Journal of Constructional Steel Research 148 (2018) 627–638

Contents lists available at ScienceDirect

Journal of Constructional Steel Research

Behaviour of structural sub-assemblies of steel beams with openings in fire conditions

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ARTICLE INFO

Article history:
Received 30 March 2018
Received in revised form 7 June 2018
Accepted 20 June 2018
Available online xxxx

ABSTRACT

Beams with web openings represent an attractive system for multi-storey buildings characterized by long spans. Openings in web of steel beams enable building services to be integrated within the constructional depth of the floor, thus reducing the total floor depth. This paper employs the general finite element software ABAQUS to numerically model the behaviour of restrained structural subassemblies of steel beam with web openings to concrete filled tubular column under fire loading scenarios. Steel beams, in this case, are axially restrained which results in a drastically different behaviour when compared to unrestrained beams. In this research, a comprehensive finite element (FE) study of the behaviour of structural subassemblies of steel beams with openings under fire scenarios is conducted. Four sizes of perforated steel sections with seven different opening configurations are modelled and studied in order to understand the significance of their effects. Moreover, the influence of applied load ratios in addition to the level of axial restraint are examined. Consequently, considerations for the performance of axially restrained perforated steel beams under fire scenarios is provided.

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1. Introduction

Perforated Beams have many architectural and structural applications that promote their use. They provide space for services hence reducing the required floor height in multi-storey buildings. Many researchers have experimentally and numerically studied the performance of perforated beams at ambient temperature. Available research studies focused on the behaviour of open web steel beams at room temperature while focusing on opening shapes and sizes, cost optimization, collapse mechanisms, vierendeel action across openings, web post resistance and deflection [1–8].

Despite the enormous amount of research literature on perforated steel beams at ambient temperature, few publications can be found on the behaviour of perforated steel beams in fire. Liu and Liew [9] performed a series of finite element analyses on simply supported cellular beams with large openings, constituting 75% of beam's height, at elevated temperatures using SAFIR software. Nadjai et al. [10, 11] carried out four full-scale fire tests on axially unrestrained simply supported composite cellular beams. Following the above-mentioned experimental program, a number of other numerical and experimental fire studies have been carried out on perforated beams such as those by Wong et al. [12], Wong et al. [13], Bihina et al. [14], Vassart et al. [15], Goodfellow et al. [16]. Nadjai et al. [29] conducted a full-scale test of long span 15 m cellular beams under realistic fire. Wong and Burgess [17], Bihina et al. [18] and Ellobody and Young [19] studied the influence of tensile membrane action on fire-exposed composite concrete floor-steel beams with web-openings. Heidarpour and Bradford [20] focused on the elastic local buckling of web of I-section beams as one of the main failure modes of perforated beams at elevated temperatures. Wang et al. [21] and Nadjai et al. [22] recently conducted experimental and numerical studies on open-web steel and composite beams while targeting reaching adequate safety under fire conditions through passive protection. However, the common factor between all the above studies is that they were carried out on axially unrestrained simply supported composite cellular beams. Without considering the axial restraint, reported results have shown that the failure mode for beams under fire is the same as the one observed under the ambient temperature: mostly web post buckling or vierendeel mechanism. Consequently, the fire did not cause any noticeable difference in beam's behaviour.

Many researchers pointed out the importance of beam-to-column joint modeling and level of axial restraint on the global behaviour of structures. Efforts performed by Maggi et al. [26], Shi et al. [25] and

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https://doi.org/10.1016/j.jcsr.2018.06.023
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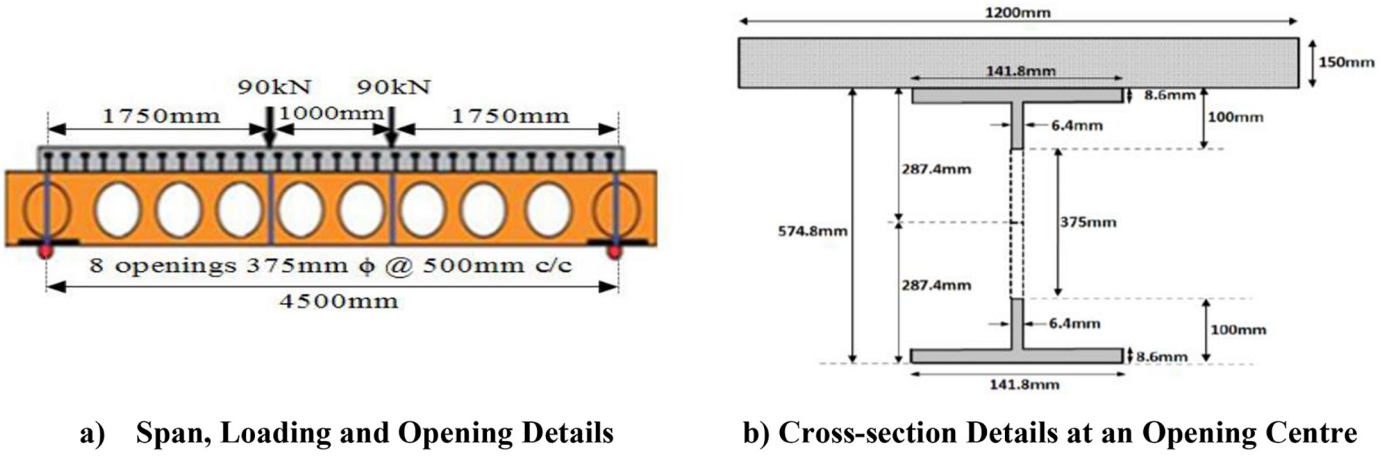

Fig. 1. General arrangements and geometric details of test beam A [10, 11].

