TESTING ANALYSIS ON SUPER HEAVY LOADING ON XIAOWAN ARCH BRIDGE

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ABSTRACT

The theory calculation analysis results and test results used in the construction 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 give some analysis and comments on the structural performance under special loads (Motor-vehicles 86 grades (also called automobile-class 86), Platform truck weighing 3000kN (also called trailer-class 300), 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.

Keywords: steel box handle- basket arch, super heavy load, load test, testing analysis

INTRODUCTION

Xiaowan Arch Bridge is a auxiliary project in Xiaowan hydropower station at Lancang River in Yunnan province. It is also the only vital access to Xiaowan hydropower station. Because heavy electromotor have to be threaded through this bridge, the design loads are the super heavy loads: automobile-class 86, trailer-class 300，pedestrian loading 3.5kN/m^2 (The axle weight and the arrangement of axles are show 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. And the configuration of the main arch ring is reverse catenary in the arch plane. 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 degree toward the direction of bridge axis, so get the shape of handle-basket. The distance between arch-crown and arch-core is 4.7m, and the transverse distance between the two springs is 25.60m.

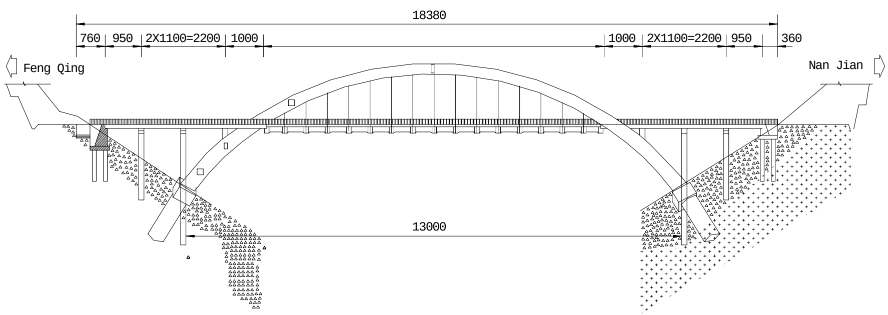

Figure 1. Elevation drawing of Xiaowan Arch Bridge (unit: cm).

The whole bridge has 17 pairs of suspenders located at the plane of arch ring (Fig.1 and Fig.2). The longitudinal beams under the deck cover on the prestressed cross beams, and the cross section of the longitudinal beam is "∏" type. The total effective width of the deck is 12.3m. There are two traffic lanes and one sidewalk which width is 0.75m each on the bridge deck. Xiaowan Arch Bridge had been built on December 31th 2002. It is the first welded steel box handle-basket arch bridge in China, and loads is the super heavy loads. Through the method of service load test, we can check on the whole quality and health

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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 focus on static test introduction.

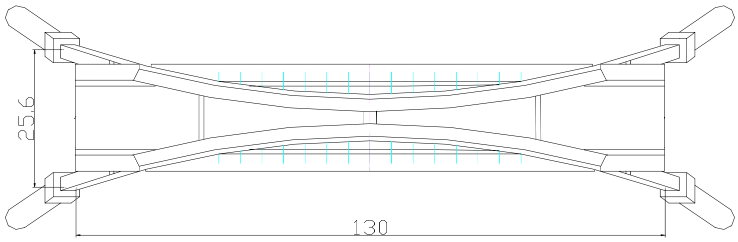

Figure 2. Horizontal plan of Xiaowan Arch Bridge(unit: m).

