Research on three dimensional detection system of fatigue cracks of steel box girder

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Abstract. The fatigue cracks are inevitably existed in steel bridges after they are working for a fairly short time because of the environmental pollution, overloaded vehicles and larger numbers of automobiles. How to efficiently detect the fatigue cracks, especially the initial fatigue cracks, become one of the most important question to be solved for the steel box girder. The static and fatigue tests of the orthotropic steel bridge deck models were carried out in this research paper, which presented the fatigue damage developing laws, compared the test results with homogeneous test results in existing documents. Three dimensional micro detection scheme of fatigue cracks in steel box girder with three dimensional detection system is studied. Through the data from the testing design, the important characteristic width and length of the fatigue crack can be achieved, which can be used for the grasping of the mechanism of the steel box girder.

1 Abstract

The steel bridge structure should not only inherit the crowd, vehicle load etc, but also inherit chemical corrosion such as the Marine environment, atmospheric environment, ice, salt [1-2]. The use of steel box girder bridges as the main load-bearing components can be traced back to Germany after world war II, because of the shortage of steel, German needs to build and rebuild a large number of Bridges to restore the post-war economy, in order to solve this problem, Germany began using a new type of bridge bearing structure which is designed by its high strength steel and welding technology, and the new structure is called as steel box girder [3-5]. It is summarized that the cause of fatigue crack of orthotropic steel bridge panel is that the principal stress and surface deformation. In china academy of railway sciences the mechanical characteristics of the orthotropic steel bridge panel by the static experiment of the real bridge, dynamic experiment of the real bridge, and the full-scale model static test were all studied [7-8].

Up to the present, No fatigue design standard on orthotropic steel bridge deck has appeared in any country’s bridge design code. Further research needs to be carried out both on stress amplitude definition and detail constitution classification.

2 Design of the specimen

The sectional steel box girder specimen is designed by referring to the sectional steel box girder of the Yangtze bridge, and its shape and size as shown in Figure 1 and Figure 2. The coating solutions of specimen is as follows: The external of U longitudinal is sprayed 3 layers, zinc.
silicate shop primer is 15μm, epoxy micaceous iron oxide intermediate paint is 150μm s, epoxy is 100μm; The interior of U longitudinal is sprayed 1 layers, zinc silicate shop primer is 15μm; Steel box girder bridge deck driveway is sprayed 3 layers, zinc silicate shop primer is 15μm, epoxy zinc rich primer is 75μm, high solids high build epoxy tar paint is 250μm.

\[ \varepsilon_x = \varepsilon_{45}^v = \frac{1}{2} (\varepsilon_{45}^v + \varepsilon_{90}^v - \gamma_{xy}) \]

\[ \varepsilon_{45}^v = \frac{1}{2} (\varepsilon_{45}^0 + \varepsilon_{90}^v - 2\varepsilon_{45}^v) \]  

\[ \varepsilon_y = \varepsilon_{90} \]

From Eq.(2) and Eq.(3), then we have:

\[ \varepsilon_{\text{max}} = \frac{\varepsilon_x + \varepsilon_y}{2} + \sqrt{\left(\frac{\varepsilon_x - \varepsilon_y}{2}\right)^2 + \left(\frac{\gamma_{xy}}{2}\right)^2} \]  

\[ \tan 2\alpha_0 = -\frac{\gamma_{xy}}{\varepsilon_x - \varepsilon_y} \]  

Due to \( \alpha_1=0^\circ, \alpha_2=45^\circ \) and \( \alpha_3=90^\circ \), we have:

\[ \varepsilon_{\text{max}} = \frac{\varepsilon_{45}^0 + \varepsilon_{90}^v + \sqrt{3}(\varepsilon_{45}^v + \varepsilon_{90}^v)}{2} \]  

\[ \tan 2\alpha_0 = \frac{2\varepsilon_{45}^v - \varepsilon_{45}^0 - \varepsilon_{90}^v}{\varepsilon_{45}^v - \varepsilon_{90}^v} \]

