Influence of de-fill on performance of concrete-filled steel tubular columns

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ABSTRACT*:* This Paper is designed to bring forward the inevitability of the existence of de-fill in concrete-filled steel tube and study its unknown impact on the performance of concrete-filled steel tube through the brief introduction of the development of concrete-filled steel tube arch bridge. This Paper also discusses its relevant theoretical analysis as well as initial results of the test research and summarizes research results, and therefore bears relevantly great significance for the design of concrete-filled steel tubular arch bridge.

1 INTRODUCTION

Over centuries, the arch has found multiple applications in the construction of buildings and bridges. In modern times, arch bridges have again become economically competitive thanks to the development of new construction methods and material technologies. Concrete filled steel tubular (CFST) arch bridges have been building in China since 1990. With the trend of increasing the use of steel material and decreasing the labor in bridge construction due to the rapid development of economy, CFST arch bridge became a good alternative to achieve a kind of balance between reinforced concrete arch bridges and steel arch bridges. In addition, it has a more pleasing appearance. Therefore, many CFST arch bridges have been built in China in recent decades.

Wuxia Yangtze River Bridge in Wushan city, open to traffic in January 2005, is a half-through concrete filled steel tubular arch bridge with a clear span of 460m and a rise-span ratio of 1/3.8, kept the first span record in CFST arch bridges in the world. The bridge width is 19m, in which 15.0m for traffic lane and 2×1.5m for walk side road as well as 2×0.5m for rails. The arch ribs are twin of CFST trusses. The axis is a catenary curve with a parameter m of 1.55. The width of a rib is 4.14m; its height of the rib varies from 7.0m in crown to 14.0m in the spring. The center distance of the two ribs is 19.7m. Four chord members in each rib are steel tubes Φ1220×22mm filled with C60 concrete. The vertical and the diagonal web members are made up of steel tubesΦ610×12mm. The lateral bracing members of the CFST chords are also hollow steel tubes of Φ711×16mm.

Due to the complicated structure, many researches are carried out on this bridge, such as the study on the influence of initial stress on the load carrying capacity of concrete-filled steel tube, shrinkage and creep of big-diameter concrete-filled steel tube, load carrying capacity and fatigue stress of in the joint of steel tubular truss, the impact of de-fill, which means that the steel tube and concrete will be disjoined, on the performance of concrete-filled steel tubular columns.

Along with the development of CFST arch bridges, many problems met in practice have been solved by our bridge engineers with their insisting studies and researches. But with regard to de-fill of steel tube and concrete caused by the shrinkage of concrete, it is still lack of studies. Moreover, it should be noted that this phenomena in experiment is considerably different with that in practice. Taken short concrete filled steel tubular columns as an example, when the specimens are made up, they are placed upright before the test. In this way it can be ensured that the steel tube and the concrete are adhesive. However, as far as the arch ribs in practice are concerned, they are curved. In order to make the concrete easy to pour, there are some special requirements for the concrete, such as high fluidity, high usage of water. Compared with the common concrete, the shrinkage of the concrete is larger. This will lead to de-fill of CFST members, in company with other factors.

To this deficiency, different measures are taken to make up for it. Pouring additional grout into the tube or applying expansive concrete is favorite measure in practice. It is noteworthy that they are efficient to improve the performance of CFST members with larger de-fill. However, when de-fill is less than 10mm, it is not suitable to use the abovementioned measures. It was neglected in the past. Consequently, the additional grout is not necessary. But whether it is reasonable is still worthy to discuss. To provide an insight into the above problems, this paper present the influence of de-fill on load carrying capacity of CFST short columns, and a limited value is given after the analysis.

2 CONSTITUTIVE LAWS OF CONCRETE IN CFST MEMBERS

One feature with applications of the concrete into the steel tube is that they are restricted by the steel tube under pressure, in which the concrete is compressed from three directions. Obviously, the constitutive law of concrete will be different. Conventionally, the following constitutive relations, proposed by Prof. Zhong Shan-tong, have been employed in the analysis of CFST members. This constitutive equation accounts for the main nonlinear features typical of the mechanical behaviour of concrete under two-direction pressure.

$$\sigma_c = \sigma_u [A \frac{\varepsilon}{\varepsilon_0} - B(\frac{\varepsilon}{\varepsilon_0})^2] \qquad \varepsilon \le \varepsilon_0 \tag{1}$$

$$\sigma_c = \sigma_U (1-q) + \sigma_u q (\frac{\varepsilon}{\varepsilon_0})^{(0.2+\alpha)} \qquad \varepsilon > \varepsilon_0 \tag{2}$$

