Finite element analysis of thin-waist concrete-filled steel tubular short column under axial compression

IOP Conf. Series: Earth and Environmental Science **267** (2019) 042107 doi:10.1088/1755-1315/267/4/042107

Finite element analysis of thin-waist concrete-filled steel tubular short column under axial compression

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Abstract. A three-dimensional non-linear finite element (FE)model for thin-waist concrete filled steel tubular (CFST) columns is established. The mechanical properties of thin-waist CFST short columns under axial compression are analyzed. The ultimate strength and the axial load-axial curves calculated by the FE model are in good agreement with the experimental results. The FE model presented in this paper can be used for reference in the non-linear analysis of CFST columns.

1.Introduction

1.1Research Background and Significance
Based on the well-functioned finite element analysis software and high-performance computer hardware, a detailed mechanical analysis of the designed structure is carried out to obtain the real structural stress information as far as possible. In the design stage, safety evaluation and design parameters modification can be made for all possible problems. According to relevant information, more than 60% of the problems of a new product can be eliminated in the design stage, and even more. The construction process of some structures also needs fine design. To achieve this, we need analysis methods such as finite element analysis.

1.2 Contents and Methods of This Paper
Based on the objective of improving the restraint effect on core concrete in concrete filled steel tube, this paper introduces a design structure of thin waist concrete filled steel tube. Under vertical load, thin waist steel tube tends to deform inward.Thus, an active restraint force is applied to core concrete to improve the restraint effect on concrete and restrain the development of micro-cracks (damage)[1] so as to improve the ultimate bearing capacity. However, there are few experimental studies on the mechanical properties of thin waist concrete filled steel tubes. With the highly programmed finite element method, which is not constrained by the actual size of the project, the cost is low, the solution speed is fast, and the results are credible. Therefore, it is necessary to find a numerical simulation method suitable for thin-waist concrete filled steel tube, and to discuss the non-linear performance and ultimate bearing capacity of thin-waist concrete filled steel tube combined with the existing experimental data. In this paper, appropriate confined concrete constitutive model and concrete damage calculation model are selected. Finite element simulation of thin waist concrete filled steel tubular short columns is carried out by using finite element software ABAQUS. The simulation results are in good agreement with the existing experimental results.

2.Finite Element Analysis of Thin-waist Concrete Filled Steel Tubular Short Columns under Axial Compression

2.1Forward

There are three key points in simulating confined concrete filled steel tubular: one is to use reasonable confined concrete constitutive model to simulate the improvement of plastic properties of core concrete under restraint effect, because the plastic damage model is too small for calculating plastic strain under three-dimensional compression; the other is to reasonably select the important parameters in the constitutive model of core concrete, which are determined by these important parameters. The yield criterion of concrete impact; the third is to select a suitable concrete damage calculation model, because the traditional damage factor calculation method is too large.

2.2Finite Element Modeling

2.2.1 Unit Selection

The wall thickness of steel tube is smaller than that of core concrete, because the shell element with four-node full integration scheme is used to simulate. In order to achieve the necessary calculation accuracy, the Simpson integral of nine integral points is adopted in the direction of shell element thickness. The core concrete is composed of three-dimensional solid elements with eight-node reduced integral scheme. Comparisons show that the linear element and the quadratic element satisfying the mesh accuracy requirements can obtain better results in the analysis of concrete filled steel tube under axial compression.

2.2.2 Mesh Generation

The accuracy of finite element calculation is also related to mesh generation. The closer the theoretical mesh division is, the higher the accuracy of calculation is. However, a lot of computing resources are wasted. It is found that when the mesh is divided into 5-20 mm, the mesh size has little influence on the calculation results. Therefore, the mesh size of steel tube, concrete and end plate in this model is taken as 10 mm, and the mesh generation is shown in the figure.

