Journal of Constructional Steel Research 151 (2018) 25–40

Contents lists available at ScienceDirect

Journal of Constructional Steel Research

Component tests and numerical simulations of composite floor systems under progressive collapse

Bo Yang [a,b], Yong Yang [a,b], Xu-Hong Zhou [a,b], Qiang-Fu Jiang [a,b], Shao-Bo Kang [a,b,*]

[a] Key Laboratory of New Technology for Construction of Cities in Mountain Area (Chongqing University), Ministry of Education, Chongqing 400045, China
[b] School of Civil Engineering, Chongqing University, Chongqing 400045, China

ARTICLE INFO

Article history:
Received 18 April 2017
Received in revised form 30 August 2018
Accepted 12 September 2018
Available online xxxx

Keywords:
Shear connector
Double angle-cleat connection
Flush end plate connection
Experimental study
Component-based joint model
Finite element analysis

ABSTRACT

This paper presents experimental and numerical studies on the behaviour of components and composite floor system under column removal scenarios. Shear connectors, double angle-cleat connections and flush end plate connections were extracted from a three-dimensional composite floor system and tested under different loading conditions. The load-displacement curves of these components were compared with the results predicted from existing models. A simplified numerical model was developed to simulate the behaviour of composite floor systems subject to progressive collapse, in which the properties of springs were determined from component tests. The model was then validated against experimental results in terms of load-displacement relationship and failure mode. Finally, parametric studies were conducted to investigate the effects of slab thickness, aspect ratio and reinforcement. Numerical results suggested that the aspect ratio of slabs has the most significant effect on the load capacity of composite floor systems under progressive collapse scenarios.

1. Introduction

Since the partial collapse of the Ronan Point apartment tower in 1968, the behaviour of structural members against progressive collapse has been extensively investigated. The collapse of the World Trade Center in 2001 stirred up another flurry of research studies on the robustness of steel and concrete structures subject to extreme loads. In the last decades, a great number of experimental tests have been carried out on steel and composite structures under column removal scenarios. These tests mostly focused on beam-column joints [1] and two-dimensional frames [2–5]. Three-dimensional steel frame tests were conducted to study the force transfer mechanism of skeletal frames [6]. Numerical simulations have also been performed on different types of steel connections [7,8]. In recent years, three-dimensional floor systems have been tested under column removal scenarios to quantify the contribution of the composite slab to structural resistance [9,10]. It was observed that composite action between steel beams and the concrete slab affected the resistance and deformation capacity of floor systems [11]. However, only limited test data are available on three-dimensional composite floor systems. Furthermore, refined modelling methods to simulate the robustness of three-dimensional composite slabs were of complexity and low efficiency and need further improvement.

Composite action between the steel beam and the slab is generally provided by several types of shear connectors, among which shear studs have been widely used in construction practice. The shear resistance of shear studs can be obtained from the standard push-out tests [12–14], which was suggested in Eurocode 4 [15]. Finite element modellings were carried out by Qureshi et al. [15] on composite beams with trapezoidal profiled sheeting. Nonetheless, the influence of re-entrant profile decking on shear behaviour has rarely been investigated. Composite slabs with re-entrant profile decking developed higher load capacities [16] and it can also be used to replace reinforcement at the bottom of composite slabs [17]. This type of profile decking has been used in the test of three-dimensional composite floor system [11]. However, its behaviour under push-out load remains largely unknown and needs further experimental study. For steel structures and composite structures, connections are usually more vulnerable than members, so joint behaviour governs the robustness of structures. To accurately study the progressive collapse resistance of steel composite structures, the ultimate joint behaviour subjected to large deformations needs to be investigated. Yang and Tan [18] concluded that bolted beam-column joints under pure tension dominated the structural resistance against progressive collapse. As for flush end plate connections, beam flange may sustain compression force when subjected to hogging moment, and thus its compressive behaviour is also crucial to joint behaviour [5,11].

* Corresponding author at: Key Laboratory of New Technology for Construction of Cities in Mountain Area (Chongqing University), Ministry of Education, Chongqing 400045, China.
E-mail address: kang0119@cqu.edu.cn (S.-B. Kang).

