

Post-earthquake fire performance of industrial facilities



PEER Transportation Systems Research Program

Principal Investigator: **Erica C. Fischer**, Ph.D., P.E, Oregon State University

Student Investigators: **Walker Maddalozzo**, Oregon State University



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 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. OpenSees has been utilized to perform analyses on seismic performance of structures and fire performance of structures through the simulation of large plastic deformations.

Objective:

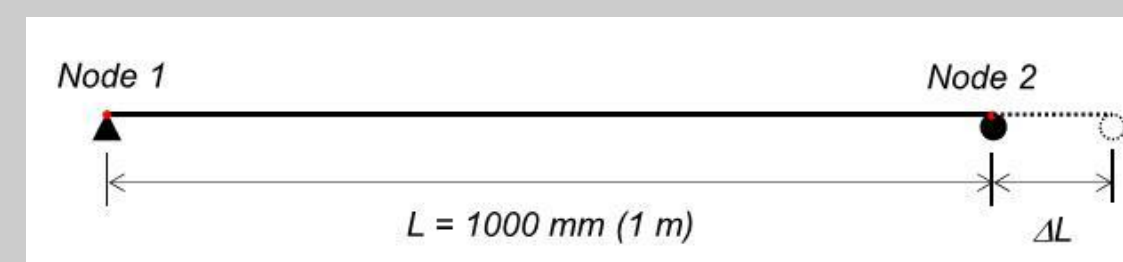
To benchmark and document OpenSees for the Thermal-Mechanical environment, development of benchmarking examples for temperature-dependent material and thermal properties, and development of a multi-story structural model for post-earthquake fire simulations.

OUTLINE OF PROJECT

STEP 1: Benchmark temperature-dependent thermal and mechanical material models using simply supported beams

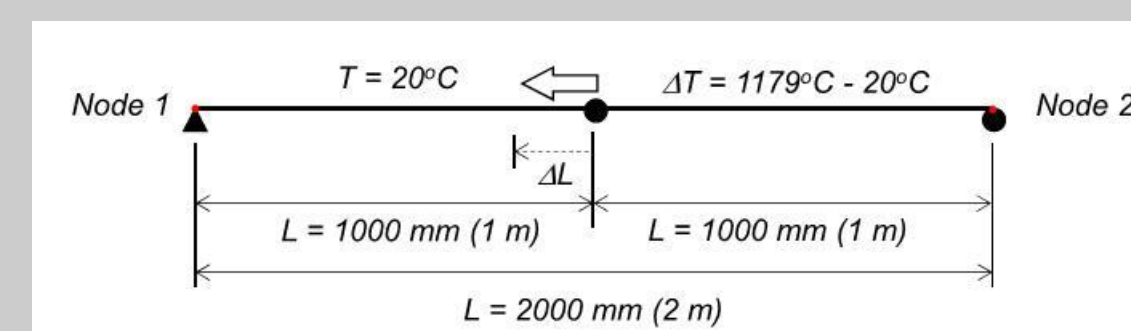
Example 1: A 1 m long beam is heated to 1179°C and the thermal expansion of Node 2 is measured.

