STOCHASTIC ANALYSIS OF STRUCTURES IN FIRE BY MONTE CARLO SIMULATION

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BACKGROUND

Structure-fire interaction involves a propagation of uncertainty that affects each stage of the sequentially coupled analysis (**Fig. 1**). For example, uncertainties in the compartment geometry, type and distribution of fuel, and ventilation conditions result in a fire load that cannot be predicted with great precision. Additional uncertainties associated with the material properties of the structure, the thermal and structural boundary conditions, and magnitude of applied loads lead to further challenges in determining how the structural system will respond in an actual fire scenario.

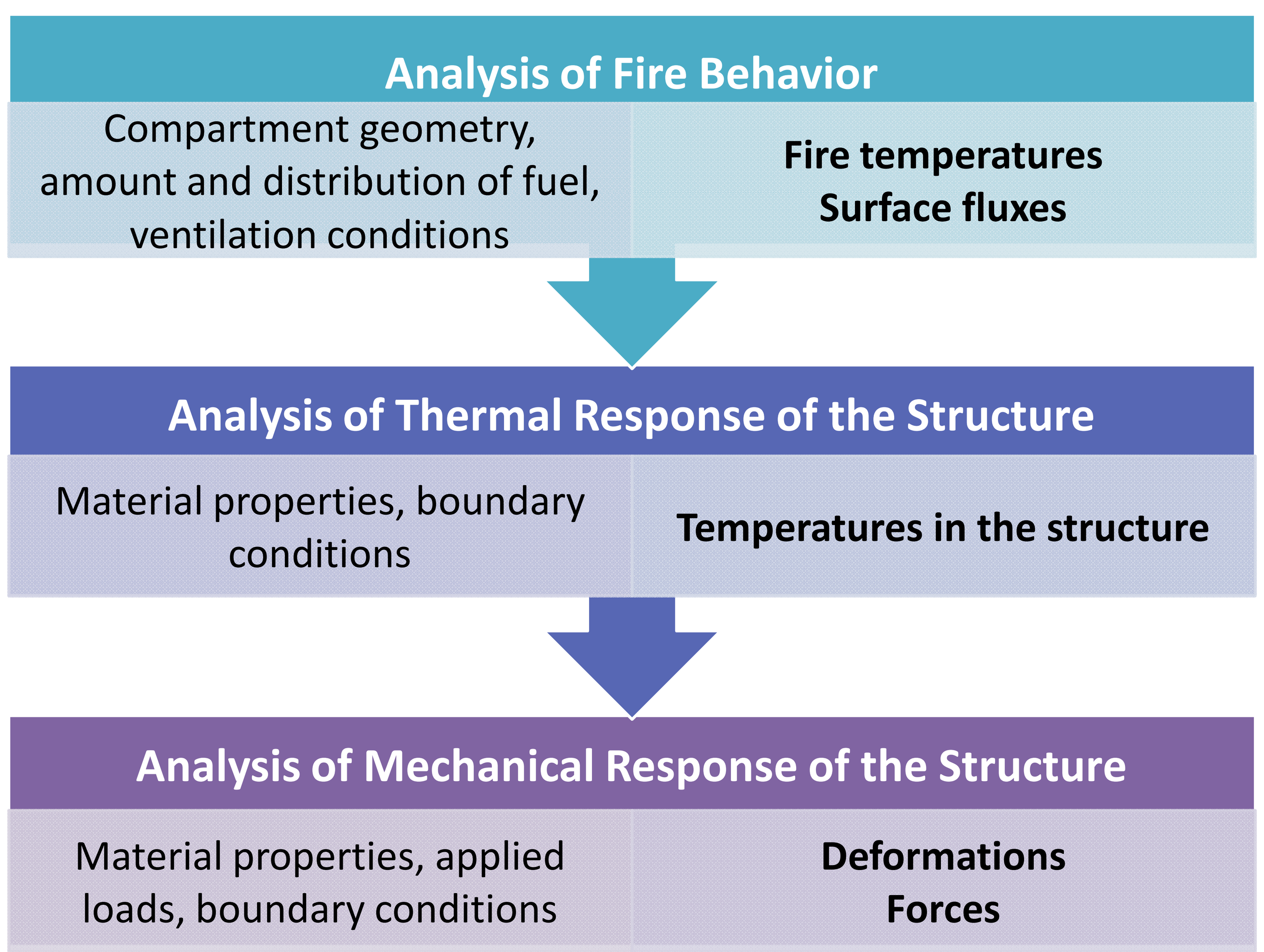

Fig. 1 Propagation of uncertainty in the structural fire simulation

METHODOLOGY

This work uses a reliability-based framework to assess the performance of a protected steel beam (**Fig. 2**) given uncertain fire and load effects. The analysis involves:

1. Characterizing the sources of uncertainty;
2. Quantifying the probabilistic characteristics of each uncertain parameter;
3. Defining performance criteria for the structure;
4. Evaluating the structural response stochastically using Monte Carlo simulation; and
5. Calculating the probability of failure.

