Research on the super live load tests of Xiaowan Bridge in China

L. Zhang
Guizou University, Guiyang, China

Z. Tian
Changsha University of Science & Technology,Changsha,China

H. Huang
Guizou Express Way Development Corporation, Guiyang, China

ABSTRACT: The theoretical calculation analysis results and test results drawn from the special load testing of Xiaowan Arch Bridge is described in this paper. It is the first welded steel box handle-basket arch bridge with a main span of 130m in China. The purpose of the paper is to show the actual working state, as well as to analyze and comment on the structural performance under special loads (Motor-vehicles 86 grades, Platform truck weighing 3000kN and Pedestrian loading 3.5kN/m^2). Following that, some valuable conclusions can be drawn. These conclusions might be helpful to the readers in the field of bridge construction and performance evaluation.

1 GENERAL INSTRUCTION

Xiaowan Arch Bridge is an auxiliary project in Xiaowan hydropower station at Lancang River in Yunnan province. Because heavy electromotor have to be transported through this bridge, the design loads are the super heavy loads: automobile-class 86, trailer-class 300 and pedestrian loading 3.5kN/m^2 (The axle weight and the arrangement of axles are shown in Fig.3). These kinds of loads are the heaviest highway bridge design loads in China. The longitudinal layout of the bridge is half-through steel box handle-basket arch. The computing span of the ring course is 130m. The calculated rise in the plane of the main arch is 40.376m. The main arch revolves 15 degrees in the direction of bridge axis, forming the shape of handle-basket.

Xiaowan Arch Bridge was completed on December 31, 2002. It is the first welded steel box handle-basket arch bridge in China. By the method of service load test, we can check on the whole quality and health condition of the bridge, and then establish foundations for the long-term monitor, as well as give some design considerations for building the same kind of bridge in future. The bridge's load test is composed of three parts: static test, forced vibration test and environment stochastic excitation model test. This paper focuses on introducing some fruits of the static test and moving load test.

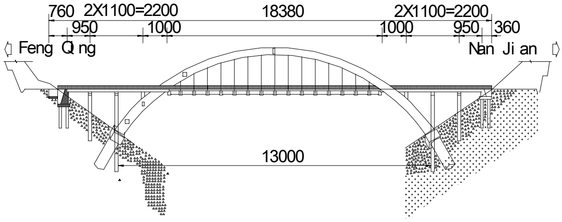

Figure 1 :Elevation drawing of Xiaowan Arch Bridge (unit: cm)

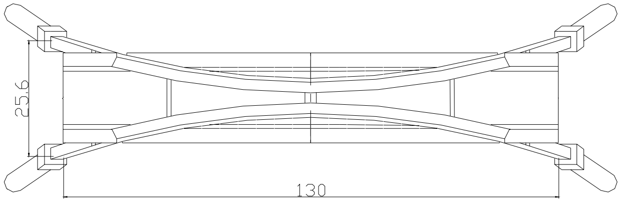

Figure 2 : Flat graph of Xiaowan Arch Bridge (unit: m)

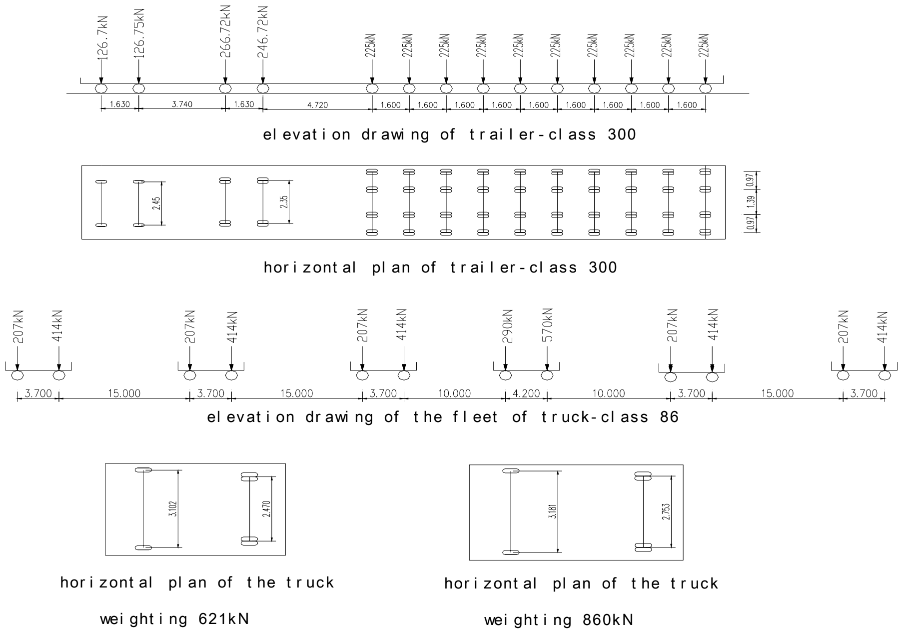

Figure 3 :Design load (Unit: m)

