Experiment Study of Fatigue Loading on Cable-Girder Anchorage of Cable-Stayed Bridge

Dali Zhang, Qingfeng Gao, Baofeng Liu, Xiaozhen Li, and Lin Xiao

***Abstract*—WuSuBridge of HEIXIAZI Island is cable-stayed bridge with single tower and single plane. The cable-girder anchorage with anchor-box is adopted to connect the cable with the steel girder. Due to large quantities of plates being used in this structure, complex configuration and severe stress concentration, the fatigue behavior of the steel-anchor-box subjected to service live loads need a careful research. According to the theoretical analysis of the anchor structure by finite element method, and design a full-scale test model to simulate the anchor structure. Combined with the design traffic flows and the relevant regulations compute the fatigue loading. The theoretical analysis and fatigue test results show that the stress of the anchor structure is much less than fatigue allowable stress under the fatigue loading. The fatigue performance of the anchor structure is satisfy the regulatory requirement, and has a sufficient safety margin.**

***Index Terms*—Cable-stayed bridge, steel-anchor-box, cable-girder anchorage, fatigue test.**

I. Introduction

WuSuBridge of HEIXIAZI Island is cable-stayed bridge with single tower and single plane, the span arrangement is 140m+140m. The single cable plane is parallel arranged, 13 cables are arranged at each side along the vertical of the bridge. The biggest cable force is 3794kN. The section form of single-box with dual-chamber is used at the steel girder, and the cable-girder anchorage with anchor-box is adopted to connect the cable with steel girder, as show in Fig. 1. Two steel anchor boxes share one middle web, and connect with the side-web of the steel girder respectively. The steel anchor box is composed by two webs and a bearing plate. Between the upper and lower web of the anchor box arrange two stiffeners along the cable center. The cable through the hole on bearing plate and is anchored on the plate. Depending on the four welds, cable force is transferred to the girder section, between the main girder webs and anchor box webs.

In recent years, the majority of steel cable-stayed bridge completed at home and abroad have specialized research about the cable-girder anchorage zone. The span length is 890m of Japan Tatara Bridge, theoretical study and full scale model test have completed in order to test its safety and reliability. In China, the model test of the Second Nanjing Yangtze River Bridge, Anqing Yangtze River Bridge , Suzhou-nantong Yangtze River Bridge and Shanghai Yangtze River Bridge have been completed [2], [4]. The results show that the cable-girder anchorage zone has complex stress state and indicate stress concentration. Theoretical study results is different from the model test results [2], [4]. In addition, the steel-anchor-box of WuSuBridge is arranged side by side, and middle web is carried the cable force from two anchor-boxes and with higher levels of stress. Therefore, by the model test to research the structure fatigue resistance is particularly important. According to the full-scale fatigue test, research the structure stress distribution and anti-fatigue properties of the welds under the fatigue loading, and evaluate the structure safety reserves.

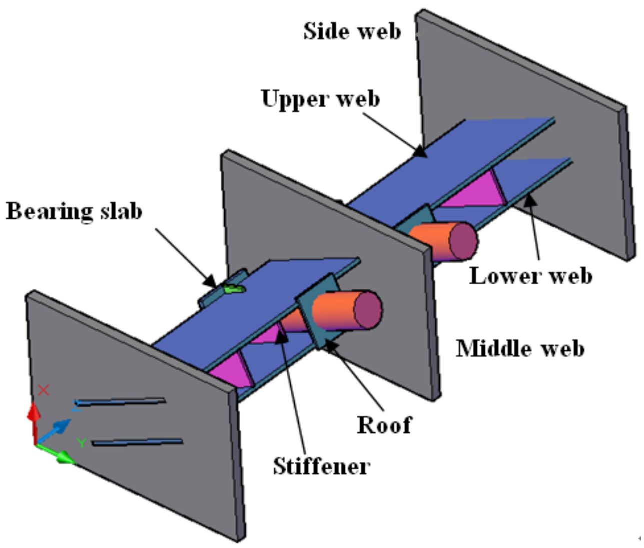

Fig. 1. The anchor box of wusubridge.

II. The Design of Fatigue Test

A. Theoretical Analysis

In order to research the fatigue properties of the anchor structure and the surrounding area, a test model which accurately reflect the structure actually statement under the live load is designed depending on the detailed analysis of the actual structure. Theoretical analysis by the software-ANSYS and the computational model is established combining with the shell element and solid element. First, a standard segment of the steel girder is selected as the study object and the finite element analysis model is established. Then, the model is simplified combining with the calculation of theoretical analysis and experiment condition. The stress

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distribution of anchor box must be contrast to, for achieving a good simulated to the actual structure by the test model of small-scale trials. The compared models is shown in Fig. 2.