The paper focuses specifically on the implementation of a sequentially coupled stochastic simulation in the finite element analysis software Abaqus (2010) using Python scripting commands. To demonstrate the approach, 1000 Monte Carlo simulations were carried out. Latin Hypercube sampling was used to reduce the total number of simulations required.

APPLICATION

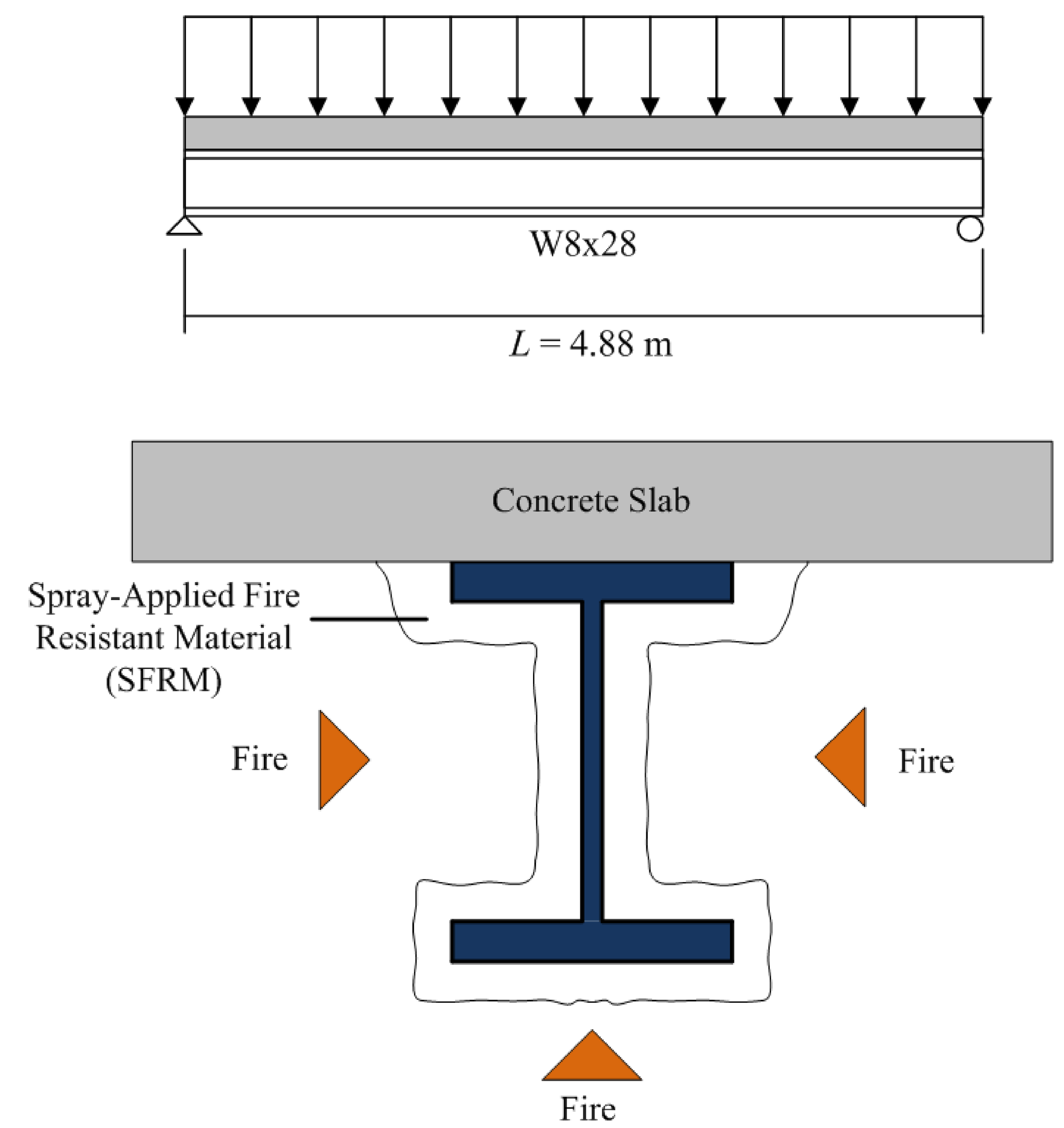

Fig. 2 Protected steel beam exposed to natural fire

As illustrated in **Fig. 3**, two parametric studies were run in Abaqus, each of which utilized a Python script file that generated a finite element model for each combination of random parameters. The input file (.inp) for each finite element analysis was written in terms of the uncertain parameters associated