Brunesi et al. [23] included proposing modeling procedures to account for partial restraint of different connection shapes under static and cyclic loads. Heidarpour and Bradford [24] investigated the behaviour of T-stub assembly in steel beam-to-column connection at elevated temperature and showed the significance of accurate modeling of beam-to-column connection in design. The first study for the behaviour of axially restrained steel beams in fire was performed by Yin and Wang [27]. They carried out a short numerical parametric study on a steel beam spanning 8 m while considering single and multiple rectangular openings. Heidarpour and Bradford [28] presented a generic nonlinear model of isolated steel beam, restrained at its two ends, at elevated temperature based on a validated finite element model. One of the other research efforts investigating influence of axially restrained perforated beams was performed by Nadjai et al. [29]. The authors carried out a large-scale fire test on composite cellular beams with circular and elongated circular openings forming parts of a full structure. Najafi and Wang [30] conducted the latest numerical study exploring the behaviour of axially restrained steel beams with web openings at elevated temperatures using ABAQUS software. However, so far, most of these experimental and numerical simulations considered the behaviour of isolated perforated steel beams with or without axially restraint structures without considering the real behaviour of the joint or the levels of resulting axial forces. Therefore, in the current research, a 3-D finite element model is created and validated using the commercial software package ABAQUS, in order to study the behaviour of structural subassemblies of steel beams with openings in fire. Accordingly, a parametric study is performed considering different factors including opening size, opening shapes, load ratio and level of axial restraint.

2. Validation of the finite element model

Finite element model must be validated before being used in a parametric study. There are no available test results in the published literature for axially restrained steel beams with web openings in fire. As a result, the finite element model was validated against the test data of two experimental fire tests on axially unrestrained simply supported composite cellular beams with symmetric (Beam A) and asymmetric (Beam B) steel beam sections, as reported by Nadjai et al. [10, 11]. The geometry, opening details and arrangements of the two tests specimens are shown in Figs. 1 and 2. Both beams were 4.5 m long with cellular cross sections and were made of steel Grade S355. The symmetric Beam "A" was produced using UB 406x140x39 for both the top and bottom tee-sections, having a finished depth of 575 × 140 CUB, 39 kg/m. The asymmetric beam "B" was constructed of UB 457x152x52 for the bottom tee-section and UB 406x140x39 for the top tee-section, having a finished depth of 630 × 140/152 ACUB, 46 kg/m. Both tests used a 150 mm thick by 1200 mm wide C35 concrete slab with wire mesh reinforcement A142, having yield strength of 460 N/mm^2. Full shear

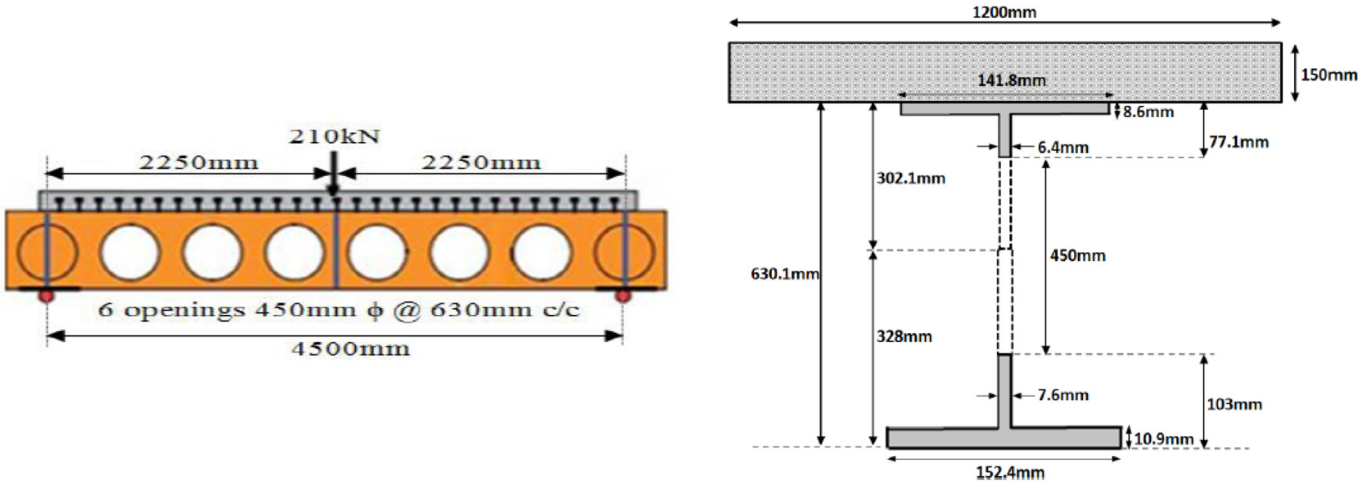

Fig. 2. General arrangements and geometric details of test beam B of Nadjai et al. [10, 11].

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