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Ultimate strength of a beam-to-column joint in a composite slim floor frame

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ABSTRACT

The paper studies numerically the behaviour of a beam-to-column joint between a hat-shaped steel beam (WQ-beam) and a concrete-filled composite column in a slim floor steel-concrete composite frame. 3D continuum elements are used in the discretization of the joint with contact surfaces between the components. Both material and geometrical nonlinearities are included. The computational results are verified by comparing them to experimental results. The verified model is applied to study the development of the load-transfer mechanisms in the joint. The load carrying capacity of the joint is categorized on the base of five parameters: the flange width, the web height, the wall thickness and the corners of the console, and the gap between the WQ-beam endplate and the column face. In addition, a criterion to evaluate the limit load of the joint is proposed. The design capacity of the joints from the proposed criterion is compared with the values calculated according to both other criteria and design code. It can be concluded that the proposed criterion is suitable for estimating the resistance of the studied joint.

1. Introduction

A slim floor system is constructed by containing the supporting steel beams within the depth of the floor deck. The slim floor systems have been extensively applied in commercial and residential buildings, hospitals etc. because it provides a floor system with minimum constructional depth, and it offers important benefits in terms of cost and fire resistance. The structural behaviour of composite slim floor system has been studied in terms of the integrated composite slim floor beam and in terms of the connection between the asymmetric slim floor steel beams and columns [1–6].

One type of slim floor beam, called WQ-beam, has been manufactured and widely applied in Nordic Counties. The WQ-beam is hat-shaped, torsional-rigid, box beam and is intended to speed up erection of multi-storey buildings due to the use of the standardised steel and precast concrete elements. Several types of joints, such as claw joint, bolt joint, or bracket joint have been used to connect WQ-beam and column [7]. A novel beam-to-column joint for connecting WQ-beam to concrete-filled composite column has been developed in recent years because of low construction costs, simple installation process, high installation tolerance, and easily ensured quality control. The main components of the joint include circular concrete-filled composite column, WQ-beam with an endplate, steel console with an endplate, and tension-bar shown in Fig. 1(a). The steel console (short RHS tube) is welded to the concrete filled CHS columns in the factory. At construction site, the WQ-beam can be released from the crane after it has been put down to the console. The endplate of the WQ-beam is cross on the top flange of the steel console. The tension-bar, which is inserted through the column, is designed as lateral bracing and will be welded to the column and the WQ-beam at the construction site. The floor slab can be hollow-core or composite concrete slab with a concrete topping.

Since design rules, related to this type of joints, are neither provided in EN 1994-1-1 [8] nor in EN1993-1-8 [9], a series of static tests have been performed on full-scale double-sided beam-to-column joints by the research group at Tampere University of Technology [7]. The results of one type of joint have been sent to the authors' research group for further studies. From the test results [7], especially from the load-deformation curves, two phenomena are noticed: no clear value for the yield load can be observed; and the peak loads have normally been reached through large deformations in most tests. For the joint studied in this paper, the peak load has not even been reached before the termination of the tests to protect the testing equipment. It seems that the joints exhibit high ductile behaviour because the loads carried by the joint still increase after initial yielding. Therefore, it is necessary to further investigate the load transferring mechanisms inside the joint; and check if the large deformations in joint are acceptable for determination of the capacity of the joint. Further investigation, on selecting a suitable failure criterion for the limit capacity, is necessary.

In this regard, a 3D finite element model is constructed by using the general purpose finite element software ABAQUS [10]. ABAQUS/Explicit is selected because it can effectively handle severely nonlinear

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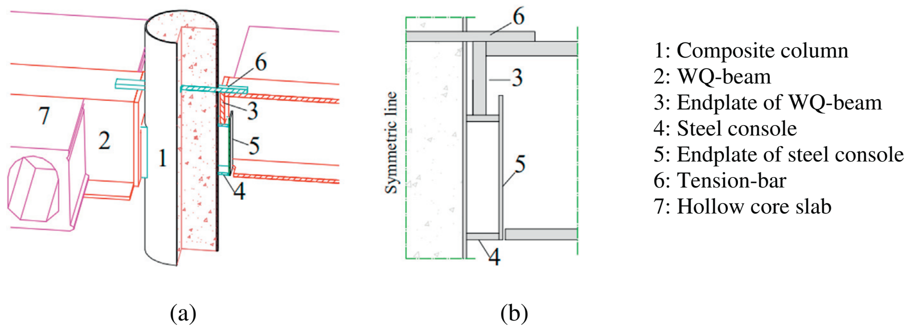

Fig. 1. A novel joint for composite slim floor frame. (a) Main components of the joint; (b) Detailed components of the joint.

behaviour of structures, for instance contact problems. The FE results are validated by the test results and the load transferring mechanisms inside the joint are investigated. Accordingly, different criteria used to determine the ultimate capacity of the joint are discussed. Finally, five parameters, which presumably have the main influence on the ultimate capacity of the joint, are concluded and eventually, a reasonable criterion is proposed, based on the results of parametric studies. The proposed design strength is evaluated by using the design equations which are provided for general joints.

