Thin-Walled Structures 116 (2017) 113–123

Contents lists available at ScienceDirect

Thin-Walled Structures

journal homepage: www.elsevier.com/locate/tws

Post-earthquake fire performance of flange-welded/web-bolted steel I-beam to hollow column tubular connections

Qian-Yi Song[a,c,*], Amin Heidarpour[b], Xiao-Ling Zhao[b], Lin-Hai Han[c]

[a] China Southwest Architectural Design and Research Institute Corp. LTD. Chengdu, Sichuan Province 610093, China
[b] Department of Civil Engineering, Monash University, VIC 3800, Australia
[c] Department of Civil Engineering, Tsinghua University, 100084, China

ARTICLE INFO

Keywords:
Flange-welded/web-bolted connection
Cyclic loading
Pre-damage
ISO-834 fire curve
Post-earthquake fire
Hollow columns

ABSTRACT

Natural extreme events such as earthquake and fire are destructive for building structures. Earthquake is not only a destructive extreme event but also can trigger other extreme events such as fire. The possible post-earthquake fire (PEF) can be a more destructive scenario for building structures. For safety reasons, it is necessary to capture the behaviour of structural components under PEF scenario. This study aims to investigate the behaviour of flange-welded/web-bolted steel I-beam to box column connections subjected to PEF scenario. Experimental tests were carried out on two groups of steel connections under ISO fire. In each group, four connections were fabricated with the same specifications in which one connection was tested under fire only while the other three connections were tested under cyclic loading and subsequent fire. During the fire stage, the connections were subjected to constant static load equivalent to 30% of their ultimate monotonic loading strength. The furnace temperature, temperature distribution of connection and the beam deflection of connection were measured during the fire tests. It was found that the load-carrying capacity of the flange-welded/web-bolted connections decreases significantly with the increase of pre-damage level induced by cyclic loading. Additionally, in order to study the temperature distribution of the connections under fire, preliminary finite element modelling was carried out for a heat transfer analysis on the basis of uniform fire exposure.

1. Introduction

Natural disasters such as earthquake and fire can cause severe damage to cities and properties. Wide and huge structural damages are usually caused by ground motion due to earthquake. Depending on seismic intensity, steel structures may survive with various degrees of damage from no damage to collapse through earthquakes [1–3]. Especially in low to moderate seismic risk regions, such as Australia, the unprepared cities are also prone to damage by the low probability but high consequences earthquake events [4]. Damage of steel structures induced by earthquake is complex and it could be observed as residual deformation, loss of fire protection material, fractures, etc. It was also shown that the pre-damage caused by cyclic loading or high-strain loading would affect the mechanical properties of mild steel at elevated temperature [5–7]. The reported experimental investigations of simple welded and double-angle bolted steel I-beam to tubular column connections under cyclic loading have demonstrated cummulative damage process of different damage patterns under seismic loading [8–10]. Cyclic loading tests of other types of steel and composite connections also showed various cummulative damages [11,12]. The partially damaged structural components, connections or even systems, which survive in earthquake, are much vulnerable under secondary actions such as fire [13] and aftershocks [14]. For the possible post-earthquake fire (PEF) events, fire-resisting capacity of various structural connections would be affected by seismic loading significantly.

Several investigations can be found about post-earthquake fire behaviour of structures. Zaharia and Pintea [15,16] discussed the effect of damage level induced by the earthquake on the fire resistance of unprotected steel moment resisting frames. Della Corte et al. [17] investigated the fire resistance of the steel moment-resisting frames. It was found that the pre-damage caused by an earthquake is a key factor which influences the behaviour of steel structures [18,19] and steel-concrete composite joints [20–25] subjected to PEF. It indicated that when the residual deformation is not large enough the connection behaviour under fire would not be obviously affected by the pre-damage. Recently, the fire tests of simple welded connections with and without pre-damage showed significant decrease of the fire-resisting capacity [26] in which fracture was found one of the main damage that significantly affected deterioration of steel connection behaviour under

* Corresponding author.
E-mail address: soujy.qy@gmail.com (Q.-Y. Song).

http://dx.doi.org/10.1016/j.tws.2017.03.012
Received 1 June 2016; Accepted 8 March 2017

PEF. Residual deformation and residual strain/stress states were considered in a preliminary FE modelling investigation of steel connections exposed to PEF [27]. Moreover, Taylor [28] examined the factors involved in determining the safety of tall buildings exposing to PEF. Braxtan and Pessiki [29] presented investigation about damage patterns of sprayed fire resistive material on steel structural components due to a strong seismic event. Mostafaei and Kabeyasawa investigated the material degradation and heat penetration of a concrete building structure after earthquake [30]. Collier [31] presented the project endeavoured to quantify the resultant reduction in the fire resistance of a series of plasterboard lined lightweight timber and steel-framed walls.