2 STATIC TEST

2.1 Analysis of static test

(1) FEM of Structural

Plane model: the main arch plane revolves 15 degrees in the direction of the bridge axis and forms handle-basket space structure, so it is more accurate to take space structure as mechanical analysis model. But because tensile force of the suspenders which are caused by moving load will not lead to torsion effect of main arch, as the result of the same plane they are located in, the main arch is supposed to be under plane stress. When the structural model is set up, main arch box with 15 degrees' slope is rotated to the vertical direction, and this method will not influence the calculation of loading location, but only has a little influence on the inner force caused by loads.

Space model: FEM (finite element model) was developed using the computer program ANSYS with beam element, slab element and shell element. The main arch and longitudinal beam are simulated through beam elements, the deck are simulated through shell elements, the suspender are simulated through link elements.

(2)Control Section

The inner force influence line (Fig.5) of each section of main arch can be drawn using the plane frame program. The most disadvantageous inner force and corresponding load longitudinal position are also obtained, and then inner forces envelope (Fig.6, Fig.7) of main arch sections is also obtained by the use of the dynamic programming method. According to inner force's envelope, control sections on the load of automobile-class 86 and trailer-class 300 are the sections of springing, 1/4 span and mid-span. The bigger value of inner force under two kinds of loading combinations is adopted to control the critical section's inner force. (Two lines of automobile-class 86 fleet + pedestrian loading, trailer-class 300)

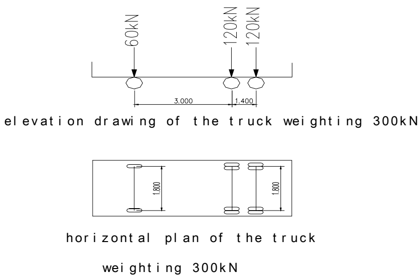

Figure 4 :loading truck (Unit: m)

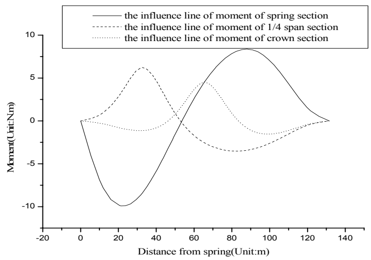

Figure 5 : Influence line of moment

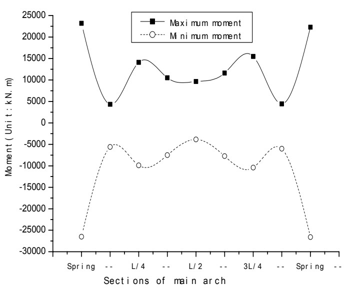

Figure 6 :Moment envelope of main arch under trailer-class 300

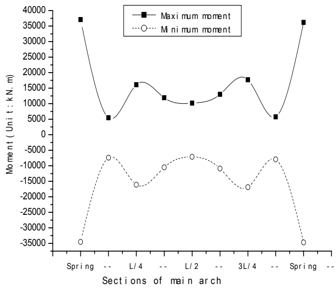

Figure 7 : Moment envelope of main arch under two lines of automobile-class 86 fleet + pedestrain loading

(3)Test loading, the location of loading and efficiency coefficient

Loading-vehicles (each weigh 300KN, dump truck) of the test are not in accord with the request of standard vehicles (automobile-class 86, trailer-class 300), so the values of control sections' inner force on design load is transformed to the equivalent maximum calculation values of the same sections' inner force on test load vehicles according to the maximum calculation. Efficiency coefficient of static's test:

$$\eta_i = \frac{S_{star}}{s \bullet \delta} \quad (1.05 \geq \eta_i \geq 0.8)$$

where S_{star}=Calculation value of deflection or inner force on test load vehicles,S=Calculation value of deflection or inner force on design load vehicles,□=Dynamic coefficient for design standard load, here (super heavy load) is 1 and i=one single item of test's.

The efficiency coefficient is shown in Table 1.

2.2 Static test contents

(1)The choice of test contents

According to the result of the test analysis, test sections of main arch are spring section, L/4 section and crown section; considering the peculiarity of Xiaowan Bridge, based on the calculated values of suspenders' tension, the first row suspenders (rigid suspender) and the second row suspenders (semi-rigid suspender) were confirmed as test suspenders to be checked in order to test the actual maximum cables force of partial components of the bridge. Meanwhile, the corresponding anchor plate which locates at the first row suspender and second row suspender on the arch is selected to check the local actual stress state; the cross beam of middle part of the deck was selected to test its bearing capacity. As a rather large moment exists at the consolidate joint of the post and bent on the arch, a test item on the post is made also.