Goal: Benchmark thermal expansion modeling techniques



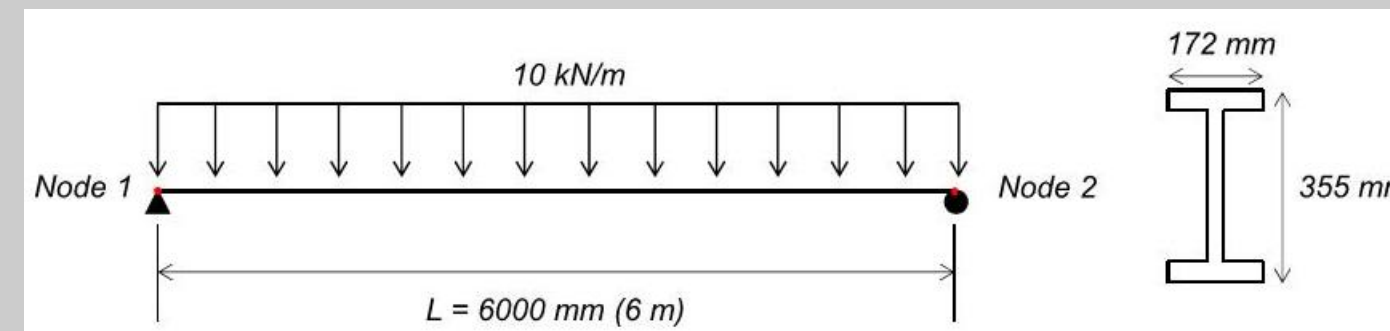
Example 2: A 2 m long beam is divided into two equal sections. The left section remains at ambient temperature (20°C), while the right section is heated to 1179 °C

Goal: Benchmark thermal expansion modeling techniques and thermal-mechanical modeling techniques



Example 3: A 6m long I-shape has a uniform dead load of 10kN/m applied and is heated to 1200 °C. Beam analyzed using both Linear & Corotational Geometric transformation & with right support both restrained and non-restrained.

Goal: Benchmark thermal-mechanical modeling techniques.

