ERPem
Edinburgh Research Partnership in Engineering and Mathematics
http://www.erp.ac.uk

The behaviour of pre-damaged reinforced concrete structural systems in fire

Joanne Knox, Pankaj Pankaj and Asif Usmani

School of Engineering and Electronics, The University of Edinburgh, UK

Corresponding author: Joanne.Knox@ed.ac.uk

Introduction

It is known that when severe earthquakes occur, major fires often follow in the damaged structures, and as fires cannot be dealt with effectively, greatly weakened structures need to be able to sustain fire loads. This study considers the response of a single storey reinforced concrete portal frame subjected to earthquake damage followed by fire, modelled using the finite element package Abaqus. Both material and geometric nonlinearities are included in the models. Continuum plasticity is used to model post-elastic behaviour and damage. The aim of the study is to examine the response qualitatively rather than seek quantitative answers.

The Test Structure and Material Model

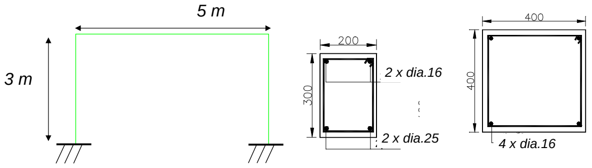

Figure 1: (a) The reinforced concrete portal frame test structure, (b) the beam cross-section and (c) the column cross-section.

In the test structure (Fig. 1) concrete is modelled using the concrete damaged plasticity model available in Abaqus. The post yield behaviour is assumed to be perfectly plastic at any given temperature. In order to partly conform to Eurocode 2 (1996) on structural fire design both Young's modulus and yield stress are assumed to decrease with increasing temperature.

Applied Loadings

Earthquake loading and damage is induced by applying a lateral displacement controlled push at the beam level. Fire loading is applied only to the nodes of the beam and an exponential fire curve is used to calculate the linear thermal gradient over the depth of the beam (-2.3°C/mm) and the uniform temperature increase applied at mid-depth (365.5°C) in a 900°C fire after 60 minutes. Realistically the temperature gradient would not be constant over the depth of the beam due to concrete's low thermal conductivity.

Fire Loading Only

If static loads (dead and imposed) are ignored then in spite of the temperature gradient, which should cause bowing downwards in the beam, joint rotation due to the constant temperature increase causes upward bowing, as seen in Fig. 2a.

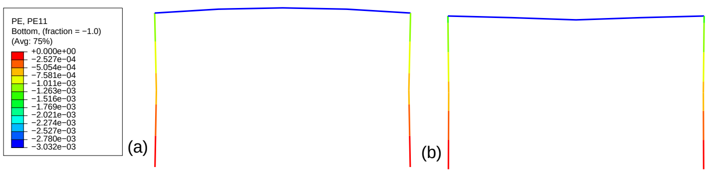

Figure 2: (a) Deformed shape under fire loading only and (b) deformed shape under UDL and fire loading (magnification x200 in both)

Upward bowing is no longer present when a realistic UDL is applied to the beam (included in all subsequent analyses), and the largest plastic strains are confined to the central elements of the beam, see Fig 2b. Both the UDL and the thermal gradient cause tension at the base of the beam; whereas a constant temperature increase induces compression and causes joint rotation at the ends of the beam. This reduces the amount of thermal bowing downwards.

Earthquake and fire loading

Consider the application of earthquake loading (in the form of a push) in one direction, its removal and application of fire loading as discussed above. Results are seen in Figs. 3 & 4.

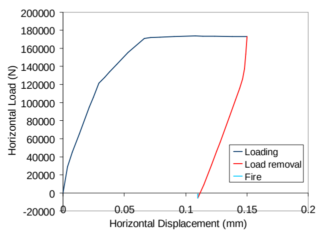

Figure 3: Load-horizontal deformation (at the point of load application)

The lateral load causes the largest compressive plastic strains to occur at the right end of the beam and the largest tensile plastic strains at the bottom end of the right column (see Fig. 4a). The tensile plastic strain at the left end of the beam is larger in magnitude than the compression found at the right; due to lower tensile yield strength.