(2)Distribution of measure points

The distribution of measure points is illustrated in Fig.8 and Fig.9. The strain gauges were fixed in the top and bottom of the cross section at the plate of the mid-span, quarter span, spring and web-plate of each spring. Embedded strain gauge is arranged on the bottom of the middle section of cross beam. The deflections of the controlled points on the decking and main arch are observed by High-performance total station electronic theodolite (Swiss LEICA TC2003). The local stress observation points on the anchor plates of the bridge were arranged on the place of suspender No.1 and suspender No.2 (including the U type board).

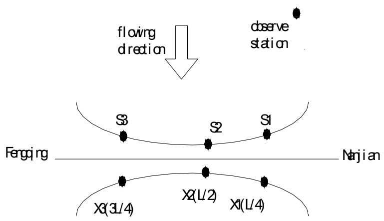

Figure 8 :Deflection observation points of main arch

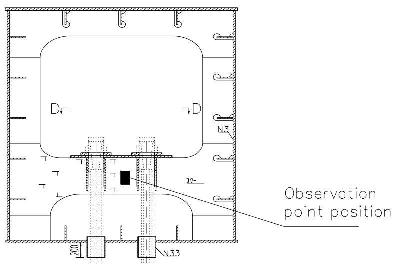

Figure 9 :Stress observation points of anchor slab

(3) Test loading

The maximum test loading case employs 14 dump trucks (Fig.4)，each weighing 300kN (self weight + loading weight), because it is difficult to simulate the design load in testing.

(4)Test performance and efficiency coefficient

Table .1 Contents of static load test on Xiaowan Arch Bridge

load case	efficiency coefficient	Contents of Load test	Format of loading(the number of truck)
1	0.86	The biggest negative moment on spring	Symmetric loading.(12)
2	0.78		Un-symmetrical loading(8)
3	0.85	The biggest sagging moment on crown	Symmetric loading(9)
4	0.7		Un-symmetrical loading(8)
5	0.82	The biggest pulling force on the first suspender in Nanjian bank	Symmetric loading(9)
6	0.89	The biggest sagging moment on L/4 section	Symmetric loading(12)

7	0.74		Un-symmetrical loading(8)
8	0.81	The biggest stress of post-bracket beam	Symmetric loading(9)
10	0.81	Tension of the second suspender in Nanjian bank and stress of anchor slab	Symmetric loading(3)
11	0.92	The biggest sagging moment on the middle section of cross beam	Symmetric loading(4)
12		Torsion of the whole bridge	L/4 Un-symmetrical loading(14)
13		L/4 Un-symmetrical loading of the whole bridge	Proceed with the Un-symmetrical loading of performance 1
14		Tension test of the longest suspender	Proceed with the test of the biggest sagging moment of the arch crown

*note: 1. trailer-class 300 is the control load in the un-symmetrical loading test, two lines of automobile-class 86 fleet + pedestrian loading are the control load in the other tests.
2. as to un-symmetrical loading test, the efficient coefficient can't reach 0.8 in any case of loading distribution.

2.3 The contrast between test results and theoretical value

Deflections and stress increments of some control sections are as follows:

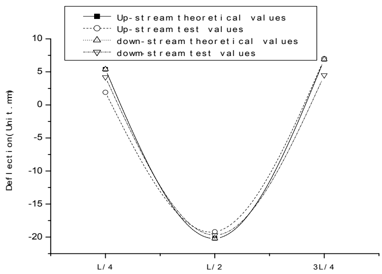

Figure 10 :Deflections of main arch under performance 3

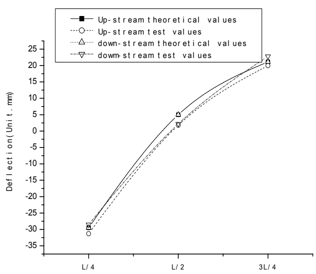

Figure 11 :Deflections of main arch under performance 1

Table 2 : Stresses increment of control sections

Load case	Test section	Observation points' position		Theoretical increment MPa	Test increment MPa	Check coefficient
1	Nanjian-bank spring	Up-stream	Top-plate	20.25	20.16	1.0
			Web-plate	-28	-26.67	0.95
			Bottom-plate	-35.29	-38.01	1.08
2	Nanjian-bank spring(*non-symmetric)	Up-stream	Top-plate	12.37	13.02	1.05
			Bottom-plate	-7.73	-7.08	0.92
			Top-plate	-24.92	-23.94	0.96
6	L/4	Up-stream	Bottom-plate	-19.78	-18.06	0.91
			Top-plate	10.79	8.19	0.76

