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Numerical study of rigid steel beam-column joints under impact loading

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ABSTRACT

This paper presents the numerical simulations of rigid steel beam-column joints under impact loads. In the model, beams, columns and bolts are simulated by solid elements and surface-to-surface contact pairs are defined to take account of the interactions between beams and columns. Besides, a fracture model in ABAQUS is simplified to correlate the fracture strain to the stress triaxiality. Explicit dynamic solver is used in the simulations to overcome the problems of convergence induced by contact and fracture. Comparisons between numerical and experimental results demonstrate that the model is capable of predicting the dynamic responses of beam-column joints under impact loading with reasonably good accuracy in terms of the impact load and vertical displacement. Besides, the horizontal tension force in the joints can also be obtained from the numerical model, which shed light on the development of horizontal tension to resist the imposed impact load. Furthermore, a series of parametric studies is conducted to investigate the effects of impact energy and span-depth ratio (SDR) on the response of steel joints. Practical recommendations are provided for the design of steel joints under impact loading in accordance with the parametric studies. Finally, conclusions are drawn from the numerical simulations.

1. Introduction

Progressive collapse is defined as the spread of an initial local damage in a structure to surrounding elements which eventually leads to the collapse of a disproportionately large part or the entire structure [1]. Various types of design approaches have been introduced in relevant design guidelines to mitigate progressive collapse [2,3]. Among them, the alternate path method has been widely accepted as an effective way to evaluating the integrity and robustness of building structures. It considers a single column removal scenario as a standard design scenario and generally relies on the mobilisation of catenary action in the bridging beam and tensile membrane action in the slab system to mitigate progressive collapse [4].

Till date, extensive experimental and numerical investigations have been conducted on the behaviour of various types of steel beam-column joints subject to catenary action. Yang and Tan studied the resistance and deformation capacity of bolted steel beam-column joints under middle column removal scenarios through experimental tests [5] and proposed acceptance criteria for the rotational capacity of joints in accordance with a series of numerical simulations on the effects of bolt number and beam depth [6]. Khandelwal and El-Tawil simulated the catenary action capacity of special steel moment resisting frames with welded joints and reduced beam sections [7], in which different material and geometric properties of the frames were considered. Besides, a wide variety of beam-column joints with seismic design were modelled and best practice was recommended for the design against progressive collapse [8]. In the study on the dynamic behaviour of beam-column joints under high-rate loading, a methodology for combined rotation-extension testing was proposed by Tyas et al. [9]. Ribeiro et al. [10] conducted a series of numerical simulations by using ABAQUS to study the dynamic behaviour of T-stub joints. The effects of load magnitude, load application time and T-stub flange thickness were considered in the parametric study. Free fall tests were carried out to investigate the behaviour of web cleat and flush end plate joints under sudden column removal scenarios and to quantify the dynamic increase factor when catenary action was considered as the primary mechanism to resist progressive collapse [11,12]. The tests mentioned above indicated that the catenary action provides primary resistance rather than flexural when a large deformation occurred. The component model based on tensile spring was proposed by Fang [13], Yang [14] and Ribeiro [10] to predict the behaviour of beam-column joints under extreme loading.

To the authors' knowledge, limited studies consider the beam-column joints subjected to impact loads. This topic has been more or less neglected by the scientific community during many years, but it has received increased attention during the last few years. The impact loads might come from the impulse imposed by columns on the upper storeys due to the lack of supports. In addition, debris of structural members caused by accidental explosions may also generate impact loads on the beams, which has also to be properly considered. Experimental test was directly way to study the structures subjected to impact

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loads. However, numerical method was also chosen by researches to solve such problems due to its economy, efficiency and safety. Sabuwala et al. [15] studied the behaviour of fully restrained steel connections subjected to blast loads using finite element analysis. Rahbari [16] focused web shear failure of angle-cleat connections. The effect of rate of applied loading on connection response has been investigated by ANSYS LS-DYNA. Grimsmo et al. [17,18] carried out both experimental and numerical tests about end-plate beam-column joints subjected to impact and quasi-static loading. Tests results indicated that shear failure was more likely to occur than flexural failure under impact loads. Al-Rifaie et al. [19] focused on the behaviour and failure mode of end plate connections under lateral impact at two loading regimes. The related quasi-static tests were also carried out to find dynamic increase factors in impact tests.

In this paper, numerical models are developed for rigid steel beam-column joints subject to impact loading. Fracture models for ductile and shear failures are simplified and employed in the numerical simulations. The models are validated against experimental results of steel joints. Besides, a series of parametric studies is conducted on the effects of drop weight, releasing height and span-depth ratio (SDR) on the dynamic response of steel joints. Finally, practical implications and conclusions are drawn from numerical results.