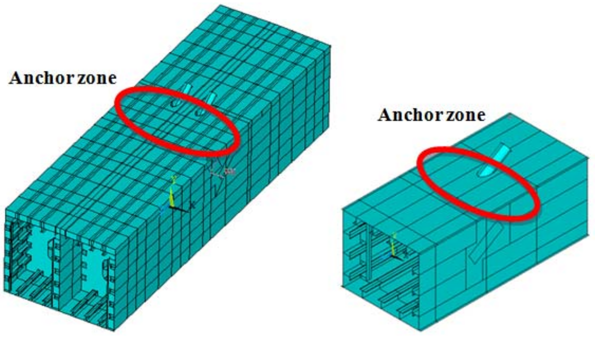

Fig. 2. Finite element model of actual structure and test model.

Through comparative analysis of stress distribution of the test model and the actual structure, the half of original structure—the single cell box structure is selected as the test model. In order to prevent the decentration in loading process, move the anchor box of the test model to the center of the main girder. According to the conclusion of the finite element analysis, the stress distribution of the test model and the actual structure is basically same. Therefore, the test model can better simulated the stress state of the bridge

B. The Design of the Test Model

The actual simple-box double-cell girder is simplified to single cell box structure. It is 5 meters long, 2 meters high, and 2.25 meters wide. The type of all slabs and welding methods are exactly the same as the actual structure. The power transmission beam is adopted in the fatigue test, the test model shown in Fig. 3. The cable direction is vertically downward. In order to facilitate the model fix on, a support is designed in the bottom of the test model. In order to prevent the test model dislocation in the loading process, the model bottom is anchored in the geosynclines.

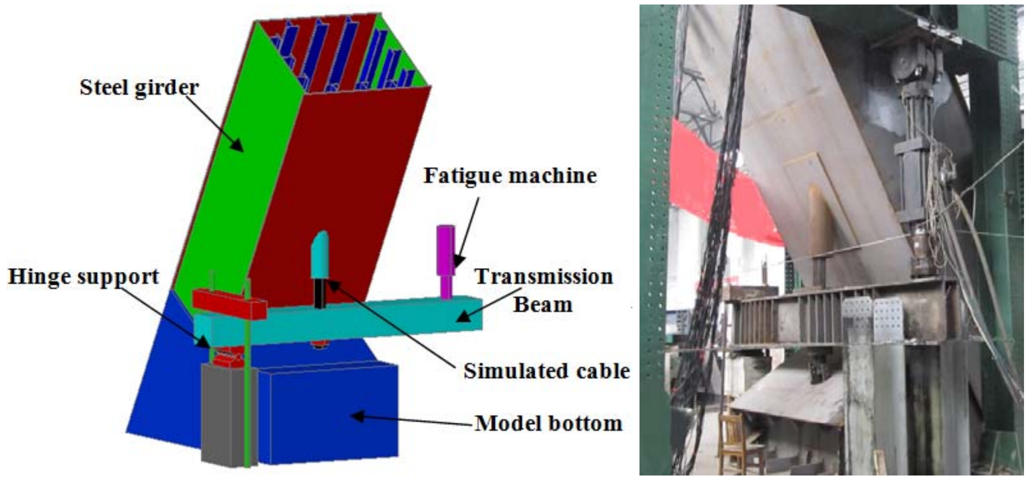

Fig. 3. Test model layout.

TABLE I: SLAB THICKNESS AND YIELD STRENGTH.

Name	Girder web	Anchor web	Stiffener	Fearing slab	Anchor roof
Thickness[mm]	24	32	24	40	20
Yield strength[MPa]	355	355	355	330	355

The test model is produced by the China Railway Shanhaiguan Bridge Group Co. Ltd. The important welds undergo a rigorous magnetic particle inspection and ultrasonic testing. All panels of the model are Q370qE. Thickness of each plates and yield strength with plate thickness reduction are shown in the Table I.

The 1000kN automatic hydraulic servo fatigue testing machine which is produced by MTS is used in the test, the accuracy of the machine is±0.5% at static load and ±1.0% at dynamic load.

C. Test Program

By combining FEM analysis results, measuring points are arranged at welds side and high stress zones and stress concentration area. Due to the complexity of the anchor box, three dimensional strain rosettes were used in the test. 54 measuring points are arranged on the main girder webs, and 28 measuring points are arranged on the anchor-box webs, and 8 measuring points are arranged on the stiffeners, and 6 measuring points are arranged on the bearing slab, and 4 measuring points are arranged on the anchor-box roof. Measuring point of the main slabs shown in Fig. 4.

