Journal of Constructional Steel Research 104 (2015) 137–154

Contents lists available at ScienceDirect

Journal of Constructional Steel Research

Behaviour of composite beam–column joints under a middle-column-removal scenario: Component-based modelling

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ARTICLE INFO

Article history:
Received 26 September 2013
Accepted 1 October 2014
Available online 29 October 2014

Keywords:
Beam–column joints
Progressive collapse
Web cleat
Flush end plate
Composite slab
Column-removal scenario
Component-based model

ABSTRACT

In this paper, component-based models of composite beam–column joints under a middle-column-removal scenario have been proposed. Two types of connections, namely, composite web cleat and flush end plate connections, are analysed. Middle joints under sagging moment and side joints under hogging moment are both considered. Failure criteria are introduced for most connection components, which enable the component-based models to predict the failure of these two types of composite joints. In general, these component-based models give acceptable predictions of the composite beam–column joint behaviour under a middle-column-removal scenario. In addition, frame analyses were conducted incorporating the developed component-based models for the composite joints. The main objective of the frame analyses is to identify the differences in structural performance between an isolated joint and a frame model under a middle-column-removal scenario. Finally, parametric studies are carried out to investigate the effects of reinforcement ratios, profile decking and composite slabs on structural behaviour incorporating the composite joint model. Based on energy-based analysis, dynamic effect is also considered and dynamic load-carrying capacities of composite frames are obtained. It is also found from a parametric study that the beam span-to-depth ratio has a great influence on the frame behaviour under a middle-column-removal scenario.

1. Introduction

Since the collapse of the World Trade Centre towers in 2001, many research works have been conducted in order to investigate the structural resistance to progressive collapse. Three research methods, including experimental tests [5,18,19,21,23,37–40], numerical simulations [11,12,16,20,32–34,36] and analytical derivations [2,4,39], have been used among these research studies. Among them, experimental test is the most effective and convincing method. However, it may not be suitable for every researcher and engineer because of the financial and time cost of the experimental test. Due to the complexity of progressive collapse analyses, finite element method is also usually used to simulate the complex loading and structural response. For the analyses of beam–column connections, detailed 3D FEM solid modelling is needed to obtain accurate responses of joints under progressive collapse condition. However, due to the complexity of using detailed joint models and significant computational cost, it is not feasible to use this method for conventional design although this numerical tool is used extensively in research. A more practical and simplified method of modelling joints is needed for analysing the behaviour of the whole structure against progressive collapse. Therefore, in this paper a mechanical model is proposed based on analytical derivations to simulate the composite joint behaviour under missing column scenarios. This method is practical and can be used in design office.

Alashker and El-Tawil [2] proposed a design-oriented model to compute the load-carrying capacity of composite steel concrete floors subjected to interior column loss. In this model, it is assumed that floor collapse is resisted through the development of membrane action in the slab elements and catenary forces in the steel beams. However, this model is only validated by numerical simulation results and Alashker and El-Tawil [2] recommended further experimental tests for the model validation. In addition, the whole load–displacement curves of the floor system cannot be predicted well by this model and only large deformation responses can agree with the numerical simulations. Besides, only shear tab connection was considered and the connection failure mode is assumed as bolt tear-out [32]. Further analytical works are needed in order to consider other types of connections and different failure modes.

EC3-1-8 [7] and EC4-1-1 [8] recommend component-based method for the analysis and design of steel and composite joints. In this method, the joint is divided into several individual components. The joint behaviour can be predicted by the assembly of various connection components.

In order to develop a better understanding of the behaviour of building structures under column-removal scenarios, the structure group at

