

APPLICATION OF CONCRETE FILLED STEEL TUBULAR ARCH BRIDGES AND STUDY ON ULTIMATE LOAD-CARRYING CAPACITY

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Abstract. *Concrete Filled Steel Tubular (CFST) arch bridges have been developed rapidly in China since 1990. About two hundred CFST arch bridges have been built or are now under construction. In this paper, after a brief introduction of CFST arch bridge, four typical bridges are presented as case studies. After that the experimental studies and nonlinear finite element analyses on ultimate load carrying capacity of CFST arch are introduced.*

1 INTRODUCTION

Concrete filled steel tubular (CFST) arch bridges have been building in China since 1990 under the background of fast development of economy and the requirements of sound highway networks. CFST members have better strength than those of masonry or reinforced concrete and can provide larger stiffness than steel tubes. An interactive force under axial compression confines the concrete core, which greatly improves its load-carrying capacity and ductility, and also delays the steel tube from local buckling. As a result, the spans of arch bridges can be enlarged with the use of CFST members.

Another important advantage of the CFST arch bridges is that the thin-walled steel tubular arch itself can be erected with lower self-weight than concrete members and more outstanding stiffness than shaped steel members. The erected steel tubular arch can be filled with concrete without falsework and formwork. This makes the erection of arch bridges with long spans possible, improves the construction speed and saves the cost for construction.

The structural configuration of CFST arch bridges can be divided into many types. The arch rib may consist of a singular tube or dumbbell section with two tubes or a trussed form with more than two tubes. Depending on the deck location in vertical direction, there are deck arch, through arch and half-through arch bridges. Both through arch and half-through arch configuration are most widely used in CFST arch bridge in China. The CFST arch bridges can also be classified into lateral bracing, no bracing, lift-basket arch bridges according to lateral connection. Additionally, according to thrust in an arch to the substructure, there are true arch bridge and tied arch bridge.

The ordinary erection methods used in CFST arch bridges are the cable crane method and the swing method. As for cable crane method, steel tubular arch ribs are divided into several segments. Both main and auxiliary cables are used to maintain stability and balance during construction. The segments are erected one by one from the spring towards the crown.

The swing method includes the vertical swing method and the horizontal swing method. Using the horizontal swing method, two half leaves of arch ribs are fabricated on both banks of the river with their ends supported on horizontal hinges at the abutments. With the help of hydraulic jacks, two prefabricated ribs can be rotated horizontally to the closer position. The advantage of this method is that the traffic disruption in the erection process is minimal when a CFST arch bridge over a railway or a frequently used waterway is built. The vertical swing method also begins with fabricating two half leaves of ribs on vertical hinges at abutments, but the half leaves are erected at ground level to save falsework, then rotated vertically into closer position with hydraulic jacks. Sometimes, a combination of both the horizontal and the vertical swing method is used during the erection of one CFST arch bridge.

There are about 200 of such bridges have been built or under construction in China, in which 23 of them have a span more than 200m (Table 1)^{i,ii}.

No	Bridge Name	Completion Year	Main span (m)	Rise-span Ratio
1	Wushan Yangtze Bridge in Chongqing	Under construction	460	1/3.8
2	Maochaojie Bridge in Hunan	Under construction	368	1/5
3	Yajisha Bridge in Guangzhou	2000	360	1/4.5
4	Nanning Yonghe Bridge in Guangxi	Under construction	338	1/5
5	Chunan Nanpu Bridge in Zhejiang	2003	308	1/5.5
6	Fengjie Meixi River Bridge in Chongqing	2001	288	1/5
7	No. 3 Hanjiang Bridge in Wuhan	1999	280	1/5
8	Dongguang Shidao Bridge in Guangdong	Under construction	278	
9	San-an Yongjiang Bridge in Guangxi	1998	270	1/5
10	Yibin Rongzhou Bridge in Sichuan	Under construction	260	
11	San-men Jiantiao Bridge in Zhejiang	2001	245	1/5
12	No. 5 Hanjiang Bridge in Wuhan	2002	240	1/5
13	Tongwamen Bridge in Zhejiang	1999	238	1/4.82
14	Beipanjiang Railway Bridge in Guizhou	2001	236	1/4
15	Pizhou Cannal Bridge in Jiangsu	2002	235	1/4
16	Liujing Bridge in Guangxi	1999	220	1/5
17	Nannidu Bridge in Hubei	Under construction	220	1/5
18	Hechuan Jialinjiang Bridge in Chongqing	2002	210	1/4
19	Zigui Qinggan River Bridge in Hubei	1998	208	1/4
20	Wangchun Bridge in Hunan	2003	208	1/5
21	Meishan Minjiang Bridge in Sichuan	Under construction	206	1/5
22	Mianyang No.3 Fujiang Bridge in Sichuan	1997	202	1/4.5
23	Nanghai Sanshanxi Bridge in Guangdong	1995	200	1/4.5

Table 1 : CFST arch bridges (span \geq 200m)

2 CASE STUDIES^{ii, iii}

2.1 Qunyi bridge

The Qunyi Bridge, located in Fuan City, Fujian Province, China, is a half-through CFT arch bridge with a clear span of 46.00m and a clear rise of 15.333m, giving a rise-to-span ratio of 1/3. General views of this bridge are shown in Figs. 1 and 2. The bridge was designed by the author himself and was taken as a prototype for the experimental models A-CFST-AS 1 and A CFST-AA in Table 2.

