Experimental research on fatigue of tubular-plate joints for concrete-filled steel tube arch bridges

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ABSTRACT: Based on generations of concrete-filled steel tube arch bridges' joint type, fatigue test model of single joints for tubular-plate is designed. Under invariable amplitude, the fatigue test is done, which show the design fatigue strength of concrete-filled steel tubular-plate joints (CFSTPJ) under welded seam can be used to that of CFSTPJ under shear stress safely, and the design fatigue strength of CFSTPJ is 80 MPa.

Keywords: concrete-filled steel tube arch bridges, tubular-plate joints, fatigue test,

Being the conventional bridge type, arched bridge has been widely used in China and the appearance of concrete-filled steel tube arched bridge (CFST) definitely promotes the development of arched bridge, since it not only increases the bearing capability of material, but also simplifies the construction method.

Amid of all the arch structures, the truss arch of CFST arched bridge is an ideal structure type to construct large span arched bridge. The most important factor is the joint of the structure. There is stress concentration not only caused by the profile of structure but also caused by the flaw of welded seam at the joint. Stress concentration will lead to the fatigue of a structure, yet the research on fatigue life of CFST joint which influences structure's safety is few and the detailed design is ignored.

Gusset and intersecting connection are two kinds of welding joints for tubular structure, and have been used in bridge, yet the research on its fatigue test is few.

Y-type and K-type joints are the most common used joint types of CFST arched bridge. Base on Y joints, this paper studies the single joints whose stress is in the most serious state, and designs single joints model of concrete-filled steel tubular-plate joints (CFST-plate joints) to do the fatigue test, which would be the reference to the similar joints' fatigue design.

1. GENERAL SITUATION OF FATIGUE TEST

The dimensions of fatigue test model are shown in figure 1, both of which are DY-type triangular plane trusses. Main pipe (N1) and secondary pipe (N3) are made of Q235B while the diagonal brace [18 structural sections. Low-hydrogen electrodes are used to welded gusset and main pipes.

Stiffening plate is designed on gusset to control the external displacement, and all the welded seams are shined by scouring wheel to improve the fatigue strength.

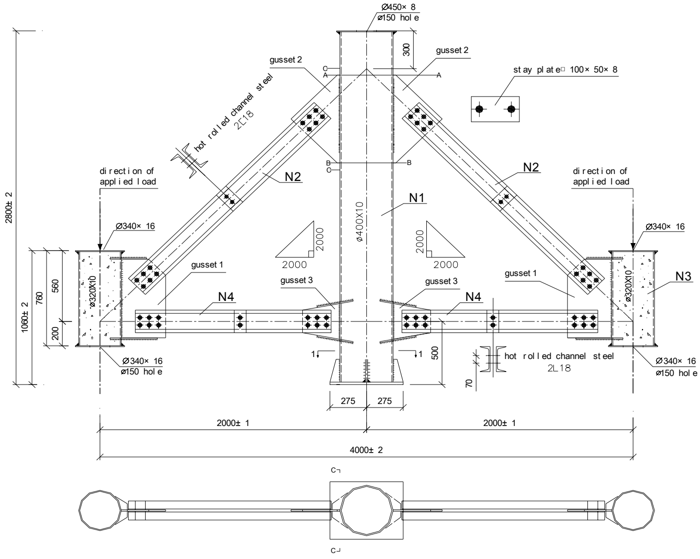

Figure 1: Tubular-plate joints model of concrete-filled steel tube

The load mode is shown in Fig. 2

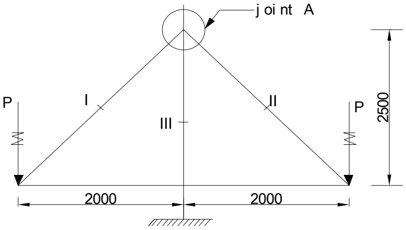

Figure 2: Load picture of model test

The bottom of main pipe is connected to the ground while the load is loaded on secondary pipe（N3）symmetrically, as shown in Fig.2 and 3.

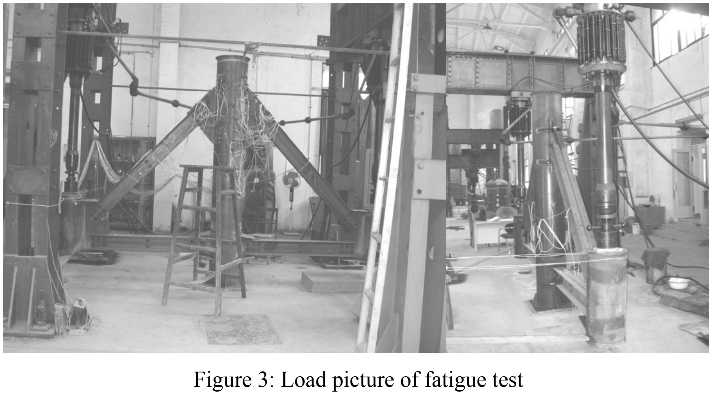

Figure 3: Load picture of fatigue test

2. FINITE ELEMENT ANALYSIS OF TUBULAR-PLATE JOINTS

A CFST-plate joints model is established with ANSYS 7.0 to definite the stress distribution. The steel tube and concrete both use SOLID 95 element while the gusset use sub model, whose mesh division is shown in Fig.4.