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http://dx.doi.org/10.1016/j.jcsr.2014.10.003
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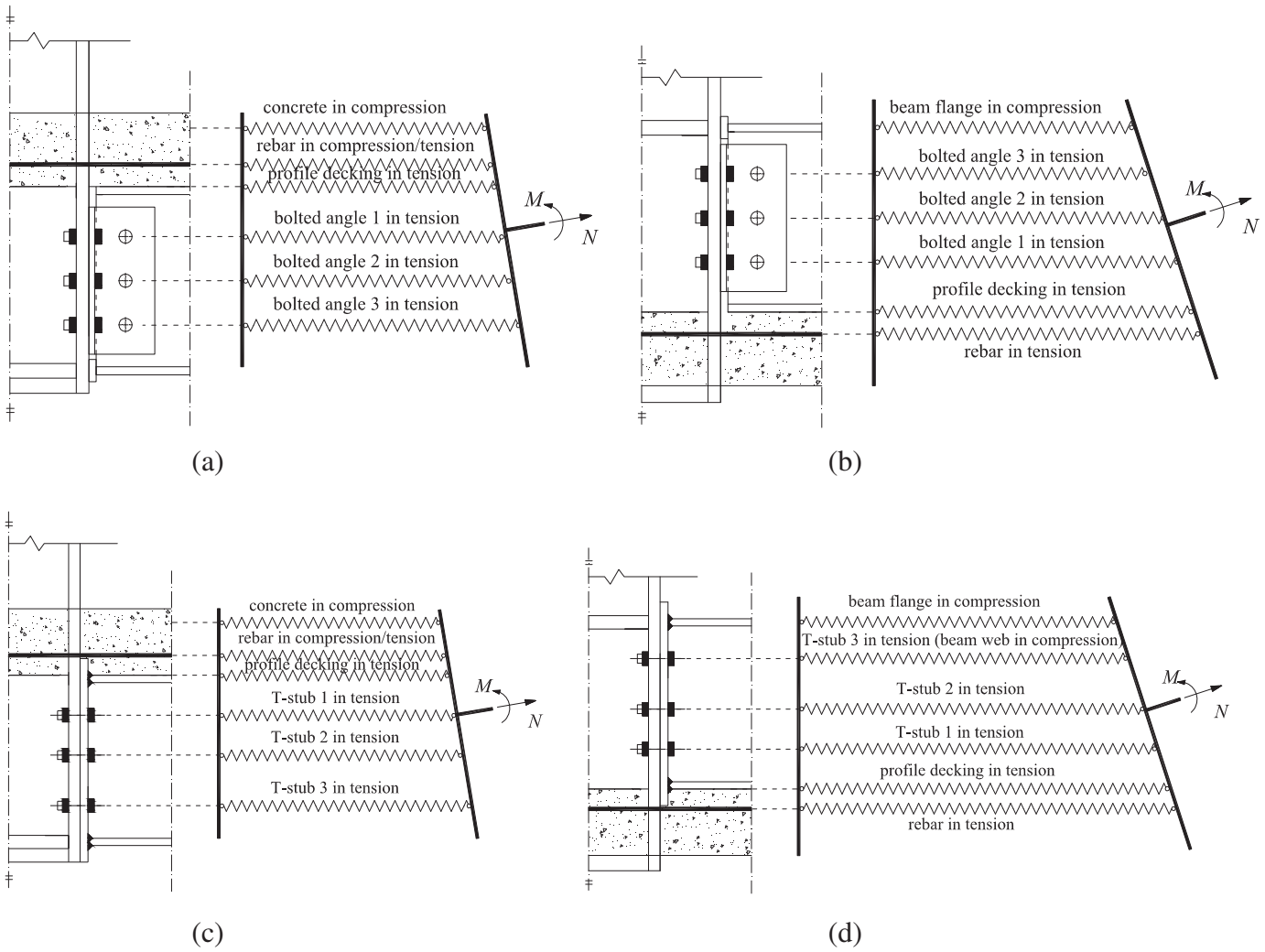

Fig. 1. Component-based models of composite beam–column joints: (a) web cleat connection at middle joint; (b) web cleat connection at side joint; (c) flush end plate connection at middle joint; and (d) flush end plate connection at side joint.

Nanyang Technological University has conducted a series of research projects to investigate the behaviour of steel, composite and concrete structures under column-removal scenarios [27,37,38,40–42]. Yang and Tan [40] conducted five experimental tests to investigate the behaviour of composite beam–column joints under a middle-column-removal scenario. Composite web cleat and flush end plate connections were studied. Two types of joints including middle and side joints were both tested to failure.

In the past, numerical and analytical models have also been developed to simulate the behaviour of composite beam–column joints [3,13,14,22,24,30,35]. However, these studies only included moderate joint deformations and were limited to moment–rotation relationships. In this study, component-based models are developed to predict the behaviour of composite beam–column joints up to total failure under a middle-column-removal scenario. The experimental results obtained from the tests of Yang and Tan [40] are used to validate the proposed component models. Finally, frame analyses are conducted incorporating the developed component-based models.

2. Component-based modelling of composite beam–column joints

In this section, component-based modelling of composite beam–column joints will be presented. The behaviour of composite beam–column joints under a middle-column-removal scenario can be predicted by these models. The experimental results presented by Yang and Tan [40] provide essential test data for the development and validation of the proposed component-based joint models.

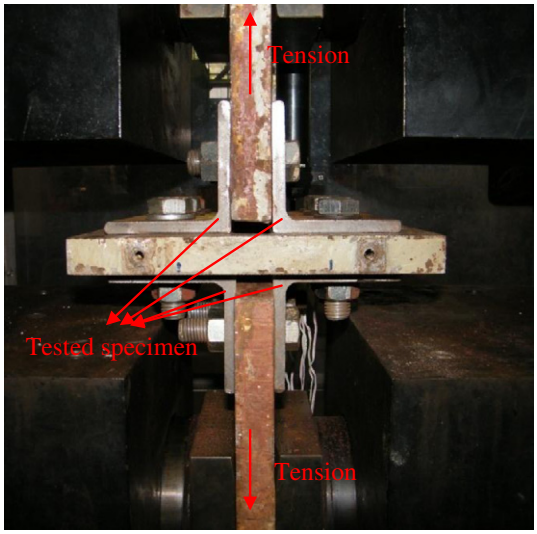

Fig. 2. Component test set-up.