Generally, for CFST arch bridges with small span, the single tube is used as the rib. The arch rib in Qunyi Bridge is a single steel tube of $\phi 800\text{mm} \times 14\text{mm}$, filled with C30 concrete. The parallel arch ribs are braced by two lateral steel tubes near the crown and two reinforced

concrete cross-beams near the abutments with diagonal steel tube struts.

The reinforced concrete deck system carries 12m wide roadway and two 1.5m wide sidewalks. It consists of cast-in-place continuous reinforced concrete slabs of 200mm thickness, supported by cross beams and two small longitudinal beams. It is hung from the arch ribs by $109 \phi 5$ mm high strength steel strand hangers underneath the ribs and supported by reinforced concrete spandrel columns over the arch ribs. The bridge was constructed from 1996 to 1998 and opened to traffic in July 1998.

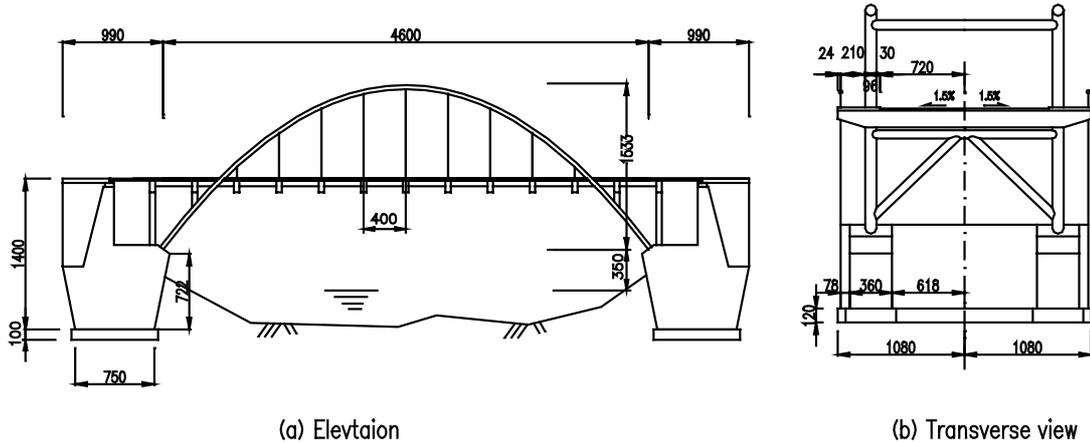


Fig.1 Elevation of Qunyi Bridge (unit: cm)



Fig. 2 Completed Qunyi Bridge

2.2 The Second Yellow River Bridge in Zhengzhou

When CFST arch bridge is constructed in plain area, tied through arch can be used. Generally the tied beam is made of pre-stressed concrete. In these structures, because the thrusts are carried by the tied girders, the foundations and abutments or piers are simpler and cheaper. However, erection difficulty will increase with span due to the fact that the horizontal reactions are not available until the deck is completed. Thus, this type of bridge is used in span about 100m. The Second Yellow River in Zhengzhou, China, is one of such bridges.

The bridge carries 4 lanes in each direction in one of the two separate bridges. The main part consists of 8 identical 100m simply supported spans. The length between neighboring piers is 100m, and the clear span is 95.5m. Ratio of rise to span is 1/4.5. The main bridge adopts cantenary curve shape with parameter value m of 1.347 as its arch axis. The centre to centre distance of two ribs is 22.377m and three hollow steel tubular braces (one straight line member and two K-shaped braces) connect the two ribs to form the space structure. The configuration of superstructure is illustrated in Fig. 3.

