APPLICATION OF CONCRETE-FILLED STEEL TUBE ARCH BRIDGES IN CHINA

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SUMMARY

In a Concrete-Filled Steel Tube (CFST) arch, the infilled concrete core delays local buckling of the steel tube, while the steel tube reinforces the concrete core to resist tension stresses and improves its compression strength and ductility. Therefore, CFST arch bridges become a good alternative to Reinforced Concrete (RC) arch bridges or steel arch bridges and have been widely applied in China during the rapid development of economy in the last decades. Since the Wangcang Bridge completed in 1990 as the first CFST arch bridge in China, up to January 2015, more than 400 CFST arch bridges, with the span over 50 m, have been built or are under construction. This paper briefly introduces the survey on the number and characteristics of CFST arch bridges in China at first. Then analysis is carried out based on the factors of structural type, erection method, geometric parameter, and material. It will provide a comprehensive understanding of the application of CFST arch bridges in China.

Keywords: *China, Concrete Filled Steel Tube, arch bridge, survey, analysis, application.*

1. INTRODUCTION

Since the Wangcang Bridge completed in 1990 as the first Concrete-Filled Steel Tube (CFST) arch bridge in China, the developoment of CFST arch bridges is thriving over the next twenty years. Up to January 2015, 413 CFST arch bridges been built or under construction, with the span over 50 m, are collected in this paper. The number is 99 more than Fuzhong Liu's in 2010 while 197 more than Yalin Yang's in 2005. This paper briefly introduces the survey on the number and characteristics of CFST arch bridges in China at first. Then analysis is carried out based on the factors of structural types, erection method, geometric parameter, and material. It will provide a comprehensive understanding of the application of CFST arch bridges in China.

2. APPLICATIONS OVERVIEW

2.1. Construction trends

In a CFST arch, the infilled concrete core delays local buckling of the steel tube, while the steel tube reinforces the concrete core to resist tension stresses and improves its compression strength and ductility, which has obvious advantages in terms of materials,

construction, etc. Since the first CFST arch bridge in China (Wangcang Bridge) was built in 1990, CFST arch bridge has become a popular arch bridge. Table 1 and Figure 1 show the growth trend of CFST arch bidges in China (Including 396 bidge examples). According to the development trend, the constuction number of CFST arch bridges in China has a substantial growth since 1993. The construction development can roughly be divided into three stages. The first stage is in 1990-1994, years of exploration phase, when 9 CFST arch bridges were completed. The second stage is in 1995-1999, years of promotion phase, when 69 CFST arch bridges were completed, with an average anual growth of 14 per year. The third stage is from 2000 till now, years of overall application of CFST arch bridgs, when 346 CFST arch bridges have been built, with an average anual growth of 14 per year. (Due to the lag of literature and data, the number of statistics in recent years may be much less than the actual built number).

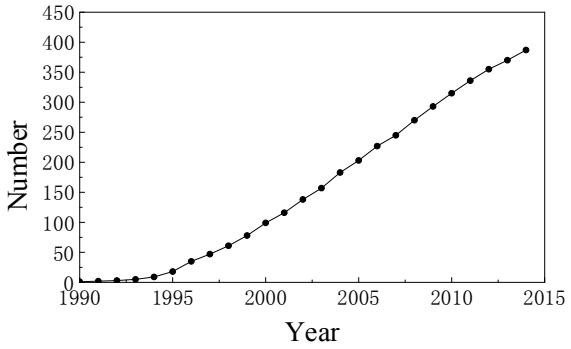

Fig. 1. *Growth trend of CFST arch bridges.*

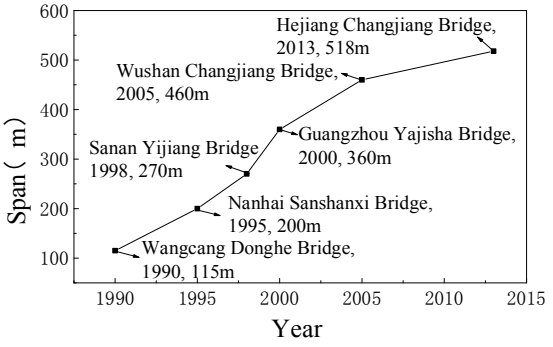

Fig. 2. *Growth trend of largest span of CFST arch bridges.*

The growth trend of the largest span of CFST arch bridge is showed in Fig. 2. As we can see from the figure, the span of CFST arch bridges increased from 115m in 1990 to 530 m in 2013 (The Hejiang Changjiang Bridge built in 2013, which is the largest one in recent decades). There are 362 CFST arch bridges been built, with the span less than 200m, accounting for 85% of the total. With technology developing and spanning capabilities increasing, the application of CFST arch bridges in China is much more

widespread. CFST arch bridges have become a good alternative compared to Reinforced Concrete (RC) arch bridges or steel arch bridges. No matter from the aspect of amount or span, the development of CFST arch bridges tends upward.

