BEAVIOR OF SQUARE STAINLESS STEEL COLUMNS AFTER ELEVATED TEMPERATURE

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Twelve finite element models of square stainless steel columns after elevated temperature were tested to investigate behavior of these columns after elevated temperature under axial compressive load in this paper. The elevated temperatures, height of column and wall thickness were set as the parameters in the test. The effects of temperature, height of column and wall thickness on the ultimate vertical bearing capacity of square stainless steel columns were studied in this paper. The comparison of load-displacement curves and failure models between the finite element models with experimental results indicated that the results of finite element model are agreement with the experimental results well. The results indicated that when the stainless steel tube columns subjected to elevated temperature, stress increased rate in the middle of the surface was greater than that at the edge of the surface. The ultimate bearing capacity decreased with the square stainless steel columns subjected to elevated temperature. The negative influence of elevated temperature could be reduced by increasing the wall thickness of stainless steel tube columns. And the negative influence of increasing stainless steel tube column height could be reduced by increasing the wall thickness of tube column.

Keywords: Square stainless steel column, Finite element model, Ultimate vertical bearing capacity, Failure mode.

1 Introduction

Stainless steel has many advantages to be used in civil engineering, such as high capacity, light weight and beautiful. However, the fire resistance of stainless steel columns is bad. The investigation of behavior of square stainless steel columns after elevated temperature is important and necessary to avoid the loss of life and property.

Han (2000, 2001) have investigated the ultimate fire resistance behavior of concrete filled steel tube columns, which columns subjected to elevated temperature according to the ISO standard temperature elevation curve (ISO 834, 1975). Gardner (2006) compared the mechanical and thermal properties of stainless steel and carbon steel, which indicated that the strength and stiffness retention of austenitic stainless steel at elevated temperature is superior to that of carbon steel. Uy (2011) studied the performance of concrete filled stainless steel tube columns. The results show that stainless steel tube reinforced concrete columns have broad engineering application prospects. Tao (2014, 2016) studied the fire resistance of concrete filled stainless steel tube columns. The results indicated that concrete filled stainless steel performance was good for the fire resistance.

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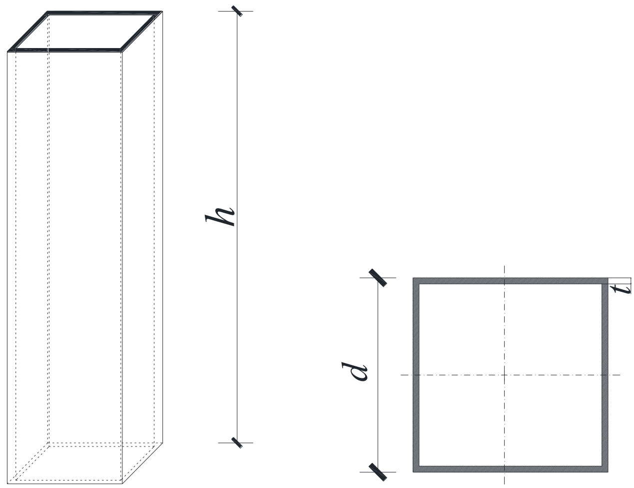
It is concluded that concrete filled stainless steel tube columns have great capacity of the fire resistance from these researches mentioned above. Nevertheless, there is little theoretical research about the ultimate vertical bearing capacity of stainless steel tube columns after elevated temperature. This paper mainly studied the effects of temperature, the height of column and wall thickness on the failure modes and ultimate vertical bearing capacity of square stainless steel columns.

2 Finite Element Model

The finite element program ABAQUS was used for numerical analysis of square stainless steel tube (SST) columns after elevated temperature. The main objective of finite element model (FEM) was to validate itself against experiments (Zhang, et al., 2018). The ultimate vertical bearing capacity and failure modes obtained from finite element models were compared with the experimental test. In finite element model, materials, loading, boundary conditions and contact interaction for the specimens were taken into account.

2.1 *Material models*

At elevated temperature, the density of stainless steel (ρ_s) is often considered to be independent of the stainless steel temperature. The ρ_s is 7850 kg/m^3 in this paper. The dimensions of finite element models were defined according to the values measured in the experimental tests (Zhang, X.Y., et al.). Table 1 showed the size and properties of these specimens including the height of column (h), wall thickness (t), Diameter (d), temperature (T), modulus of elasticity (E_c) and Poisson ratio (v). The diagram of specimen was shown in Fig.1.



