Journal of Constructional Steel Research 97 (2014) 48–58

Contents lists available at ScienceDirect

Journal of Constructional Steel Research

Effect of shear on fire response of steel beams

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ARTICLE INFO

Article history:
Received 5 September 2013
Accepted 27 January 2014
Available online 26 February 2014

Keywords:
Steel
Fire resistance
Shear capacity
Flexural capacity
Beams
Finite element modeling

ABSTRACT

Fire resistance of flexural members is derived based on flexural limiting criterion with no consideration to shear failure. However, under certain conditions, shear capacity can degrade at a higher rate than moment capacity in steel beams exposed to fire and this can lead to early failure of beams. This paper discusses the effect of shear on fire resistance of steel beams. For studying this phenomenon, a three-dimensional nonlinear finite element model capable of predicting fire response of steel beams is developed using the finite element package ANSYS. This model is capable of predicting fire response of steel beams under different conditions such as loading pattern, web slenderness and fire insulation. The finite element model is applied to evaluate fire response of beams with different geometrical configurations. It is shown that shear capacity can degrade at a higher rate than flexural capacity in certain scenarios and hence, shear limiting state can be a dominant failure mode in such flexural members.

1. Introduction

Structural members, when exposed to fire, experience loss of capacity and stiffness due to temperature induced degradation in strength and modulus properties of constituent materials. When the capacity at the critical section of a beam drops below the applied moment due to loading failure occurs in the member. The time to reach this failure is referred to as fire resistance. In current practice, failure in beams under fire conditions is evaluated based on flexural limit state without any consideration to shear capacity. This is in contrast to ambient temperature design, where a beam is generally designed to satisfy flexural limit state and then checked for shear resistance. Deriving failure in fire exposed beams based on flexural limit state, although valid for most common scenarios, may not be representative in certain situations where shear forces are dominant or shear capacity degrades at a rapid pace with fire exposure time. Also, in the case of beams with slender webs, shear capacity degrades at a much rapid pace than flexural capacity due to local buckling occurring in webs resulting from rapid rise in temperatures in webs.

Shear forces can be dominant in beams under certain loading configurations such as high concentrated (point) loads acting on the beam, as in the case of transfer girders. The most common example arises from concentrated loads near end of beams connecting to offset columns in buildings [2]. Another case where shear can control the design is in beams with reduced cross-sectional area (coped beams). Coped beams are usually used at beam-to-column joint connections. Moreover, short span beams subjected to high loads can fail due to shear rather than flexural effects. Further, in beams with slender webs, such as deep beams and plate girders, reserve shear capacity can be much lower at ambient conditions and under certain situations shear effects can trigger failure in fire exposed deep beams.

A review of literature clearly shows that most previous studies focused on fire behavior of beams where bending effects dominate response [1–5]. These studies considered effects of various factors on flexural response of steel beams such as restraint conditions, inelastic response, thermal gradients etc. Unfortunately, the effect of shear force capacity was not considered in evaluating fire response beams. In one notable study, Dharma and Tan [1] have developed a finite element model to evaluate inelastic rotational behavior of steel beams subjected to fire conditions. They applied this model to study the effect of web and flange slenderness on fire response of steel beams. The authors reported a noticeable decrease in flexural and shear capacity with an increase in flange and web slenderness. In addition, they reported that moment capacity of fire exposed steel beams decreases significantly in beams with slender webs due to occurrence of local buckling in webs. However, no specific observations were made with regard to the influence of web slenderness on shear capacity in fire exposed beams.

To evaluate the effect of shear on response of a fire exposed beam, a numerical study is carried out using a three-dimensional nonlinear

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http://dx.doi.org/10.1016/j.jcsr.2014.01.018
0143-974X/

finite element model. This model can trace the fire response of hot-rolled or built-in W-shaped beams subjected to significant bending moment and shear force. This model is applied to examine the influence of shear on fire response of beams under different loading configurations, web slenderness and fire insulation parameters.

2. Response of steel beams to fire

In conventional design, beams are subjected to significant levels of bending moment and thus failure typically occurs when the applied moment due to loading at the critical section exceeds the moment capacity. Therefore, under ambient conditions, beams are typically designed to satisfy flexural limit state and then checked for shear limiting criteria. However, when exposed to fire, beams experience significant loss of moment and shear capacity with fire exposure time. In current practice, failure in fire exposed beams is evaluated by considering flexural strength limit state with no consideration to shear limit state or local buckling limits. Although such rationale can be valid for most common scenarios in buildings, it may not be valid in certain situations such as the case of transfer girders or beams with slender webs.