Table 1. *Number of CFST arch bridges built each year.*

Built Year	Number	Cumulative Number	Proportion	Cumulative Proportion
1990	1	1	0.26%	0.26%
1991	1	2	0.26%	0.51%
1992	1	3	0.26%	0.77%
1993	2	5	0.51%	1.28%
1994	4	9	1.03%	2.31%
1995	9	18	2.31%	4.62%
1996	17	35	4.36%	8.97%
1997	12	47	3.08%	12.05%
1998	14	61	3.59%	16.64%
1999	17	78	4.36%	20.00%
2000	21	99	5.38%	25.38%
2001	17	116	4.36%	29.74%
2002	22	138	5.64%	35.38%
2003	19	157	4.87%	40.26%
2004	26	183	6.67%	46.92%
2005	20	203	5.13%	52.05%
2006	24	227	6.15%	58.21%
2007	18	245	4.62%	62.82%
2008	26	271	6.41%	69.23%
2009	23	294	5.90%	75.13%
2010	22	316	5.64%	80.77%
2011	21	337	5.38%	86.15%
2012	19	356	4.87%	91.03%
2013	15	371	3.85%	94.87%
2014	17	388	4.36%	99.23%
Under Construction	3	391	0.77%	100.00%
Total	391			

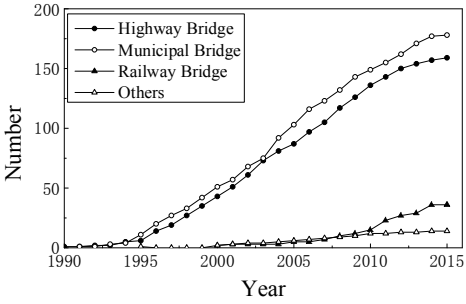

Fig. 3. *Growth of different CFST arch bridge.*

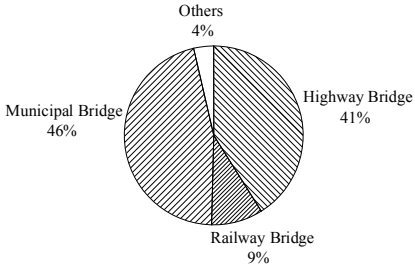

Fig. 4. *Industry distribution of CFST arch bridge.*

2.2. Industry distribution

CFST arch bridges can be divided into four categories by industry uses: highway bridges, municipal bridges, railway bridges and others (such as pedestrian bridges and dock trestles). Fig. 3 and Fig. 4, respectively, shows industry classification growth of CFST arch bridges and industry distribution of CFST arch bridges in China (Including 387 bridge examples). CFST arch bridges first appeared in highway bridges, followed by municipal bridges, which also get lots of applications. Seen from Fig. 3 and Fig. 4, CFST arch bridges are mainly used in highway bridges and municipal bridges in China, representing 87% of the total, both of which are considerably close in the total amount and the growth rate, basically presents the overall developing trend of CFST arch bridges in China.

3. STRUCTURE SYSTEM AND CONSTRUCTION METHOD

3.1. Number and span range

According to the deck location and whether there is a horizontal thrust, CFST arch bridge can be classified as (thrust) deck arch bridge, (thrust) half-through arch bridge, flying-bird arch bridge, (partial thrust) through rigid-framed tied arch bridge, (no thrust) through arch-girder composite structure arch bridge, and others. Fig. 5 shows the number proportion of variety forms of CFST arch bridges (Including 413 bridge examples), through arch-girder composite structure bridge and half-through arch bridge have the largest number, the proportion reached respectively 31.82% and 26.08%.

Fig. 6 shows the number distribution of the variety forms in different span (Including 413 bridge examples). As the figure shows, there are 365 CFST arch bridges in China with the span range of 50 m ~ 20 0m, the span of through arch-girder composite structure bridge is mainly in the range of 50 m ~ 100 m, and the other four forms are mainly in the range of 50 m ~ 100 m, equally the range of 100 m ~ 200 m. However, CFST arch bridges in China are more and more implicated in the span of more than 300 m, for example, the Sichuan Hechuang Bridge built in 2013 reached a span of 518 m.

