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Realistic modelling of thermal and structural behaviour of unprotected concrete filled tubular columns in fire

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Abstract

This paper employs the commercial finite element analysis package ANSYS to model the thermal and structural behaviour of isolated CFT columns in fire. Although CFT columns have been numerically analysed by many researchers, this paper presents details of a number of features which have often been neglected by many researchers, including the influence of an air gap and slip at the steel/concrete interface on CFT column temperatures and structural behaviour, the sensitivity of CFT fire resistance to concrete tensile behaviour and CFT column initial imperfections. The finite element model is validated by comparing the simulation results against experimental results of standard fire resistance tests on 34 CFT columns with different structural boundary and loading conditions. A numerical parametric study is then performed to investigate the sensitivity of simulation results to different assumptions introduced in the finite element model. The results of these numerical studies show that whether or not including slip between the steel tube and concrete core in the numerical model has minor influence on the calculated column fire resistance time. The fire resistance of CFT columns with an air gap is generally slightly higher than that without an air gap. However, including slip gives a better prediction of column deflection behaviour. Using different tensile strength or tangent stiffness of concrete has a minor effect on the calculated column fire resistance. Different amounts of column initial deflection have some influence on column fire resistance times. Nevertheless, the influence is relatively small so that it is acceptable to use a maximum initial deflection of $L/1000$ as commonly assumed by other researchers.

Keywords: Concrete filled columns; ANSYS modelling; Fire resistance; Air gap; Initial imperfection; Thermal modelling; Structural modelling

1. Introduction

The advantages of concrete filled tubular (CFT) columns are numerous, including attractive appearance, structural efficiency, reduced column footing, fast construction and high fire resistance without external fire protection. These attractions have enabled CFT columns to be used in all types of construction. CFT column applications are particularly widespread in countries such as China, Japan and Australia. For example, a number of Chinese textbooks [6,18,23] have been entirely devoted to CFT columns.

In fire, the behaviour of a structure is much more complex than at ambient temperature. Changes in the material properties and thermal movements will cause the structural behaviour to become highly nonlinear and inelastic. It has not been possible for approximate analytical methods of sufficient accuracy to be developed to fully track CFT column behaviour in fire and numerical simulations are necessary. In general, the calculation of the fire resistance of a column involves calculation of the temperatures of the fire to which the column is exposed, the temperature in the column and its deformations and strength during exposure to the fire. A considerable amount of research has been carried out by numerous researchers to investigate fire behaviour of CFT columns (e.g. [5,9,13,20]). However, despite extensive numerical simulations of CFT columns in fire, most of the existing simulations adopt similar assumptions, some of which may not be realistic representations of actual CFT column behaviour. One aspect concerns the steel/concrete interface. Although under fire exposure it is possible for the bond between the steel tube and the concrete core to be broken, the majority of researchers have assumed perfect contact between the steel tube and concrete core. [14–16] appear to be the only researchers to have considered including

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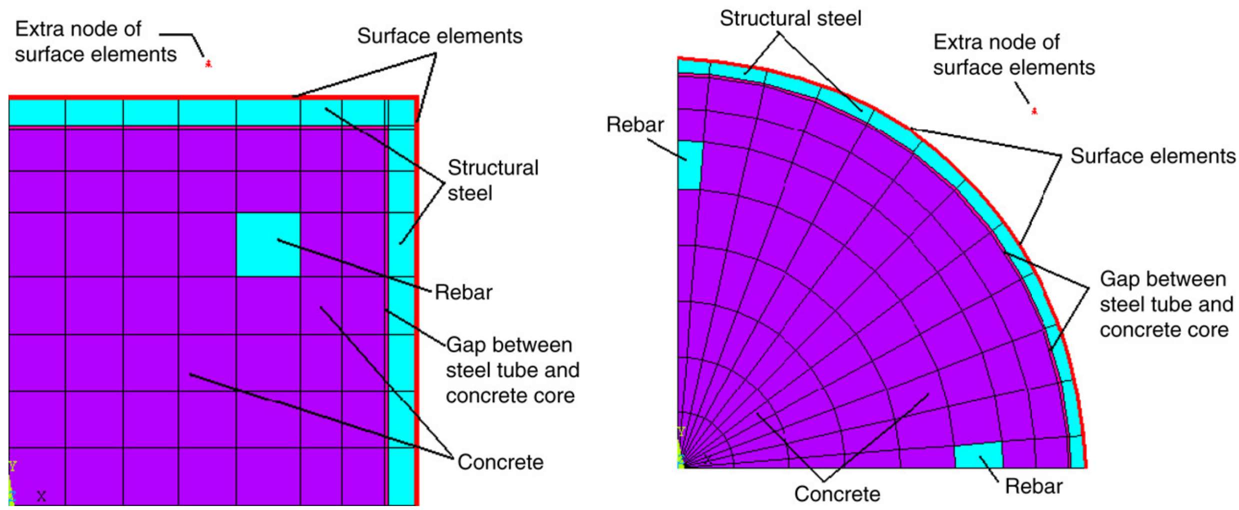

