# Post-earthquake fire performance of industrial facilities

## *PEER Transportation Systems Research Program*


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## Motivation:

Post-earthquake fires present a significant threat to the infrastructure on the West Coast of the US. While a large seismic event could cause potential economic and social disruption, facilities that house large fuel loads are at risk to post-earthquake fires. These facilities are typically industrial facilities that are connected to major transportation networks (i.e. airports, port facilities). Fires impose large plastic deformations in gravity framing members that must be resisted by the structural components. The open source finite element software, OpenSees, therefore provides a great opportunity to incorporate this type of modeling capability. Previous researchers have performed post-earthquake fire investigations using OpenSees; however, they have not included the gravity framing system in the model.

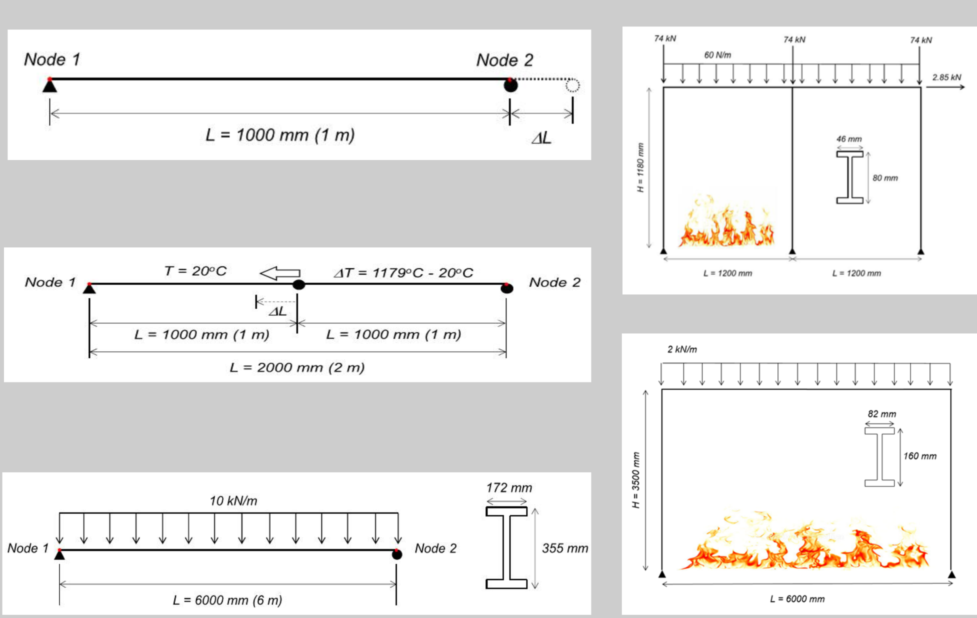
## Goals and Objectives:

The goals of this research project are to:

- Develop benchmarking examples of fire modeling in OpenSees for the engineering community,
- Use benchmarked modeling methodologies to simulate the behavior of 2D moment resisting frames subjected to an earthquake following by different compartment fires,
- Compare the behavior of moment resisting frames in post-earthquake fire to fire only scenarios, and
- Develop three-dimensional modeling capabilities for gravity framing systems in OpenSees to simulate large plastic deformations of the gravity system of a steel-frame building.

## PROJECT OUTLINE

### 1. Develop benchmarking examples of fire modeling in OpenSees for the engineering community in OpenSees (3.1.0)




- Calculate thermal expansion[1]
- Calculate internal forces
- Calculate midspan displacement
- Frame analysis
- Input user-defined time-temperature curves
- Benchmark against experimental data[2]

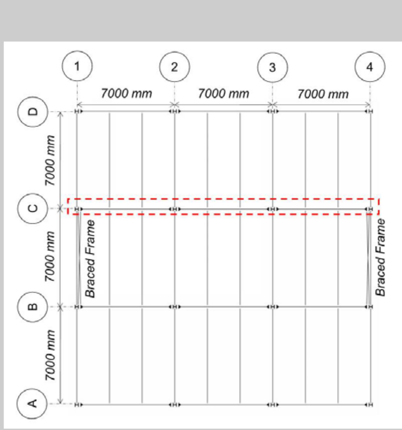
### 2. Simulate the behavior of 2D moment resisting frames in post-earthquake fire scenarios