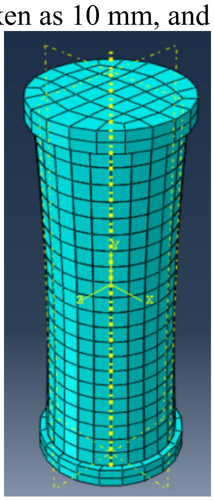

Figure 1.Finite element model

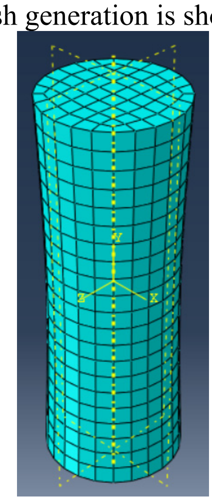

Figure 2.Solid concrete element

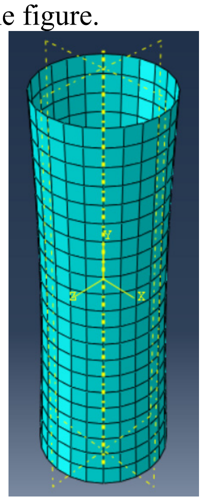

Figure 3. Steel tube shell element

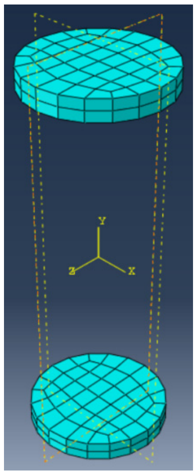

Figure 4.Solid end plate element

2.2.3Interface Contact

IOP Conf. Series: Earth and Environmental Science **267** (2019) 042107 doi:10.1088/1755-1315/267/4/042107

In this paper, the definition of interface contact is as follows: the normal contact of the interface adopts hard contact, that is, the contact pressure transmitted by steel tube and concrete surface is infinite; there is no contact pressure produced when not contacted; and the two surfaces are not allowed to penetrate each other. Tie is adopted between the loading plate and steel tube and concrete, and displacement loading is adopted in the loading mode, without considering the effect of steel tube buckling on the bearing capacity under the ultimate state.

2.2.4Boundary Conditions and Loading Mode

The boundary conditions at both ends are hinges. The displacement/rotation angle is used to model the boundary conditions. The lower end restricts the degrees of freedom in the directions of U1, U2 and U3, and the upper end restricts the degrees of freedom in the directions of U1 and U3. In order to obtain the descending section of the curve, displacement loading is adopted and the incremental iteration method is used to solve the nonlinear equations.

2.2.5Selection of Parameters

Definition of coagulation expansion angle[2]: With the increase of expansion angle, the bearing capacity of the structure increases, but the increase is not obvious. However, the exact value of concrete expansion angle has not yet been accurately stated. Generally, it is considered that 30 degrees is appropriate, so the expansion angle is 30 degrees in this paper.

Concerning the definition of concrete viscous coefficient[3]: the bigger the viscous coefficient is, the bigger the stiffness of the structure is, the smaller the viscous coefficient is, and the smaller the stiffness is. At the same time, the calculation efficiency is also lower and the convergence is difficult. In this paper, the viscous coefficient of 0.0005 is selected and the result is satisfactory.

Definition of modulus of elasticity[4]: Although the ultimate bearing capacity and peak strain of concrete increase with the increase of dimension pressure, the change of modulus of elasticity is very small, so the change of modulus of elasticity is not taken into account when the finite element modulus of elasticity is input.

2.2.6Steel Constitutive Equation

The steel used in this paper is 20 # steel with a carbon content of 0.2%(<0.25%). It belongs to high quality low carbon steel. For low carbon steel, the secondary plastic flow model is adopted. The stress-strain relationship consists of five stages: elastic section (oa), elastic-plastic section (ab), plastic section (bc), strengthening stage (cd) and secondary plastic flow section (de) (Zhong Shantong, 1994).

2.2.7Concrete Constitutive

In this paper, an improved Mander[5] constitutive model is used to simulate the finite element analysis of thin waist concrete filled steel tubular short columns. The simulation results are in good agreement with the experimental results. Therefore, an improved Mander constitutive model is adopted in this paper.

2.2.8Damage Calculation of Concrete

Based on Najar damage theory and modified damage calculation model, this paper calculates the damage variable of concrete under compression. The damage factor-inelastic strain figure is obtained. The load-displacement curve obtained by simulation is in good agreement with the experimental results.

2.2.9Verification of Finite Element Model

In this paper, the performance of slender waist concrete filled steel tubular stub columns under axial compression is analyzed. The specimen is L/D=3. The section parameters are as follows: the diameter

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of the end of the steel tube is 152 mm, the diameter of the middle part is 140 mm, the thickness of the steel tube is 4 mm, and the length is 420 mm. The diameter and thickness of the loading plate are 160 mm and 20 mm respectively.