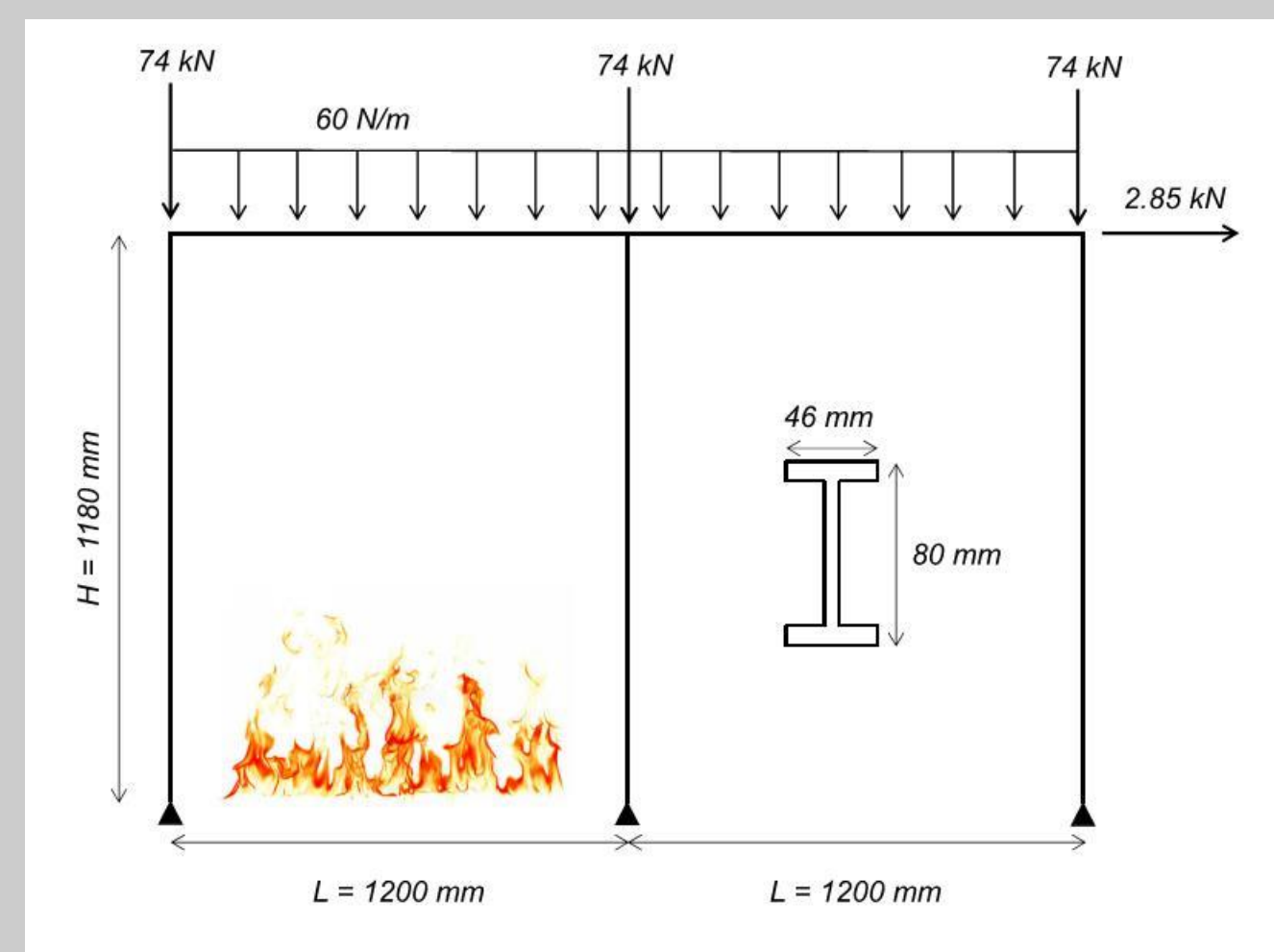


STEP 2: Benchmark modeling methodology for response of structures to fire

