Study on the mechanical property of low magnesia ore high strength concrete-filled steel tubular columns

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Abstract: The high strength low magnesia ore concrete-filled steel tubular (CFST) column under eccentric loading was studied in this paper. The experiment of seven groups of different eccentricity ratio was conducted, and the details of experiment and test methods were introduced. The experimental ultimate load of each test was compared with design loads from several domestic specifications, and the bearing capacity of specimen with different confinement index was simulated. The results of load-vertical deflection curves show that when the eccentricity is the same and the capacity is 12% higher than that of steel tube high-strength concrete eccentrically compressed short columns, the distribution of longitudinal strain along the section height of steel tube in the two types of short columns basically conforms to the assumption of flat section. According to the results of the research, it was suggested to adopt confinement index of 1.1-1.4 in the practical project with the same to the common high strengthen concrete, and the layout of small eccentric load should be used in the structural design so as to better utilize the mechanical properties of the materials.

1. Introduction

Concrete filled steel tube structure is a kind of constraint by the concrete and the function of new type structure of steel pipe combination, which has high bearing capacity, good plasticity and toughness, good fireproof performance, high construction efficiency, etc. Most of the research around the circular concrete-filled steel tubular columns at home and abroad are mainly focus on the analysis the influence of the eccentricity and slenderness ratio on the mechanical properties of component. A large number of literature[1-3]analyze the mechanical properties of the specimens by making experiments. Wang Liangang[4] analyzes the influence of the eccentricity on the mechanical properties of the bias column, then the calculation formula of the ultimate bearing capacity of the CFST columns was given. Chen Baoshun[1] analyzes the effect of eccentricity on the ductility of concrete-filled steel tube. The results show that the eccentricity had no effect on the ductility of the specimens. Farid Abed[5] confirmed that when the restraint ability of steel is reduced, the restraint index will also decrease, and
the theoretical value and experimental value will be different, the ultimate bearing capacity of the specimen is smaller. In 1970s, Matkovic suggested that substance reacts with air to form a carbonized phase when magnesite cement is exposed to air[6].

Chen[1] has done some research on the stress-strain relationship under the eccentric load. The influence of eccentricity or other factors on CFST have made great progress at home and abroad. Chen Baochun[1] makes a great experiment of CFST, but only the ordinary concrete in the steel is used. Therefore, this paper makes an in-depth study on the factors that affect the mechanical properties of high-strength low magnesia ore CFST(HSLMO-CFST), and the test results with the theoretical calculation results is compared from several different specification. At the same time that the validity of the standard formula is verified, we analyze the effect of the confinement index on the mechanical properties of the stressed specimen with the best matched criterion, and summarize the experimental rule. It can provide reference basis for the modification of steel tube concrete structure design specification, and provide suggestions for the selection of the confinement index and the load arrangement mode of the practical project.

2. Experimental program

2.1. Design and fabrication of columns

Seven specimens were designed, and the experimental factors are eccentricity. Q235 steel is used to weld the steel tube, steel elastic modulus $E = 2.06 \times 10^5 \, N/mm^2$, yield strength experiment and other parameters are follows: the steel pipe diameter is 165mm, 219mm, the thickness of the steel is 2.5 mm, the slenderness ratio is 12, 14, 18, and comprehensive strength of concrete cube is 66Mpa, the eccentricity were 1.3, 1.55 and 2.0. Confinement index of three groups of components are set by the technical specification for concrete filled steel tube structure[10].

Concrete cube and the configuration of concrete specimens are conducted in the structure of the laboratory of the school, the concrete is mixed with fly ash composite Portland cement, adding appropriate amount of water reducing agent to improve the mechanical performance of concrete. The mixture ratio of the specimens for water: cement, sand, gravel, silicon powder, high efficiency water reducing agent = 150, 491:597:1070: 38:3.952, the strength is 66Mpa. The concrete is inserted from a round hole of 80 mm which was reserved, vibrated with an inserted vibrating rod of a diameter of 5mm, 30 to 40 cm concrete layer is inserted each time, then the steps is repeated until the steel tube is filled, then using cement mortar to wipe the end of the tube. The experimental environment used was normal indoor standard of curing 28 d, and the curing room is the structure of the laboratory of the school, the inner concrete strength is confirmed by the 150 mm * 150 mm * 150 mm cube concrete in the equal conditions experimentally.