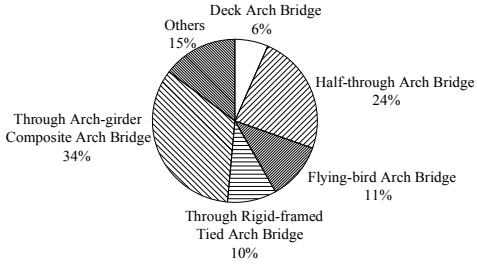

Fig. 5. *Number proportion of variety forms.*

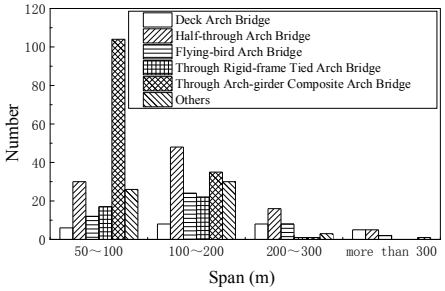

Fig. 6. *Number distribution of variety forms in different span.*

3.2. Construction methods

Stiffened scaffolding methods of CFST arch bridge mainly include scaffolding construction, cantilever construction and swing construction. This article also includes other types of construction methods (Integral lifting method and overall push method, etc.). Figure 7 shows the relationship between the construction methods and structure forms of CFST arch bridge in China (Including 325 bridge examples). Deck arch bridges and half-through arch bridges mainly adopt cantilever construction, through arch-girder composite bridges mainly adopt scaffolding construction, and flying-bird arch bridges, through rigid-framed tied arch bridges adopt cantilever construction and scaffolding construction. As for swing construction, it is rarely used.

3.3. Industry distribution

Figure 8 shows the distribution of the structural system in different industry of CFST arch bridge in China (Including 389 bridge examples). As we can see in the figure, most

of half-through bridges are applied in highway bridges, followed by municipal bridge; Through arch-girder composite arch bridges and through rigid-framed tied arch bridges are used in most of the municipal bridges; Followed by highway bridge; Railway bridges are fewer, most of which are through rigid-framed tied arch bridges and through arch-girder composite bridges.

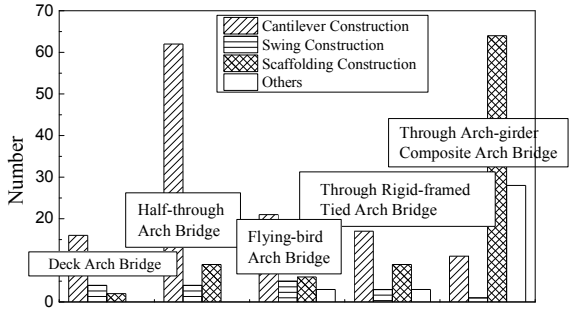

Fig. 7. *Relationship between construction methods and structure forms.*

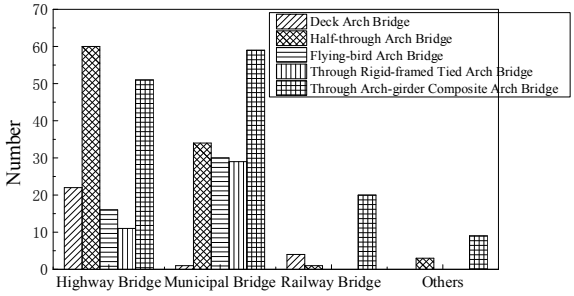

Fig. 8. *Distribution of structural system in different industry.*

4. GEOMETRIC PARAMETER

4.1. Rib material

Various stages of steel pipe usage of CFST arch bridge in China are showed in Fig. 9 (Including 214 bridge examples). Main materials used for arch rib steel are Q235 steel and Q345 steel, but in recent years, Q235 steel is gradually replaced by Q345 steel and high strength steel Q390 appears. According to statistics, strength of infilled concrete core generally reaches more than C40, only five CFST arch bridges built before 2005 used C30. As is shown in Fig. 10, it can be divided into three stages (Including 323 bridge examples), including period before 2005, period from 2005 to 2010 and period after 2010. As time goes on, the usage of concrete C50 and C55 is increased and even high-strength concrete C60 is gradually used in CFST arch bridges while concrete C45 and strength below are reduced.

To give full play to the mechanical characteristics of concrete filled steel tube and guarantee the stability of the steel tube wall, it is necessary to limit the ratio of the diameter to wall thickness. Fig. 11 shows the scale map of the ratio of pipe diameter D to

wall thickness t of CFST arch bridges in China (Including 321 bridge examples). As is seen in the figure, 97% of the ratio ranges from 35 to 100, and most of that are between 35 and 70.

