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Post-fire seismic behavior of reinforced concrete structural walls

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ABSTRACT

A potential but infrequently studied hazard is the sequential occurrence of earthquakes and fires. Fire hazards following an earthquake can be significant due to increased likelihood of fires igniting, increased demands on firefighting resources, and potential obstacles to timely response. Increased ignitions and longer burn times can have significant structural impacts on reinforced concrete (RC) structures which are usually considered to have superior performance in a fire. The impact of this fire induced structural damage on the lateral load resistance of RC structures, particularly RC structural walls, is not well understood but may be critical in the event of aftershocks and/or future earthquakes. Given the severity of the consequences of reduced lateral load resistance, it is important for engineers to better understand fire-earthquake hazards in RC walls. This paper presents numerical studies to investigate the impact of fire damage on the lateral load resistance of flexure-controlled RC structural walls, including a parametric study to identify influential wall characteristics. Results indicate that fire damage decreases the load-bearing capacity and the stiffness of RC walls under reversed-cyclic loads. Curvature is shown to be a better indication of fire induced failure. At failure, damage may shift to the web of a wall after fire exposure becomes more severe. Wall characteristics which significantly influence the residual wall response quantities were identified to be wall thickness, boundary element length, and axial load ratio.

1. Introduction

To date, there are no documented failures of buildings due to fire-earthquake hazards, and in fact, the full or partial collapse of modern buildings during an earthquake is rare. However, fire following earthquakes has caused significant damage in modern earthquakes. Approximately 5000 buildings were damaged in the fire following the 1995 Kobe earthquake [1], and numerous fires were reported following the Loma Prieta Earthquake [2] in 1989 and the Northridge earthquake [3] in 1994. Post-earthquake fire in urban regions has the potential to be particularly destructive as (i) the breakage of utility lines increases the likelihood of fire ignition, (ii) a strong earthquake may cause extensive damage to passive and active fire-defense systems in a structure, and (iii) it may take considerably more time to control a fire due to blocked roads, hindered communication systems, disability of water supply system and limited available response teams. The increased ignitions and longer burn times may significantly degrade the material properties of a building such that the structural integrity is compromised. In such an event, buildings that may have been relatively undamaged following the original event may be at risk for significant damage or collapse in subsequent earthquakes. Post-fire earthquake scenarios may also arise in the event of a fire preceding an earthquake. Consequently, resilient design and evaluation of existing infrastructure necessitates an understanding of structural performance under such hazards.

A number of studies have been conducted on the influence of fire on the mechanical strength of reinforced concrete components. Post-fire material tests [4–6] have shown that the mechanical properties of concrete degrade after fire exposure and do not fully recover after cooling. The mechanical properties of reinforcing steel also degrade after exposure to elevated temperatures [7,8]. Tests investigating the response of concrete components have been primarily focused on frame-elements. The impact of fire on the load bearing capacity and stiffness of columns has been investigated by Lie et al. [9] and Cheng et al. [10]. El-Hawary et al. [11,12] experimentally showed that the fire exposure time has a significant impact on the behavior of beams. Xiao et al. [13] showed that fire exposure can transform the failure mode of a frame subjected to reverse-cyclic loads from strong-column-weak-beam to strong-beam-weak-column with poor cyclic performance. Xiao et al. [14] and Liu [15] tested reinforced concrete (RC) walls under reversed cyclic loading and found that fire decreased the stiffness and lateral load carrying capacity of walls; however, the low aspect ratios of the walls corresponded to shear failures and the drift capacity of walls with a flexure-controlled response is unknown.

In this paper, the post-fire earthquake performance of reinforced concrete structural walls is investigated. RC structural walls are

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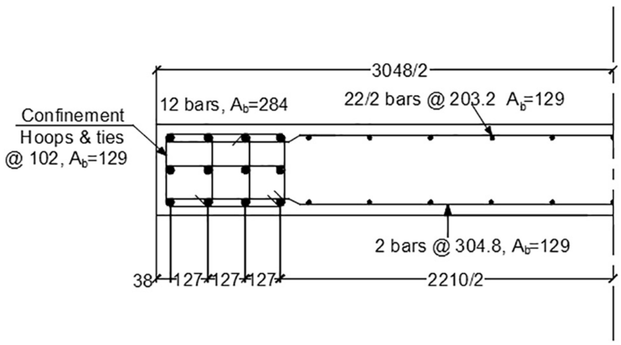

Fig. 1. Cross section of the reference wall (unit: mm).

common in the design of multistory buildings subjected to ordinary and hazardous loads. For lateral loads such as wind and earthquakes, walls provide lateral stiffness and strength. Due to the non-combustibility and low thermal conductivity of concrete, RC walls are known for good fire performance, often working as fire walls to suppress the spread of fire in a building.