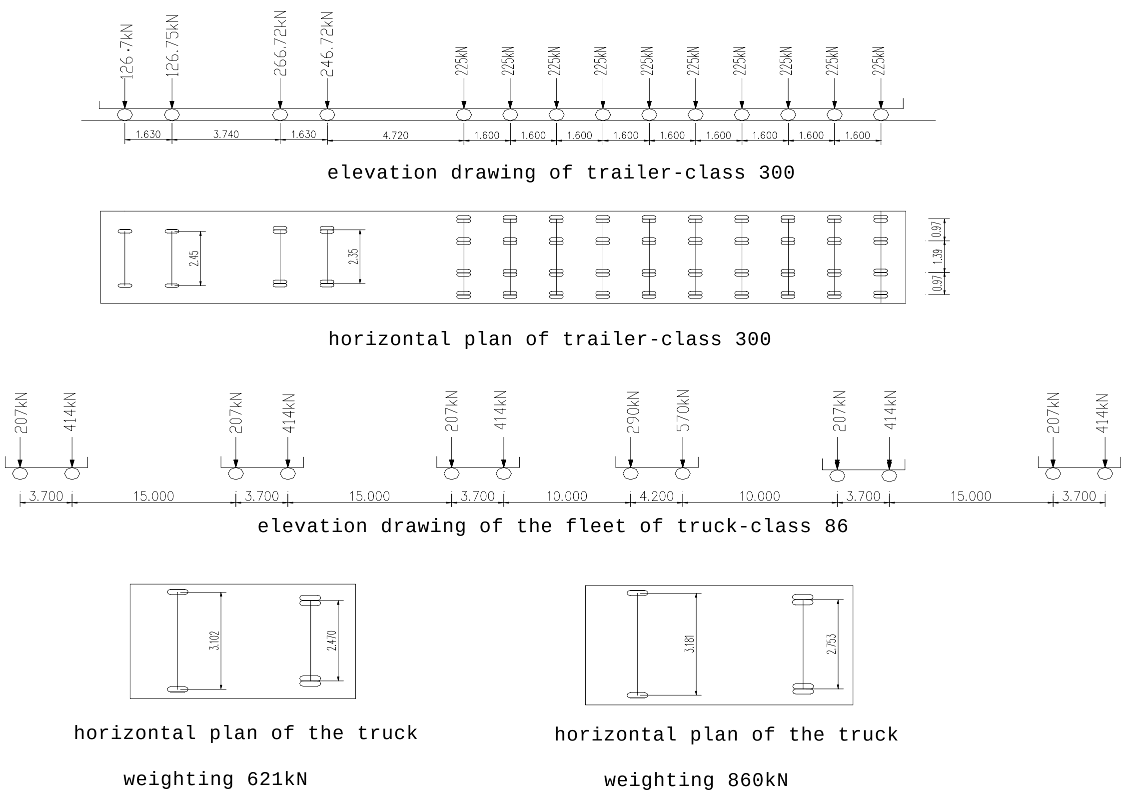

Figure 3. Design load (Unit: m).

STATIC TEST

Analysis of static test

FEM of structural

Plane model: the main arch plane revolves 15 degrees toward the direction of the bridge axis and forms handle-basket space structure, so taking space structure as mechanical analysis model is more accurate. But because tensile force of the suspenders which are caused by moving load can't 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. (See the comparison of plane mode and space model in Fig.4). In order to make the model of main arch correspond to actual structure (Arch axes are the same), main arch is divided into 304 units and every unit is 0.4-0.5 meter long in the direction of the X-axis.

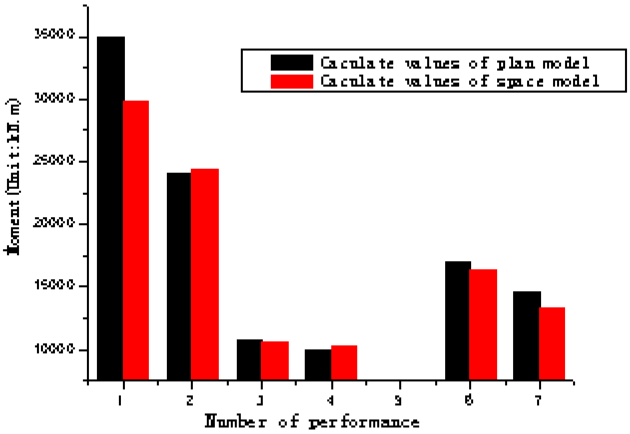

Figure 4. Moments of control sections of main arch.