Where

$$\sigma_U = f_{ck}[1 + (\frac{30}{f_{cu}})^{0.4}(-0.0626\xi^2 + 0.4848\xi)] \tag{3}$$

$$\varepsilon_0 = \varepsilon_c + 3600\sqrt{\alpha} \qquad (\ \mu\varepsilon\ ) \tag{4}$$

$$\varepsilon_c = 1300 + 10 f_{cu} \tag{5}$$

$$A = 2 - K \qquad B = 1 - K$$

$$K = (-5\alpha^2 + 3\alpha)(\frac{50 - f_{cu}}{50}) + (-2\alpha^2 + 2.15\alpha)(\frac{f_{cu} - 30}{50}) \tag{6}$$

$$q = \frac{K}{0.2 + \alpha} \qquad f_{ck} = 0.8 f_{cu} \qquad \xi = \frac{\alpha f_y}{f_{ck}} \qquad \alpha = A_s / A_c$$

Consequently, the constitutive equation can be obtained uniquely as the yield strength of steel tube, the concrete strength and the ratio of steel are known.

Fig. 1 shows the relationship between axial loads and the strain of steel. It can be observed that the curves get their peak when the vertical strain of steel tube is 3000 με when ξ is less than 1.0. Thus, in the analysis, it is defined that the CFST members get its load carrying capacity when the strain of steel tube is 3000με.

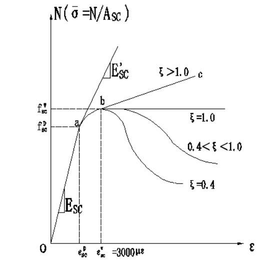

Fig.1: N- ε curve of concrete-filled steel tube under axial load

3 FINITE ELEMENT METHOD ANALYSES

3.1 Finite element model

The analysis of the columns is accomplished by finite element method. As shown in Fig.2, all of the specimens were of the same size: the steel tube is Φ273×8mm with a height of 1000mm; the strength of the concrete filled in it is of C60; the de-fill value is 0, 5, 10, 20, 40, 80mm respectively. In the analytical model, the de-fill value is regarded as the height of de-fill, that is *t* in Fig.2.

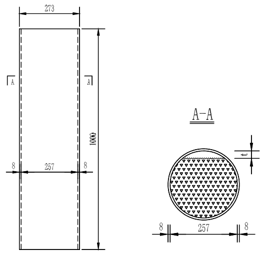

Fig. 2 De-fill value of deficient concrete-filled steel tube

The analysis is on the assumption that: steel tube is adhered quite well to concrete, effect of shrinkage, creep, and temperature of concrete are neglected. Fig.3 shows the element division of the model. The boundary condition is that imposing one direction restriction at lower part and imposing surface load at upper part.

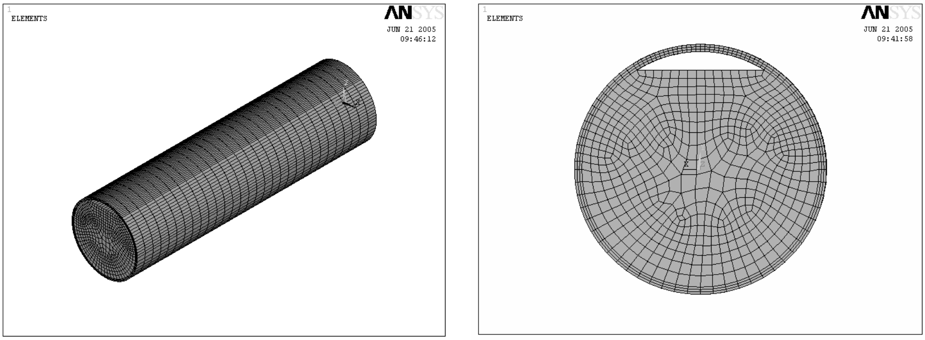

Fig. 3: Element division of the model

3.2 Results

3.2.1 Comparison of the ultimate load carrying capacity specimens

Concrete-filled steel tube will enter the first plastic stage when it is subjected to axial loads. Accordingly it will cause consolidation in circle direction, and therefore in the analysis of the ultimate load-bearing capacity of components, component axial strain is used as the distinguishing standard: that is, when the strain on the very core of a component reaches 3000με, the specimen reaches its ultimate load carrying capacity.

Table1. Ultimate load-bearing capacity corresponding to different disengaging value

De-fill value (mm)	0	5	10	15	20	40	80
Disengaging rate	0%	0.41%	1.14%	2.08%	3.18%	10%	34.5%
Ultimate load carrying capacity (KN)	8735	8685	8600	8501	8348.7	7557	5856

As seen from Table 1 and Fig.5, the main trend of specimen's load carrying capacity is declining; however, when the de-fill value is less than 20mm, the declining of specimen's load carrying capacity is not obvious: 1-8348.7/8735=4.4%

Along with the increase of de-fill value (de-fill rate), the axial strain of the specimen is asymmetrically increasing; when the de-fill value exceeds 10mm (the de-fill rate is 1.2%), the asymmetry of strain is more obvious. Calculation analysis indicates: along with the increase of de-fill value (de-fill rate), the asymmetry of specimen's strain is also increasing.