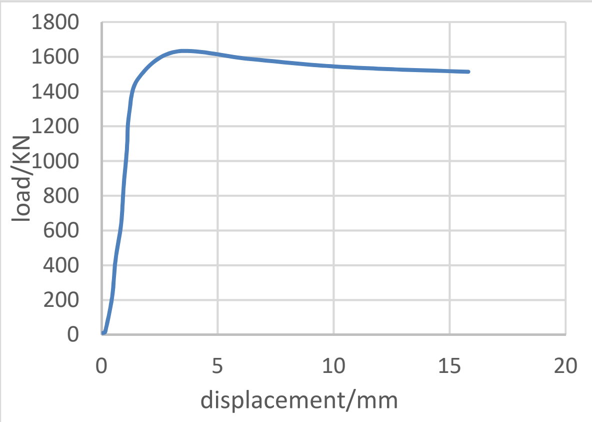

Figure 5.Load-displacement curve under finite element analysis

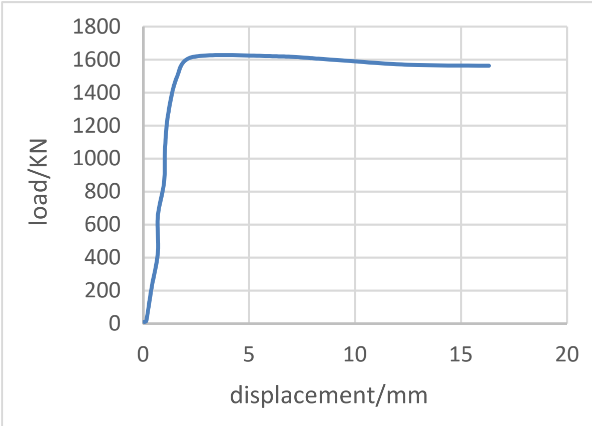

Figure 6.Load-strain curve under test

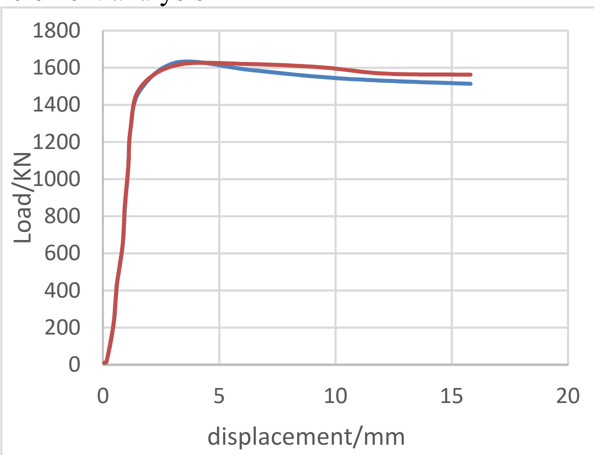

Figure 7.Load-strain comparison diagram

From the load-displacement curve, it can be seen that there is no obvious downward section after reaching the ultimate bearing capacity of thin-waist concrete-filled steel tubular columns, and there is an upward trend of loading, that is, the strengthening section appears.

2.2.10 Force Analysis

From the stress cloud chart , it can be seen that when the ultimate load of thin waist concrete filled steel tube is about 0.4-0.5 times, the steel tube has obvious active restraint effect on concrete. However, only when the ultimate load of CFST members is about 0.7-0.85 times, can the steel tube restrain the concrete passively.