with the particular heat transfer or structural analysis. Random values for each parameter were generated in Matlab (2010) using the appropriate, mean, covariance, and probability distribution. Once the analysis was completed, a separate Python script was executed to compile the results from each of the simulations.

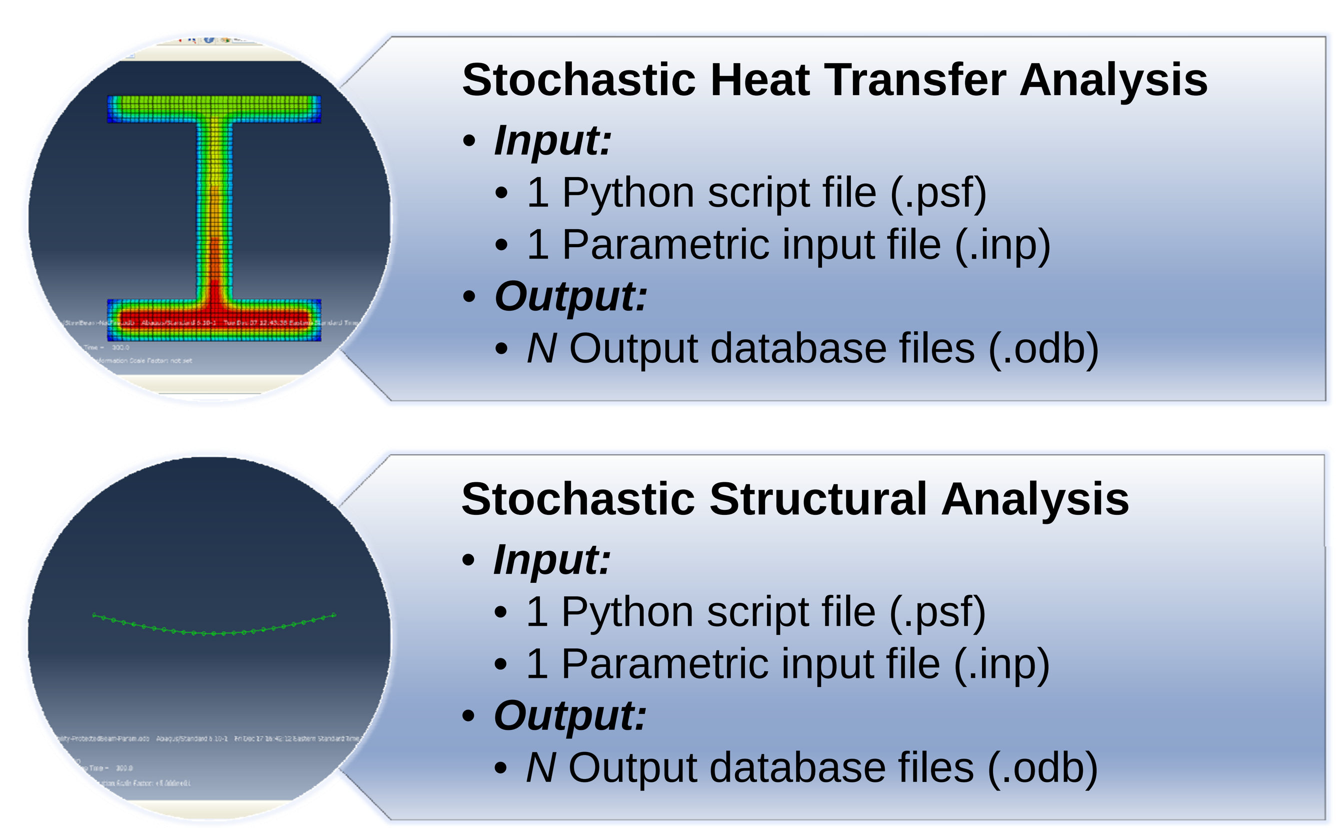

Fig. 3 Stochastic simulation in Abaqus

RESULTS AND CONCLUSIONS

Results are illustrated in the figures below (**Fig. 4-6**). While there are a range of possible scenarios, the beam generally performed adequately, with failure only occurring in 1.3% of the cases. It should be noted that this finding is inconclusive at present since a relatively small number (i.e., 1000) of Monte Carlo iterations were conducted.