Although the post-fire earthquake performance of walls has been investigated in limited experimental studies [14,15], it is important to better understand the behavior of flexure-controlled walls, including the failure mechanisms and the influence of design parameters typically understood to impact the performance of walls under seismic loading, such as axial load ratio and boundary element confinement. Numerical simulations were conducted using SAFIR and OpenSees to utilize the benefits of each for modeling fire and seismic demands, respectively. An overview of the simulation approach is presented in Section 2. Section 3 provides an in-depth analysis of a reference wall exposed to multiple fire scenarios to establish trends in the impact of fire on the seismic response. In Section 4, characteristics of the reference wall are altered to establish the influence of typical wall characteristics on the post-fire seismic response. A summary of results and recommendations for future research needs is presented in Section 5.

2. Description of models

To simulate the post-fire seismic response of walls, it is necessary to utilize a methodology that can accurately account for both the thermal

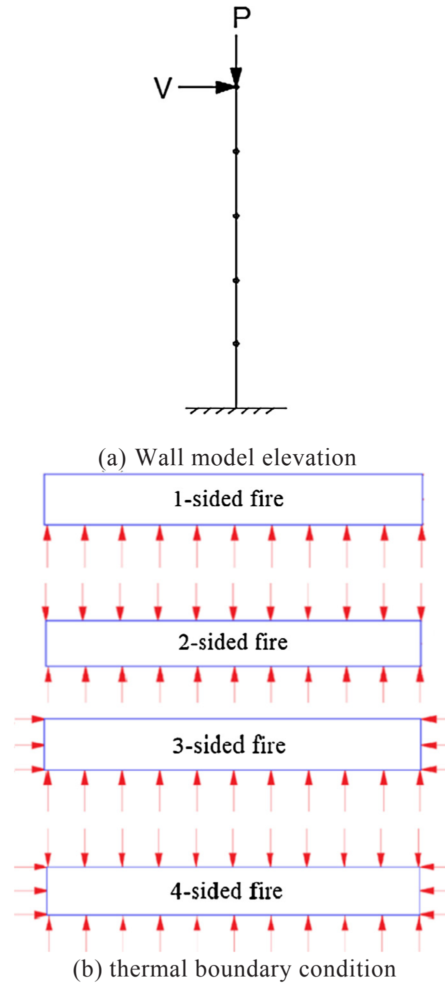

Fig. 2. Boundary conditions (a) mechanical boundary conditions for five story wall (b) thermal boundary conditions applied to first floor of wall; arrows indicate heated sides and other sides are exposed to room temperature.

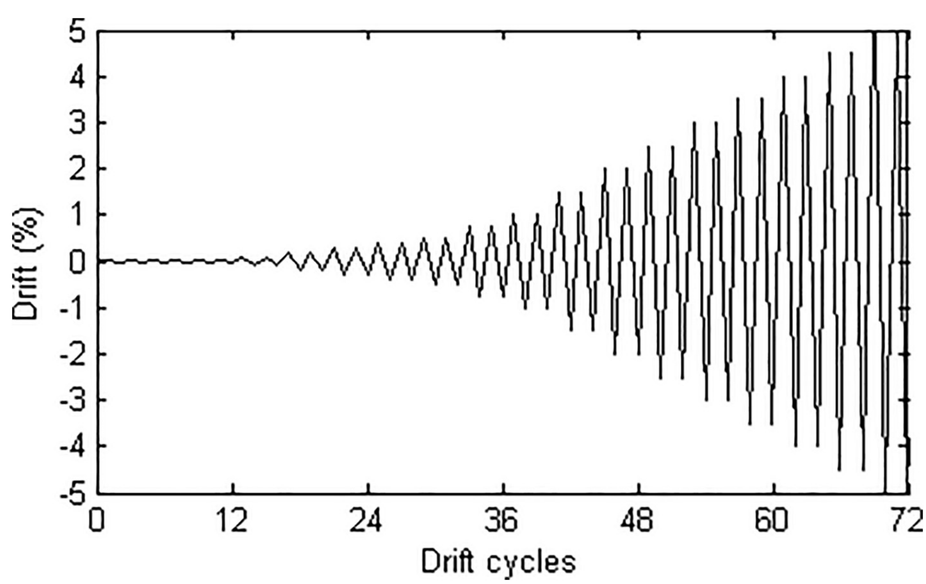

Fig. 3. Applied drift history for seismic analysis of walls.