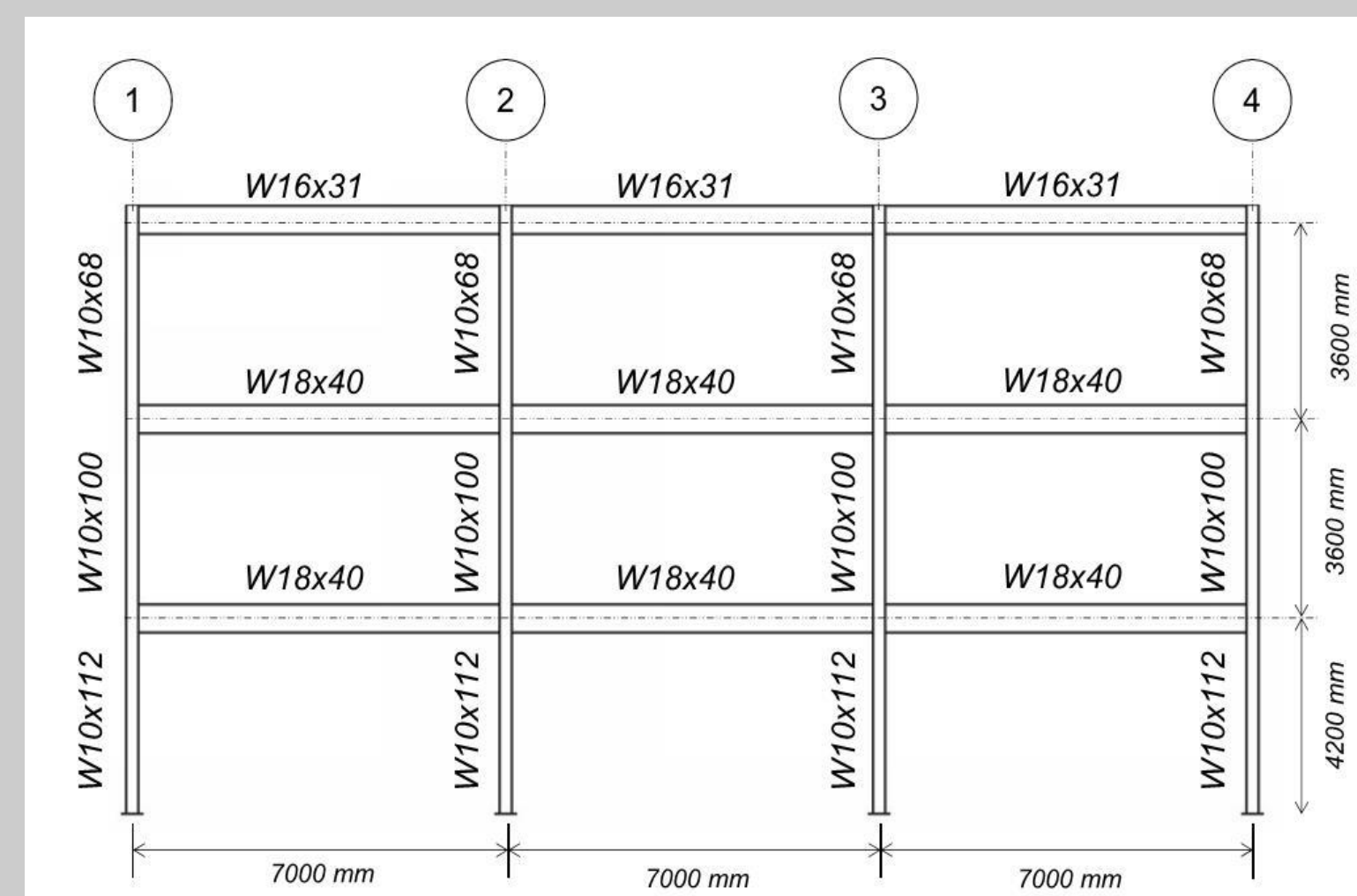
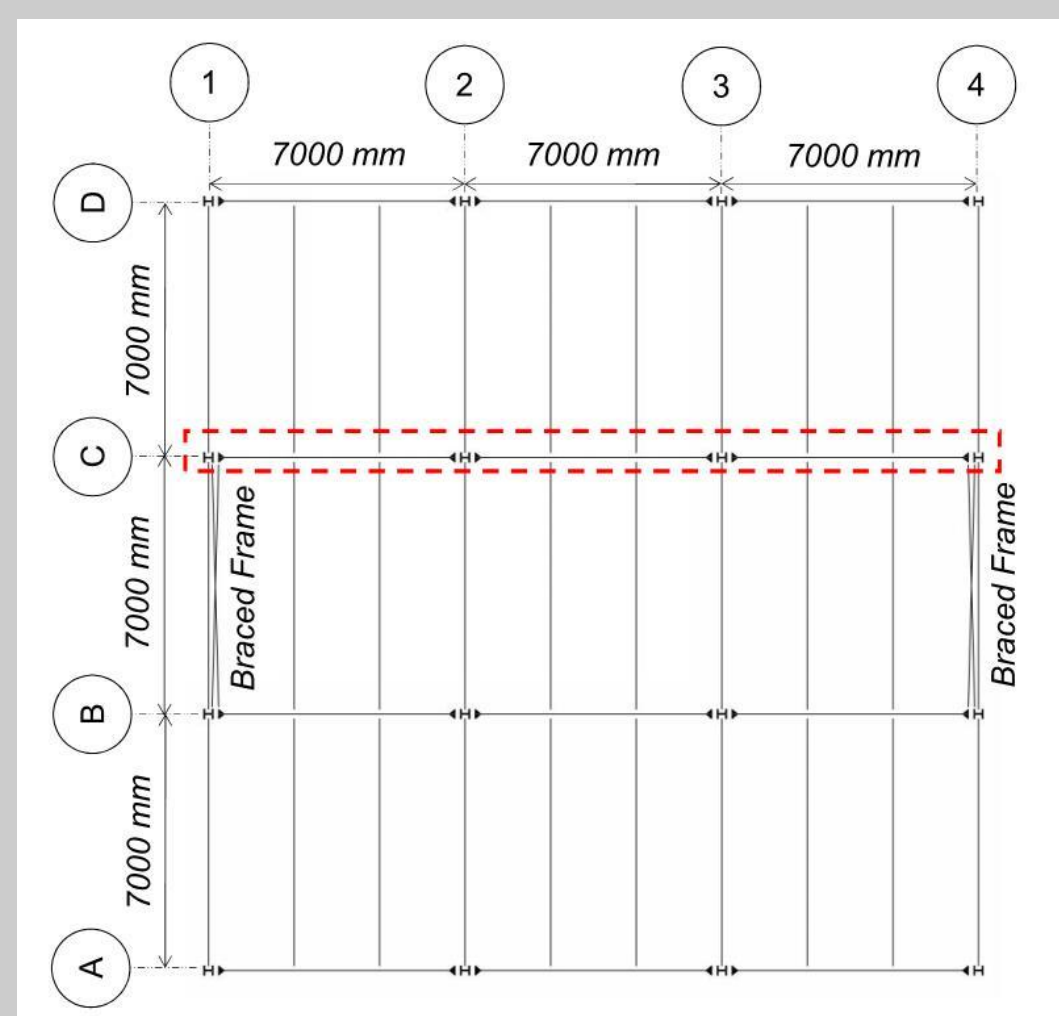
ZSR1² Frame:

One bay of a two-bay portal frame is exposed to a compartment fire and gravity loads. Horizontal and vertical displacements are recorded.

Goal: Benchmark thermal-mechanical modeling techniques in a portal frame.

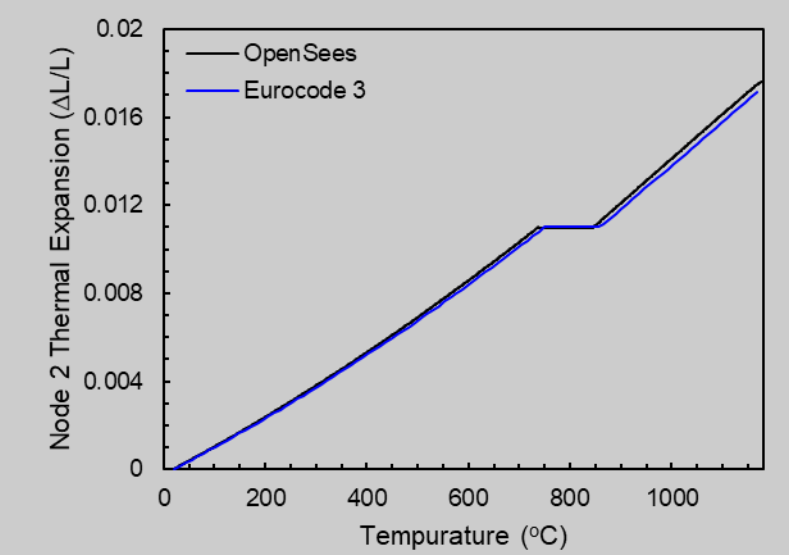


STEP 3: Use benchmarked fire modeling methodology to simulate post-earthquake fire performance of industrial facility³