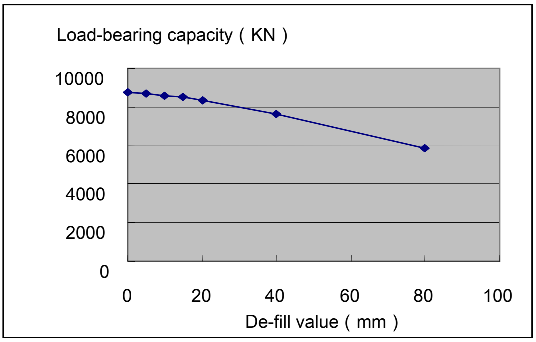

Fig. 4 The changing chart of load-bearing capacity

4. EXPERIMENTAL PROGRAM

4.1 Test specimens

To verify the theoretical analysis, the experiments were carried out. The size of the specimen is the same with the analytical model. There are 7 specimens were tested. Table 2 shows the specimen in detail. The material of the steel tube is Q345-C.

Table 2 Specimens of the test

No.	Number of specimen	De-fill value (mm)
1	3	0
2	2	9
3	2	15

In the test, place the specimens firstly on the test apparatus accurately and stably; then, set four strain test apparatus around the middle of the short column of tested concrete-filled steel tube; and set the meters to allow the model to be loaded repeatedly under low load until the load strain become stable. At last, Load according to the set loading progression, and test relevant data.

4.2 Test results and analysis

The dead load test adopts the mode of loading gradually. Firstly, having three-time pressure test, and then loading from 0 until the load where the specimen is failed and test three groups of stress-strain value data. The first group has three specimens, and the de-fill value should be 0, but the difference coefficient of one of the specimens should exceed 15%, without counted into data settlement; the second group has two specimens, and the disengaging rate is 1.12%; the last group has two specimens, and the disengaging value is 2.04% .

As seen from the above chart, for the strain corresponding to the same stress, the higher the disengaging value is, the larger the strain is. In other words, the disengaging value is in direct ratio to strain value, its ultimate intensity is in direct ratio to disengaging value too.

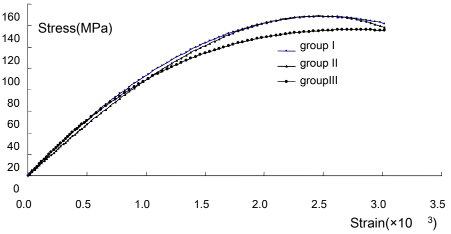

Fig.5: The relationship between strain and stress of the specimen

It can be shown in Fig.6 that different de-fill value of concrete-filled steel tube has different impact on its ultimate load carrying capacity. If the de-fill rate are confined to a limited magnitude, the de-fill rate have little effect on its ultimate load carrying capacity; When the de-fill rate exceeds certain limited range, its de-fill rate will affect the ultimate load carrying capacity of concrete-filled steel tube greatly.

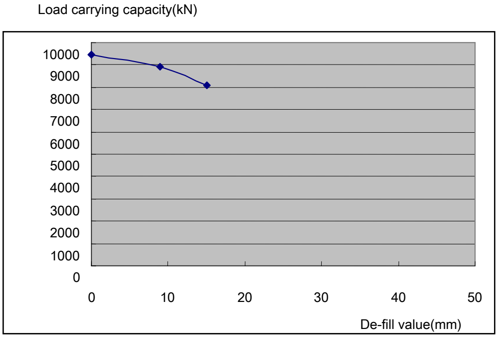

Fig.6 : The relationship between load carrying capacity and de-fill value

5 CONCLUSION

The following conclusion could be drawn from the research result of this test and finite element analysis:

(1) The de-fill value of concrete-filled steel tube has certain effect on when concrete-filled steel tube enters its plastic zone, that is, the larger the de-fill value is, the smaller the load value when concrete-filled steel tube entering its plastic zone; Whereas the smaller the de-fill value is, the larger the load value is when concrete-filled steel tube entering its plastic zone.

(2)The de-fill value of concrete-filled steel tube has certain effect on the ultimate load carrying capacity of the concrete-filled steel tube, that is, the larger the de-fill value is, the lower the ultimate load carrying capacity of the concrete-filled steel tube is; Whereas the smaller the de-fill value is, the higher the ultimate loading carrying capacity of the concrete-filled steel tube is.

(3) It is indicated from this test, when the de-fill rate of concrete-filled steel tube is less than 1.2%, it has so little effect on stiffness of concrete-filled steel tube and its ultimate load-bearing capacity that it can be neglected; whereas when the de-fill rate of concrete-filled steel tube exceeds 1.2%, it is recommended to repair the de-fill of concrete inside steel tube.

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