Finite element simulation of recycled large aggregate self-compacting concrete short columns with steel tubes

Jianchao Wang1*, Guangzhuo Ma1 and Wentao Yang2
1School of Civil Engineering, Shenyang Jianzhu University, Shenyang, Liaoning, 110168, China
2Sinopec Shengli Oilfield, Dongying, Shandong, 257001, China
*Corresponding author’s e-mail: wangjianchao005@163.com

Abstract. In order to study the mechanical properties of recycled large aggregate self-compacting concrete filled steel tube(RLA-SCCFST) and promote the research and application of the structure, the mechanical properties of nine groups of RLA-SCCFST short columns under axial compression were studied by ABAQUS simulation. Comparing the results of finite element simulation with the test results, it is found that: 1. The simulation results of the load-vertical strain curve are in good agreement with the test results, and the maximum error of the ultimate bearing capacity measured by the simulation and the test is within 3%; 2. The ultimate bearing capacity and ductility of RLA-SCCFST specimen increase with the increase of steel pipe wall thickness, recycled large aggregate strength and self-compacting concrete strength, and the ultimate bearing capacity of specimen decreases with the increase of recycled large aggregate content.

1. Introduction
Recycled concrete has been regarded as the most effective way to solve the problem of waste concrete since it came out. However, the development of recycled concrete structure has been restricted by various factors, and its application in practical engineering is still rare. Recycled concrete components should not only ensure the mechanical properties of the structure, but also improve the utilization rate of recycled concrete as much as possible and reduce the cost and improve the economy. At present, the research and application of recycled concrete is mainly to crush waste concrete into aggregate to replace natural aggregate[1]. If the aggregate size is increased from general "coarse aggregate" to "large aggregate", a lot of manpower, material and financial resources will be saved in aggregate production.

At present, some scholars have studied this kind of recycled concrete component with "large aggregate"[2]. Based on the previous research, the research group has carried out innovative research, and poured recycled large aggregate and self-compacting concrete(SCC) into the steel tube. Through the test, it is proved that the recycled large aggregate self-compacting concrete filled steel tube(RLA-SCCFST) has not less than the mechanical properties of reinforced concrete column. In view of the existing finite element simulation software has shown a strong simulation and calculation function in the field of construction engineering, most of the structures can be simulated in various stress states by using the finite element software. The calculation is accurate and a lot of experimental funds are saved. In order to further explore the mechanical properties of the structure form and promote its development, this paper based on ABAQUS to develop the RLA-SCCFST short column
components, and the simulation of axial compression is carried out.

2. Material constitutive model

The material property of steel pipe is defined as ideal elastic-plastic material. The constitutive model uses "five stage secondary plastic flow model"(formula 2.1-2.3):

\[
\sigma_s = \begin{cases} 
  E_s \varepsilon_s & \varepsilon_s \leq \varepsilon_p \\
  -A\varepsilon_s^2 + B\varepsilon_s + C & \varepsilon_p < \varepsilon_s \leq \varepsilon_y \\
  f_y & \varepsilon_y < \varepsilon_s \leq \varepsilon_y^* \\
  f_y \left[1 + 0.6(\varepsilon_s - \varepsilon_y^*)/(\varepsilon_u - \varepsilon_y^*)\right] & \varepsilon_y^* < \varepsilon_s \leq \varepsilon_u \\
  1.6f_y & \varepsilon_s > \varepsilon_u 
\end{cases}
\] (2.1)

\[
A = 0.2f_y/(\varepsilon_y - \varepsilon_p)^2, \quad B = 2A\varepsilon_y + Ae_p^2 - B\varepsilon_p
\] (2.2)

\[
\varepsilon_p = 0.8f_y/E_s, \quad \varepsilon_y = 1.5\varepsilon_p, \quad \varepsilon_y^* = 10\varepsilon_y, \quad \varepsilon_u = 100\varepsilon_y
\] (2.3)

Where, \(E_s\) is the elastic modulus of steel, \(\varepsilon_p\) is the strain corresponding to the proportional limit of the steel, \(\varepsilon_y\) and \(\varepsilon_y^*\) are the strains corresponding to the fore-and-aft stresses on the yield platform, respectively. \(\varepsilon_u\) is the corresponding strain of steel tensile strength. \(A, B\) and \(C\) are parameters.

The material properties of core mixed concrete are defined by the plastic damage model. According to the existing research experience [3-5], many attempts have been made to finally determine the value of expansion angle \(\emptyset\) in the model as \(30° \sim 55°\), the value of viscosity coefficient as 0.0005, and the rest as recommended. The compressive stress-strain relationship of concrete-filled steel tubular proposed by Han L.H. Research Group[6] is used as the constitutive model of core mixed concrete(formula 2.4-2.10):

\[
y = \begin{cases} 
  \frac{2x - x^2}{x} & (x \leq 1) \\
  \frac{x}{\beta_0(x - 1)^2 + x} & (x > 1) 
\end{cases}
\] (2.4)

\[
x = \varepsilon/\varepsilon_0, \quad y = \sigma/\sigma_0
\] (2.5)

\[
\sigma_0 = f_c
\] (2.6)

\[
\varepsilon_0 = \varepsilon_c + 800 \cdot 0.2 \cdot 10^{-6}
\] (2.7)

\[
\varepsilon_c = \left(1300 + 12.5 \cdot f_c^c\right) \cdot 10^{-6}
\] (2.8)

\[
\beta_0 = \left(2.36 \times 10^{-5}\right)^{0.25+0.5\xi} \cdot f_c^{1.05} \cdot 0.5 \geq 0.12
\] (2.9)

\[
\xi = A_s f_y / A_c f_c k
\] (2.10)

Where, \(\sigma_0\) and \(\varepsilon_0\) are the strain corresponding to the peak stress and peak stress of concrete respectively, \(f_c^c\) is the compressive strength of concrete cylinder, \(\xi\) is the constraint effect coefficient, \(\beta_0\) and \(\varepsilon_c\) are coefficients.