While the application shows much promise for the future, the computational demands required to perform three sequentially coupled Monte Carlo simulations with embedded finite element simulations calls for a more computationally efficient approach. On-going work is being conducted to explore the parallelization of the simulation to improve the efficiency of the Monte Carlo method for structure-fire applications.

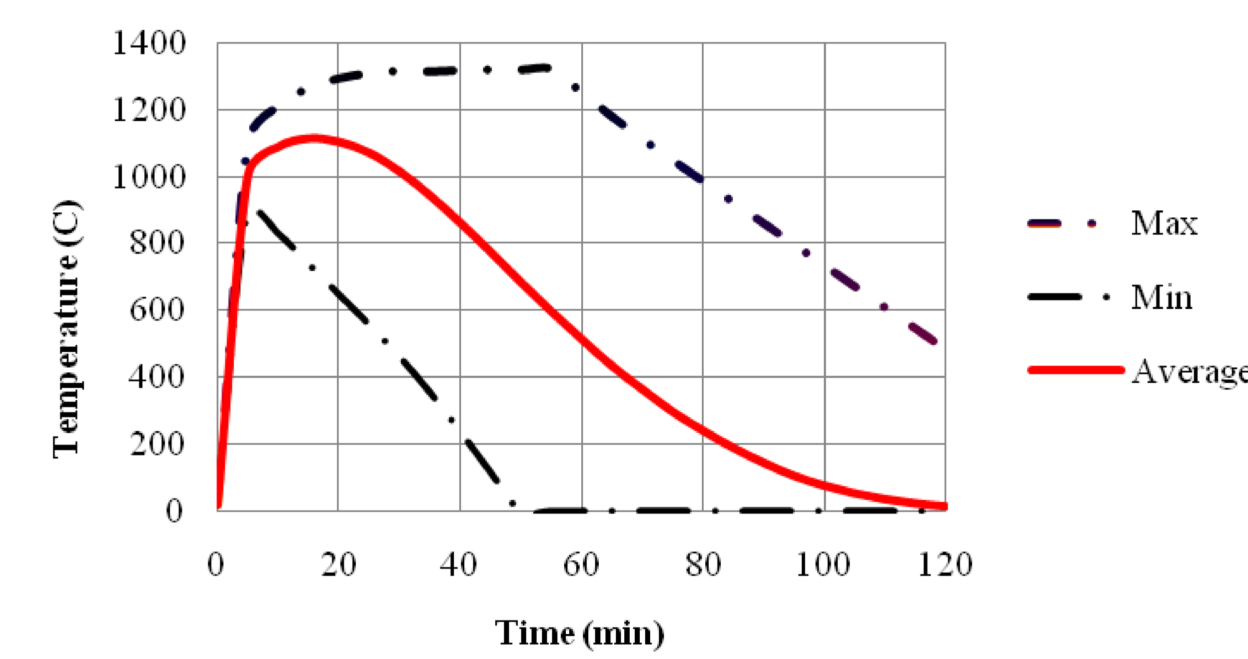

Fig. 4 Compartment temperatures

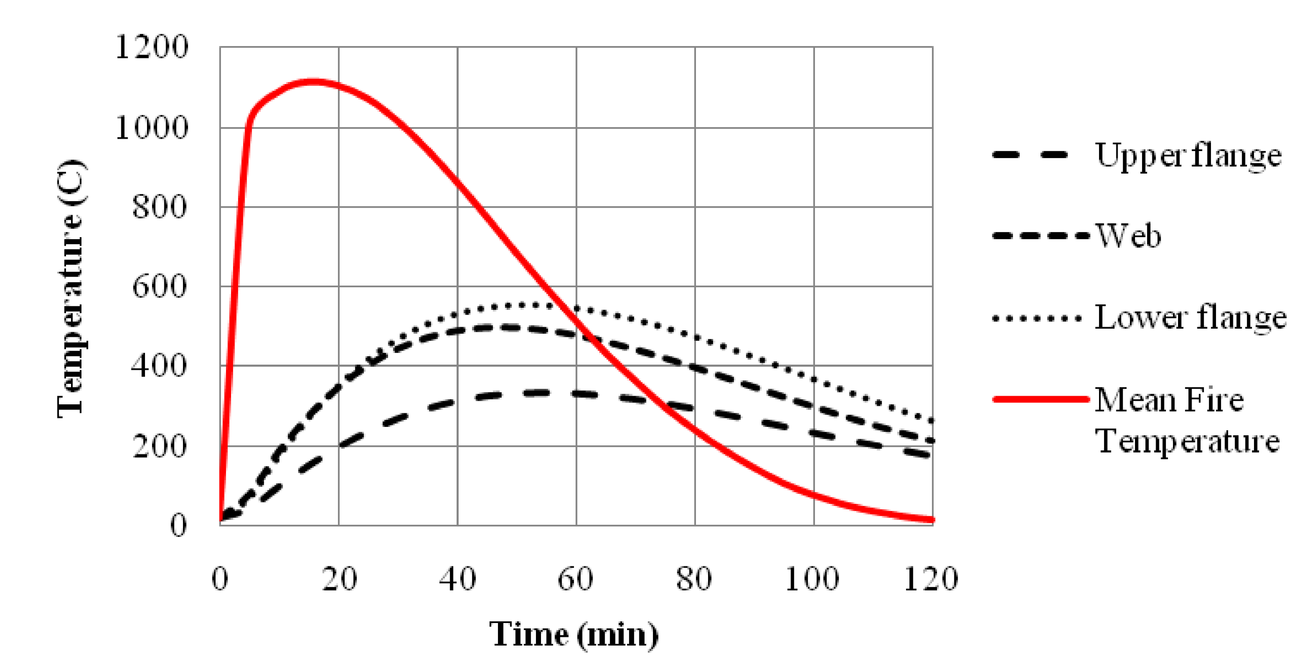

Fig. 5 Average steel temperatures

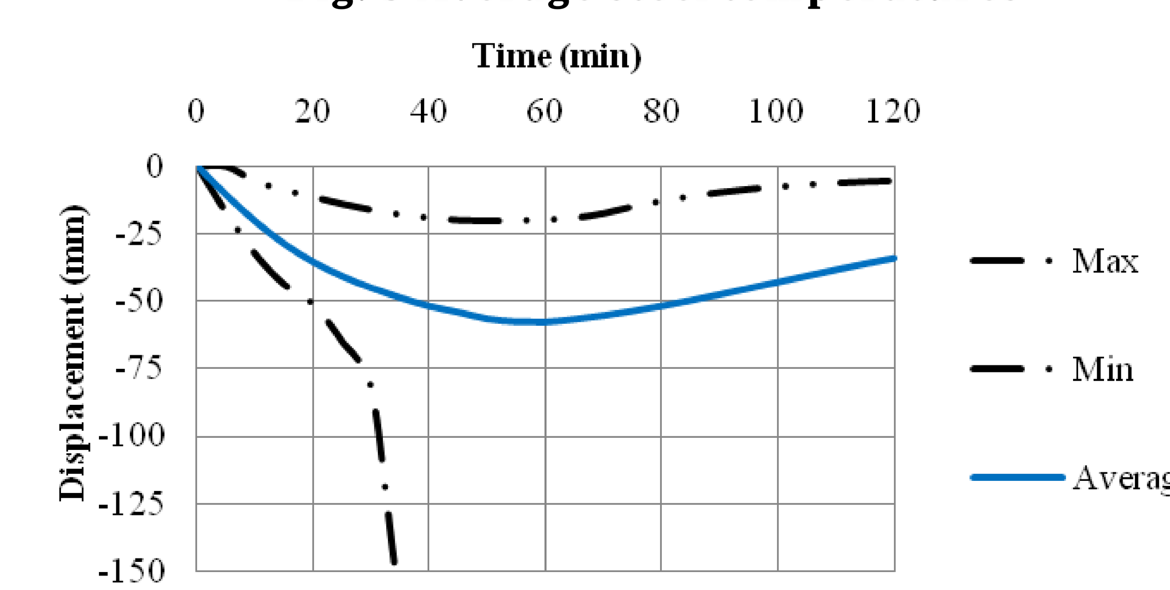

Fig. 6 Mid-span displacement