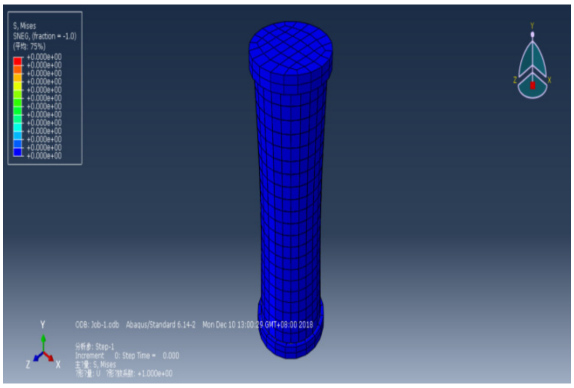

Figure 8.Stress cloud chart steel tube

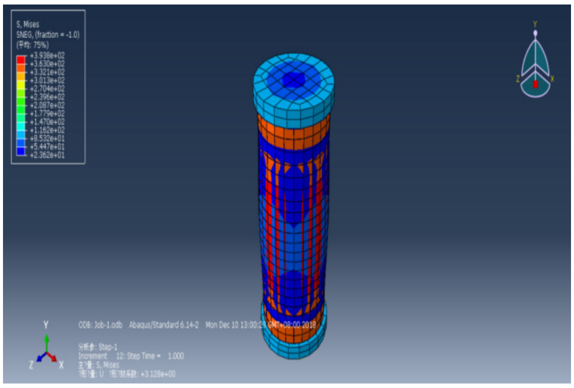

Figure 9.Stress cloud chart of concrete filled

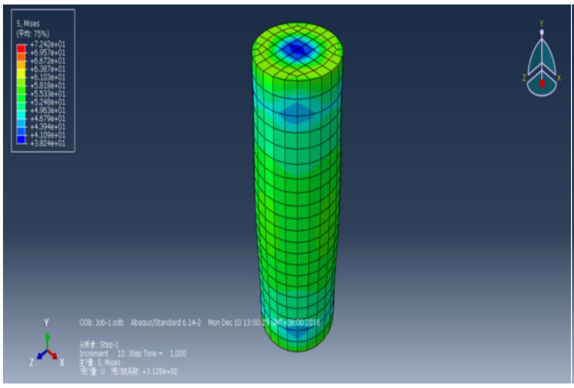

Figure 10. Stress cloud chart of concrete

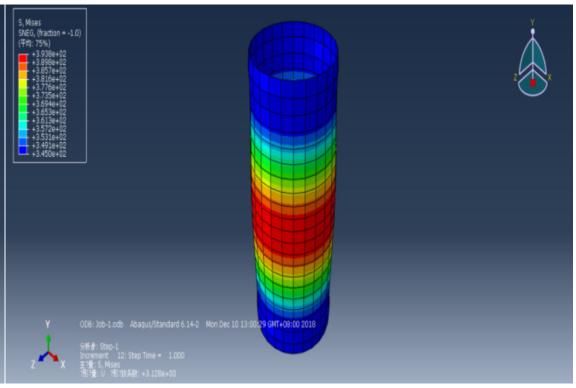

Figure 11.Stress cloud chart of steel pipe

2.2.11 Summary

In this chapter, appropriate steel, concrete constitutive models and modified concrete damage models are used to simulate the CFST specimens in this paper. The simulated load-displacement curves are in good agreement with the experimental load-displacement curves. It shows that the constitutive parameters and simulation process adopted in this paper are suitable for the finite element simulation of thin-waist CFST short columns.

3.Conclusions

(1)In this paper, the finite element analysis software ABAQUS is used, and the modified Mander confined concrete constitutive model and the modified concrete damage calculation model based on Najar damage theory are used to simulate the slender waist steel tube columns. The simulation results are in good agreement with the experimental results. It shows that the constitutive parameters adopted in this paper can be used to simulate the slender waist steel tube columns subjected to axial compression.

(2)when the ultimate load of thin-waist concrete filled steel tube is about 0.4-0.5 times, the steel tube has obvious active restraint effect on concrete. However, only when the ultimate load of CFST members is about 0.7-0.85 times, can the steel tube restrain the concrete passively. It shows that the thin waist concrete filled steel tubular members can restrain core concrete earlier without additional conditions.

Acknowledgments

This work is financially supported by the National Natural Science Foundation of China (51678151) and Program for New Century Excellent Talents in Fujian Province University, NCETFJ (GY-Z18154). The financial supports provided for this work are greatly appreciated.

References

[1] Changdong, Li Chunlong. Damage Evolution of Actively Constrained Concrete Cylinders[J].Journal of Chang'an University: Natural Science Edition,2015,35(5):65-72.
[2] Xie Ping, Dong Yuli. Study on elastic-plastic damage constitutive model of concrete under different confining pressures[J].Journal of Coal Science,1996(3):265-270.
[3] Liu Jinsong, Liu Hongjun. Finite element analysis of ABAQUS reinforced concrete[J].Equipment Manufacturing Technology,2009(6):69-70.
[4] Xie Ping, Dong Yuli. Research on constitutive models of elastic-plastic damage of concrete under different confining pressures[J].Journal of Coal Science1996(3)265-270.
[5] Qi Hongtuo. Static Behavior of Concrete Tube Constrained Members under Axial and Bias Compression[D].Harbin Institute of Technology,2014.