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Fatigue Analysis of Weld Seam of Steel Box Girder of Jiangyin Bridge Based on Health Monitoring System and BS5400 Code

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Abstract: The fatigue crack propagation and structural health monitoring system of the welds of Jiangyin Bridge were analyzed statistically and the fatigue damage status of each weld survey was evaluated based on BS5400 specification. The results show that the fatigue crack of the weld of Jiangyin Bridge mainly occurs at the fillet welds of the 6th, 8th, 9th and 12th of the heavy lane and the lane. The stress points of the measuring points are mainly in the range of 0 ~ 10MPa, and the fatigue life of each measuring point is more than 100 years, which is located in the U-rib side wall perpendicular to the fillet weld UC-2 measuring point stress amplitude is larger, more prone to fatigue cracks, fatigue life is minimal.

Key words: Steel box girder; weld; fatigue crack; structural health monitoring; fatigue life

0 Introduction

Steel box girder because of its small weight, torsional rigidity, beautiful structure, construction speed and other advantages has become a long-span bridge construction of choice. Steel box girder generally use the whole welding structure, the huge number of weld joints, the site construction will inevitably exist welding quality and welding residual stress and other issues in the bridge service cycle under the alternating load prone to fatigue cracks, so the weld fatigue Life has become the most concerned about the bridge managers. The calculation method of routine fatigue life is to simulate the vehicle load in the case of general calculation. Because of the assumption that the algorithm has various assumptions, it cannot really reflect the actual force of the bridge. The most reliable means is to directly load ~~the stress of the s~~teel box girder under the load of the sensor, and get the real stress time curve. With the development of the computer technology, the development of the structural health monitoring system makes the stress of the steel box girders real possible. Jiangyin Bridge structural health monitoring system has gone through three stages, the first stage for the 1999 bridge built by the British SES company established, in view of the then sensor technology and computer technology constraints, resulting in monitoring data gradually distorted, and monitoring of the aging of the instrument is important, the maintenance is difficult, the system utilization value is not high; the second stage is 2005, through the domestic scientific research institutions, using the latest sensing technology and calculation means to upgrade the system for the first time in the original system foundation on the update, and the addition of a new monitoring equipment; the third stage for the second upgrade in 2012, the use of three-dimensional simulation technology, the system interface was upgraded, and the addition of weld fatigue and other key parts of the bridge maintenance monitoring.

1. Monitoring of weld fatigue under health monitoring system

Jiangyin Bridge daily traffic flow reached 75,000, of which the proportion of heavy vehicles accounted for 30%, far more than the design is expected. In the case of large traffic flow, the weld fatigue crack began to appear in 2011. In order to better monitor the fatigue crack, in the second upgrade of Jiangyin Bridge structural health monitoring system, 22 fatigue monitoring points were added to the main bridge, and the stress changes of the typical welds of the bridge were realized in real time.

1.1 Weld fatigue crack distribution

Jiangyin Bridge steel box girder roof arranged a total of 48 U-ribs, 24 upstream and downstream, U rib number from the outside to the inside of the increase, the same upstream and downstream numbers. Through the analysis of the multi-year crack detection of the bridge, it is found that the fatigue crack mainly occurs at the fillet weld of the U-rib, the top plate and the diaphragm, as shown in Fig. At the same time, a percentage distribu-