(a) Full view of the specimen (b) Top view of the specimen

Figure 1. Diagram of specimen

Table 1. Details of specimens

Specimen	Temperature (T/°C)	Wall Thickness (t/mm)	Height of Column (h/mm)	Diameter (d/mm)	Modulus of elasticity (E_c/GPa)	Poisson ratio (v)	Ultimate vertical bearing capacity (kN)
FEt1.5-h320-T25	25	1.5	320	80	200	0.3	68.78
FEt1.5-h320-T500	500						52.22
FEt1.3-h320-T25	25	1.3					37.56
FEt1.3-h320-T500	500						27.32
FEt1.5-h240-T25	25	1.5	240				64.57
FEt1.5-h240-T500	500						58.25
FEt1.3-h240-T25	25	1.3					39.75
FEt1.3-h240-T500	500						33.60
FEt1.5-h160-T25	25	1.5	160				75.66
FEt1.5-h160-T500	500						64.24
FEt1.3-h160-T25	25	1.3					42.83
FEt1.3-h160-T500	500						38.67

2.2 *Analysis process*

The finite element analysis process included two parts: high temperature fire stage simulation and axial compression stage simulation. In the part of high temperature fire stage simulation, the temperature was improved according to ISO standard temperature elevation curve (T=20+345lg(8t+1)). Both of two ends of stainless steel column are assumed to be hinge joint. The upper surface of column was restrained along the horizontal two axes and the bottom surface of column was restrained in all three directions. Displacement control was used for nonlinear analyses. Three-dimensional eight-node solid elements with reduced integration C3D8R were used in the FEM models. The finite element mesh was one layer in the thickness direction to obtain accurate results and less computational time. The typical finite element mesh of stainless steel tube columns was shown in Fig. 2.

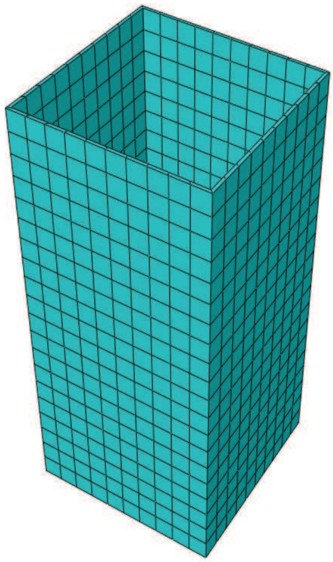
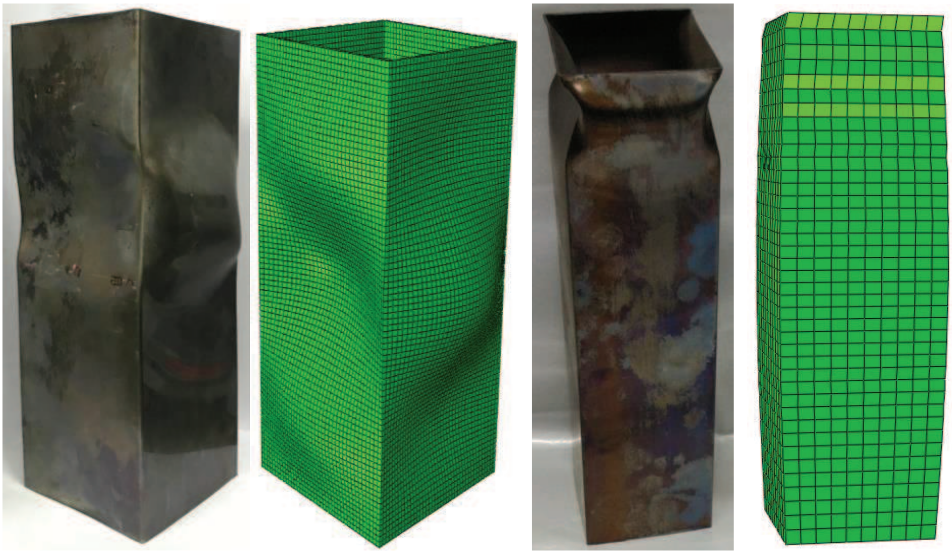


Figure 2. Typical finite element mesh

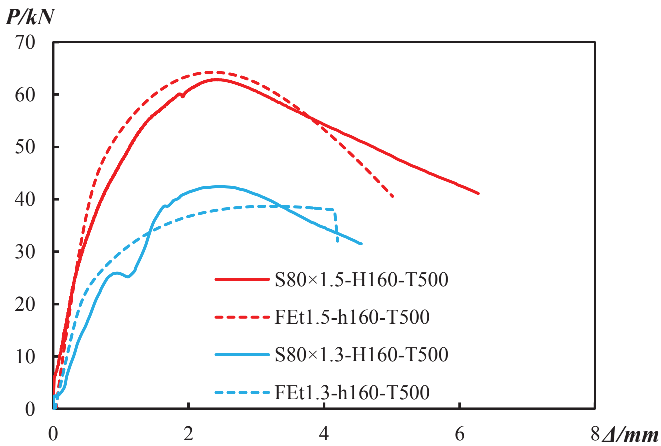
3 Analysis of the Results

According to the finite element model analysis, following results could be obtained including stress distribution of columns after elevated temperature, failure model, ultimate vertical bearing capacity and load-displacement curves.