2. Previous impact tests

Wang [20,21] carried out the experimental tests of rigid steel beam-column joints subject to impact loads. In total, nine steel joints were tested experimentally under impact loading. Fig. 1 shows the test setup and specimens for steel joints under impact loads. In the experimental programmes of rigid steel beam-column joints under drop weight impact, beam-column joints, comprising a steel beam and a middle column stub, were extracted between the inflection points of steel beams in a prototype building structure. Two pin supports were designed at both ends of the joints through which the joints were

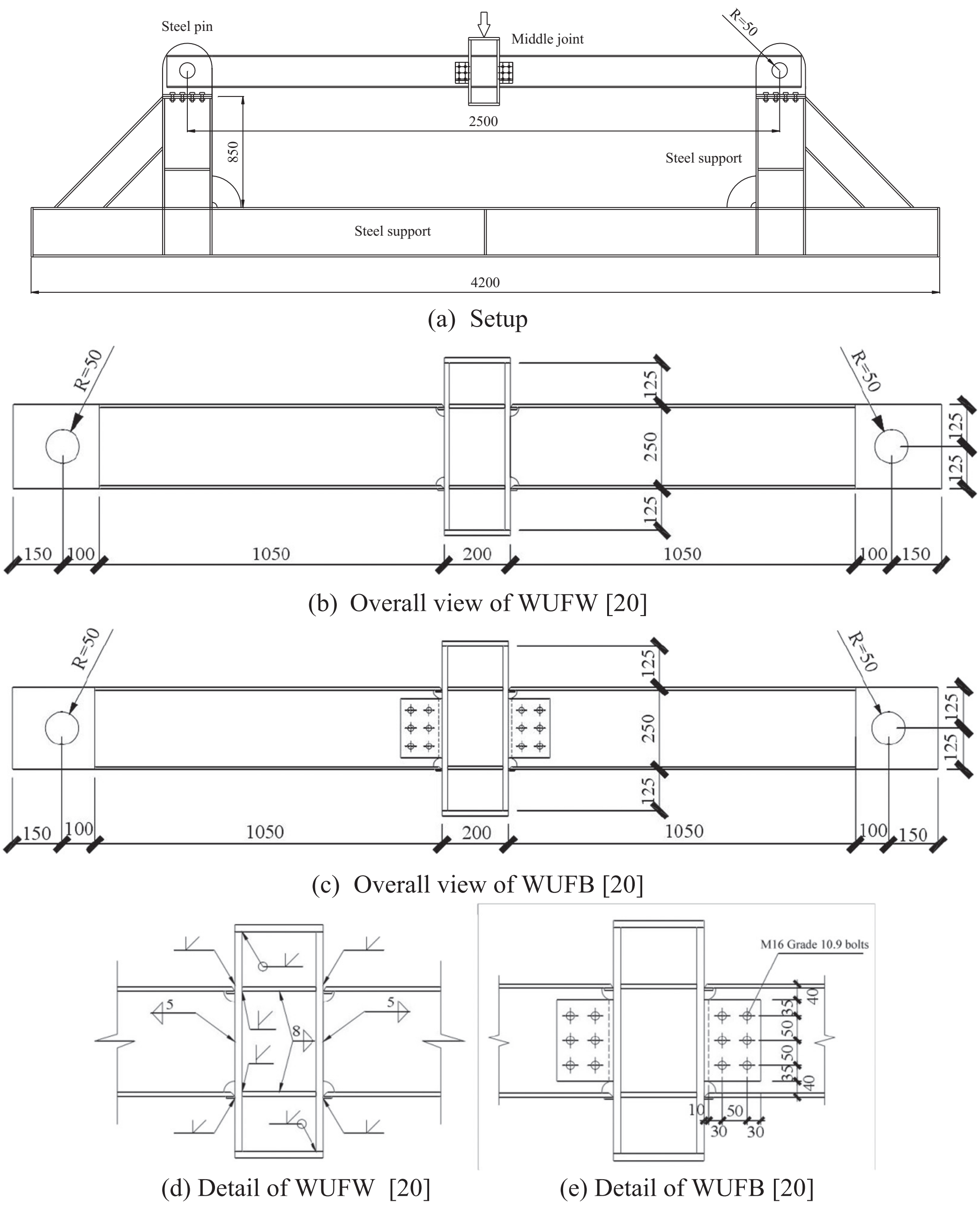

Fig. 1. Test setup for steel joints under impact loads.