**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 shaping beam has a uniform dead load of 10kN/m applied and is heated to 1200°C. Beam analyzed using both linear & Constitional 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

- ZSR1 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 facility

**RESULTS OF BENCHMARKED EXAMPLES**

**Example 1:** OpenSees temperature-dependent thermal expansion benchmarked against Eurocode 3. Critical number of steps required is 1,000 in OpenSees.

**Example 2:** OpenSees temperature-dependent thermal expansion benchmarked against Eurocode 3. 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-695 far-field ground motions will be used to develop an envelope 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 curve, (2) a light fuel load, and (3) a heavy fuel load. Varying fires are calculated using the Eurocode parametric time-temperature curve 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:**

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