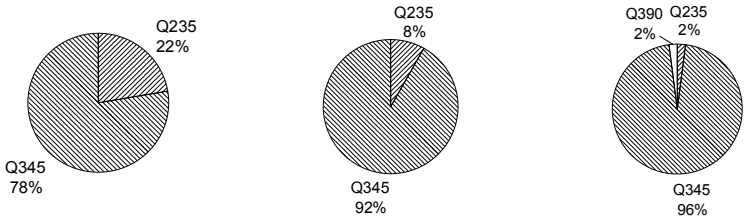

Fig. 9. *Various stages of steel pipe usage of CFST arch bridges: a) period before 2005; b) period between 2005 and 2010; c) period after 2010.*

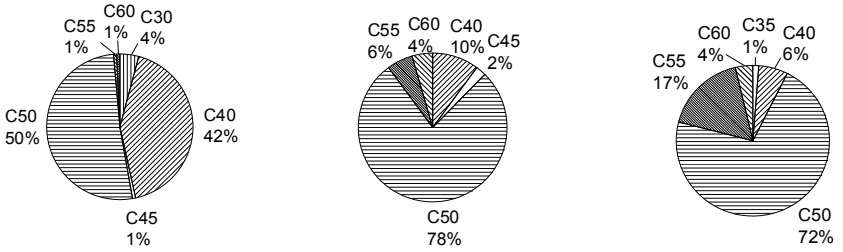

Fig. 10. *Various stages of concrete usage of CFST arch bridges: a) period before 2005; b) period between 2005 and 2010; c) period after 2010.*

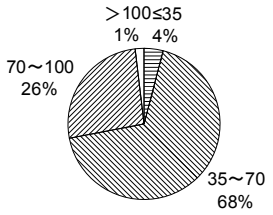

Fig. 11. *Scale map of the ratio of pipe diameter D to Wall Thickness t of CFST Arch Bridges.*

4.2. Rise-span ratio

Figure 12 shows the rise-span ratio distribution of 331 CFST arch bridges in China, the rise-span ratio of concrete filled steel tubular arch bridges are mainly distributed in 1/3.5 ~ 1/6.0, most focused on 1/4 ~ 1/5, 1/5 of the rise-span ratio is in major. Figure 13 shows rise-span ratio of different structural types of CFST arch bridges in China (Including 288 bridge examples), through arch-girder composite bridge has the largest number, deck arch bridge and through rigid-framed tied arch bridge and through arch-girder composite bridge share the most of span ratio of 1/5. The rise-span ratio of half-through arch bridge and flying-bird arch bridge ranges from 1/4 to 1/5 considerably.

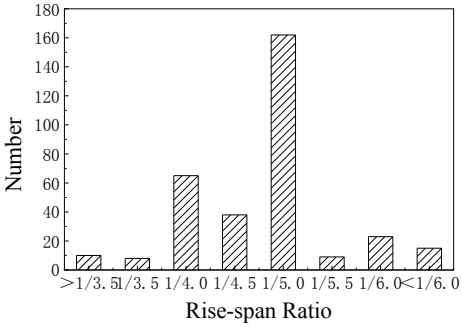

Fig.12. *Rise-span ratio distribution of different CFST arch bridges.*

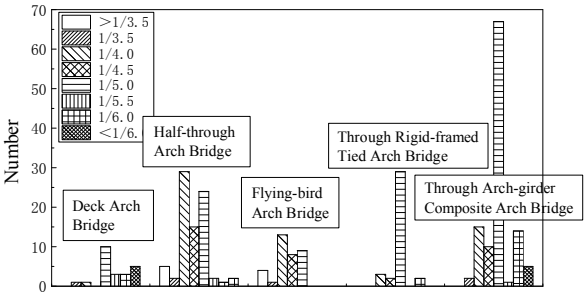

Fig. 13. *Rise-span ratio situation of different structural types of CFST arch bridges].*

4.3. Arch Axis type

Concrete steel arch bridge's arch axis mainly includes catenary, parabolic and others (Including high-order parabolic, spline functions, etc.). Fig. 14 shows axis type statistical comparison of CFST arch bridges in China (Including 345 bridge examples). Parabolic and catenary account for 52% and 44%, respectively. Most of CFST arch bridges been built within 100m span use parabolic [4], fewer catenary and several circular curve. Fig. 15 shows the relationship between structural types and arch axis types (Including 295 bridge examples). Deck arch bridge, half-through arch bridge and flying-bird arch bridge mostly use catenary, while through rigid-framed tied bridge arch and through arch-girder composite bridge mostly use parabolic, especially through arch-girder composite bridge, accounting for 80.8%.