Space model: FEM (finite element model) was developed using the computer program ANSYS with beam element, slab element and shell element.

Control section

The inner force influence line (Fig.6) of each section of main arch is in drawing by using the plane frame program. The most disadvantageous inner force and corresponding load longitudinal position are also obtained, and then inner forces envelope (Fig.7, Fig.8) 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).

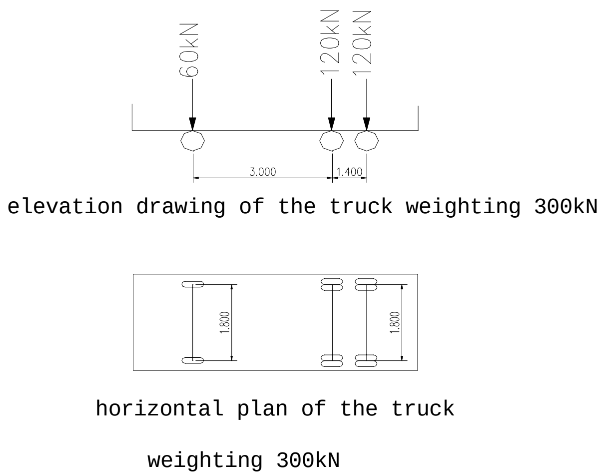

Figure 5. Loading truck (Unit: m).

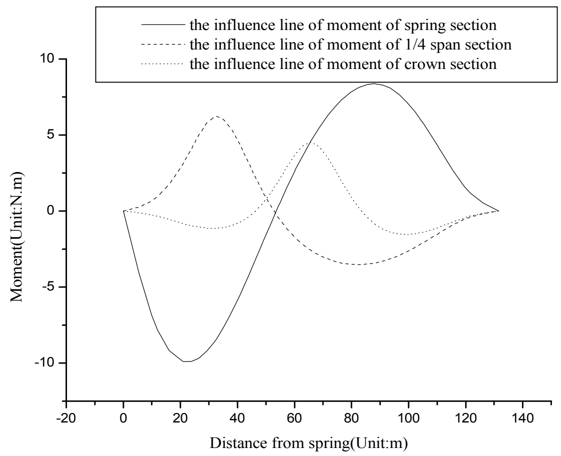

Figure 6. Influence line of moment.

The comparison of plane model and space model is shown on Fig.4. According to the graph, as far as steel box handle-basket is concerned, the plane model can meet the requirement of load testing analysis when the deflection of main arch is not more than 15 degrees and suspenders lies in the plane of the main arch.

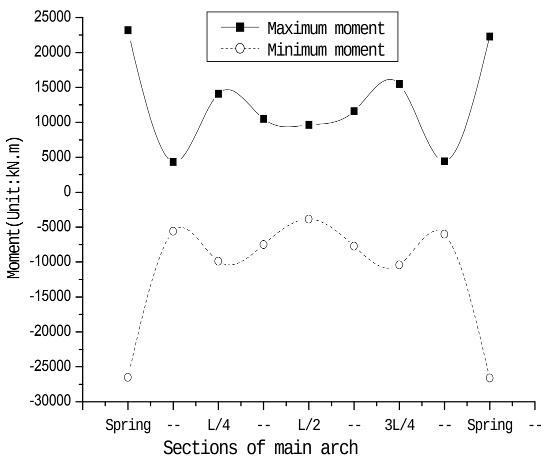

Figure 7. Moment envelope of main arch under trailer-class 300.