https://doi.org/10.1016/j.jcsr.2018.09.008
0143-974X/

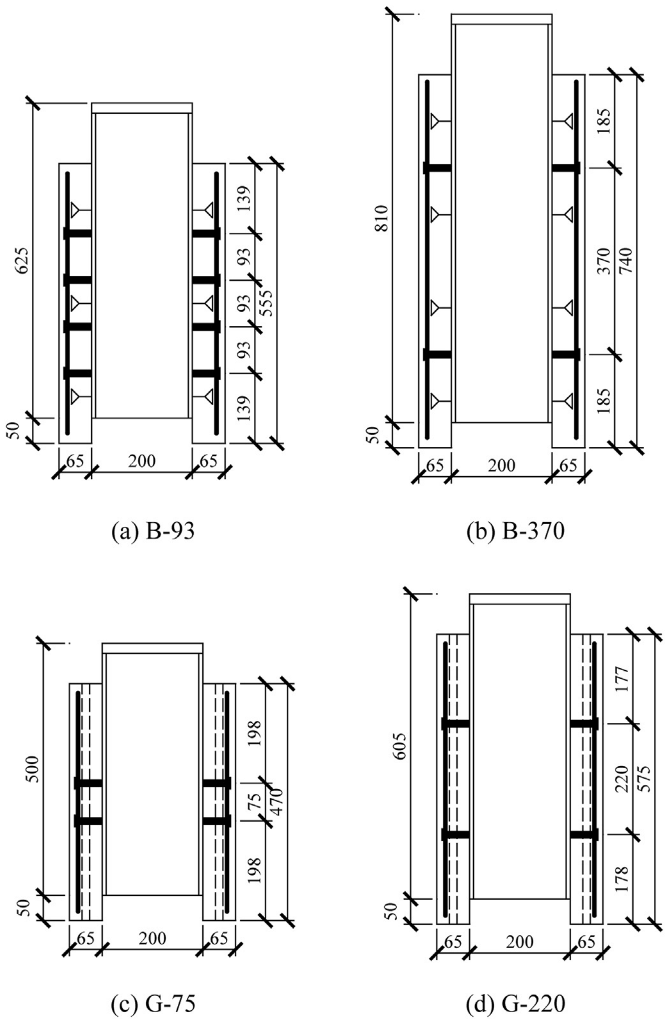

Fig. 1. Front view of shear connectors.

With regard to numerical simulations of composite floor systems, detailed finite element models always require relatively high computational cost due to a large number of elements and considerable interactions [19]. To improve the efficiency, connections are often assumed to be fully rigid or pin and no damage is introduced [20]. But Attempts have been made to further simplify the modelling by adopting component-based joint model and shell elements in the floor system [21,22], which treated the component of end plate or angles in bending as an equivalent T-stub [23]. Further numerical simulations and validations against experimental results are necessary by considering different components in the composite floor system.

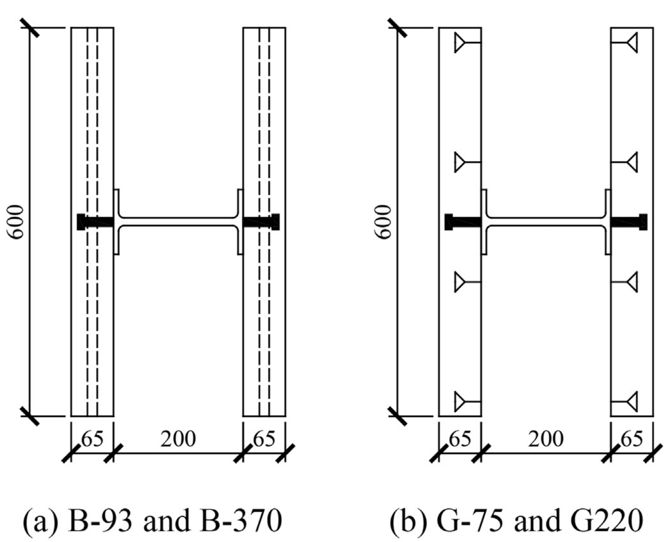

Fig. 2. Plan view of shear connectors.

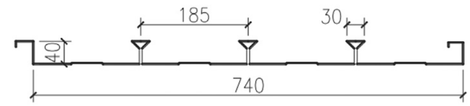

Fig. 3. Section of the profiled sheeting.

Table 1
Material properties.

Material	Yield stress (MPa)	Ultimate stress (MPa)	Young's modulus (GPa)
Steel beam	378.9	531.5	205.1
Profile decking	341.7	396.3	197.1
Steel mesh	339.7	501.3	213.9

This paper describes experimental and numerical studies on the resistance and failure mode of a composite floor system under an internal column removal scenario. Push-out tests were conducted for shear connectors between steel beams and concrete slab. As for girder-column and beam-girder connections, tension and compression tests were carried out to investigate the response under large deformation and to quantify the properties of each component respectively. Comparisons were made between experimental results and calculated values from existing models. Furthermore, the experimental results of the shear connector and components were incorporated in a numerical model to simulate the response of a composite floor system under a column removal scenario. The model was validated through test data and utilized for parametric studies to investigate the effects of slab thickness, aspect ratio and reinforcement on progressive collapse resistance under column removal scenarios.

2. Push-out tests on shear connectors

2.1. Specimen design and test setup

To investigate the behaviour of shear studs between steel beams and composite slab and to provide information on the properties of shear connections, four push-out tests were designed and conducted in accordance with Eurocode 4 [24]. Two typical configurations of profile steel decking were considered, namely, the ribs either perpendicular or parallel to the supporting beam. The former was to study the behaviour of shear connectors between secondary beams and composite slab, while the latter studied the behaviour between girders and composite slab. Figs. 1 and 2 show the geometry of specimens. In each specimen, a

Table 2
Load capacities and corresponding slips of specimens.

Specimen	Load capacity (kN)	Average load capacity of each stud (kN)	Slip at load capacity (mm)	Slip at failure (mm)
B-93	382.1	47.8	2.1	7.9
B-370	250.0	62.5	2.9	9.5
G-75	152.1	38.0	2.5	9.3
G-220	283.5	70.9	3.2	13.5