Load removal causes the structure to displace leftwards (Fig 4b); this can also be seen in Fig. 3. However, the plastic strain profile and the deformed shape are not significantly altered.

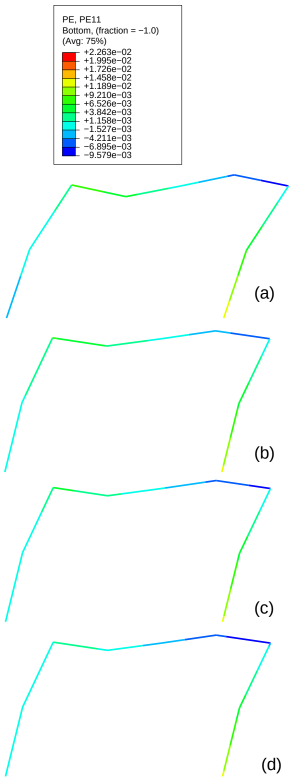

Figure 4: Deformed shape (magnification x10) after:
(a) Loading (push) to the right, (b) Load removal, (c) 60% of fire loading, (d) End of fire step

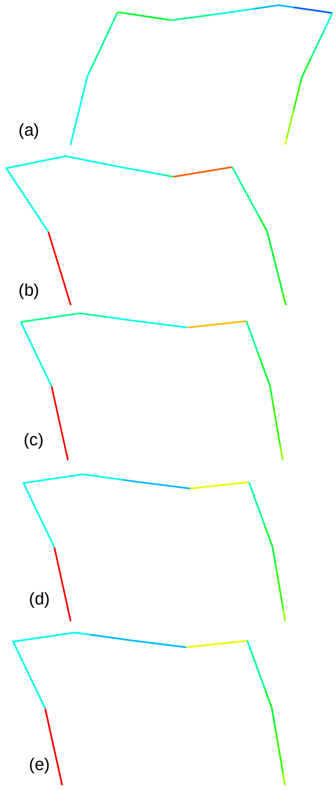

Figure 5: Deformed shape (magnification x10) after:
(a) Removal of rightward loading (identical to Fig. 5b), (b) Leftward loading, (c) Load removal, (d) 80% of fire loading, (e) End of fire step

Figures 4c and d are for the fire application step, when in the beam, the compressive strains (at the right side) increase, while the tensile strains (at the left side) decrease. This is due to expansion of the beam, due to the constant temperature increase, causing compression.

Now consider the application of loading as: push in one direction, followed by load reversal, load removal and finally application of fire load. The development of deformation and principal plastic strains is shown in Fig. 5. Load reversal leads to all plastic deformation becoming tensile (see Fig. 5b) and it remains tensile throughout the second load removal step. Throughout the beam, the value of tensile plastic strains present during the fire step decreases as fire loading increases, due to the expansion of the beam as previously. The load-deformation plot is shown in Fig. 6.

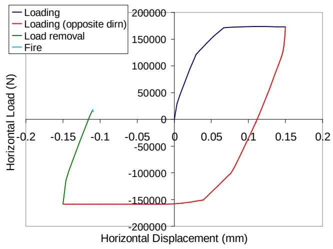

Figure 6: Load-horizontal deformation (at point of application)

Conclusions

- *Fire loading causes plastic strains to be distributed in the beam.*
- *Column rotation acts against temperature gradient and uniformly distributed load, preventing or limiting downward thermal bowing.*
- *Fire loading of the beam after application of seismic forces appears to have little effect on the columns. It induces compressive strains in the beam, thereby increasing compressive or reducing tensile plastic strains.*
- *Application of seismic forces causing plastic damage changes the behaviour of the structure under fire loading – instead of symmetrical compressive plastic strains being induced, areas of varying tensile and compressive strain are caused within the beam.*
- *Ongoing research considers more realistic thermal gradients and the effect when temperature loading is applied to columns as well as to the beam.*