7	L/4 (*non-sym.)	Up-stream	Bottom-plate	-14.13	-11.34	0.80
			Top-plate	7.34	5.67	0.77
3	L/2	Up-stream	Bottom-plate	-19.6	-17.59	0.90
			Top-plate	12.47	10.92	0.88
4	L/2 (*non-sym.)	Up-stream	Bottom-plate	-15.22	-13.02	0.86
			Top-plate	7.39	6.82	0.92
8	Mid-span section of post-bracket beam	Bottom of mid-span section of post-bracket beam		33.05	29.14	0.88
	Joint of post bracket Above arch ring	Joint of the pole of post bracket above arch		45.66	39.28	0.86
11	Mid-span section of cross beam	Bottom of mid-span section of cross beam		6.35	5.28	0.83

*Note: "Load case" ref. Table 1'

3 DYNAMIC TEST

3.1 Basic items measured by dynamic load test

The super heavy loads just thread through this bridge twelve times at a very low speed, so the dynamic increment coefficient is decreased or ignored even under this condition. But as dump trucks (each weighing 30T) always passed through the bridge during the construction of Xiaowan hydropower station, it is reasonable that we use them to carry out dynamic test to evaluate the bridge's long term health condition.

Evaluating whether the biggest dynamic strain, stress and deflection meet the requirements of design by measuring the dynamic characteristic of the bridge structure as a whole under the dynamic load, especially the dynamic frequency, flap, acceleration, flap type and so on which the bridge reflect when both the vehicles in all kinds of service condition, and the single heavy vehicles pass through the bridge at different speeds. Meanwhile structure can be analyzed by the structure dynamic model simulation calculation.

3.2 The main result of the dynamic load test

(1) The test result of moving load test, braking test and impact test as follows:

Table 3 : The test result of moving load test, braking test and impact test

Test performance	Measure section	The biggest dynamic increment coefficient	The biggest dynamic strain με
Moving load test (single test truck)	Section of crown	1.2199	15.7
	Section of spring	1.282	-18.05
Moving load test (two trucks at the same direction)	Section of crown	1.1628	20.5
Braking test	Section of crown	1.21	11.03
	Section of spring	1.14	-15.78
Impact test	Section of crown	1.228	19.41
	Section of spring	1.26	-18.58

(2) In the dynamic test, the dynamic increment coefficient of the single vehicle's test is bigger than that of double vehicles' test. The dynamic increment coefficient of the single vehicle's test can be traversed into the dynamic increment coefficient of design load by corresponding relations between them. The biggest dynamic increment coefficient is 1.01, when the vehicles run on the non-obstacle road. According to the above results, we can believe that the actual dynamic increment coefficient of the Xiaowan Arch Bridge is in the rational range.

(3) The maximum synthesizing displacement of the deck is 3mm in the moving loads test (the truck speed is 50 km/hr). The synthetically displacement of the deck is 11mm in the impact test (the truck speed is 25 km/hr). When the vehicles brake on the bridge (the truck speed is 25 km/hr), the synthesize displacement of the deck is 8mm.

4 RESULT ANALYSIS

(1) From the contrasting data of Table 2, we can know that the bending deflection and stresses of control sections of main arch coincide well with theoretical values. The bending deflection and stresses also meet the requirements in "China *Standard of Road Engineering Quality Evaluation*" under test loads. That is to say both of the rigidity and strength of this bridge meets the design requirements and at the same time verifies the exactness of the calculating model.

(2) From test data in Table 2, we know that under test loads the local stress in sections on the top of post-bracket above arch ring, the middle of post-bracket beam and the middle of cross beam are all less than theoretical values. That is to say, stress in these key sections coincides with the design requirements and there is no possibility of local failure under special loads. The test result of maximum tension of suspender shows that the tension meets the requirements with certain safety reserve.

(3) Although all measures were tried to keep the strain position away from areas of stress concentration, several check-coefficient in testing-datum of main arch concerning sections are somewhat large, because of many complex factors of local stress concentration (including pressing, pulling, screw and shearing) and local sunshine temperature stress.

(4) The result of sport roadster, obstruction crane, brake test show that Xiaowan Arch Bridge has large integrated displacement response, so during the service period one should enhance the maintenance of pavement, and make sure that there are no big drags on deck, and ensure the smoothness of floor to avoid too hard dynamic impacting. And emergency braking must be avoided when automobile is running at high speed.

5 CONCLUSIONS

Xiaowan Arch Bridge load test results show that steel box handle- basket arch bridge is an optional bridge form. Under super heavy this structure form is rationally formed, reliably structured with good rigidity, strength and stability. It is a kind of better bridge structure form which is worth spreading.

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