Transfer girders used where large free space is needed, i.e. in lobbies and conference halls, can be subjected to high shear forces; resulting from concentrated loads arising from supporting columns or walls. Further, webs in W-shape sections or plate girders are usually thinner (slender) than flanges. These webs can be exposed to higher thermal (fire) loading; since they are exposed to the fire from two sides (larger surface area). Hence, strength properties of steel in the web can degrade at a higher rate than that in flanges. Once exposed to high temperatures, shear capacity of steel beams can degrade at a much higher rate than flexural capacity since area of the web is the main contributor to shear capacity.

These situations, wherein shear limit state can dominate, are illustrated by tracing response of a typical steel beam from loading stage to failure under fire exposure. Fig. 1 shows a simply supported beam subjected to two different loading scenarios. The moment and shear capacity of the beam at ambient conditions and after 2 h of fire exposure is plotted in Fig. 1. In the case of a beam subjected to uniformly distributed loading (UDL), failure typically occurs when the applied

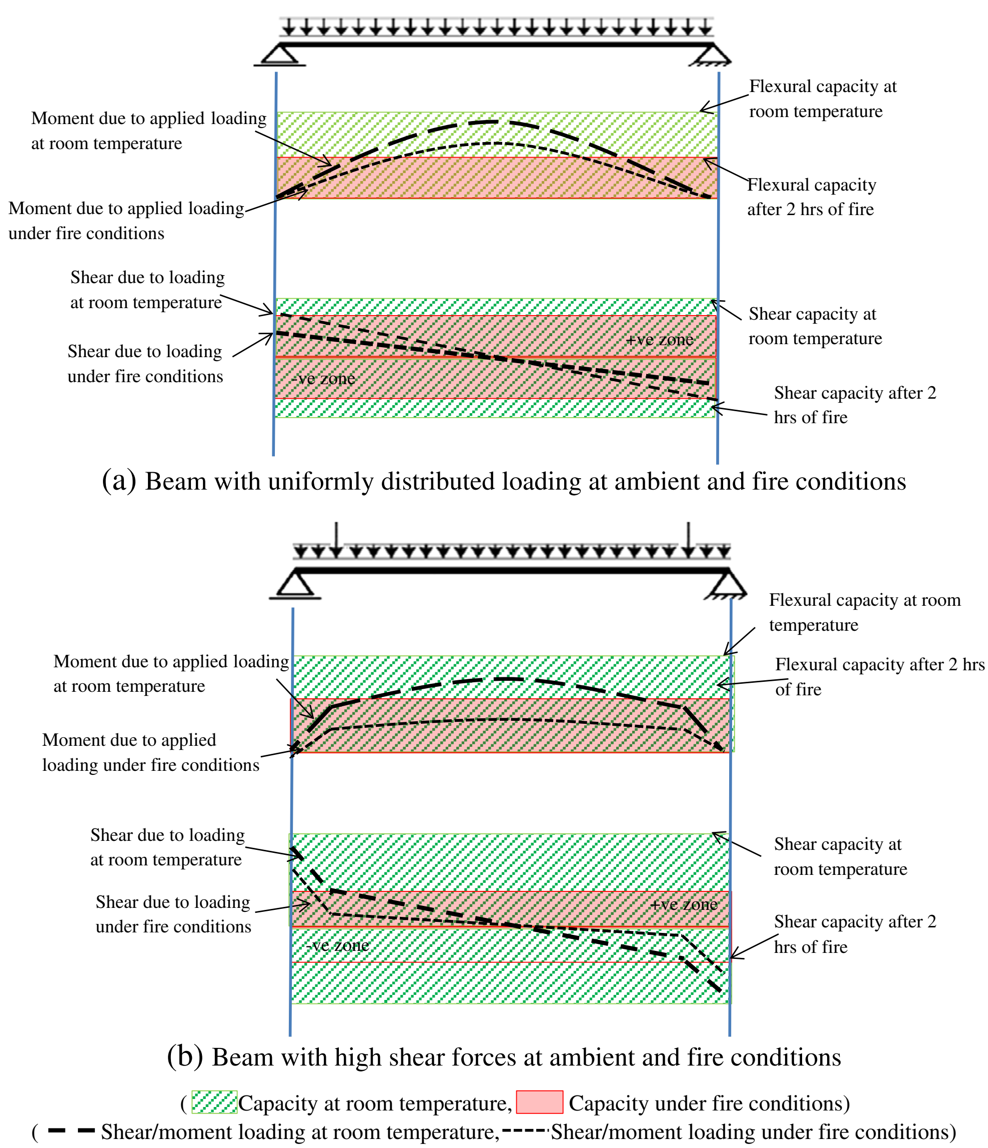

Fig. 1. Variation of bending moment and shear force under different loading scenarios.