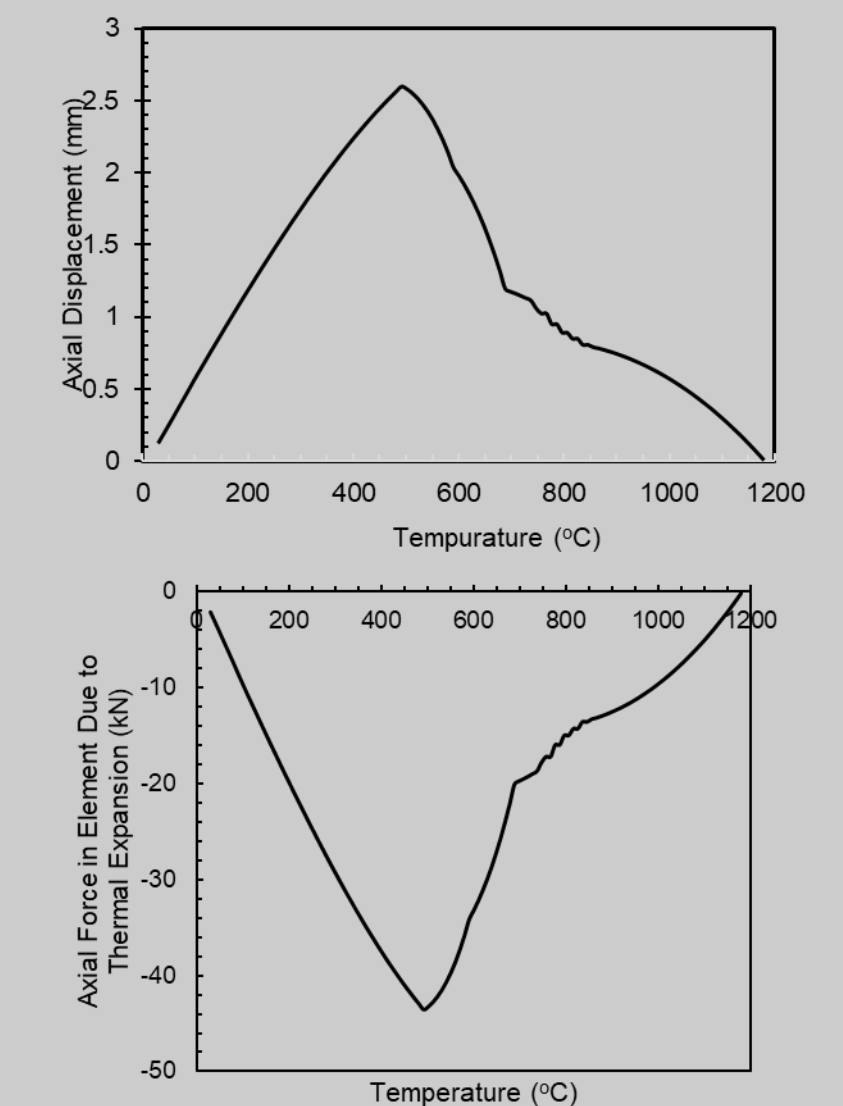


RESULTS OF BENCHMARKED EXAMPLES

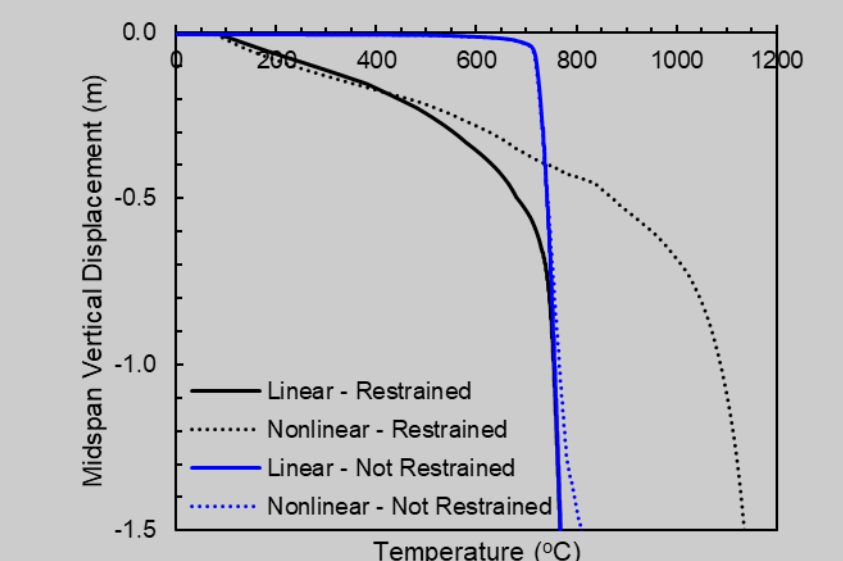
Example 1: *OpenSees temperature-dependent thermal expansion benchmarked* against Eurocode 3⁴. Critical number of steps required is 1,000 in OpenSees.