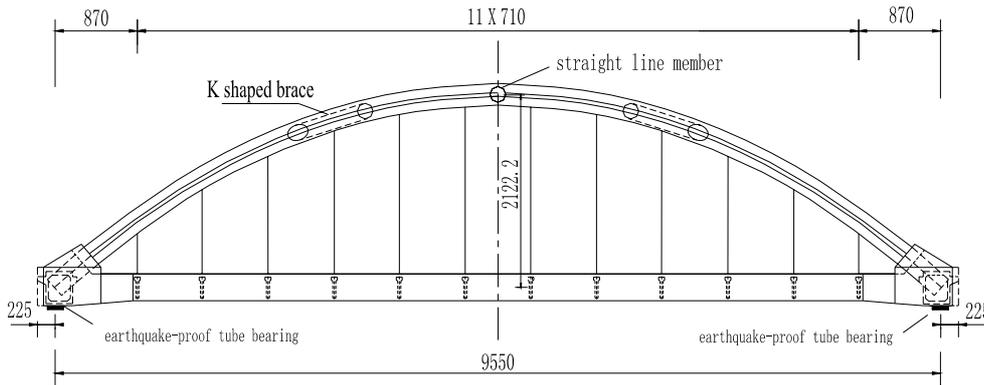


Fig. 3 General configuration of the Second Yellow River in Zhengzhou(unit:cm)

Each bridge comprises two 2.4m high arch ribs of dumbbell cross-section. The dumbbell section is generally used as arch rib when the bridge span varies from 60 to 120. It composes of two CFST tubes and two plates webs. It can provide large flexural stiffness than single tube, make the fabrication easier and give a simple view compare to truss section.

In dumbbell section, the tube diameter D ranges from 450mm to 1500mm, mostly between 750~900mm, with D/L (L —clear span) ranges from 1/60 to 1/150. The rib height H is from 1200mm to 2000mm, H/L from 1/30 to 1/60 and D/L from 1/2.11 to 1/2.67. D/L is usually 1/2.5. The thickness of the steel tubes ranges from 8mm to 16mm, most of them are 10mm. Generally the D/L and H/L decrease as the span increase. The steel tube used in the Second Yellow River in Zhengzhou has a diameter of 1000mm and thickness of 16mm thick, filled with C50 concrete in the upper and lower tubes (Fig. 4).

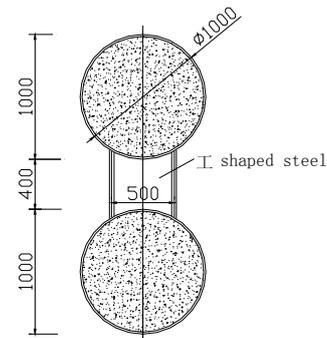


Fig. 4 Dumbbell shaped arch rib(unit:mm)

The hanger rod is made of high tensile strength wires protected by two layers of Polyethylene. The tied beam is a pre-stressed concrete box girder with 2.0m wide and 2.75 high. The four supports of one superstructure are 1750t rubber basin carriers. The substructures use hollow piers and group pile foundations. The bridge is under construction and will be completed in 2005.



Fig. 5 Construction of the Second Yellow River in Zhengzhou

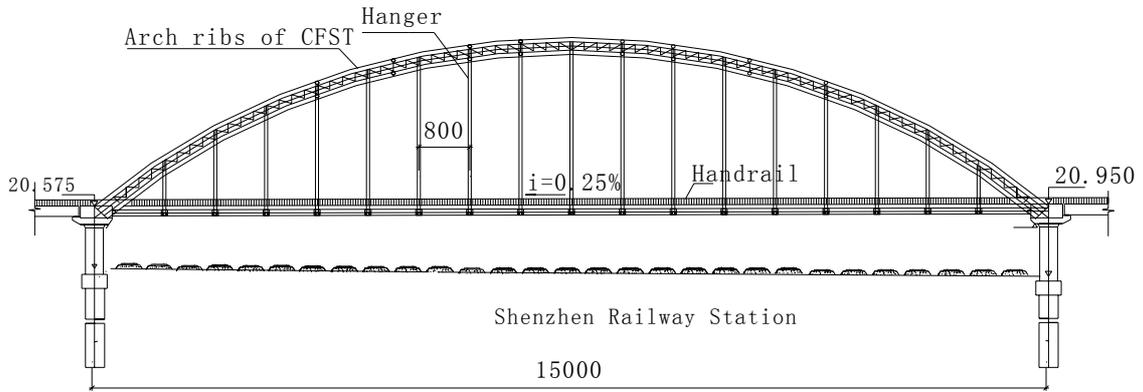
2.3 Shenzhen Beizhan Bridge

Beizhan Bridge is located in Guangdong Province, crossing over 29 rails of railway extended from Shenzhen North Station. The main span is a rigid-framed tied arch bridge with a span of 150m. The clear width of the bridge is 23.5m. The ratio of rise to span is 1/4.5 and the axis is a centenary curve with a parameter m of 1.167. The two arch ribs are fixed into the tops of the piers to form an arch frame, therefore the cantilever launching method can also be used in erecting the steel tubular arch, like the fixed true arch. In this way the construction of this type arch bridge is easier than the tied arch bridge with supports.