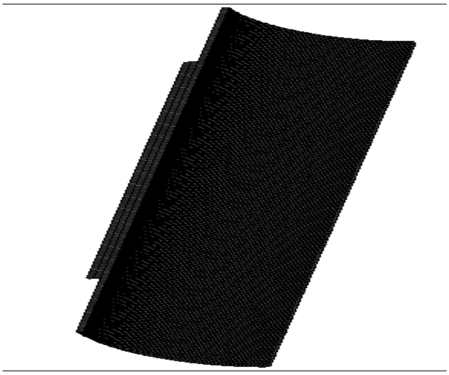

Figure 4: Mesh division of submodel at joints

During CFST-plate joints, the stress distribution, including circumferential, radial, and axial stress, are complex, which result that when solving the stress concentration factor, the average stress of brace section is taken as the standard, which is similar to the hollow tube.

It is shown that in the intersecting tubular joints, the fatigue cracks develop vertically to the radial of the tube. And due to the circumferential stress, the cracks keep on developing.

The radial stress concentration factor distribution at main tubular joints of the welded seam between gusset and main tube from A-A to B-B (Fig.1) is shown in Fig.5

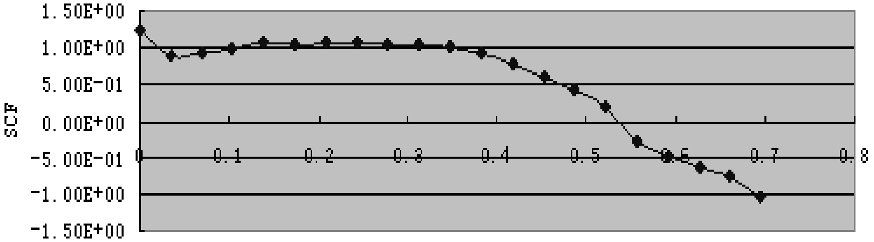

Figure 5: Concentrated coefficient distribution of hoop stress along welded seam at main tubular joints

It is shown that the maximum radial stress concentration factor is 1.25, at main tubes' joints, and from A-A to B-B, the radial stress concentration factor decreases gradually until the radial stress at B-B becomes compressive stress. Compare with multiplanar joint, the chord member of CFST-plate joints can be supported by concrete, the level of stress and stress concentration factor must be cut down effectively

The welded seam of C-C at CFST-plate joints is in a compound stress state, including shear stress and normal stress. As a criterion to judge fatigue strength, equivalent stress range including influence of shear stress and normal stress can be adopted, the formula of equivalent stress range can be expressed bellow: $\Delta\sigma_{eq} = \sqrt{\Delta\sigma^2 + \Delta\tau^2}$

With the finite element, it is shown that the stress at A-A is not only the most disadvantageous, but also concentrated severely. The main tubes' joints of A-A is the place where the fatigue crack may be found most likely.

3. FATIGUE TEST RESULTS

The fatigue tests focus on the fatigue life of CFST-plate joints. The two samples are named XPCFJ1, XPCFJ2 respectively, whose loading and inactivation conditions are shown in Table 1.

Table 1 : Loading and inactivation condition of fatigue test sample for tubular-plate joints

sample		XPCFJ1	XPCFJ2
Stress range (MPa)	$\Delta\sigma_1$	60.15	60.15
	$\Delta\sigma_2$	-	69.79
	$\Delta\sigma_3$	-	79.97
	$\Delta\sigma_4$	-	89.61
Bottom limit stress (MPa)	σ_{min}	19.28	19.28
Top limit stress (MPa)	σ_{max1}	79.43	79.43
	σ_{max2}	-	89.07
	σ_{max3}	-	99.25
	σ_{max4}	-	108.89
Total loading times (10^4)		53.38	310
Condition of inactivation		Cracks appeared at the position of weld seam which is between the joint plate and the tube, finally the structure damaged .(out of plane fatigue)	There was no cracks till the loading time arrived 310e4. Model of the experiment was intact.

$\Delta\sigma_1$, $\Delta\sigma_2$, $\Delta\sigma_3$, and $\Delta\sigma_{4.}$ show nominal stress amplitude values of the diagonal brace when loaded variably.

Situations of the two samples are as followed:

(1) XPCFJ1: due to the deviations during the mode manufacturing and installing, the load is incomplete symmetric on XPCFJ1, which results in outer deformations of gussets, belongs to out of plane fatigue.

When the stress amplitude $\Delta\sigma 1$ comes to 60.15MPa and the number of the load 500.1 thousand, the cracks are found in the toe of weld which is 6.5cm from the top point of gusset-main pipe weld.