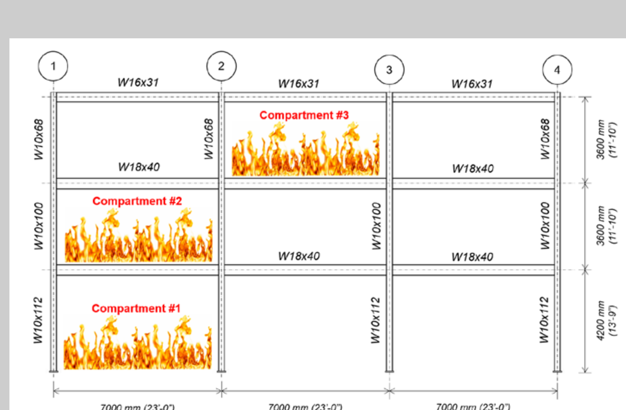
**Ground motions**

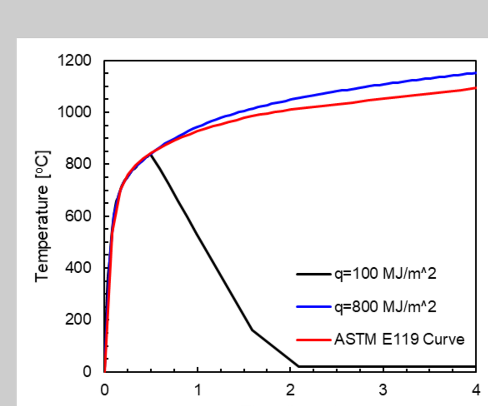
The building was designed for Seismic Design Category D[4]. Loma Prieta earthquake ground motions were used to develop an envelop of potential structural damage to the frame. Nonlinear dynamic analysis was completed in OpenSees.

**Fire Analysis**

The fire analysis was performed on the 2D frame using fire curves with varying fuel loads. These fuel loads represent: (1) a light fuel load and (2) a heavy fuel load. Varying fires are calculated using the Eurocode parametric time-temperature curve[5] with constant opening factors. Three different compartment fires were considered. Damage due to post-earthquake fires and only a fire hazard were compared using the following metrics: damage type, collapse time, and critical members.




### 3. Develop 3D modeling capabilities for fire behavior of gravity framing systems in OpenSees

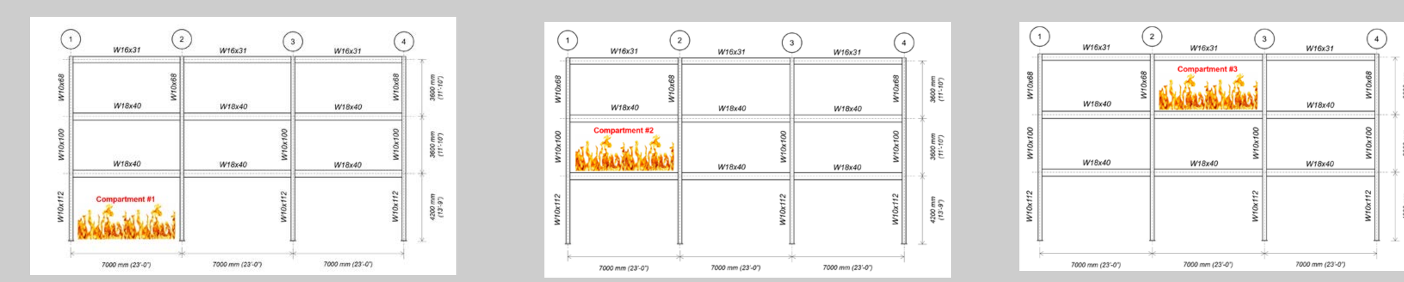
3D behavior of steel-frame gravity systems is important to the behavior ofa steel-frame building during fire because of catenary action of the floor. Therefore, connection modeling and composite beam modeling must be explicitly accounted for, otherwise the survival time of the gravity system is underestimated.