Although the above mentioned investigations are related to behaviour of structures as a system under PEF, the experimental investigations on the structural components are still limited since various elements and complex factors might be involved. In this study, experimental investigation was carried out on the thermal-mechanical behaviour of two groups of flange-welded/web-bolted steel I-beam to hollow steel column connections affected by pre-existing damages induced by seismic loading. Cyclic loading tests were carried out and resulted in pre-damaged connections with different damage degree. Thus, ISO fire tests were conducted on the connections. Temperature distribution over various parts of the connections at elevated temperature were analysed and compared with the heat transfer analysis results on the basis of uniform fire exposure. Finally, the fire-resisting capacity of the connections with and without pre-damage were compared and analysed. The experimental results reported in this study provide understanding of effect of seismic loading induced damage on the fire-resisting capacity of the flange-welded/web-bolted steel connections. It indicates the necessity to evaluate structural behaviour under the PEF scenarios for safety reasons.

2. Experimental tests

2.1. Specimens and fabrication

Two groups of flange-welded/web-bolted steel connections were fabricated for the experimental investigation in this study. Four connections with the same configuration details were prepared in each group. Details of the flange-welded/web-bolted connections are shown in Fig. 1. All I-beams were made of 200UB22.3 (Grade 250 steel) [32]. The square tubular columns, with the cross-section of 200 mm × 200 mm made of the Grade 350 steel, were adopted. The tubular columns of the thickness of 5 mm and 9 mm were used which formed the two connection groups. The adopted steel angle was 65 mm × 65 mm × 6 mm whilst 8.8M10 bolts were used. The end plates on the columns were 8 mm thick steel plates while the stiffeners were welded on the I-beams at 1 m away from the column panel surface where the point load was exerted on the beam. The measured geometric properties of the fabricated columns and I-beams are listed in Table 1.

Table 1
Geometric properties of the connections (dimension in mm).

No.	Column			Beam			B_f/B_c
	B_c	t_c	B_c/t_c	$B_f \times H$	t_f	t_w	
CCH5F	200 × 200	5.07	39.45	131.6 × 203.0	6.64	5.14	0.658
CCH5EF22							
CCH5EF30							
CCH5EF38							
CCH9F	200 × 200	8.75	22.86	131.6 × 203.0	6.64	5.14	0.658
CCH9EF22							
CCH9EF30							
CCH9EF38							

Note: The meaning of the characters used in the specimens labels is as follows: C-connection, W-welded, H-hollow section box column, F-fire, EF-post-earthquake fire. The label 5 and 9 indicate the thicknesses of the tubular column wall in millimeters.

The two connection groups were labelled as CCH5 and CCH9, indicating this combined type connections with hollow tubular columns with the wall thicknesses of 5 mm and 9 mm, respectively. The 4 connection specimens in each group were labelled in terms of the loading scenario. For example CCH5**F** and CCH9**F** indicated the connections subjected to **f**ire loading while CCH5EF22 indicates the connection subjected to post-**e**arthquake **f**ire after experiencing **22** seismic loading cycles. It is noted that the average leg size of the fillet welds between the angle legs and the tubular column wall was measured as $t_w = 6$ mm; while the design thickness of the single-V welds between the I-beam flanges and the tubular column wall was taken as $t_w = 5.5$ mm.

2.2. Loading protocols and setup

In each group, the 4 connections were tested under different loading scenarios. One connection without pre-damage was tested under fire and it was taken as control test for comparison. The other 3 connections were first pre-damaged by cyclic loading and then subsequently tested at elevated temperatures. The cyclic loading protocol recommended by AISC-341 [33] was adopted in this research as shown in Fig. 2a. The

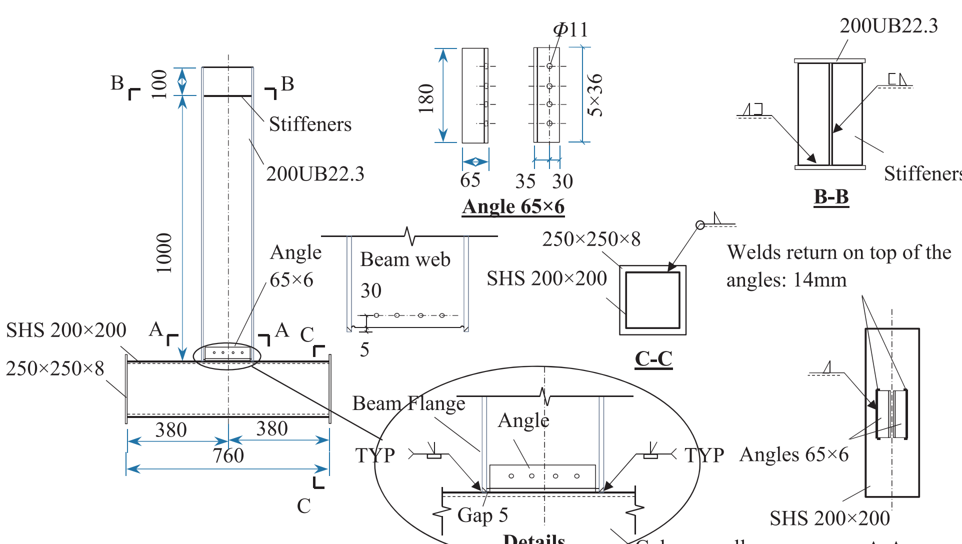

Fig. 1. Configuration details of flange-welded/web-bolted connections.