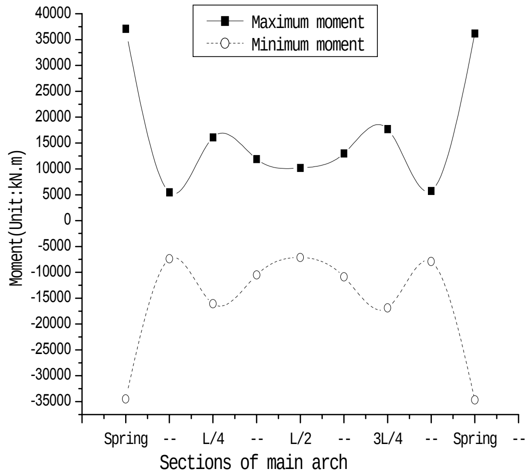

Figure 8. Moment envelope of main arch under two lines of automobile-class 86 fleet + pedestrian loading.

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

$$\eta_i = \frac{s_{star}}{s \bullet \delta} \quad (1.05 \geq \eta_i \geq 0.8)$$ [5]

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

δ —Dynamic coefficient for design standard load, here(supper heavy load) is 1.

i- one single item of test's

The efficiency coefficient is shown in Table 1.

Static test contents

The choice of test contents

With the theory analysis results, test sections of main arch are spring section, L/4 section and crown section; 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 the actual maximum cables force. Meanwhile, the corresponding anchor plate which located at the first row suspender and second row suspender on the arch is selected to check the local actual stress state; Meanwhile, No.9 cross beam of middle part of the deck were selected to test it's the 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.

Arranging of measure points

The arranging of measure points is illustrated in Fig.9 and Fig.10. The strain gauges were fixing 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 on the anchor plates of the bridge were arranged on the place of suspender No.1 and suspender No.2 (include the U type board).

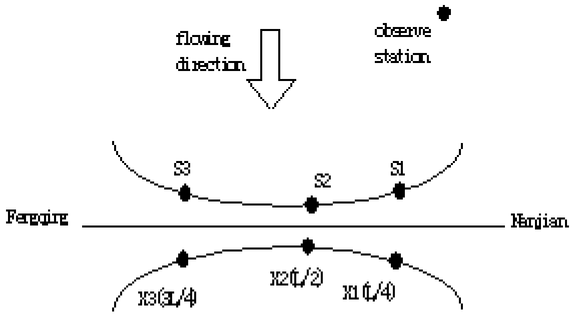

Figure 9. Deflection observation points of main arch.

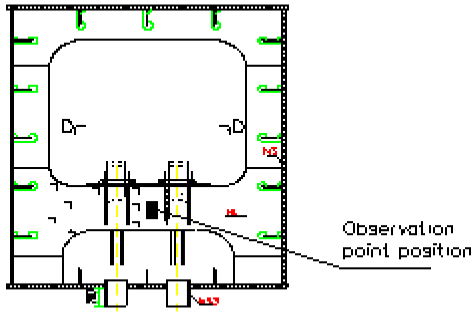

Figure 10. Stress observation points of anchor slab.

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)	The observation of testing
1	0.86	The biggest negative moment on spring	Symmetric loading.(12)	Control section stress increment, the relative deformation of the main arch, deformation of the deck
2	0.78		Un-symmetrical loading(8)	
3	0.85	The biggest sagging moment on crown	Symmetric loading(9)	Control section stress increment, the relative deformation of the main arch, deformation of the deck
4	0.7		Un-symmetrical loading(8)	
5	0.82	The biggest pulling force on the first suspender in Nanjian bank	Symmetric loading(9)	Tension increment of suspender, stress increment of anchor slab
6	0.89	The biggest sagging moment on L/4 section	Symmetric loading(12)	Control section stress increment, the relative deformation of the main arch, deformation of the deck
7	0.74		Un-symmetrical loading(8)	
8	0.81	The biggest stress of post-bracket beam	Symmetric loading(9)	The stress increment of the max. responsive section of the post-bracket pole
10	0.81	Tension of the second suspender in Nanjian bank and stress of anchor slab	Symmetric loading(3)	Tension increment of suspender, stress increment of anchor slab
11	0.92	The biggest sagging moment on the middle section of cross beam	Symmetric loading(4)	Stress increment in the cross beam
12		Torsion of the whole bridge	L/4 Un-symmetrical loading(14)	Control section stress increment, the relative deformation of the main arch, deformation of the deck
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 hit 0.8 in any case of loading distribution.