Fatigue load is a constant amplitude sine wave load, P_{max}=600kN, P_{min}=100kN, the loading times is 2,000,000. Due to higher load amplitude and lager load point displacement, the loading frequency is restricted at 1Hz. In order to study the stress development and the stress state in the process of fatigue test, the machine will be stopped and taken once static test after each interval of fatigue load. Model cracking and unusual situation must be check when the fatigue load stopped. The cycle times of static loading are as follows:0 → 100,000 → 300,000 → 500,000 → 800,000 → 1,000,000 → 1,250,000 → 1,500,000 → 1,750,000 → 2,000,000. Static test load is imposed by fatigue machine in the fatigue test. The static load level shown in Table II. Keep loading for 5minutes at each level so as to measure strain, and data must be collected three times at each level.

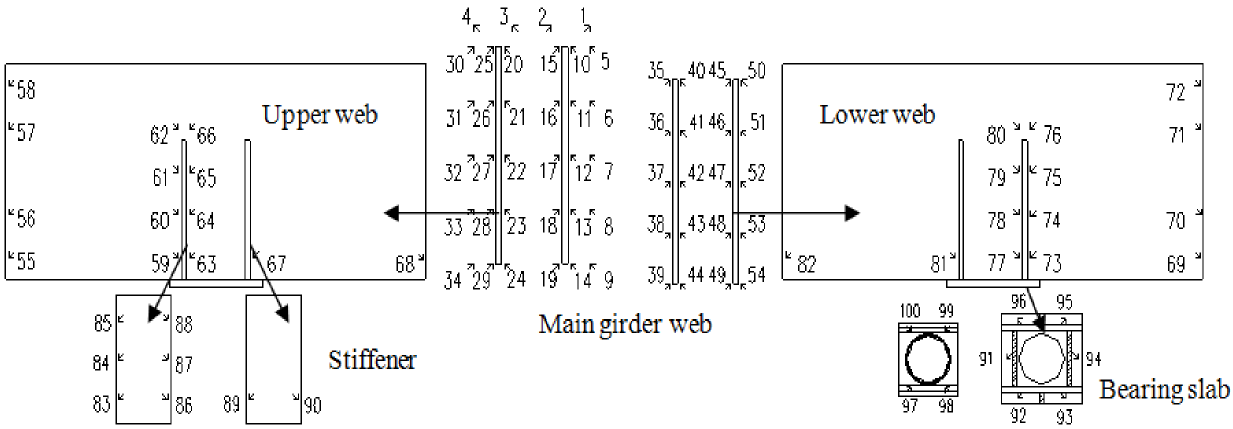

Fig. 4. Testing points on anchorage structure.

TABLE II: STATIC LOAD AND LEVEL.

Load level	1	2	3	4	5	6	7
Load[kN]	0	100	200	300	400	500	600

TABLE III

Point No.	The stress of static test(600kN)in different cycle times											
	0	500 thousand	1 million	2 million	0	500 thousand	1 million	2 million	0	500 thousand	1 million	2 million
	σ_1 [MPa]				σ_3 [MPa]				σ_e[MPa]			
14	-0.43	-1.38	0.5	-1.24	-11.67	-17.02	-14.3	-16.76	11.47	16.37	14.55	16.17
19	0.88	1.42	2.29	-0.37	-8.68	-11.92	-10.29	-13.43	9.15	12.69	11.60	13.24
29	2.2	3.57	3.6	2.64	-8.55	-10.67	-10.7	-11.94	9.85	12.84	12.88	13.45
39	1.25	2.51	2.68	0.07	-9.9	-12.41	-11.98	-14.77	14.09	13.84	13.51	14.80
44	0.47	1.15	2.29	-0.59	-9.74	-12.55	-11.59	-14.11	13.43	13.17	12.88	13.83
49	2	2.71	2.51	0.76	-9.8	-13.31	-14.11	-15.36	14.85	14.85	15.51	15.75
53	0.28	0.66	1.14	-0.85	-10.83	-14.66	-14.04	-15.45	10.99	15.00	14.64	15.05
54	-0.47	-0.41	0.21	-2.79	-12.53	-16.89	-16.11	-19.11	16.59	16.69	16.22	17.88
59	-7.85	-9.24	-9.06	-12.88	-17.70	-22.66	-22.44	-25.62	20.63	19.73	19.56	22.19
60	-1.99	-2.06	-2.92	-4.11	-8.84	-11.94	-11.78	-13.89	8.05	11.05	10.63	12.36
63	-5.37	-7.96	-8.24	-9.85	-14.85	-20.74	-21.26	-22.55	13.03	18.13	18.57	19.58
64	-4.47	-5.31	-4.83	-7.76	-8.15	-10.59	-10.17	-12.84	7.11	9.17	8.81	11.20
73	-5.60	-6.92	-6.64	-6.32	-13.55	-17.28	-17.46	-18.28	15.70	15.06	15.26	16.08
74	-0.85	-0.40	-0.97	-2.33	-8.50	-10.80	-11.23	-12.27	8.13	10.61	10.77	11.29
77	-3.21	-3.50	-2.95	-6.80	-12.69	-16.00	-16.35	-23.00	15.64	14.57	15.09	16.46
78	-3.05	-2.93	-2.54	-6.78	-8.20	-9.67	-9.66	-14.52	7.20	8.59	8.67	12.58
86	-5.66	-7.68	-7.22	-9.62	-11.84	-15.92	-14.58	-15.38	13.73	13.79	12.63	13.46
87	-1.62	-2.77	-2.37	-2.48	-6.73	-9.63	-8.73	-9.62	6.10	8.59	7.81	8.65

