Available online at www.sciencedirect.com

ScienceDirect

Journal of Constructional Steel Research 64 (2008) 268–274

JOURNAL OF CONSTRUCTIONAL STEEL RESEARCH

www.elsevier.com/locate/jcsr

Experiment on restrained steel beams subjected to heating and cooling

Guo-Qiang Li[a,b,*], Shi-Xiong Guo[a]

[a] Department of Structural Engineering, Tongji University, 1239 Siping Road, Shanghai, 200092, PR China
[b] State Key Laboratory for Disaster Reduction in Civil Engineering, Tongji University, 1239 Siping Road, Shanghai 200092, PR China

Received 20 April 2007; accepted 23 July 2007

Abstract

This paper describes the performance of restrained steel beams in fire experiments that were completed recently in the Fire Laboratory of Tongji University. It is shown that restrained steel beams have better fire-resistant capability than isolated steel beams. At the beginning of heating due to fire, an internal axial compression force was produced in the restrained beams by thermal expansion. When the temperature was up to a certain value, the internal axial compression force in the beams began to decrease, and eventually the compression force vanished and the tension force was initiated, due to the increase in the deflection of the beams causing a catenary action. This phenomenon explains why a restrained steel beam has higher fire-resistant capacity than an isolated steel beam. After the fire went out, a larger tension force was produced in the restrained steel beams by contraction as the temperature decreased. In addition, local buckling at the bottom flange of the beams near the ends was observed in the experiments. According to the results from the experiments, the stiffness of the axial restraint plays an important role in the behavior of restrained steel beams subjected to heating and cooling in a fire.

Keywords: Steel structure; Restrained steel beam; Fire resistance; Catenary action

1. Introduction

Before 1990, research on the fire resistance of steel structures was mainly focused on isolated members, such as girders, columns and floor slabs, etc. In 1990, a fire occurred in a partly completed 14-storey office block at the Broadgate development in London [1]. From the investigation after the fire attack, it was found that the behaviour of the beams was strongly influenced by restraint provided by the surrounding structural components. Possible beneficial effects, such as catenary action of the beams or membrane action of the composite slabs, were not evident because only relatively low steel temperatures less than 600 °C were reached during the fire, but interactions between different structural members in a completed structure subjected to a fire drew the attention of researchers. In September 1996, a program of full-scale fire tests was completed on an eight-storey composite steel-framed building in the UK at Cardington Laboratory, to investigate the behaviour of a real steel-framed structure under real fire conditions. The typical 'runaway' displacement of isolated steel beams in the standard fire test did not occur to the steel beams in the building, even though the temperature of the bottom flange of the beam had exceeded 800 °C, which indicates that a steel beam in a framed structure, with the aid of restraint from surrounding members, has better fire-resistant capability than an individual steel beam [2]. However, it was found that local buckling of the bottom flange occurred near the beam-to-column connection during heating, because of tremendous compression stress at this point resulting from restrained thermal expansion. Damage of the beam-to-column connections was also observed, where bolts on the header plate of the beam sheared, due to thermal contraction of the beam during cooling [1,2].

So, it is necessary to carry out additional experiments to obtain a more detailed understanding of the behaviour of restrained steel beams subjected to fire. Considering that it will be very expensive to perform a fire test on a steel beam in a completed steel structure, an experiment on a single steel beam with restraint is often employed to simulate the behaviour of beams in a completed structure.

* Corresponding author at: State Key Laboratory for Disaster Reduction in Civil Engineering, Tongji University, 1239 Siping Road, Shanghai 200092, PR China. Tel.: +86 21 65983313; fax: +86 21 65983431.
E-mail address: gqli@mail.tongji.edu.cn (G.-Q. Li).

0143-974X/$ - see front matter © 2007 Elsevier Ltd. All rights reserved.
doi:10.1016/j.jcsr.2007.07.007

Using this method, Li [3], Liu [4] and Cong [5] conducted some fire tests on restrained steel beams. Li et al. [3] conducted a fire experiment on axially restrained steel beams. In the test, noticeable axial forces in the beam were measured. Liu et al. [4] investigated the effect of restraints on steel beams through fire experiments. In this test, it was pointed out that the restraint effect is important for the behaviour of the beam in fire conditions and catenary action was observed.

On the other hand, Huang and Tan [6] and Yin and Wang [7] analyzed restrained steel beams using finite-element methods. A simplified method was proposed by Yin and Wang [8,9] to predict the behaviour of restrained steel beams subjected to fire. Li and Guo [10] studied the behaviour of a restrained steel beam during the cooling phase, and a theoretical method was proposed. However, these theoretical studies cannot be validated comprehensively by the few experimental results at present.

Although lots of experimental and theoretical research on the restrained steel beams has been carried out in the past decade, damage to the beam-to-column connection of the restrained steel beams has not been investigated in detail, and the behaviour of restrained beams during cooling has seldom been addressed. Considering the shortcomings of previous tests, fire tests on two specimens of restrained steel beams with normal, rigid beam-to-column connections were carried out at the Fire Laboratory of Tongji University. In the tests, the behaviour of restrained steel beams subjected to heating and cooling was investigated.