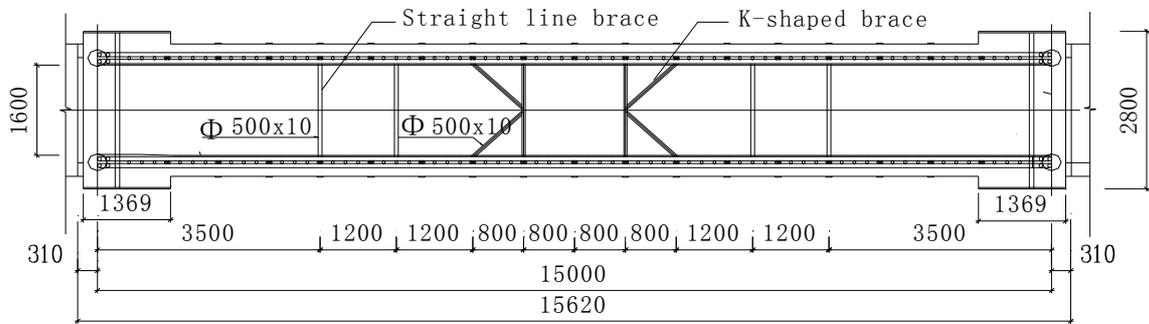
In order to balance the thrust of dead load to the piers, high tensile strength wires are used to pre-stress horizontal forces at the arch rib spring. The weight of the tied member almost does not increase with the bridge span, and the outplace stability is good for the fixed arch ribs. So such bridges have better crossing capacity than the tied arch bridge and are used widely in CFST arch bridges in China. The Beizhan Bridge is a typical tied rigid-frame CFST arch bridge.

In general, for a CFST arch bridge, when the span is larger than 120m, the arch rib is composed of truss with CFST chords and others steel members. CFST truss arch ribs are used in Shenzhen Beizhan Bridge. The four chord members in each rib are steel tubes of 750mm diameter and 12mm thickness, filled with C50 concrete (Fig.6 and Fig.8).

Another type of rigid-frame tied CFST arch bridge is a three span bridge with the main span of half-through configuration and the two side spans as deck configuration of cantilevered half arches. The bridge is tied by the pre-stressed steel bar at the end of the side spans and the arch ribs are fixed on the pier. It is called half-through rigid frame arch bridge, sometimes the fly-bird looking bridge (because of its appearance) or self balanced arch bridge. The Yajisha Bridge in Guangzhou City is one of this type, with spans of 76m+360m+76m. It is the largest one of CFST arch bridges completed^{iv}



(a) General view



(b) Plan view

Fig. 6 Elevation and Plan view of the Shenzhen Beizhan Bridge (unit:cm)



Fig. 7 Shenzhen Beizhan Bridge

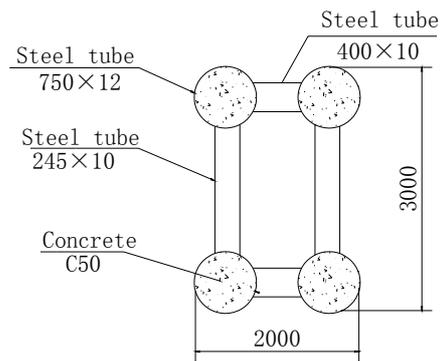


Fig. 8 Cross Section of Arch Rib (unit:mm)

2.4 Wu-shan Yangtze River Bridge

The Wu-shan Yangtze River Bridge is located in the Reservoir of three Gorges, China. It is a half-through CFST arch bridge with a clear span of 460m and a rise to span ratio of 1/3.8. The bridge width is 19m. It is under construction currently and will be completed in 2004. When it is open to traffic, it will be a CFST arch bridge with the largest span in the world.

The arch ribs are twin CFST trusses. The axis is a catenary curve with a parameter m of 1.55. The width of a rib is 4.14m; the 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 $\Phi 1220 \times 22\text{mm}$ filled with C60 concrete. The web members are made up of steel tubes $\Phi 610 \times 12\text{mm}$. The lateral struts of the chords in a rib are also hollow steel tubes of $\Phi 711 \times 16\text{mm}$. The general layout of the bridge is shown in Fig.9.