## RESULTS OF 2D POST-EARTHQUAKE FIRE ANALYSIS:

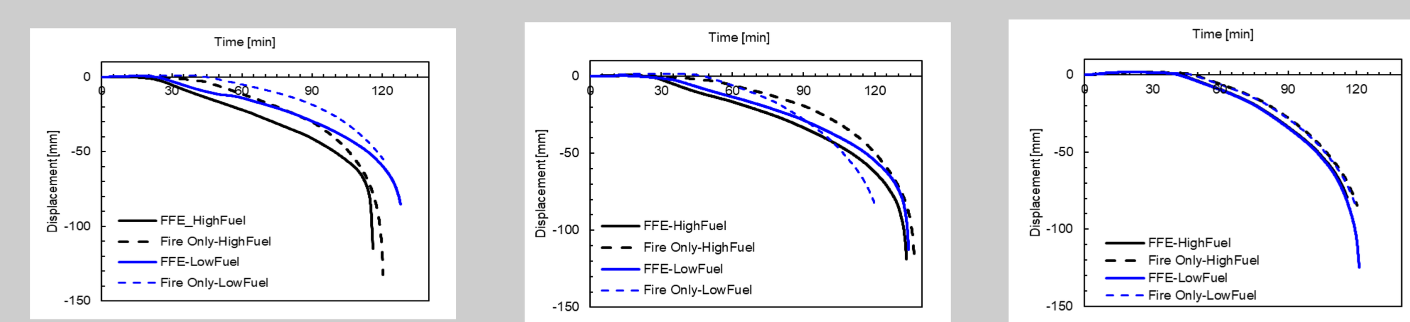
**Conclusions:**

Seismic damage to moment-resisting frames does not influence the post-earthquake fire performance of a 2D frame (given the connections do not fracture). This conclusion is consistent with previous findings[6,7]