III. ANALYSIS OF THE TEST RESULTS

The measurement data of the important test point in the following Table III.

The following results can be obtained by the analysis of the data in the Table:

1) According to the static test conclusion at the 0 cycle times, measurement points stress level are overall lower. Most of the point equivalent stress is less than 30 MPa, and far less than the yield strength of the material.
2) Compared with the static test data after 0, 500thousand, 1million, 2million times fatigue cycle, can be found the stress remained unchanged of the measuring point.

Stress curves with the cyclic times as shown in Fig. 5.

The results show that the stress distribution and stress values of the test model do not change with the fatigue cycle times. And the structure do not occur the stress redistribution in the fatigue loading process.

After the test, check the welds of the test model, do not find any cracks. The ultrasonic testing prove that the quality of the welds carrying the majority cable force the same as the test before. Does not find any fatigue damage.

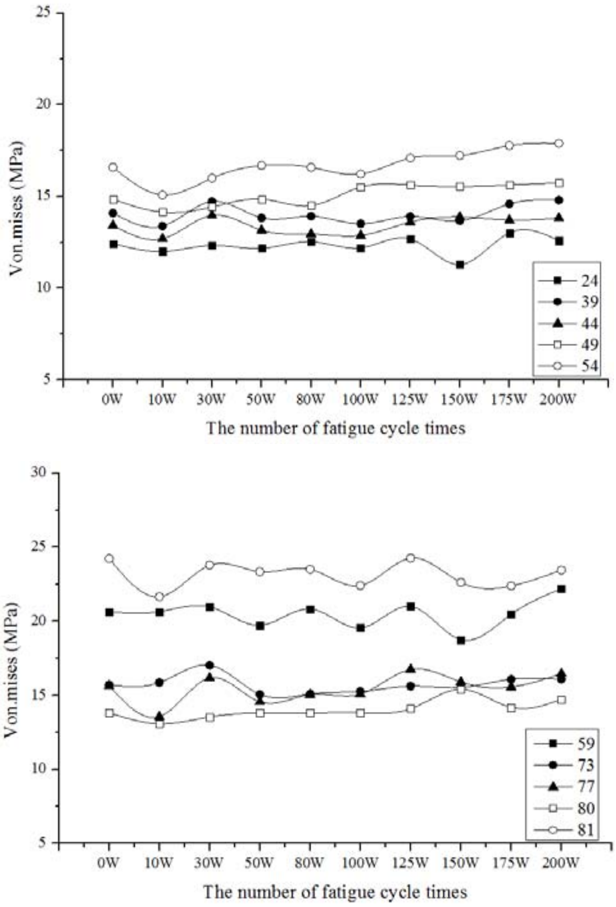

Fig. 5. Stress curves with the cyclic times.

IV. CONCLUSIONS

From the analysis above, the main conclusions are listed as follows:

1) The fatigue model show a realistic simulation of the actual bridge force characteristic in the operation phase, the simulation is good, and the data is accurate and reliable.
2) After 2 million fatigue cycles, the stress of the measuring point is essentially unchanged. The test results show that the structure fatigue strength is satisfied the specification requirement, and have enough safety reserves.
3) The analysis conclusion proved that the anchor structure of WuSuBridge does not occur fatigue failure in the 120 years of the design operation period.

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