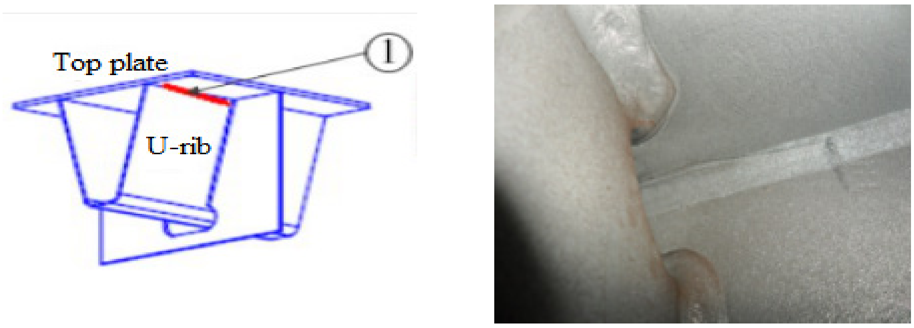

Figure 1 Typical fatigue crack location diagram and on-site inspection real map

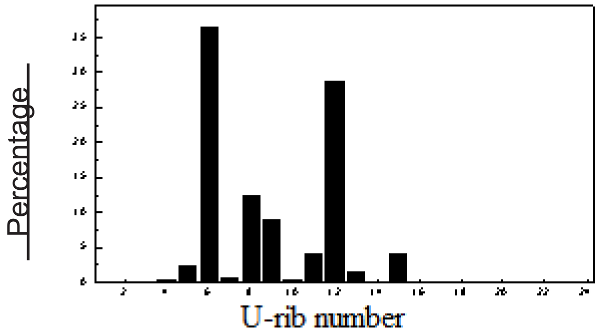

Figure 2 Fatigue crack distribution at the U-ribs

tion of the number of fatigue cracks occurring at different U-rib positions can be obtained, as shown in Figure 1. It can be seen from Figure 2 that the fatigue crack of the weld is mainly distributed in the cross section of the steel box girder on the 6th, 8th, 9th and 12th U-ribs (the upper and lower distributions are the same) 8, 9 and 12 U-ribs are basically in the heavy lane and lane track location, the number of vehicles, the shaft is heavy, resulting in a greater number of cracks, and in the ultra-lane and emergency stop position where the U-ribs are basically free of fatigue.

1.2 Fatigue measuring point layout

Select a steel box beam section, in the upper and lower heavy lane and lane track with the location of the 6 U-ribs and 12 U-ribs, a total of 22 fatigue monitoring points. Measuring points from the cross-section of the cross-section of the cross-20cm, each U-ribs 4 points (shown in Figure 3), 4 U-rib for total 16 points. Also in the upper 6th at the top of the U-ribs at the end of the end of the cap hole attached to the side of the U-ribs and cross slab at the side of the installation of strain flowers, a total of two strain flowers (shown in Figure 4), the system sampling frequency of 20Hz [2].

