Available online at www.sciencedirect.com

ScienceDirect

Procedia Engineering 210 (2017) 544–550

Procedia Engineering

www.elsevier.com/locate/procedia

6th International Workshop on Performance, Protection & Strengthening of Structures under Extreme Loading, PROTECT2017, 11-12 December 2017, Guangzhou (Canton), China

An approach for evaluating fire resistance of steel beams considering creep effect

Weiyong Wang[a,b]*, Linbo Zhang[a]

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

Abstract

Most of previous studies on fire resistance of restrained steel beams neglected creep effect due to lack of suitable creep model. This paper presents a finite element model (FEM) for accessing the fire resistance of restrained high strength Q460 steel beams by taking high temperature Norton creep model of steel into consideration. The validation of the established model is verified by comparing the axial force and deflection of restrained beams obtained by finite element analysis with test results. In order to explore the creep effect on fire response of restrained Q460 steel beams, the thermal axial force and deflection of the beams are also analyzed excluding creep effect. Results from comparison infer that creep plays a crucial role in fire response of restrained steel beam and neglecting the effect of creep may leads to unsafe design. A simplified design approach to determine the moment capacity of restrained Q460 steel beams is proposed based on the results of parametric studies by considering creep effect.

Peer-review under responsibility of the scientific committee of the 6th International Workshop on Performance, Protection & Strengthening of Structures under Extreme Loading

Keywords: Fire resistance; creep; restrained beams; high strength steel; simplified approach

1. Introduction

The fire response of steel beams has been extensively studied in the last years [1], while the majority of them have been performed on isolated steel members. Realistic beams are generally under axial and rotational restraint by the surrounding structures, which influence its fire behavior, resulting in considerable difference between reality and

* Corresponding author. Tel.: + 15086885068
E-mail address: wywang@cqu.edu.cn

1877-7058 © 2017 The Authors. Published by Elsevier Ltd.
Peer-review under responsibility of the scientific committee of the 6th International Workshop on Performance, Protection & Strengthening of Structures under Extreme Loading.
10.1016/j.proeng.2017.11.112

previous studies. More and more studies and experiments on restrained members under fire conditions have been carried out recently. Liu et al. [2] tested the behavior of axially restrained steel beam in fire, considering non-uniform temperature distribution in beam section. The test revealed the effect of axial restraint on catenary action, which may be able to prevent the beam's deflection from running-away at high temperature. Li and Guo [3] investigated the response of two restrained steel beams during heating and cooling phases. The consequence showed that fire performance of restrained steel beams is superior to that of isolated beams and the stiffness of axial restraint has significant effect on response of restrained steel beams in heating and cooling process.

High strength steels have been extensively applied in modern engineering applications in China due to its higher strength and strength to weight ratio. One such widely used high strength steel type is Q460 steel, similar to ASTM A575 Gr65 steel in North America. The mechanical properties of high strength Q460 steel has distinctive degradation way at high temperature compared to mild steel due to different chemical composition and fabrication process. Wang et al. [4] performed tension testing on high strength Q460 steel in various high temperatures and obtained yield strength and elastic modulus as a function of temperature. In comparison to mild steel, it was shown that high strength Q460 steel has slower reduction of strength and stiffness in temperature range of 20~800℃.

In exposure to certain level of stress, even far below the yield stress, the steel structure can develop slowly and permanent deformation. This phenomenon is referred to creep and will be severe when subjected to high temperature for a long time, which may lead to premature failure without proper consideration in fire resistance design. Therefore, the influence of creep under fire conditions has been a focus emphasized by many researchers. Tan et al. [5] proposed a finite element program, considering both geometric and material nonlinearities, and a creep model, which can precisely predict the collapse load and critical temperature of steel frame in various conditions. It was shown that creep became dominant beyond 400 ℃. A series of numerical studies conducted by Kodur and Dwaikat [6-7] indicated that the impact of creep in high temperature on the fire resistance behavior of restrained mild steel beams is considerable and there is a better agreement between experimental results and analysis accounting for creep effects.

The current fire design codes, which mainly based on isolated mild steel beams, have not proposed effective method to evaluate fire performance of restrained high strength steel beams, let alone taking creep effect at high temperature into consideration. A comprehensive study was carried out by Wang et al. [8] on the high temperature creep strain in high strength Q460 steel and a corresponding constitutive creep model was presented. There is still a challenge in incorporating Q460 creep strain into fire resistance design due to lack of understanding of creep effect and practical design approach that can predict the fire response of restrained Q460 steel structures in fire. To overcome this knowledge gap, a numerical investigation was carried out and an approach is presented for evaluating fire resistance of restrained Q460 steel beams by employing the creep effect. The novelty of the current method lies in not only taking creep effect into consideration, but also simplicity and convenience.

2. Material properties of Q460 steel at elevated temperatures

2.1. Mechanical properties

There are huge differences of the reduction factor of mechanical properties between high strength Q460 steels and mild steels at elevated temperatures in consideration of the chemical compositions and fabrication process of high strength Q460 steels varying from those of conventional steels. Therefore, the proposed equations derived by Liu et al. [9] are selected to determine the yield strength and elastic modulus reduction factors of Q460 steel for a given exposed temperature.

$$\begin{cases} f_{yT}/f_y = \varphi(T) = -5.59\times10^{-14}T^5 + 1.38\times10^{-10}T^4 - 1.21\times10^{-7}T^3 \\ \qquad + 4.18\times10^{-5}T^2 - 4.67\times10^{-3}T + 1.07 \qquad\qquad 20°C \le T \le 800°C \\ E_T/E = \psi(T) = -1.38\times10^{-9}T^3 + 7.4\times10^{-7}T^2 - 3.69\times10^{-4}T + 1.01 \end{cases} \tag{1}$$