Fire resistance of steel trusses with OpenSees

Panagiotis Kotsovinos & Asif Usmani
BRE Centre for Fire Safety Engineering, The University of Edinburgh

BRE Centre *for* Fire Safety Engineering

1. Introduction

Steel trusses are an efficient structural system, widely used in practice in order to support loads over long spans. Hence, a structural failure of a truss can have enormous consequences. Steel truss sections can be especially vulnerable to fire because of typically high surface area to volume ratios and lots room for exposure from all sides.

Figure 1. A steel truss supporting the roof of the structure

2. Background

Many finite element codes, both commercial or research based, have been developed and are commonly used for modelling structures in fire. However most of these do not offer sufficient flexibility for adding new capabilities and are also not normally accessible to users or researchers for modification. The object oriented nonlinear finite element framework (OpenSees), primarily designed for earthquake engineering simulations, offers the necessary flexibility and access needed to further expand its capabilities.

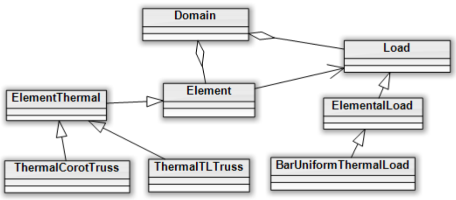

Figure 2. Classes added in the OpenSees framework

3. Why OpenSees

•Open source i.e. free

-Structural engineering community tool

-Lots of users to test it

•Object oriented i.e. easy to extend and maintain

•Finite element framework NOT software

-Library of classes

•Useful for multi-hazard analysis (Earthquake and fire)

•Strong support from PEER to developers

-OpenSees Forums, OpenSees wiki

4. Material Models of Steel

•Steel01Thermal is a uniaxial bilinear steel material with kinematic hardening

•Steel02Thermal is a uniaxial Giuffre-Menegotto-Pinto steel material with isotropic strain hardening.

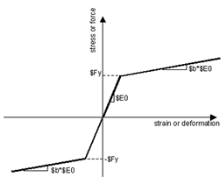

Figure 3 Steel01Thermal

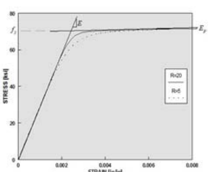

Figure 4 Steel02Thermal

5. Modelling Theory

Different finite element formulations for truss elements are used based on the Total Lagrangian and Co-rotational formulation. The resisting force of each element is given by the equation below

$$P = \sigma A BT Ln$$

Analysis of structures in fire is usually performed into two load steps. The mechanical load is applied first as the first load step and remains constant for the second thermal load step. Such an analysis often involves the use of a step by step numerical method. The most used step by step method is the load controlled Newton-Raphson method.

For each load step during the analysis an incremental displacement is found:

$$\{\Delta F\} = [K] \{\Delta u\}$$

The drawback of this load controlled procedure is that it cannot follow the equilibrium path beyond the limit points. This is the point where failure of the element takes place or a temporary loss of stability is experienced and then a post buckling path is followed. For this reason a dynamic approach has been examined to analyse structures in fire in the OpenSees framework.

6. Numerical Examples

A one member truss and a two member truss are solved and are compared with the results obtained by Lin et al.*

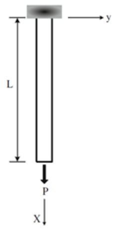

Figure 5 One member truss

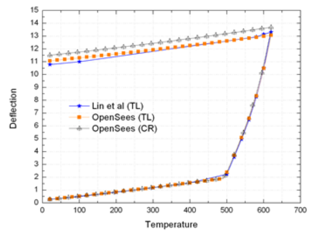

Figure 6 Deflection vs Temperature

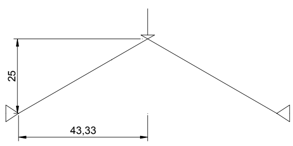

Figure 7 von Mises truss

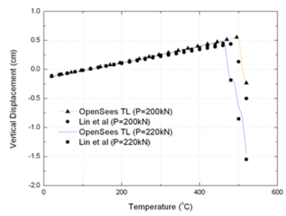

Figure 8 Deflection vs Temperature

The results show good agreement with those presented by the authors for both cases. More specifically for the von Mises truss, the dynamic analysis agree well with Generalised Displacement Control performed by the authors.

7. Conclusions

Procedures developed for modelling the fire resistance of trusses in the object oriented and open source framework OpenSees are presented. More specifically Total Lagrangian and Co-rotational formulation based elements to account for the nonlinear effects. Several numerical examples have been presented to demonstrate the procedures developed. A dynamic approach was also followed to examine the postbuckling response of a truss that loses stability through snap-through buckling.

Thanks to Jian Zhang (HW) and Frank McKenna (UC Berkeley)

*Lin T.J., Yang Y.B., Huang C.W., Inelastic nonlinear behaviour of steel trusses cooled down from a heating stage, International Journal of Mechanical Sciences 52 (2010) 982-992.