Example 2: OpenSees temperature-dependent thermal expansion benchmarked against Eurocode 3⁴. Critical number of steps required is 1,000 in OpenSees. OpenSees thermo-mechanical model is benchmarked to measure *imposed axial forces due to thermal expansion*.



Example 3: OpenSees temperature-dependent steel mechanical material properties are verified to measure *midspan displacement of beams with varying boundary conditions*. Both linear and nonlinear material properties were used.



POST-EARTHQUAKE FIRE ANALYSIS:

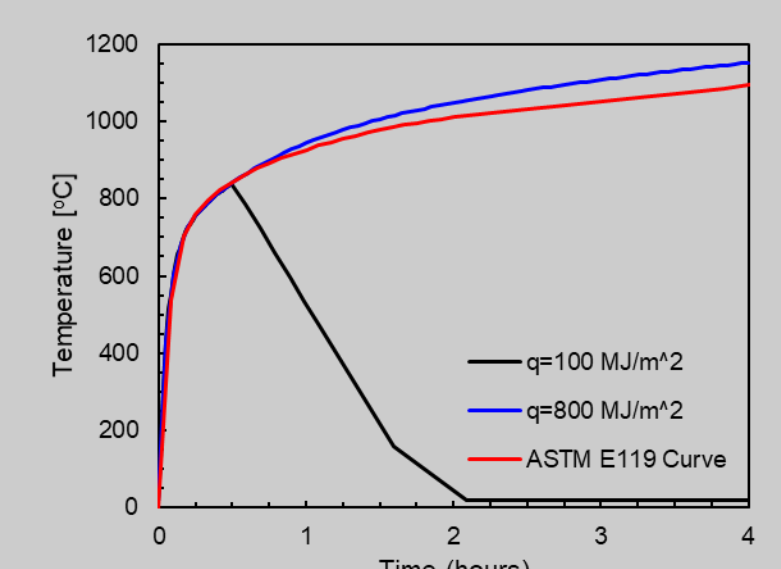
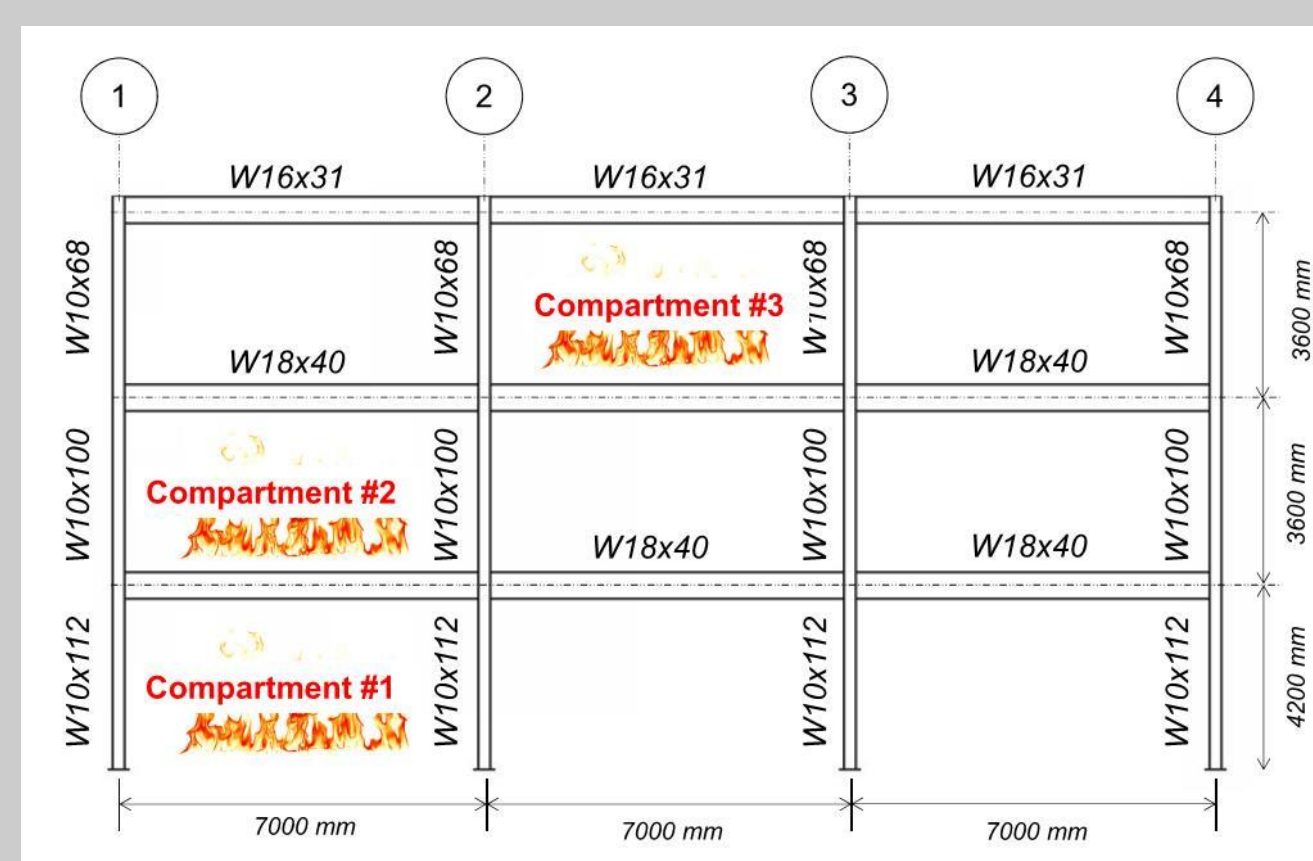
Ground motions