(a) Rectangular cross-section. (b) Circular cross-section.

Fig. 1. Finite element meshes in quarter section of CFT columns for thermal analysis.

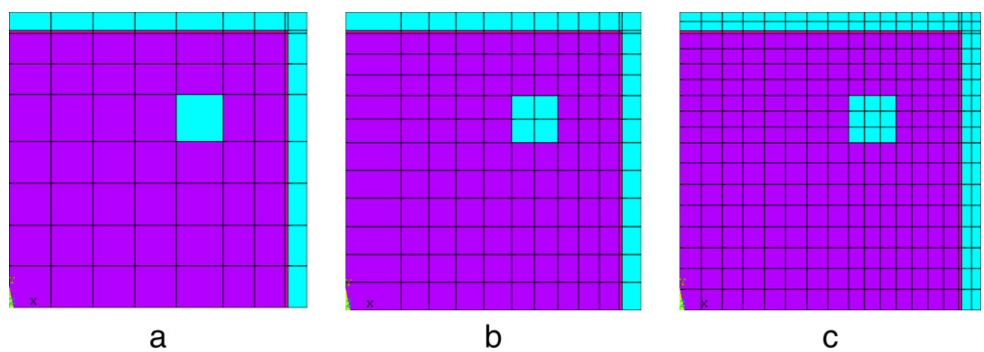

Fig. 2. Three different meshes for section SHS 200 × 200 × 6.3.

an air gap. They developed a specialist finite element analysis package SISMEF and in their simulations, an average thermal resistance equal to 0.01 [m^2 K/W] for the air gap between the steel tube and the concrete core was taken into account in the thermal model and was found to produce accurate temperature distributions in CFT columns. However, they have not extended their investigation to assess the influence of such an air gap on CFT column structural behaviour and fire resistance.

This paper employs the commercial finite element analysis package ANSYS to model the behaviour of isolated CFT columns in fire. Since the fire field along the length of a column is assumed to be uniform, the temperature distribution within the column is simulated by using a 2-D model for the cross-section, as commonly adopted by other researchers. However, the fire resistance of the CFT column is calculated by using a 3-D finite element model. The finite element analyses are checked against a large body of experimental results for validation. A series of numerical parametric studies is then performed using the validated model. The objectives of the numerical studies are: (1) to verify applications of the ANSYS software to CFT columns in fire; (2) to examine the effects of a number of factors that have, in general, not been considered in other numerical simulations. These factors include: (i) the aforementioned thermal resistance of a possible air gap between the steel tube and the concrete core, which can affect both the temperature results and structural behaviour; (ii) slip between the steel tube and the concrete core, which affects the structural behaviour of CFT columns; (iii) stress–strain model of concrete in tension at high temperatures.

2. Thermal analysis

When a CFT column is exposed to fire, due to the low diffusivity of concrete, a steep temperature gradient is expected. For the majority of situations in which a column is exposed to fire that has uniform temperature along the column length, the column temperatures may be assumed uniform over the height of the column. Thus, the temperature distribution within a CFT column cross-section can be simulated by using a 2-D model.

Because of the symmetry of the geometry and the boundary conditions when a symmetric CFT column is exposed to fire on all surfaces, only one quadrant of the column cross-section is analysed. Fig. 1(a) and (b) illustrate the typical finite element meshes for rectangular and circular cross-sections, which include solid heat conduction elements for the steel tube, the concrete core and the gap between the two materials and surface elements.

In this study, the 2-D solid thermal element PLANE55 is used to mesh the cross-section of the CFT column. The surface