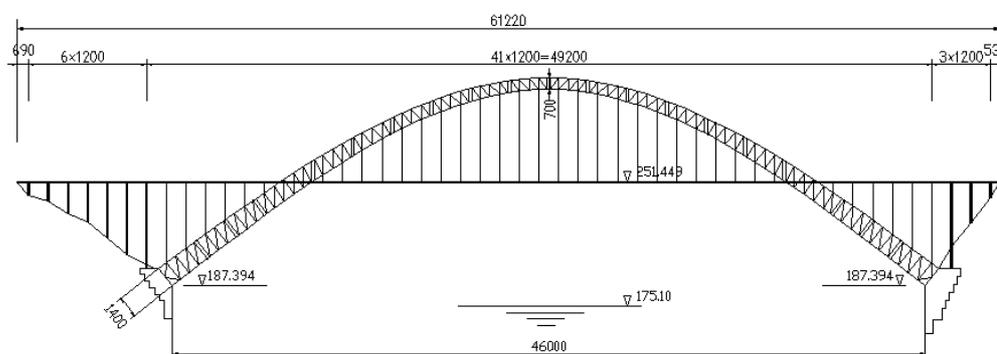


Fig 9 Elevation of Wu-shan Yangtze River Bridge (unit:cm)

Total of 20 lateral bracings connect the two parallel arch ribs together. Except two bracings at the intersection point of deck to arch ribs are composite structures of steel tubular and steel plate girder, the other bracings are steel tubular trusses, in which the bracings over the deck are in K-shape and the bracings below the deck are in a shape of two K combined back to back.

The hangers are high strength wires and the spandrel columns are CFST members of $\Phi 920 \times 12\text{mm}$ steel tubes filled with C50 concrete. The cross beams are pre-stressed concrete T-shaped beams. The pre-fabricated reinforce concrete Π -shaped beams with 12m span are laid on the top of the cross beams and the concrete in site will be poured on them to form the deck. The split abutment for each rib is located in the rock foundation.

The steel tubular arch was erected by cable crane method. Each arch rib is divided into 11 hoisting elements and each bracing is a hoisting element. The heaviest weight of the hoisting element is 128t and the design hoisting capacity is 170t. The span of the cable crane is 576m with the height of the tower of 150.22m. The hoisting member from the water level to the structure level is as high as about 260m.



Fig 10 Construction of Wu-shan Yangtze River Bridge

3 EXPERIMENTAL STUDY ON ULTIMATE LOAD CARRYING CAPACITY OF CFST ARCH

The research on CFST arch bridges focused on the structural behavior under construction and live loads, the thermal stress, the erection technique, etc., have been carried out^{3,4}. However, the theoretical researches are not able to maintain their pace with practical applications. No design theory of CFST arch bridges has been established in practice. “The Design Specification of CFT Arch Bridges” (in Chinese) and “The Construction Technique Specification of CFT Arch Bridges” (in Chinese) are still under editing. Most designers follow the design code of steel bridges and/or reinforced concrete bridges when designing CFST arch bridges. In the design theory, ultimate load-carrying capacity of a structure is one of the key issues. Therefore, we have studied this field since 1998. Total of 9 model arches were tested, a nonlinear finite element method was presented and the ultimate load carrying capacity was studied. The research begins from the study on CFST arch with single tubular rib.

3.1 Experimental study

All of the nine model arches were subjected to planar loads. Two of them were hollow steel tubular arches, two of them filled with concrete from the fixed end to the quarter point in the tubes and five of them were CFST arches (filled concrete all the tubes). Table 2 shows the test matrix of the arch models^{2, 5-8}. The letters of the names of the arch models in notations in this order, for example, B-CFST-MS-1, the first letter refers to the group, then the arch rib (CFST: concrete filled steel tube, CFSTP: concrete partially filled steel tube, ST: empty steel tube), load condition (first letter of the number of the load, M: multi-concentrated load condition and A: a concentrated load condition; the second letter for the load arrangement, S: symmetrically and A: asymmetrically).

The test results show that CFST arch has good elastic-plastic property and ductility, its ultimate load carrying capacity and the stiffness is much greater than the hollow steel tubular arch. However, concrete filled partly in the steel tube do not increase the ultimate carrying capacity very much.

The stress in the cross section and the inner force along the CFST arch rib can be redistributed after the material come into nonlinear properties. The plastic area of the rib

develops faster and larger along the axis direction than along the cross section direction. The plastic area in the CFST arch is larger than in the RC arch. The CFST arch behaviors are influenced greatly by the geometrical nonlinearity. The in-plane ultimate loads are the peak values of in-plane instability.

Model		Clear span and High Rise	Tube (D×t)	Concrete strength (MPa)	Slenderness	Load Condition
Group	Label					
A	A-CFST-AS	$L_0=460$, $h=153$	76×3.792	36.8	110	One at quarter
	A-CFST-AA					One at crown
B	B-CFST-MA	$L_0=750$, $h=150$	121×4.5	31	98.5	Two at half side
	B-CFSTP-MA			31, partly		
	B-ST-MA			No concrete	72.3	
C	B-CFST-MS-1	$L_0=750$, $h=150$	121×4.5	31	98.5	Five. symmetrically
	B-CFST-MS-2			31, partly		
	B-CFSTP-MS			No concrete	72.3	
	B-ST-MS			No concrete	72.3	

Table 2: Test Matrix of Arch Models (Unit: mm)



(a) Group A



(b) Group B

Fig. 11 Set-ups of Model Arches

3.2 Nonlinear finite element method

In general sections of CFST arch, there are both compressive force and bending moment. So it can be considered as an eccentrically loaded member. In material nonlinearity problem, the compressive and flexural rigidities of the section are not constants. They are functions of deformation of the section. In order to obtain the rigidities, a cross-section is divided into n thin strip elements and a numerical iterative method is used. The incremental load method is

used in the material nonlinearity only problem.