The section size and related parameters of this experimental component are shown in table 1 below.

| Number | Steel ratio | slenderness | Eccentric ratio |
|--------|-------------|-------------|-----------------|
| 1MZ-1  | 0.00097     | 18          | 2               |
| 1MZ-2  | 0.00097     | 18          | 1.3             |
| 1MZ-3  | 0.00097     | 18          | 1.55            |
| 2MZ-1  | 0.00054     | 14          | 1.3             |
| 2MZ-2  | 0.00054     | 14          | 1.55            |
| 2MZ-3  | 0.00054     | 14          | 2               |
| 2MZ-4  | 0.00054     | 12          | 1.3             |

2.2. Experiment device and data measurement.

The loading device used in this experiment is YJ-PY-3000 numbered with 1610-01#, which is shown in figure 1a. The maximum vertical bearing capacity is 3000KN and the oil cylinder stroke is 300mm. The model of the muti-channel hydraulic control system is YF-II /25-4, and the displacement test
adopts the static strain gauge of XL 2101B6. The strain gauge is pasted after the CFST has been maintained. Eight horizontal and vertical strain gauges was pasted at the middle of specimen, eight vertical direction of strain gauge is pasted at the 1/4 part of specimen, The nomenclature followed of strain gauge in the tests is: 1S stands for the longitudinal strain data records, 1H stands for the circumferential strain data records. In order to determine the lateral bending deflection of the specimen, several displacement gauge is arranged in each of the 1/4 and 1/2 part of the specimen length, the place of displacement gauge and strain gauge is shown in figure 1b. The value of pr-loaded loading is 10kN in this experiment, and 50kN is added in each hierarchy, which sustains about 5 minutes. Not until the specimen deformation has a considerable or strain value and dial indicator can't read did the experiment stop.

Fig.1 Equipment and section numbering

2.3. The experimental phenomena and failure pattern
At the initial loading period, the specimen is at the elastic stress stage, and the overall deformation and vertical deformation change is not obvious. As the load increased, the lateral bending specimen is going on, till the destroying load, the specimen bend slightly. The longitudinal displacement and mid span deflection enlarged greatly when it went to the the breaking load, the specimen is broken at the same time. Litter crack can be seen in all the tension side of specimen. The short column named 2MZ-1 the up-section's displacement is slightly larger than that of the mid-section , when it went to nearly 50% of the ultimate load, the displacement of cross section increased expedited and the middle-part displacement is larger than the upon displacement, the specimen bends towards the compression side when it was broken, and the surface of steel is spelled at the longitudinal tension side accompanied with cracking sound, the steel was uplifted at the compression side nearing the stiffening rib, after that, the steel at the tensile side is ripped, and the inner concrete could be seen, the damaged specimen is as shown in figure 2. Phenomenons of another specimens in the process of loading is similar to 2MZ-2, but the crossing section of the maximal displacement and longitudinal strain component is different from the 2MZ-1 short column, since that the steel of the tension side is not ripped, and the steel uplifted either. A few specimens of the dial indicator and stress meter cannot read.
3. Results
Experiment on diverse eccentricity ratio is accomplished. After analyzing the result, the point that smaller the eccentricity ratio is, earlier the confining stress produces, and bigger the area occurring confining atmosphere is, which result in higher bearing capacity. More analyses with curves of strains are as fellows.

As the figuration shows: the curve consists of three stages, when at the Elastic stage, the longitudinal strain of the specimen increased with load increases linearly, the average strain value is 2000, according to the thesis steel material performance research experiment results, the tensile yield strain of the steel tube is about, the steel tube longitudinal stress step into the yield stage, steel pipe's elastic modulus E sharply reduces, and the stress redistribute, the bearing capacity decreases, and most of the load is allocated to the core concrete. The slope of strain curve also changed, and the specimen entered the failure stage when the load reaches about 90%Nu.
Fig. 4: Load - Poisson ratio

Fig. 5: Load - mid-span deflection

Fig. 6: Confinement index - bearing capacity
3.1. Analysis on the curve of longitudinal strains:
Tensile areas of plastic steel pipe enter the plastic deformation stage, the circumferential stress increases, which will lead to the decrease of the longitudinal stress according to the Von-Mises yield criterion. The reduction of stress undertook by steel is less than the increasing of circumferential stress undertook by concrete, so the longitudinal stress increased by little, but the concrete’s increment of circumferential deformation increased rapidly, and the confining effect is obvious. According to this group of test figure, it can be found that from the yield stage, the small eccentric specimen's increment of longitudinal strain and bearing capacity are the biggest, then, the confining effect on eccentric loaded specimen is most obvious. The confining effect contributes to the plastic deformation capacity of the specimens, for eccentric loaded specimens, the confining effect is more obvious at the part of higher compressed stress. Conclusively, the specimen with larger eccentricity owns smaller bearing capacity and it perform less deformation.

