Fatigue Cracks in a Concrete-filled Steel Tubular (CFST) Trussed Arch Bridges in China

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1 Introduction

Concrete-filled steel tubular (CFST) trussed structure, adopting relatively small pipes mainly subjected to axial force to achieve greater vertical and transverse stiffness, is suitable for long-span bridges. CFST arch bridges have been rapidly developed in China since 1990; 413 CFST arch bridges with the main span length over 50 meters have been built until the end of 2014. Recently in China, fatigue cracks were found in a half-through CFST arch bridge. In this study, information on this bridge and its circumstances of the damages has been obtained from website survey and literature reviews to analyze main reasons and to provide some experience for fatigue strength analysis and fatigue life prediction.

2 Outline of bridge and cracks

2.1 Bridge

The length of half-through CFST trussed arch bridge is 166.84meters and the width is 12meters, and the main span of bridge is 136 meters. Its trussed arch rib section is 3.0meters deep and 1.6meters wide. The chord tubes use Φ550mm×8 mm steel pipes filled with C40 (concrete with compressive strength of 40MPa) and web members use Φ219mm×8 mm steel pipes, as shown in **Fig.1**. Steel is Q235 (steel with yield stress of 235MPa). It opened to traffic in January 1998.

2.2 Cracks

In April 2013, cracks were found in the connections of main arch rib and web member during the daily inspection, as shown in **Fig.2**. In total, there are nine cracks in the bridge, comprising eight in the left side of the main arch rib and one in the right side. Specific distribution of cracks is shown in **Fig.3**. The position and length of cracks are summarized in **Table1**.

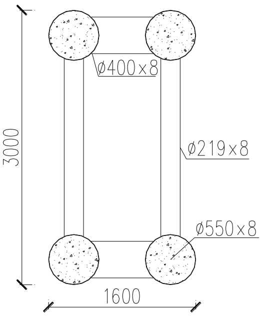
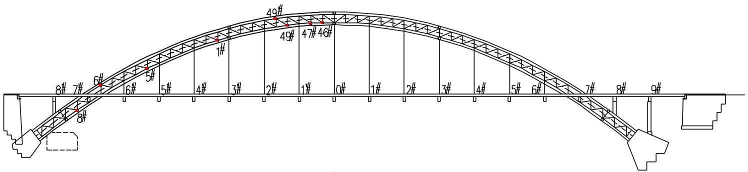
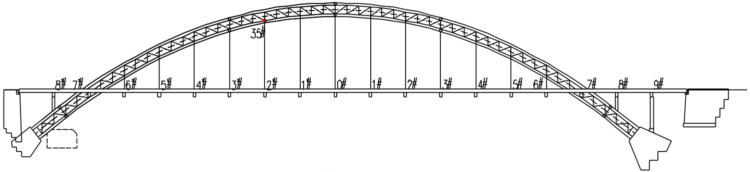


Fig.1 Cross sections of main arch rib （Unit：mm）

Fig.2 Example of crack



（a）Left



（b）Right

Fig.3 Specific distribution of welded cracks

Table1 Summary of cracks (Unit: mm)

No.	Position	Length
1#	Left, between 3'# and 4'# suspender, Left,11'#tilted web member and arch rib C	220
5#	Left, between 5'# and 6'# suspender, Left,17'#tilted web member and arch rib C	200
6#	Left, between 6'# and 7'# suspender, Left,20'#tilted web member and arch rib A	160
8#	Left, between 7'# and 8'# suspender, Left,23'#tilted web member and arch rib C	220
35#	Right, between 2'# and 3'# suspender, Left,7'#tilted web member and arch rib H	180
46#	Left, between 0'# and 1'# suspender, Left,2'#tilted web member and arch rib D	200
47#	Left, between 0'# and 1'# suspender, Right, 2'#Vertical web member and arch rib D	250
49#	Left, between 1'# and 2'# suspender, Left,5'#tilted web member and arch rib C	170
49'#	Left, between 1'# and 2'# suspender, Left,5'#tilted web member and arch rib A	200

3 Cause analysis

3.1 Design

The bearing capacity of the trussed arch rib on the condition of partial web member failure was analyzed. FE model was built by *MIDAS/CIVIL* and safety check on the components of trussed arch rib and the whole structure was carried out according to

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Keywords：Fatigue cracks; CFST Trussed arch bridge; China.