The fiber element model of CFST is used, in which the reaction of a cross-section under loading is considered as the algebraic sum of stress for each fiber, as if each material acts separately. The stress-strain relations of steel and concrete are expressed in one dimension format. The interaction of two materials is reflected in the stress-strain relation of concrete from the statistic analysis of the test data. The stress-strain relation of steel composed of four portions is considered. For stress-strain relation of concrete, the L. H. Han's model⁹ is chosen and modified.

The experimental study indicated that the apparent Poisson's ratio of compressed edge would decrease obviously with the increase of eccentricity ratio when the longitudinal strain is large¹⁰. In other words, the confinement effect of steel tube on core concrete will be weakened by the stress gradient caused by the load eccentricity ratio. Therefore, the confinement index ξ in L. H. Han's model is multiplied by a coefficient k_e to consider the influence of stress gradient caused by the load eccentricity on the confinement effect of steel tube. The modified coefficient k_e is a function of the eccentricity ratio. It is represented as follows:

$$k_e = \begin{cases} 1 - e/r_c & (e/r_c \leq 1.0) \\ 0 & (e/r_c > 1.0) \end{cases} \quad (1)$$

The Updated Lagrangian (*U. L.*) formulation is used in geometrical analysis. The iteration procedure of the modified Newton-Raphson procedure is used in solution of geometrical nonlinear problem. In analysis of a CFST arch, dual non-linearity problem, i.e., a combination problem of geometrical non-linearity and material non-linearity should be considered. In solving the dual nonlinear problem of CFST arch, a mixed procedure is used. This procedure is a combination of incremental method for material non-linearity and modified *Newton-Raphson* method for geometrical non-linearity.

The stiffness EA and EI of the element varies with the deformation and the external forces. In this paper, the rigidities EA and EI of each element are assumed to be a constant during each incremental loading. In order to eliminate the error by this method, except enough incremental step used in the procedure, the mid-point tangent stiffness matrix $[K_0]_{i-1/2}$ is used, instead of using the tangent stiffness matrix $[K_0]_i$ at the end of the last incremental step.

The material non-linearity is a subroutine nesting in geometrical non-linearity analysis. In order to improve the calculation effectiveness, the structure is analyzed with large incremental load steps at first to estimate the ultimate load and the structure behaviors. Then the load increment factors for each loading step can be determined by the pre-analytical results. The maximum displacement of the structure is taken as the control factor for analysis of a CFST arch. In this research, if the maximum displacement of the arch is larger than 5-10% of the span, the arch is considered as failure and the calculation is terminated.

Two CFST arch models in Group A (A-CFST-AS and A-CFST-AA, simply presented as A1 and A2 in the following text) are analyzed by the nonlinear finite element methods. An arch

rib is divided into 48 beam elements and a cross section into 800 strips. The load-deflection curves of the typical sections are plotted in Fig. 12.

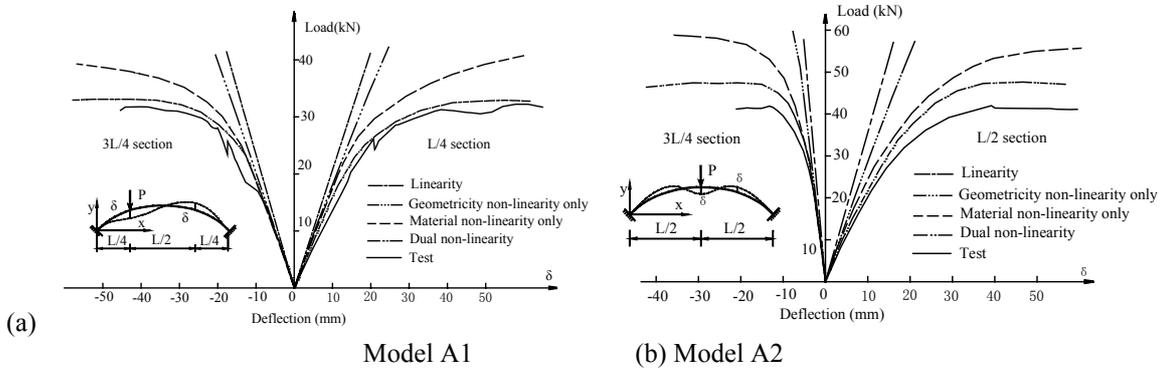


Fig. 12 Nonlinear property of load-deflection of Model A2

In the case of geometrical non-linearity only problem, the stress-strain relation is assumed as linear. Similarly, in case of the material non-linearity only problem, the geometrical non-linearity is ignored. The peak values are obtained from the load-deflection curve of the critical section. In Model A1, the critical section is the quarter section of the arch ($L/4$) and in Model A2; it is the crown section ($L/2$) of the arch.