3.2. Analysis on the curve of Poisson's ratio
The Poisson's ratio of composite materials is a value of circumferential strain to longitudinal strain which is shown in figure 4. At the edge of the tensile part of the section the Poisson's ratio is smallest, and the marginal poison ratio of the compress part is the largest, which increases in the late loading period. The Poisson ratio of steel is 0.25-0.3, and when Poisson's ratio is greater than 0.3, the confining effect occurs. Zhao Xiaoliang points out that the larger the Poisson's ratio, the more obvious the confining effect of the steel tube was, and the "2.0/3" in the figure 4 means the load on the tensile side of the test specimen with a eccentric rate of 2.0. It can be figured out in chart that the average Poisson's ratio of composite materials is 0.3, and confining effect did not occur at the elastic stage, but the plastic and strengthening stage. The Poisson's ratio of compressed part increased rapidly, and it decreases slightly at the part of tensile part, which is on account of that the compression is undertook by stress mainly and the longitudinal strain of stress developed quickly. It can be concluded that the Poisson's ratio is biggest, averaged 0.35. At the compressed part of high strength CFST, it increased rapidly with the process of experiment. The Poisson's ratio is smallest at the tensile part, and the Poisson's ratio of specimen with small eccentric ratio owns bigger increment, the effect which is significantly higher at the late period of experiment.

3.3. Analysis on the middle section deflection
Section deflection curves are as shown in figure 5, the increment of deflection is very small and the curve is steep at the early loading period. When close to failure stage, the curve slope decreases sharply, lateral deflection final value is about 100 mm, deflection curves of these three specimens are similar to half-wave sine curve. Specimen with large eccentric compression reveal the confining effect later than the other specimens, and its middle section deflection is smaller than the small one, all specimens are equipped with good ductility.

4. Analysis on mechanical property
We analyzed and contrasted the theoretical calculation results in different disciplines with the experimental results of eccentric loaded specimens. Aiming the best coincide experimental results, of which we change the confinement index, and analyse the change of capacity. The contrastive result shows that the theoretical calculation results of CECS 254:2012[17] matches best, and it can be the gist to make deeper analysis. Code for design of steel-concrete composite structure (DL/T 5085—1999)[1] Technical code for concrete filled steel tubular structures (CECS 28: 2012)[8]. Technical code for concrete filled steel tubular structures (GB 50936-2014)[10]. Technical specification for solid and hollow concrete-filled steel tubular structure (CECS 254:2012)[9]
The result is shown in the table2. It can be concluded that all disciplines have superior security reservation, and the specific value between experimental value to test value is about 1.8, discipline 4 and 2 has the similar calculation accuracy, the selected four typical domestic discipline of theoretical calculation result have different various deviation, in which the calculation result of the fourth discipline has the minimum deviation, some scholars find the calculated value of the fourth discipline is closer with the actual value after comparing, thus, the fourth discipline was selected to make more research on the influence of confinement index on various eccentricity ratio. At the tensile part, the confining stress decreased with the variation of ratio of axial compression stress to strength, and the confining effect mainly took place in the compressed region of section.

5. Conclusions

The results of load-vertical deflection curves show that when the eccentricity is the same and the eccentricity is 12% higher than that of steel tube high-strength concrete eccentrically compressed short columns, the distribution of longitudinal strain along the section height of steel tube in the two types of short columns basically conforms to the assumption of flat section. The results show that when the strength of concrete is the same, the mechanical properties of composite short columns composed of high strength concrete with low magnesia ore and thin-walled steel tube are compared with those of ordinary high strength concrete with steel tube. The main performance is that the compressive strength is stronger, but most of the damaged parts are fracture failure, and the stability performance is slightly worse.

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