Based on Hooke regularity, the equation is:

\[ \varepsilon_1 = \frac{1}{E} \begin{bmatrix} 1 & -\nu & \sigma_1 \\ -\nu & 1 & \sigma_2 \\ & & 1 \end{bmatrix} \]  

Substituting Eq.(8) into Eq.(6), then we have:

\[ \sigma_{\text{max}} = \frac{E}{1-\nu^2} \begin{bmatrix} 1 & \nu & \varepsilon_{\text{max}} \\ -\nu & 1 & \varepsilon_{\text{min}} \end{bmatrix} \]  

The Von.Mises is gained as:

\[ \sigma_{\text{eq}} = \sqrt{\sigma_{\text{max}}^2 + \sigma_{\text{min}}^2 - \sigma_{\text{max}}\sigma_{\text{min}}} \]  

\[ \varepsilon_{\text{eq}} = \frac{1}{2} (\varepsilon_{45}^0 + \varepsilon_{90}^v - \gamma_{xy}) \]

3 Three dimensional detection system and fatigue experiment design

In the research domains such as aeronautics and astronautics, steel structures are widely existed. Factually, three dimensional detection system shown in Figure 3 has been developed and applied successfully. The experiment specimen is JD1 to JD4 shown in Figure 4. Designing of the single variable corrosion solution can see the influence of the specimen in corrosion environment intuitively. So we hope to design a concentration of 1%, 3% and 5% sodium chloride corrosive gas, which is to explore the fatigue damage evolution rule of the specimen in different concentrations of gas corrosion in Figure 5 and Figure 6. The loading way is sine wave amplitude loading and the limit is 25kN/5kN. The loading frequency is for 3Hz. The specific experiment process is as follows:

Preloading: The ends of the specimen SJ1 is hinged, single point loading. It used to simulate the uniform effect of wheel load which is placed an area of 300mm×200mm of a steel plate and a piece of rubber sheet between actuators and the cover plate. The load center is in the center of the cover plate. 10kN is loading on specimen 3 times as preloading before the formal experiment beginning, which purpose is to eliminate loose contact and poor contact between plates, rubber plate and specimen.
KH-7700 Controlling System

Moving foci Lens and coaxial magnifier

**Figure 3.** Three dimensional detection system

a. Initial status of experiment specimen
b. Produced steel box of experiment specimen

**Figure 4.** Different statuses of experiment specimen

c. Failure status of experiment specimen

**Figure 5.** Multi functional corrosive sprayer equipment

Static load for the first time: Load is divided into five load to the fatigue load limit 25kN, namely 0kN, 5kN, 10kN, 15kN, 20kN and 25kN. The strain gauge reading is record under the load per level after waiting for a period of time, and then unloading to zero. When the load is decreased to zero at each step, the important characteristic width and length of the fatigue crack can be achieved with three dimensional detection system and through picture collection system and computer processor, the fatigue cracks, especially the initial fatigue cracks, are to be analyzed. Dynamic load: After completing the static load test, the fatigue machine is sat to dynamic loading, and the fatigue machine load steady load by repeatedly adjust. When the load cycles N reach the prescribed times, stopping first and then loading the five load to the fatigue load limit 25kN, recording strain gauge reading under each levels, and then unloading to zero, the last adding dynamic load.

End of the test: The experiment is stopped when testing machine position is overrun, and the number of cyclic loading and fatigue failure characteristics is recorded. And especially, the important characteristic width and length of the fatigue cracks should be recorded.
4 Conclusions

According to available results of the engineering investigation, the fatigue cracks are inevitably existed in steel bridges because of the environmental pollution, overloading vehicles and larger numbers of automobiles. The static and fatigue tests of the orthotropic steel bridge deck models were carried out in this research, which presented the fatigue damage developing laws, compared the test results with homogeneous test results in existing documents. Through the data from the testing design, the important characteristic width and length of the fatigue crack can be achieved, which can be used for the grasping of the mechanism of the steel box girder in the future.

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