level and so affects the effective width which should be considered locally for the joint characterisation.

This paper investigates the influence of parameters such as the steel reinforcement percentage, the slab width, the column shape and the mechanical properties of the concrete on the distribution of stresses in the concrete slab and so, on the definition of the joint effective width. The main aim of this work is to provide an analytical formula for the estimation of the effective width (validated through comparisons to numerical results) to be considered at the ultimate stage for the characterisation of the concrete slab in compression component; through this appropriate definition of effective width, it will be possible to predict accurate values of the strength and of the stiffness of the considered component in order to compute the composite joint characteristic through the component method.

2. Numerical simulations

In order to assess the ultimate compressive strength of the concrete slab at the joint level, VecTor2 finite element software [14] is

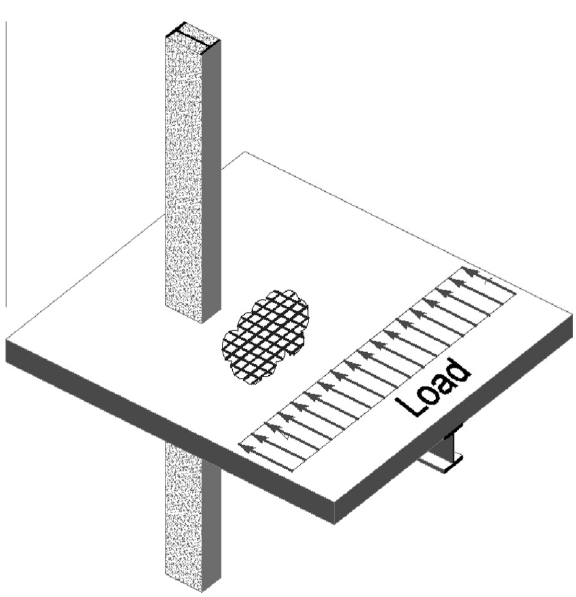

Fig. 1. Composite joint configuration.

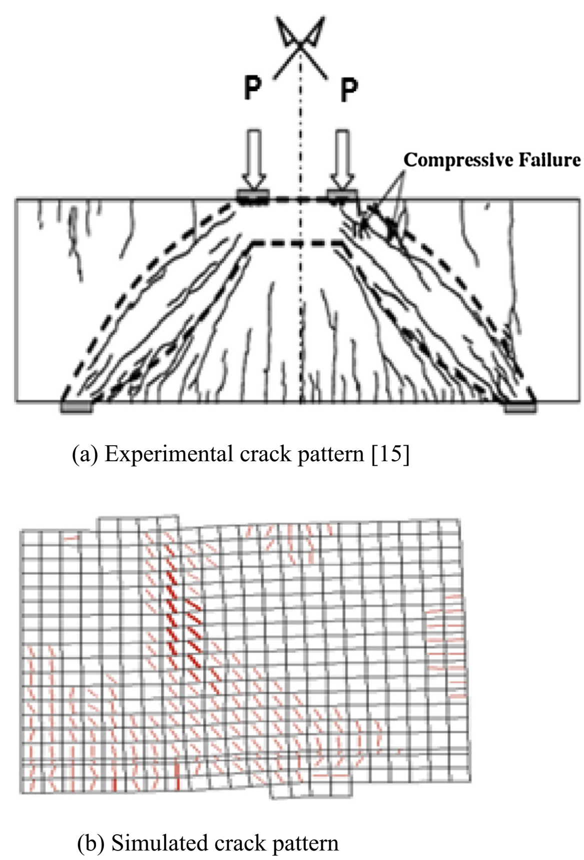

Fig. 2. Tested deep beam's parameters used for the validation.