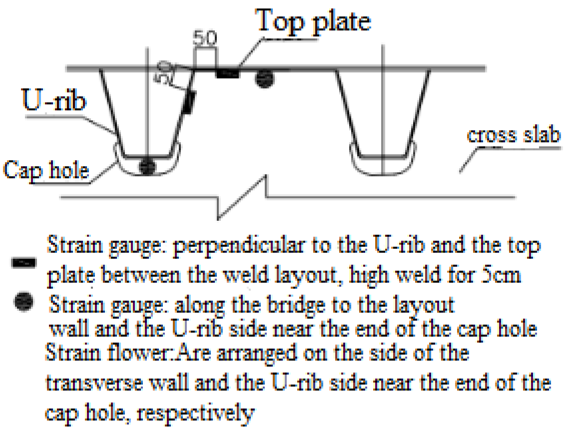

Fig.3 Distribution of U-rib measuring points

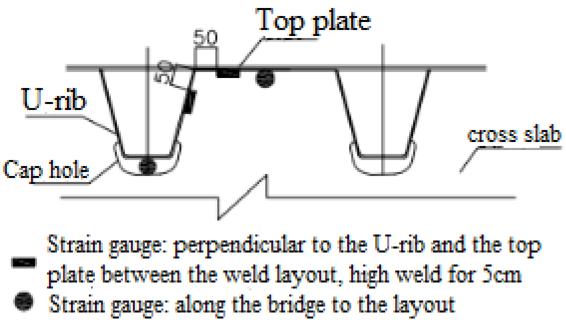

Fig.4 Distribution of U-rib strain flower

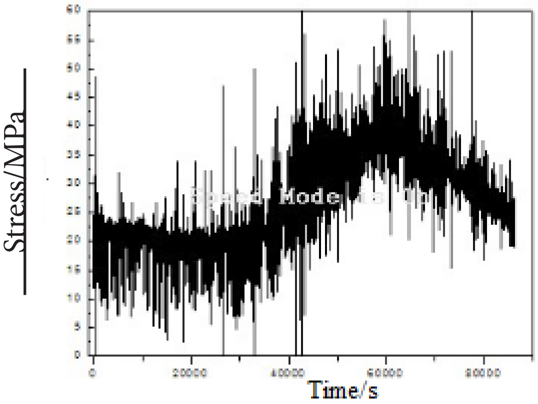

Figure 5 M-S-1 stress time scale

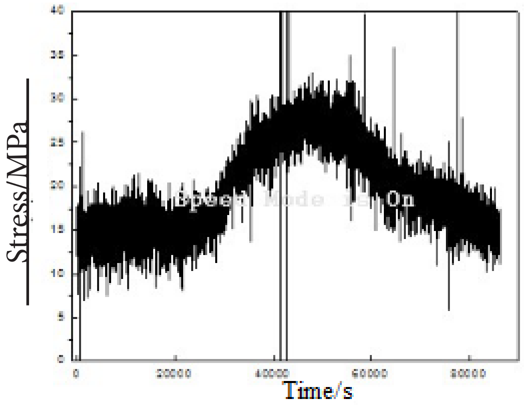

Figure 6 U-C-2 stress time course

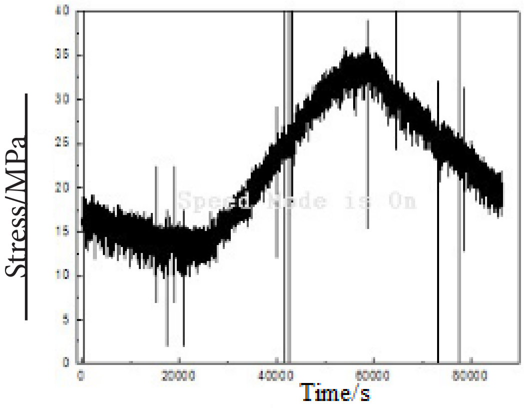

Figure 7 D-C-3 stress time course

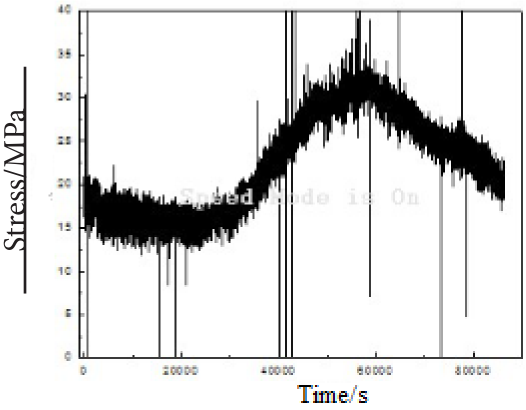

Figure 8 D-S-4 stress time course

2. Safety Analysis of Weld Seam under Health Monitoring System

Select the 1st of May, 2015 monitoring data, Jiangyin Bridge at this time the traffic volume reached 136,000, which can be considered at this time the bridge to bear the maximum load of the vehicle to the day of fatigue measured data collected, the data collected from this day's fatigue points were subjected to strain and stress time history analysis. By the limited space, the only analysis of the upstream 6 U-ribs at the four points (not including strain flower). The strain gauge of the cap hole, the U-rib and the top plate perpendicular to the weld direction and the top-bridge bridge are numbered respectively in M-S-1, U-C-2, D-C-3 and D-S-4. In the health monitoring system, the data collected and stored is strain, after multiplying the elastic modulus of the steel, the stress data can be obtained.

2.1 Stress time history analysis

Figures 5 to 8 show the stress time-history curves for the four test points on the upper 6 of the U-ribs. Although the structural health monitoring system sensors are affected by environmental influences such as temperature, humidity and electromagnetic interference, they are unavoidable in the process of data collection. There will be a jumping phenomenon, but in the figure can still see the stress of the four points in different time periods show the same changes in the law. At 6 o'clock in the morning began to measure the stress gradually increased at 3 pm to 4 o'clock to reach the maximum, which is measured with the traffic data consistent with the measured point of stress is mainly distributed in the range of 10 ~ 35MPa, When the stress will suddenly increase. The stress at the U-rib hole is smaller than that of the U-rib and the roof fillet weld, and the stress at the fillet weld of the cross slab and the top plate is small.

2.2 Fatigue stress spectrum analysis

In order to further understand the stress amplitude distribution and the number of cycles of stress amplitude at each point, it is necessary to obtain the fatigue stress spectrum of each measuring point in the stress time history curve, and only the size range and the variation rule of each measuring point stress are obtained. In this paper, the fatigue stress of each measuring point is obtained by rain-flow counting method, and the number of cycles of stress ampli-

Stress amplitude / MPa	Number of Cycles			
	M-S-1	U-C-2	D-C-3	D-S-4
0~1	264683	265076	288101	288475
1~2	40557	47981	35386	28293
2~3	9639	14575	7593	4061
3~4	2696	4971	1756	714
4~5	1196	2278	467	212
5~6	652	1416	141	62
6~7	313	949	48	11
7~8	149	655	18	5
8~9	80	458	8	1
9~10	46	393	4	2
10~11	20	249	3	1
11~12	17	219	3	1
12~13	10	167	2	1
13~20	12	485	16	9
20~40	3	113	9	7
40~60	0	9	2	0
60~80	0	0	2	0

Table 1 Stress points of the number of points measuring the number of cycles

tude is obtained. The number of cycles of stress amplitude after each data processing is shown in Table 1.

From the distribution of the stress amplitude at all levels, the stress amplitude is mainly distributed in the range of 0 ~ 10MPa, which shows that most of the time points are low amplitude stress cycles, but the U-ribs are perpendicular to the weld Of the UC-2 measurement point of the stress radiation is greater than the roof position perpendicular to the weld of the DC-3 measuring point, which is found in the actual bridge inspection along the fillet weld to the U-wall sidewall crack law is consistent. The BS5400 specification states [3] that the larger stress amplitude expands the initial imperfections of the component, thereby reducing the fatigue limit, but as time increases, the stress amplitude, which is lower than the component fatigue limit the effect. And Jiangyin bridge traffic flow, resulting in the number of steel box beam stress cycle, with the increase in operating time prone to fatigue damage.