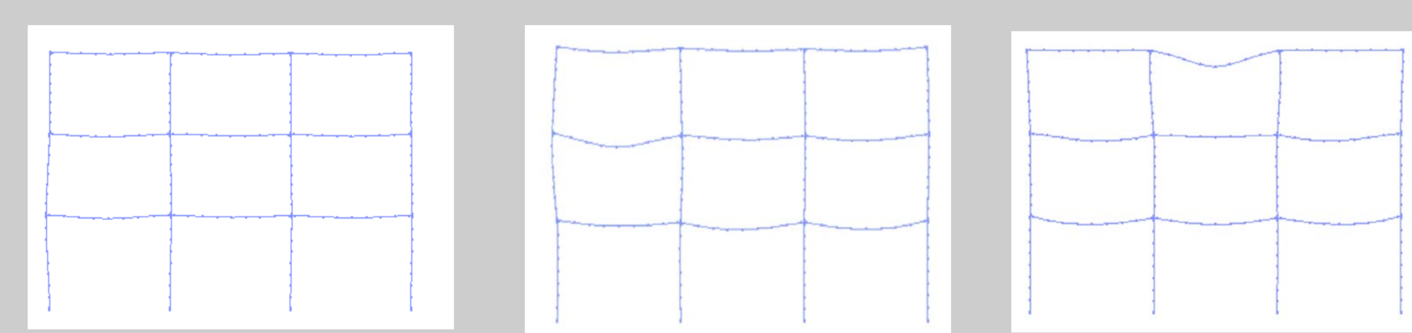
**Compartment Fire Location**



**Beam midspan displacement**



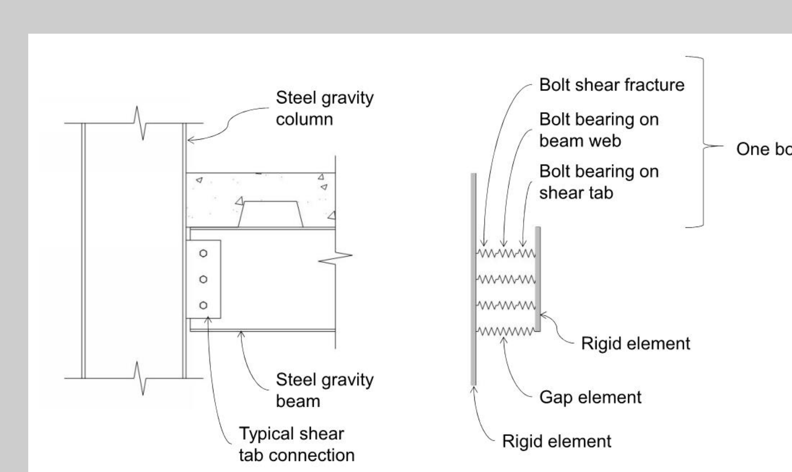

**Building deformed shape**

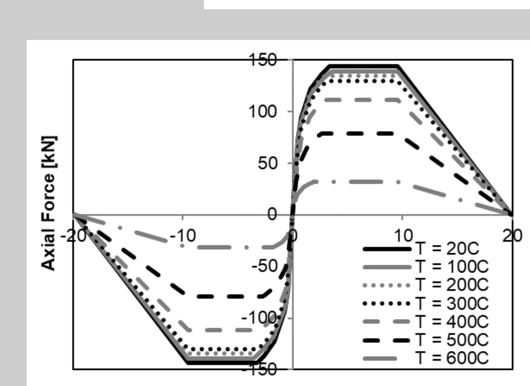


**Constitutive Connection Model for Gravity Framing Systems:**

During a fire, gravity framing connections will be subjected to large axial compressive and tensile force demands due to the thermal expansion of the beams and columns, and due to the restraint of the cooler surrounding structure. However, these connections are not designed for these loading demands at ambient temperature.

Zero-length spring elements using a constitutive material model to represent bolt/plate/web limit states at elevated temperatures for simple gravity connections. This material model will be based off of constitutive relationships developed by Sarraj (2007) and Agarwal (2011)[7, 8]




Bolt shear fracture failure mode

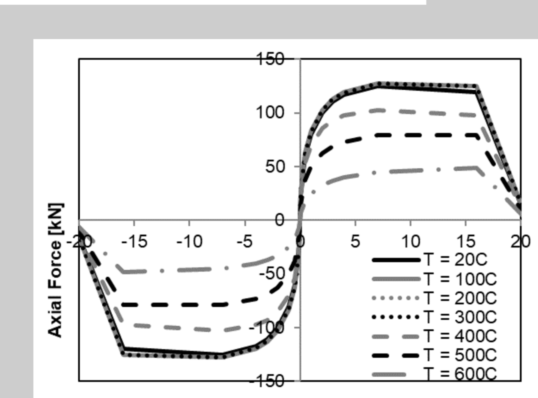



Plate bearing failure mode


**References**

[1]European Committee for Standardization (CEN). (2005). Eurocode 3: Design of Steel Structures, Part 1.2: General Rules - Structural Fire Design.

[2]Rubert A, Schaumann P. (1986). "Structural steel and plane frame assemblies under fire action." *Fire Safety Journal,* vol. 10, pp.173–84.

[3]Aksoylar, Nihan Doğramacı, et al. "The Design and Seismic Performance of Low-Rise Long-Span Frames with Semi-Rigid Connections." *Journal of Constructional Steel Research*, vol. 67, no. 1, 2011, pp. 114–126.

[4]FEMA. (2009). "Quantification of Building Seismic Performance Factors (FEMA P-695)", *Federal Emergency Management Agency*, Washington, D.C.

[5]European Committee for Standardization (CEN). (2005). Eurocode 1: Actions on Structures, Part 1.2: General Actions – Actions on structures exposed to fire.

[6]Chicchi, R. "Multi-Hazard Resilience of Steel MRF Buildings." Purdue University, December 2017

[7] Khorasani, N. (2015. "Modeling steel structures in OpenSees: Enhancements for fire and multi-hazard probabilistic analyses." Computers and Structures, vol. 157, pp. 218-231

[8]Sarraj, M.. "The Behaviour of Steel Fin Plate Connections in Fire." The University of Sheffield, July 2007

[9]Agarwal, A.. "Stability Behavior of Steel Building Structures in Fire Conditions." Purdue University, September 2011



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