The slope of the load-deflection curve considering geometrical non-linearity only is very steep. The peak value of the loads for Models A1 and A2 are 293.3kN and 179.2kN, which are much greater than the tested ultimate loads 31.9kN and 42.07kN, respectively.

The slope of the load-deflection curve considering material non-linearity only changes significantly while the load increases. This indicates that the nonlinear behavior of the CFST arch models is influenced by material non-linearity more than by geometrical non-linearity. The stress-strain relation of CFST should be emphasized in the study.

The load-deflection curve in geometrical non-linearity only problem is not very crook. However, the geometrical non-linearity should be taken into account, because CFST arch is slender, the displacements will interact with the thrusts and cause additional bending moments; this geometrical non-linearity will interact with the material non-linearity and sharpen the non-linearity of the CFST arch. This is the reason why the load-deflection curve in dual non-linearity is significantly different from that in material non-linearity only problem and the ultimate load considering material non-linearity only is much higher than that in the dual non-linearity problem.

3.3 Parameter studies on ultimate load-carrying capacity of CFST arch bridge by nonlinear FE

Rise to span ratio is an important parameter on arch structure, and exerts a tremendous influence on mechanical behavior. The curves of ultimate load-carrying capacity that changes with rise to span ratio is shown in Fig. 13. As shown in Fig. 13, when the rise to span ratio is 0.3-0.35, the ultimate load is in the peak value. Therefore, to the behavior of model arch, the appropriate range of rise to span ratio is 0.3-0.35.

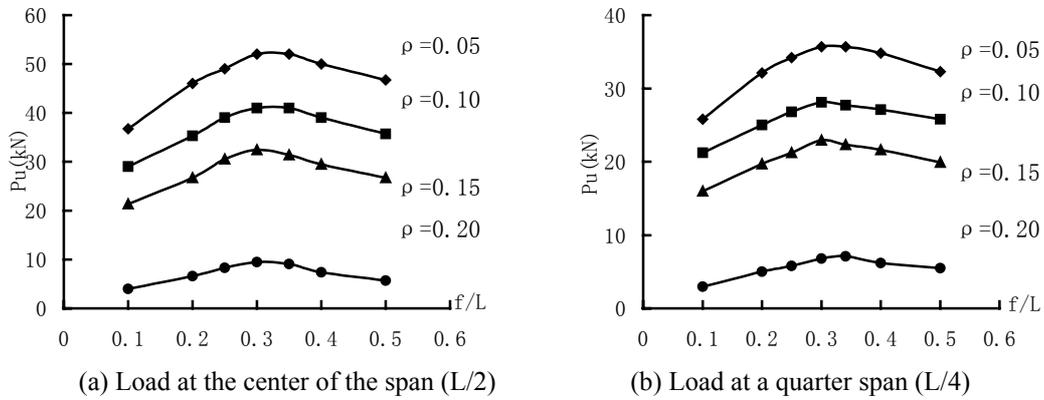


Fig.13 Related curves of ultimate load-carrying capacity to rise to span ratio

Slenderness ratio is a vital element affecting the behavior of CFST arch. The range of slenderness ratio analyzed in this paper is 80-120. The results of calculation are shown in Fig.14. The ultimate load-carrying capacity of CFST arch (single tube) changes in a index function with slenderness ratio.

One of the remarkable benefits of CFST material is that when it is compressed, the confining effect of steel tube to concrete improves the compressive strength of concrete. Therefore the steel ratio is an important parameter in CFST arch ribs. Generally for single tube, it is between 8% and 20%.