The comparison of load-displacement curves and failure model between the FEM with experimental results (Zhang, X.Y., et al.) were shown in Fig. 3. It could be found that the results of FEM are agreement with the experimental results well. According to the load-displacement curves of FEM, the ultimate vertical bearing capacity of FEM were obtained, which were shown in Table 1.



(a) Comparison of failure model



(b) Comparison of load-displacement curves

Figure 3. Comparison of FEM with experimental

3.1 Effects of temperature

The stress increased rate in the middle of the surface was greater than that at the edge of the surface with the temperature increased, which could be found from Fig. 4. In other words, the middle of the square stainless steel surface was easier to be damaged than that edge of the surface when the columns subjected to the elevated temperature. From Table 2, it could be found that the ultimate vertical bearing capacity decreased of the stainless steel tube columns after elevated temperature. The influence of elevated temperature on the ultimate vertical bearing capacity could be reduced by increasing the wall thickness of stainless steel tube columns. The higher the stainless steel tube column height was, the greater the influence of elevated temperature on its ultimate vertical bearing capacity was than that of other locations.

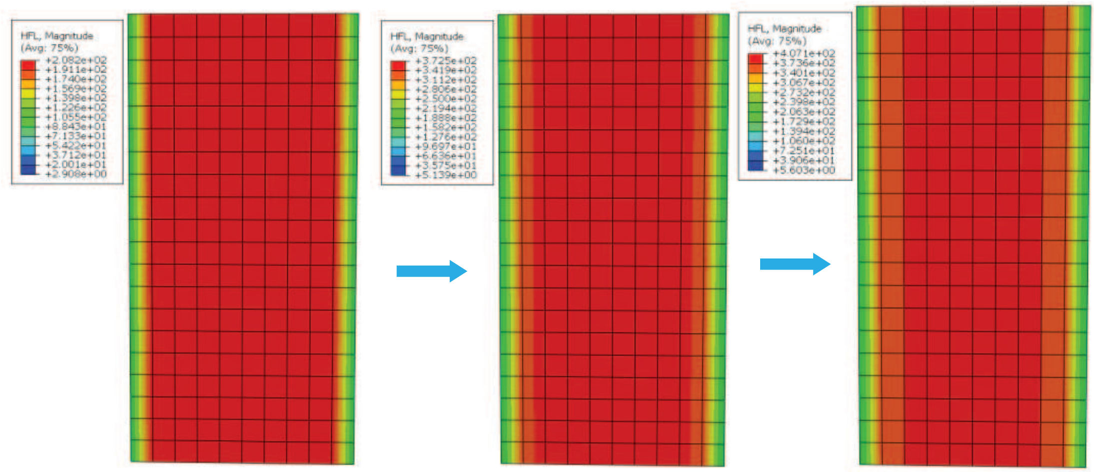


Figure 4. Stress distribution in heating process

3.2 Effects of specimen size

The influence of stainless steel tube column wall thickness on ultimate vertical bearing capacity was obvious, which could be obtained from Table 1. When increase the wall thickness of stainless steel tube column from 1.3mm to 1.5mm, the ultimate vertical bearing capacity increased by more than 60%. When the tube columns subjected to elevated temperature, the increase of ultimate vertical bearing capacity was more obvious than that of normal stainless steel tube columns for increasing wall thickness. The ultimate vertical bearing capacity decreased with the column height increased. The increase of ultimate bearing capacity was obvious with wall thickness increased for increasing tube column height. In other words, the negative influence of increasing stainless steel tube column height could be reduced by increasing the wall thickness of tube column.

4 Conclusions

This paper validated the accuracy of the FEM by comparing the residual load-displacement curves and failure model between the FEM with experimental results. The influences of elevated temperature and specimen size on the ultimate vertical bearing capacity of stainless steel tube columns were investigated in this paper. Based on the FEM results, these following conclusions can be obtained:

(i) When the stainless steel tube columns subjected to elevated temperature, stress increased rate in the middle of the surface was greater than that at the edge of the surface.
(ii) The ultimate vertical bearing capacity of stainless steel tube columns decreased when the tube columns subjected to elevated temperature. And the higher the stainless steel tube column height was, the greater the influence of elevated temperature on its ultimate vertical bearing capacity was than that of other locations.