3. Model building

The steel tube, cover plate and core mixed concrete are all solid units, 9 short column specimens are 600mm high, 200mm diameter, and the wall thickness of the steel tube is 3, 4 and 5mm respectively. The "penalty" function is adopted for the radial contact between steel tube and core concrete, and the
The friction coefficient is 0.3; "Hard" is used for normal contact and "tie" is used for connection of cover plate with steel pipe and core mixed concrete.

In order to be consistent with the experiment and to apply displacement load, the lower boundary condition of the model is set as the full constraint of the lower cover plate, and the upper constraint setting reference point RP-1 is coupled with the upper cover plate to constrain its U1, U2 and UR3 directions. Figure 1 shows the model boundary conditions and loads.

The hexahedral element is used as the main structural grid for grid division, and the size control is used for the number of grid seeds. Considering the calculation accuracy and efficiency, the approximate global size of concrete and steel pipe is determined. The stress situation of the cover plate is not the main purpose of this paper, so the size control of the cover plate is appropriately relaxed. Figure 2 shows the specific grid division.

![Model interface interaction and boundary conditions](image1)

![Grid diagram](image2)

4. Comparison of two load-strain curves
The simulation results of the load-vertical strain curve are compared with the test results, as shown in Figure 3. It can be seen from the Figure 3 that the two kinds of curves are in good agreement before the ultimate bearing capacity, and the maximum error of the ultimate bearing capacity measured by simulation and experiment is within 3%, which shows that the finite element modeling method, parameter setting and the selection of the constitutive model of steel and concrete adopted in this paper are correct, and can be used to simulate the axial compression performance research of RLA-SCCFST short column.
Figure 3. Comparison of simulation and experimental load-vertical strain curves

4.1. Influence of parameter change on load-vertical strain curve

The simulation results are compared according to the changes of four test parameters, as shown in Figure 4. It is obvious that the ultimate bearing capacity and ductility of the specimen increase with the increase of the wall thickness of the steel tube, the strength of recycled large aggregate (RLA) and the strength of self-compacting concrete (SCC); As the increase of the particle size leads to the decrease of the amount of filler in the steel pipe, the ultimate bearing capacity of the test piece shows a trend of decreasing with the increase of the amount of RLA. The influence of the wall thickness of the steel pipe on the load-vertical strain curve is mainly reflected in the falling section of the curve, the larger the wall thickness is, the smoother the falling section is, which proves that the greater the wall thickness is, and the greater the ductility of the test piece is.
5. Summary

According to the modeling method in this paper, the mechanical behavior of RLA-SCCFST short column under axial compression can be accurately simulated. Limited by the space, the mechanical performance of the test piece under axial compression is simply described here:

1. RLA-SCCFST model is similar to ordinary CFST model, but some parameters in the plastic damage model of core concrete should be adjusted;

2. The ultimate bearing capacity and ductility of the specimen increase with the increase of the wall thickness of steel tube, the strength of recycled large aggregate and the strength of self-compacting concrete, and the ultimate bearing capacity of the specimen decreases with the increase of the content of recycled large aggregate;

3. Under the parameters of this paper, the larger the wall thickness of the steel tube is, the smoother the falling section of the load-vertical strain curve is, and the ductility of the specimen is enhanced.

Through the research of this paper, it is proved that ABAQUS can be used to study the structure form, hoping that more experiments and simulation studies can be carried out in the future, and that "recycled concrete structure" can have a better development in the future!

Acknowledgements

This work was supported by Funded Project of Education Department of Liaoning Province (No. LJZ2017028), Funded Project of Liaoning Provincial Science and Technology Department (No. 20180550696).

References

[1] Guo Y.X., Li Q.Y., Wang W.Q., et al. (2015) Study on quality improvement technology of recycled coarse aggregate. Concrete, pp. 134-138.
[2] Wu B., Ji M.M. and Zhao X.Y. (2016) Research status of recycled mixed concrete and its composite members. Engineering mechanics, 33: 1-10.

[3] Xiang X.Y. (2017) Study on the mechanical behavior of steel tube self-compacting recycled concrete short columns under axial and eccentric loads. Southwest Jiaotong University, Chendu.

[4] Zeng Y., Hu L.M. (2019) Parameter calculation transformation and verification of ABAQUS concrete plastic damage constitutive model. Water Resources and Power, 37: 106-109.

[5] Tao Z., Wang Z., Yu Q. (2013) Finite element modeling of concrete-filled steel stub columns under axial compression. Journal of constructional steel research, 89: 121-131.

[6] Han L.H. (2004) Concrete filled steel tube structure: Theory and Practice. Science Press, Beijing.