POST-EARTHQUAKE RESILIENCE OF STEEL MOMENT FRAME BUILDINGS

Presenter: Rachel Chicchi, Graduate Student, Purdue University
Co-Advisor: Dr. Amit H. Varma, Professor of Civil Engineering, Purdue University
Co-Advisor: Dr. Judy Liu, Professor of Civil and Construction Engineering, Oregon State University

Fires following earthquakes cause significant loss of life and property. During an earthquake, the seismic-force-resisting system dissipates energy generated by the ground motion through inelastic behavior. For instance, steel moment frames are designed to form plastic hinges at the beam ends, acting as fuses to minimize additional damage in the remainder of the structure. Depending upon the post-yield capacity of the members, these fuses may need to be replaced after an earthquake. During a fire, the strength and stiffness of structural members decrease as material temperature increases. In addition, potential damages to sprinkler systems and debonding or cracking of fire proofing during an earthquake also make buildings more vulnerable to fire and prone to further damage. These interdependencies motivate this study on system behavior, analysis and design of steel moment frame buildings subjected to post-earthquake fire hazards.

Previous researchers [1, 2] have shown that, in the event of a gravity member failure, the lateral system can prevent the collapse of a building through load redistribution. However, if many lateral members have already yielded in the earthquake, their post-yield behavior may not be adequate to accept load redistribution from failing gravity members during a fire. In order to adequately model the complexities of load redistribution, three-dimensional (3D) modeling is preferred over traditional two-dimensional (2D) analyses approaches.

Many researchers have acknowledged the dangers of post-earthquake fires, using 2D finite element method (FEM) models to evaluate the behavior of steel-frame buildings in post-earthquake fires [3-5]. Quiel and Garlock [6] studied 2D versus 3D modeling for structures exposed to fires and concluded that the moment frame members were relatively unaffected by the modeling approach; however, the deflection of the filler beams in the 3D model was noticeably less due to the stiffness of the continuous slab. Also, gravity columns were not explicitly compared. Gravity columns often lead to building collapse in fire because they have the highest utilization ratio of all building members and decreases in column strength and stiffness with increasing temperatures leads to failures [2]. Therefore, 3D behavior is necessary to simulate redistribution of loads away from the vulnerable gravity columns and more adequately simulate real-building behavior.

For these reason, a commercially available finite element software, Abaqus, was used to develop 3D finite element method (FEM) models of a ten-story steel-frame building. A detailed description of the models is provided by Agarwal [7] and Fischer [1]. The beams and columns were modeled using B31 beam elements, and the slab was modeled using S4R shell elements. The simple (shear) connections in the building were modeled as shear-tab connections using wire connector elements that include the axial force-axial displacement-moment-rotation-temperature behavior, based on work by Sarraj [8] and Agarwal [7]. The building uses perimeter moment frames as the lateral-force-resisting system and assumes completely fixed connections in the moment frames, with plans to incorporate rotational springs at a later date to capture nonlinear behavior.

It is generally believed that a building designed to resist higher seismic loads will inherently improve multi-hazard resilience. This assumption will be tested by analyzing two buildings. One structure is located in Chicago, IL, an area of low seismicity. The other will be located in Los Angeles, CA. The buildings will be subjected to ground motions and various fire loading scenarios, durations and temperatures. Through scaling of the $\zeta=5\%$ damped spectral acceleration at the structure’s first-mode
period, incremental dynamic analysis will be conducted to illustrate the fragility of the structure when subjected to these ground motions [9]. Similarly, a cumulative distribution function will be used to show the failure time of the structure in fire. Through this approach, the post-earthquake fire robustness of the two buildings can be compared.

This project aims to: (1) identify vulnerabilities in steel moment frame buildings subjected to post-earthquake fire hazards and (2) make recommendations for improvements to specific building components that could increase the overall system performance and resilience. Best practices in seismic and fire design will be compared to one another and confirmed through a parametric study using the steel building model. This study involves modifying the original building systematically by changing gravity column sizes, gravity beam-to-column connection capacities, and lateral frame member sizes to determine if these changes mitigate or aggravate the multi-hazard damage. Preliminary results of this study will be presented on the poster and the methodology for this multi-hazard analysis approach will be explained.

References:

1. Fischer, E.C., Fire Behavior of Simple (Shear) Connections in Steel-Frame Buildings, in Lyles School of Civil Engineering. 2015, Purdue University: West Lafayette, IN.
7. Agarwal, A., Stability Behavior of Steel Building Structures in Fire Conditions, in School of Civil Engineering. 2011, Purdue University.
8. Sarraj, M., The Behaviour of Steel Fin Plate Connections in Fire, in Department of Civil and Structural Engineering. 2007, The University of Sheffield.