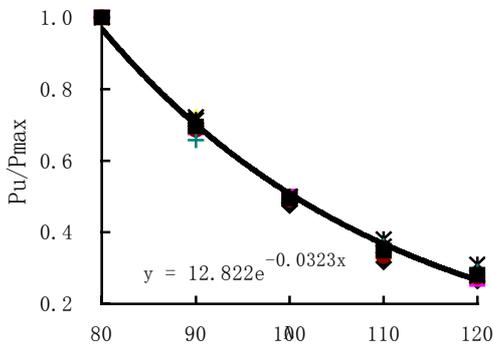


Fig.14 Influence curve of slenderness ratio and ultimate load

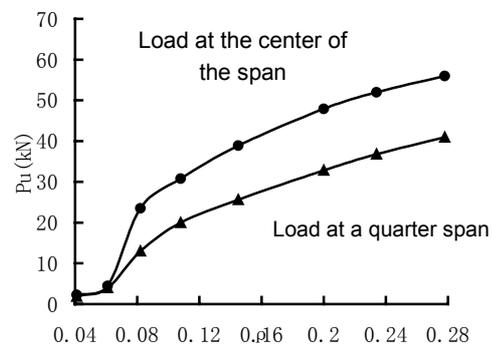


Fig.15 Related curves of ultimate load-carrying capacity and steel ratio

When steel ratio is less than 8%, the confining effect is very small, the structure will behave low ductility as reinforced concrete arch with low steel ratio. Therefore larger than 8% steel ratio have been and should be used. However, too higher steel ratio is not economic and will make the fabrication of steel tube difficult.

4 CONCLUSIONS

- In China, CFST structures have been a strong research subject since more than thirty years. The application of CFST into arch bridge has big contribution to increase the development of arch bridges. Many CFST arch bridges have been built and it is predicted that more long span bridges will be built in the future with more advancements.
- Test results of CFST model arches show that the ultimate load of an arch subjected to a symmetric loading is greater than that of an arch subjected to an asymmetric loading. The plasticity develops more rapidly along the axial direction than toward the circumferential direction. The composition of steel tube and concrete provides good ductility for the structure and avoids brittle collapse. It is seen that the global behavior of the CFT arch is more akin to that of the steel arch.
- A method to analyze the behavior of a CFST arch is presented. Both the material and geometrical non-linearities are taken into account in this method. The fiber element model of stress-strain relation of CFST is used. The solution method used for nonlinear problem is of the mixed procedure (incremental method + modified Newton iteration). The analytical results by this method agree well with the test results.
- Analyses of the nonlinear property for the CFST arch models indicate that both the material and geometrical non-linearities take important roles in the behavior of CFST arches and the influence of material non-linearity is more dominant than that of the geometrical non-linearity. However, the geometrical non-linearity should be taken into account, because CFST arch is slender, the displacements will interact with the thrusts and cause additional bending moments; moreover, this geometrical non-linearity will interact with the material non-linearity and sharpen the non-linearity of the CFST arch.
- Parameter Studies predict that when the rise to span ratio is 0.3--0.35, the ultimate load reaches in peak state. The ultimate load-carrying capacity of CFST arch (single tube) changes in an index function with slenderness ratio. Steel ratio between 8% and 20% is suitable to use in CFST arch rib (single tube).

REFERENCES

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- [i] Bao-chun Chen, Design and Construction of CFST Arch Bridge (Chinese), The China Communications Press, Beijing, China, (1999).
 - [ii] Bao-chun CHEN, Nonlinear Characteristics and Ultimate Load-Carrying Capacity of Concrete Filled Tubular Arch, PhD Thesis, Kyushu University, Japan, (2003)
 - [iii] Bao-chun Chen, Examples (1) of CFST Arch Bridge (Chinese), The China

- Communications Press, Beijing, China, (2002)
- [iv] W. Zhuang, D. Huang, "The 360m CFST arch of the Yajisha bridge", Proceedings of the Third International Conference on Arch Bridge, 677-682, Paris France (Sept. 2001)
 - [v] B. C. Chen and Y. J. Chen, Experimental Study on Whole Process of CFST Rib Arch Bridge under In-plane Loads, Proceedings of the 6th ASCCS International Conference, March, Los Angeles, 167-172 (2000)
 - [vi] Youjie Chen, Baochun Chen and Ying Lin, Test of Steel Tubular Model Arch under Non-symmetric In-plane Loads [J], Journal of Xiangtan Mining Institute, 16: 1, 53-56 (2001)
 - [vii] Ying Lin, Baochun Chen and Youjie Chen, Experimental Study on Steel Tubular Arch under Symmetric In-plane Loads, Journal of Fuzhou University (Natural Science Edition), 29: 2, 66-69 (2001)
 - [viii] Jianggang Wei, Research on Bifurcation Stability of Concrete Filled Steel Tubular Arch Subjected Axial Compression and Bending Moments, Master's Thesis of Fuzhou University, Fuzhou, Fujian, China. (2002)
 - [ix] Linhai Han, Concrete Filled Steel Tubular Structures (Chinese), Science Press, Beijing, China (2000)
 - [x] Baochun Chen, Hiroshi Hikosaka, Eccentricity Ratio Effects on the Behavior of Eccentrically Loaded CFST Columns, Advances in Structures, Proceedings of Advances In Structures--Steel, Concrete, Composite and Aluminium, Sydney, Australia, A. A. Balkema Publisher, 973-978 (2003)