The cracks’ initial point location and development direction are shown in Fig.6, and the relationship between crack development and load number in Fig.7. From the cracks which don’t appear at the shear stress’s thermal location, it is not the fatigue of shearing weld seams that make the sample damage, but the outer deformation of the gusset.

Table 2 : Crack size development of sample XPCFJ1

loading times (10^4)	50.01	50.84	52.61	53.02	53.28	53.38
Length of crack (mm)	45	90	250	314	445	520

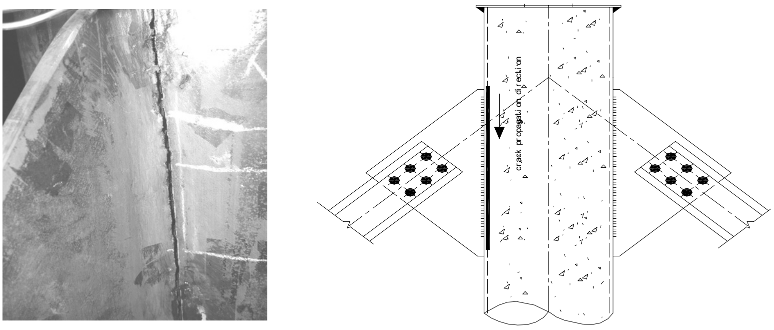

Figure6: Fatigue crack of sample XPCFJ1

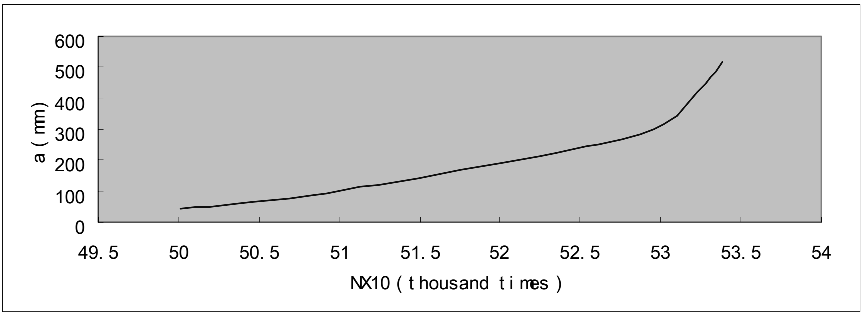

Figure7: Relationship between crack development of l1 and load number N for sample XPCFJ1

(2) XPCFJ2: According to the sample XPCFJ1 test, four stiffening plates are used at joint A of DY-type to prevent the outer fatigue during the XPCFJ2 test. The fatigue load is variable, that is $\Delta\sigma1$ comes to 60.15MPa and the number of the load 507.4 thousand, $\Delta\sigma2$=69.79MPa and the number of the load 1200 thousand, $\Delta\sigma3$ =79.97MPa and the number of the load 2000 thousand, $\Delta\sigma4$ comes to 80.61MPa and the number of the load 3100 thousand. Until the number of the load comes to 3100 thousand, cracks are not found and stop loading.

4. FATIGUE STRENGTH OF TUBULAR-PLATE JOINTS FOR CONCRETE-FILLED STEEL TUBE ARCH BRIDGE

Under shear and direct stress, the weld section of Y-type gusset about XPCFJ is in compound stress state. The finite element and fatigue test show that weld sections mainly carry on shear stress, so when determining the detailed structure, the fatigue details of steel structures under shear stress would be the main factors

The fatigue life of XPCFJ2 can be controlled by the detailed types of shearing weld seams of XPCFJ, and by Miner cumulative principle, the fatigue stress amplitude value of the tubular-plate joints with the number of the load 2 million is 88MPa.

After the tubular-plate joints are filled with concrete, the stress is improved obviously, that is concentration degree lowered, the stiffness strengthened, and compared with the hollow tubular joints, the fatigue strength increased. Taking ECCS as the reference, the allowable stress amplitude of pure shearing welded seam is 80MPa. So it is prone to be safe to take fatigue strength of shearing welded seam as the design fatigue strength of the CFST-plate joints.

It is shown that joints could still bear the fatigue load even the surfacial cracks keep on developing. Joints can still bear fatigue loads even the loaded efficient area decreases continuously. It is not until the fatigue life come to 85%~90% of the whole, the flexibility increases obviously.

5. CONCLUSION

According to the fatigue test of CFST-plate joints, the conclusions are as followed:

As to the CFST-plate joints under shear stress and normal stress, it is prone to be safe to take fatigue strength (80MPa) of shearing welded seam as the design fatigue strength of the CFST-plate joints.

Designers should pay attention to the fatigue phenomenon caused by outer deformation of gusset, the appropriate stiffness of CFST-plate joints is very important. The tests show that after the cracks are visible, compared with the whole life, the rest life which is only 6.3% of the whole life is very short. It is suggested that once cracks are visible, cracks would develop quickly and joints would be destroyed rapidly.

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