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Technical code for concrete-filled steel tube arch bridges (GB50923-2013).Their results showed that the main arch cross section strength and the overall stability of the main arch can both meet the requirements under the condition of partial web member fracture, and trussed arch rib is still able to withstand the design load even when partial web member fails.

3.2 Fabrication

Through the magnetic particle testing and ultrasonic testing, there was no crack, flash welding seam, burn through, arc pit, porosity, slag inclusion, bite edge, incomplete fusion, lack of penetration etc. So the welding quality problem is excluded.

3.3 Maintenance

In 2007, a steel stiffening truss was added to the bridge. In 2012, all suspenders were replaced. Static and dynamic tests showed that: Stiffness and strength meet the design requirements, but the bridge seriously vibrates.

3.4 Vehicle Investigation

According to vehicle investigation, a large number of heavy vehicles drove through the bridge. 24 hours traffic has reached 4000 to 6000. According to TONG's survey[1] on fatigue load spectrum for urban road bridges in Shanghai, vehicles over 9 ton may cause fatigue failure, which roughly correspond to tractors, large trucks, container vehicles in vehicle investigation. The number of such heavy vehicle has reached 400 to 600, empty car accounts for half, so daily traffic which may cause fatigue is about 3% to 4.5%. Year's traffic growth reached 6%, which aggravates fatigue issue.

4 Fatigue life analysis

4.1 FE model and vehicle load

FE model was built by *MIDAS/CIVIL*. In total, there are 1302 nodes and 2628 elements in the model. The vehicle load of Road-I level specified in *General Code for Design of Highway Bridges and Culverts* (JTG D60-2004) and shown in **Fig.4** is applied to the bridge deck. Its total weight is 550kN.

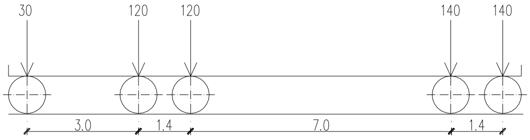

Fig.4 Vehicle load of Road-I level（Unit：m and kN）

4.2 Fatigue life

Fatigue life of the CFST joint under the maximum stress range was calculated under two loading conditions given in **Fig.5**. Stress concentration factors (SCF) and stress ranges according to hot spot stress method and correction coefficient method obtained for these two conditions are shown in **Table2**. The calculated number of cycle to failure is 1.3×10^4 times.

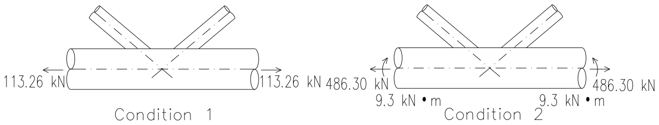

Fig.5 CFST joint under maximum stress range

Table2 SCF and stress range of CFST joint

SCF				Stress ranges (Unit: N/mm^2)	
condition 1		condition 2			
chord	brace	chord	brace	condition 1	condition 2
28.2	8.4	2.4	0	27.765	48.437

4.3 Improved design

The main parameters affecting fatigue life are diameter ratio, diameter-thickness ratio and thickness ratio[2]. When diameter ratio of bridge trussed arch rib change from 1:2.5 to 1:2.33 and diameter-thickness ratio change from 68.75 to 50, the parameter of diameter and thickness will change as shown in **Table3**. It results in the reduction of SCF and stress range as shown in **Table4.** It is found that the number of cycles to failure increases to 1.1×10^6 times.

Table3 Parameter of diameter and thickness

Parameter	Original Design	Improved Design
Chord Tube Diameter	550mm	700mm
Web Member Diameter	219mm	300mm
Chord Tube Thickness	8mm	14mm
Web Member Thickness	8mm	8mm

Table4 SCF and stress range of improved design

SCF				Stress ranges (Unit: N/mm^2)	
condition 1		condition 2			
chord	brace	chord	brace	condition 1	condition 2
7.8	4.5	2.0	0	21.504	17.673

5 Last remarks

The first CFST arch bridge in China was built only 25 years ago. However, fatigue damages occurred in CFST trussed arch bridge. With the increase of traffic volume and overloads, fatigue failure problems of CFST trussed arch bridges will become more and more frequent. Therefore, the fatigue life of a main arch rib joint of CFST trussed arch bridge will become one of the hottest topics in China.

References

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[2] FAN Wen-li. Fatigue Design of Pipe Structure Node[C]// National Tube Structure Technology Proceedings, 2001: 295-300. (in Chinese)