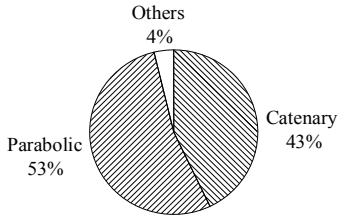

Fig. 14. *Axis type statistical comparison.*

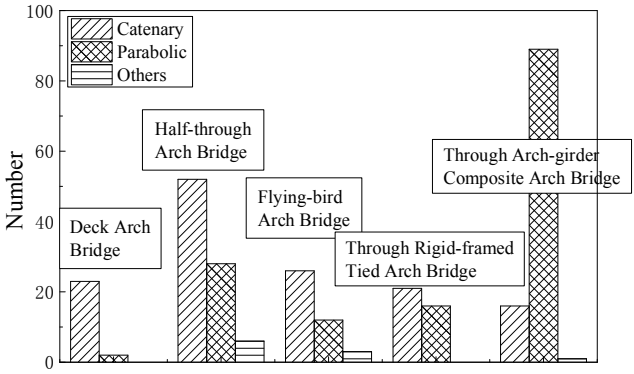

Fig. 15. *Relationship between structural types and coefficient distribution with arch axis types.*

4.4. Sectional form

Sectional form of CFST arch bridges can be divided into single tube, dumbbell-shaped and truss. Fig. 16 shows the sectional form statistics in different phases of CFST arch bridges (Including 377 bridge examples). In period before 2005, dumbbell-shaped section primarily accounts for 40%, truss section up to 36%. During the period from 2005 to 2010, truss section decreases to 32% and the dumbbell-shaped section increases to 50%, while after 2010, dumbbell-shaped section increases to 53% and truss section reduced to 40%.

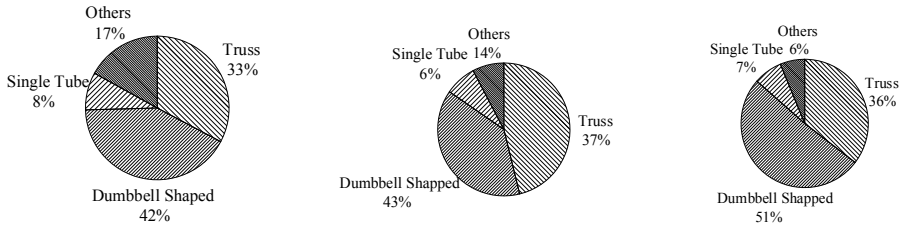

Fig. 16. *Sectional form statistics in different phases of CFST arch bridges: a) period before 2005; b) period between 2005 and 2010; (c) period after 2010.*

The relationship between arch rib section and span of CFST arch bridges in China is showed in Tab. 2 (Including 393 bridge examples). Bridges' span ranging from 50m to 75 m mainly adopt dumbbell-shaped section, single-tube section and other cross-section, while truss section is less used. Dumbbell section mostly used when the span ranges from 75 m to 150 m (65.80% ~ 48.00%), followed by Truss (11.40% ~ 42.00%), and with the span increased, the proportion of dumbbell section is decreased while the proportion of truss section increased; In the 150 m span and more, truss section becomes the dominant form of cross-section, when during the range of 150 m ~ 175 m, it accounts for 53.33 %, and at 175 m above accounts for more than 90%.

Table 2. *Relationship between arch rib section and span of CFST arch bridges.*

Sectional Forms	Truss Section	Dumbbell Section	Single Tube Section	Others
50～75m	11.9%	34.30%	29.90%	23.90%
75～100m	11.4%	65.80%	3.50%	19.30%
100m～125m	25.8%	58.10%	3.20%	12.90%
125m～150m	42.00%	48.00%	2.00%	8.00%
150m～175m	53.33%	30.00%	0.00%	16.67%
175m～200m	90.00%	10.00%	0.00%	0.00%
More than 200m	98.00%	0.00%	0.00%	2.00%

5. CONCLUSION

CFST arch bridge has been developing in China for nearly 20 years. With the progress of application research theory and experience accumulation, building number, span and scale are also increasing. It is expected that CFST arch bridge still has a broad application in China for a long time.

On the basis of the previous research, this paper continued to analyse the collected 413 CFST arch bridges in China. Firstly, this paper briefly introduces the survey on the number and characteristics of CFST arch bridges in China. Then analysis is carried out based on the factors of structural type, erection method, geometric parameter, and material. Finally, we can conclude from the research that the development trend of CFST arch bridges in China is increasing rather than decreasing.

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