2. Three-dimensional finite element model

2.1. Geometry of the joint

Totally, nine full-scale double-sided beam-to-column joints were investigated in the tests. One of the joint tests is chosen to be used in verifying the FE model. The FE model is created as based on the test setup as shown in Fig. 2(a). One end of the WQ-beam is supported by a roller while the other is connected to the column by the joint considered (see Fig. 1). The base of the composite column is bolted rigidly to the laboratory floor. The loading is generated through four identical hydraulic actuators, and it is transmitted to the WQ-beams by drawbars that are connected to loading-beams on top of the WQ-beam. The distance between the drawbars on each side of the beam is 700 mm. The middle line of one side loading-beam is at the distance of 350 mm measured from the centre of the column. No axial load is applied to the column.

Since the joint under consideration is symmetric about composite column, only one half of it is modeled, as shown in Fig. 2(b), in order to improve the computation efficiency. Table 1 shows the dimensions of each component of the joint specimen. All welds in the joint are fillet welds except the top flange of the console which is fixed to the column by a groove weld. The weld size between the console and the column is 6 mm. An endplate is welded to the other end of the console with weld size of 5 mm, likewise the tension-bar to the hollow steel section and to the WQ-beams.

2.2. Material properties

The structural steel for WQ-beam, hollow steel column, console and tension bar are modeled as elastic-plastic material with isotropic hardening both in compression and in tension. The von Mises plasticity criterion is used to define the yield surface. The yield strength and ultimate strength are 355 MPa and 510 MPa, respectively. The modulus of elasticity, E_s, and Poisson's ratio, ν_s, are assumed to be 210 GPa and 0.3, respectively. The strain of steel at the ultimate strength is defined to be 20%. True stress and true strain as input are required by the analysis software, and hence the engineering stress and strain are converted to true stress and true strain.

The material properties of the concrete in the composite column are simulated by using Damaged Plasticity Model in ABAQUS because it affords a possibility for the analysis of concrete structures under static, dynamic, or cyclic loading. The inelastic behaviour of concrete is defined by combining the isotropic tensile and compressive plasticity. The stress-strain curves of concrete in uniaxial compression and tension are employed in the FE model. The values of the stress and strain are calculated according to EN 1992-1-1 [11]. The grade of the concrete is C35/45. The parameters in this model have constant values; dilation angle ψ is 30°, the flow potential eccentricity e is taken to be 0.1, the compressive meridian K_c is 2/3 and the ratio of the compressive strength under biaxial loading to uniaxial compressive strength f_{b0}/f_c is 1.16. The tension

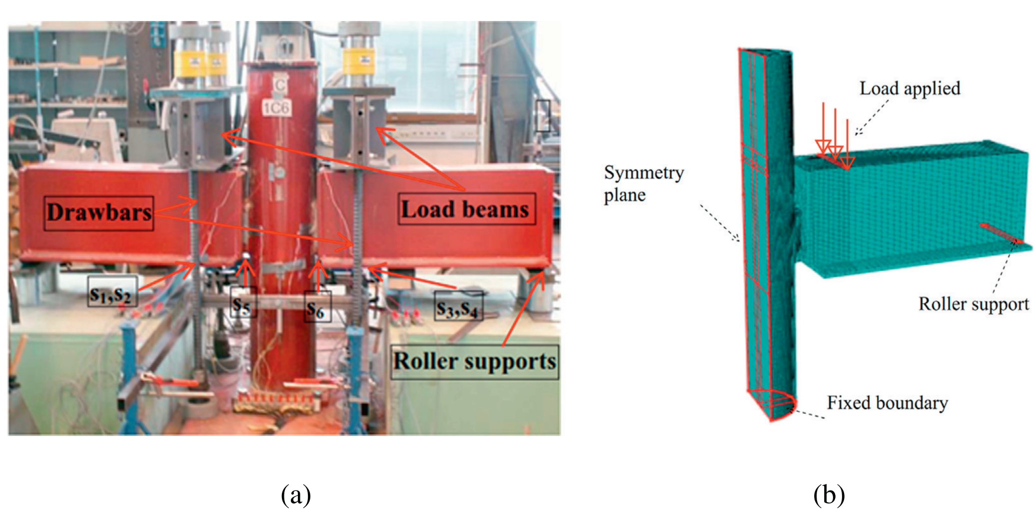

Fig. 2. Geometry of the joint. (a) Test; (b) FE model.