Simulations of the Viscoplastic Deformation of Steel Structures Under Combined Load/Fire Conditions

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Abstract

Simulations of the deformation of steel structures under variable loading rates and temperature conditions using finite element analysis with an Internal State Variable (ISV) material model are performed. A sequentially coupled thermal-stress analysis is applied to a structure under the simulated fire condition. Both the temperature dependency and strain-rate sensitivity of the material parameters have been examined by analysis of a single steel beam, a simple steel-framed structure and a two-story structure subjected to temperatures ranging from 20˚C-700˚C.

Relevance

This work provides a fundamental understanding of the deformation response of steel-structures associated with fire loadings. This work can be extended to high strain rates and model deformation and damage progression in single and multiple blast/fire events. The finite element simulation of simple and complex steel structures is a tool which can be used to examine new designs and protocols for mitigation methods aiming at infrastructure protection.

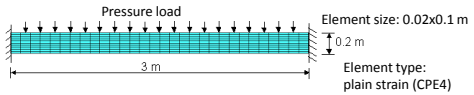
Accomplishments Through Current Year

1) ISV model has been formulated as an ABAQUS UMAT subroutine in a FE algorithm. **2)** FE simulations were carried out on single and multi steel members subjected to fire conditions. **3)** FE simulation results show that the integrated ISV model is capable of describing steel members' deformation as a function of temperature including strain-rate/temperature interaction.

Technical Approach

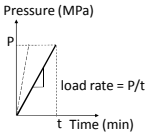
2-Dimensional Single Steel Beam

Single Steel Beam Model

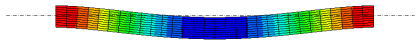


Matrix of Simulation Cases

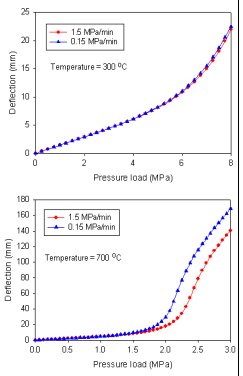
Temperature \ Loading rate	1.5 MPa/min	0.15 MPa/min
300 ºC	T3-LR15	T3-LR015
700 ºC	T7-LR15	T7-LR015



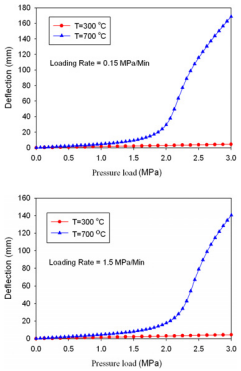
Simulated deflection of single steel beam



Loading Rate Effect



Temperature Effect

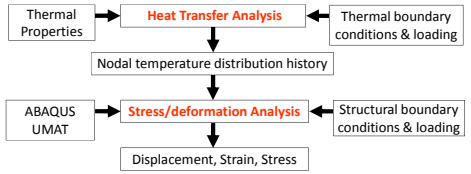


Deformation response of a steel beam: loading-rate independent at T < 300°C, loading-rate dependent at T= 700°C.

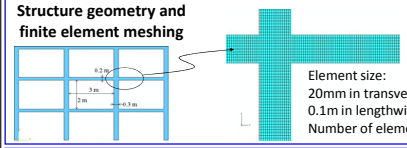
Deformation response of a steel beam is significantly affected by temperature. The steel softens at elevated temperature.

2-Dimensional Steel Structure

Simulation strategy: Sequentially coupled thermal-stress analysis

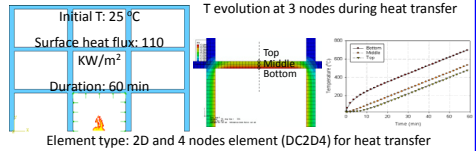


Structure geometry and finite element meshing



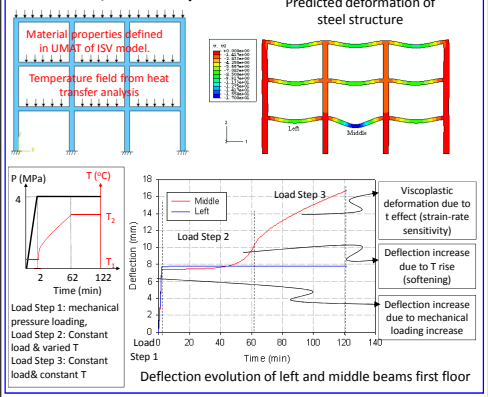
Heat Transfer Analysis

T distribution in the middle bottom cell, and T evolution at 3 nodes during heat transfer



Element type: 2D and 4 nodes element (DC2D4) for heat transfer

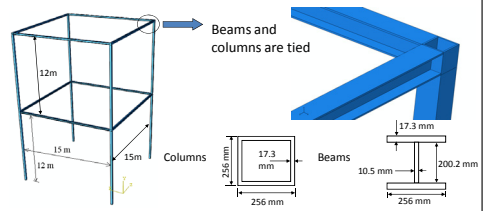
Deformation/Stress Analysis



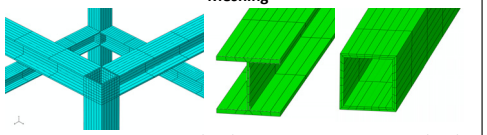
Deflection evolution of left and middle beams first floor

3-Dimensional Steel Structure

Steel Structure Geometry

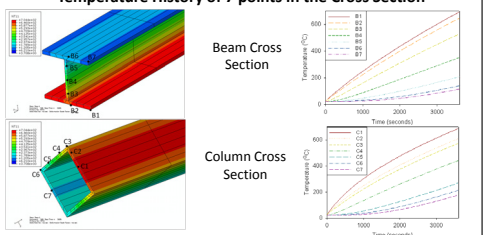


Meshing

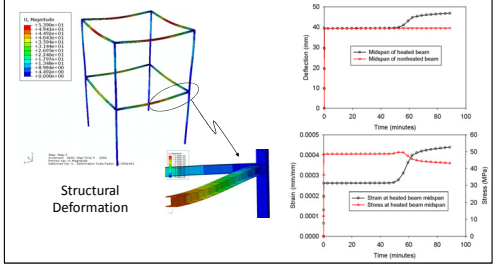


30 divisions along each beam (15m), 24 division along each column (12m)

Temperature History of 7 points in the Cross Section



Deflection, stress and strain history at the midspan of the heated and non-heated beams



Future Work

This model will be extended to high strain rate loading conditions. This will provide a predictive tool for the deformation and successive failure events of the steel reinforcing phase as a function of blast/thermal loading.

Journal Publications

Y. Sun, K. Maciejewski, and H. Ghonem, Numerical Applications of Viscoplastic Deformation of Structural Steel, J. Materials Engineering and Performance, January 2011

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