The building was designed for Seismic Design Category D. FEMA P-695⁵ far field ground motions will be used to develop an envelop of potential structural damage to the frame. Nonlinear dynamic analysis will be implemented in OpenSees.

Fire Analysis

The fire analysis will be performed on the 2D frame using fire curves with varying fuel loads. These fuel loads represent: (1) the ASTM E119 fire curve⁶, (2) a light fuel load, and (3) a heavy fuel load. Varying fires are calculated using the Eurocode parametric time-temperature curve⁷ with constant opening factors.

Three different compartment fires will be considered: one on each floor. Damage due to post-earthquake fires and only a fire hazard will be compared with regards to damage type, collapse time, and critical members.



References:

- ¹Rosário, Rúben. "Modelação Não Linear De Estruturas Metálicas e Mistas Em Situação De Incêndio No Software OpenSees." Universidade NOVA De Lisboa, Dec. 2014, pp. 1–136
- ²Rubert A, Schaumann P. (1986). "Structural steel and plane frame assemblies under fire action." *Fire Safety Journal*, vol. 10, pp.173–84.
- ³Aksoylar, Nihan Doğramaci, 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.
- ⁴European Committee for Standardization (CEN). (2005). Eurocode 3: Design of Steel Structures, Part 1.2: General Rules - Structural Fire Design.
- ⁵FEMA. (2009). "Quantification of Building Seismic Performance Factors (FEMA P-695)", *Federal Emergency Management Agency*, Washington, D.C.
- ⁶ASTM International (2016). ASTM E119-16a Standard Test Methods for Fire Tests of Building Construction and Materials. West Conshohocken, PA: ASTM International.
- ⁷European Committee for Standardization (CEN). (2005). Eurocode 1: Actions on Structures, Part 1.2: General Actions – Actions on structures exposed to fire.

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