3. Analysis of fatigue life of measuring points under BS5400 specification

The steel box girder welds produce fatigue under long periods of vehicle load, and the stress points of different welds are different and will reflect different fatigue rules under time. Normally, Steel box girder structural details of a large number of constant stress fatigue test, the measured group of stress and fatigue life test data regression analysis can be obtained from the structural details of the SN curve. In order to evaluate the fatigue life of each structural detail, first determine the fatigue level to which it belongs, and select the corresponding S-N curve. In this paper, we use the commonly used BS5400 specification to determine the S-N curve of each structural detail. According to the classification of the structural details, the fatigue grade of the MS-1 weld is F2, the roof and U-ribs are connected to the UC-2, and the DC-3 fillet weld fatigue grade is W, DS-4 weld fatigue grade B grade. The relation of σr -N (S-N) in the BS5400 specification is

$$N \times \sigma_r^{m} = K_0 \times \Delta^{d} \quad (1)$$

Where K is the number of times the component needs to break under the action of the stress amplitude σr; the parameters K_0, Δ, m can be obtained according to the fatigue grade of the structural details in the specification, as shown in Table 2; the parameter d is called the probability factor. The probability of failure is 2.3%, and the fatigue life value of each structural detail is calculated according to the corresponding SN curve of 2.3% failure probability [4].

Detail classification	K_0	Δ	m	σ_0/MPa
W	0.37×10^{12}	0.654	3.0	25
G	0.57×10^{12}	0.662	3.0	29
F_2	1.23×10^{12}	0.592	3.0	35
F	1.7310^{12}	0.605	3.0	40
E	3.29×10^{12}	0.561	3.0	47
D	3.99×10^{12}	0.617	3.0	53
C	1.08×10^{14}	0.625	3.5	78
B	2.34×10^{15}	0.657	4.0	100
S	2.13×10^{23}	0.313	8.0	82

Table 2 σr -N relationship between the parameters and fatigue limit value σ0

For the σr below the fatigue limit σ0, the σr higher than the fatigue limit σ0 is calculated according to equation (3) according to the formula (2) according to the "low-value stress cycle treatment" method in the BS5400 specification.

$$\text{When } \sigma_r \le \sigma_0, \quad \frac{n}{N} = \frac{n}{10^7}\left(\frac{\sigma_r}{\sigma_0}\right)^{m+2} \qquad (2)$$

$$\text{When } \sigma_r \ge \sigma_0, \quad \frac{n}{N} = \frac{n}{10^7}\left(\frac{\sigma_r}{\sigma_0}\right)^{m} \qquad (3)$$

According to the fatigue stress spectrum of each measuring point, the corresponding fatigue life value can be calculated, as shown in Table 3.

It can be seen from Table 3 that the daily damage of the four measuring points is very small, where the U-rib position is perpendicular to the weld. The UC-2 measurement point is greater than the daily damage at the other three positions, but the fatigue life of the four measuring point is larger than that of the bridge. However, due to the erosion of the steel and the construction quality of the weld, the weld is easy to crack at the U and the roof. This is mainly because the deformation of the U-ribs is constrained by the diaphragm under the load of the vehicle, resulting in a large out-of-plane stress at the weld location.

4 Conclusion

In this paper, the fatigue crack propagation of Jiangyin Bridge over the years and the structural health monitoring system are used to monitor the fatigue stress of the welds of the steel box girder of Jiangyin Bridge. The following conclusions are drawn:

(1) Fatigue cracks in steel box girders mainly occur at the fillet welds of U-ribs and roofs. The transverse bridge mainly occurs in the 6 #, 8 #, 9 #, 12 # U-ribs, both heavy lanes and lanes below the U-ribs, and the basic overlap with the wheel line.

(2) The stress measurement points are mainly in the low amplitude stress cycle, most of the stress amplitude in the range of 0 ~ 10MPa, where U-ribs perpendicular to the weld U-C-2 measuring point stress amplitude larger.

(3) Fatigue life is measured by the fatigue stress of each measuring point. The measurement points are more than

Measuring point	Daily damage	Life expectancy / year
M-S-1	2.16E-7	> 100
U-C-2	3.6E-6	> 100
D-C-3	3.4E-6	> 100
D-S-4	5. 7E-9	> 100

Table 3 Accumulated damage assessment results for each measuring point

100 years. However, due to the influence of environment and construction quality, the weld position is easy to produce fatigue crack which to be taken seriously.

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