2. Test arrangement

The skeleton of the experiment is shown in Fig. 1. Above the furnace is the specimen. Two specimens were tested one by one in the experiment. Each specimen was a sub-frame, including two columns at the two sides, two H-beams and a double channel beam, as shown in Fig. 2. The bottom H-beam was the restrained beam to be put in the furnace, while the top H-beam and double channel beam, to simulate the restraints, were outside the furnace and not exposed to fire. The difference between these two specimens lay in the location of the double channel beam, in order to apply different restraint stiffness to the restrained beam. In specimen 1 and specimen 2, the distance between the axes of the middle channel beam and the restrained beam were 1000 mm and 800 mm, respectively. The restrained beam was made of Q235B steel, and the other members were all made of Q345 steel. The beam-to-column connections of these two specimens are shown in Fig. 3. The difference between these two specimens was that M16 bolts were used in specimen 1, while M20 bolts used in specimen 2, since a larger internal axial force will be produced in specimen 2 due to the larger restraint stiffness. Through material tests, the average yield strengths of Q235B steel and Q345B steel were obtained as 271 MPa and 331 MPa, respectively.

In order to simulate the heat-sink effect resulting from concrete slabs on the steel beams in real building constructions, the top flange of the restrained steel beam was wrapped with

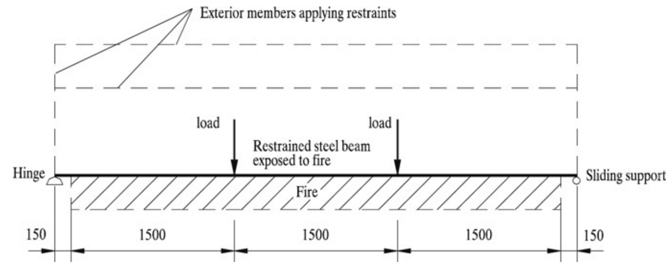

Fig. 1. Sketch of experiment.

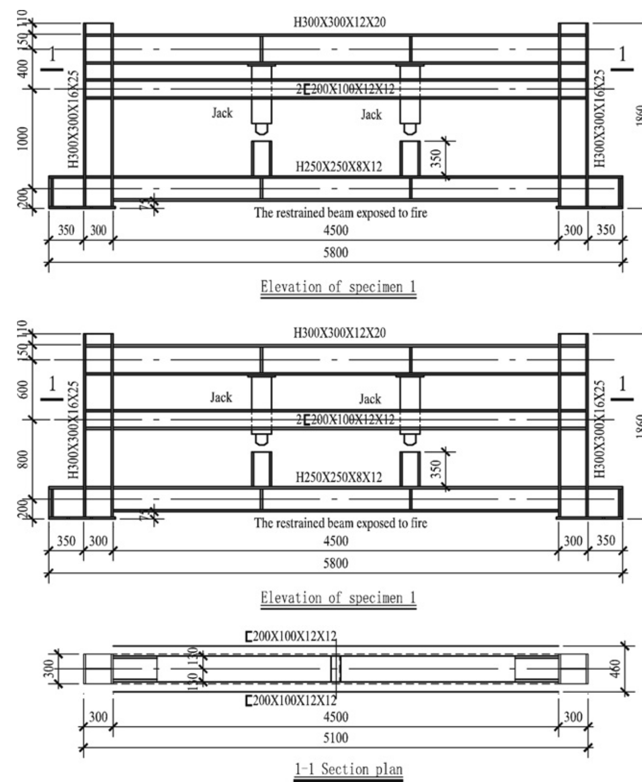

Fig. 2. Sketch of specimens.

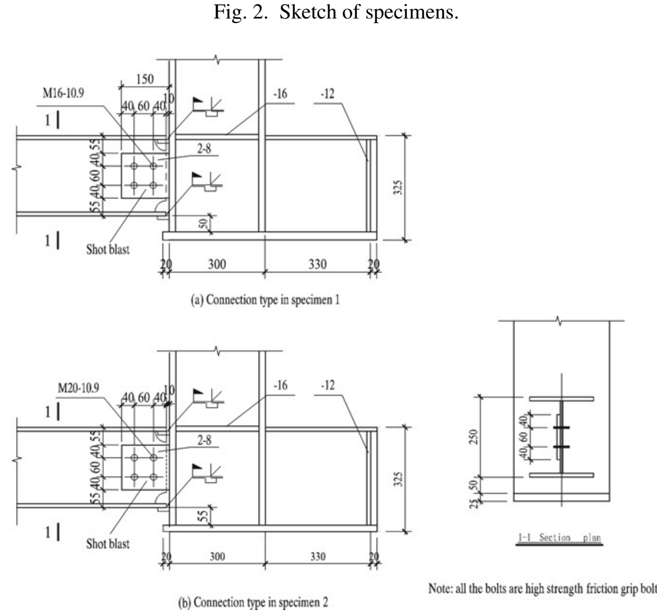

Fig. 3. Beam-to-column connections.