Test loading
The maximum test loading case employs 14 dump trucks (Fig.5)，each weigh 300kN (self weight + loading weight), because it is difficult to simulate the design load in testing. The weight of the dump truck's front axle is 60kN.The weight of its middle axle and back axle are both 240kN. The distance between front axle and middle axle is 3m, and between middle axle and back axle is1.4m.

Test performance and efficiency coefficient
According to the study of special loading test in Xxiaowan arch bridge on Lancang river and the summary of evaluation meeting about the detailed regulation of operations of Xiaowan arch bridge loading test, we can decide static load test performance of Xiaowan Arch Bridge, please refer to table 1.

The contrasting between test results and theoretical value

Deflections and stress increments of some control sections:

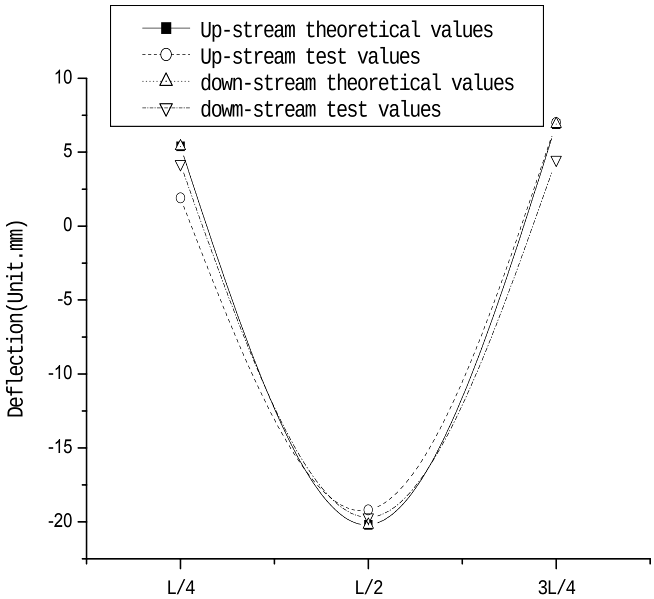

Figure 11. Deflections of main arch under performance 3.

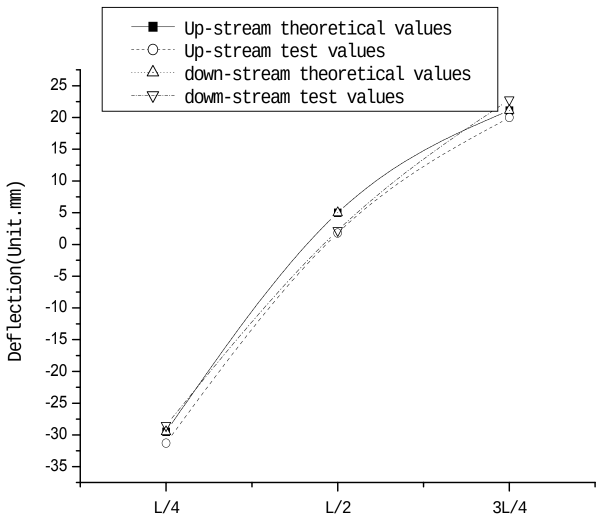

Figure 12. Deflections of main arch under performance 1.

Table 2. Suspender tensions.

Load case	Test section	Theoretical tensions increment(10kN)	Test tensions increment(10kN)	Check coefficient
5	Rigid suspender	20.86	18.83	0.90
10	Semi-rigid suspender	18.63	17.92	0.96

Table 3. 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'

DYNAMIC TEST

Basic items measured by dynamic load test

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

During the dynamic loading test, the dynamic stress of the ring course at the critical section of arch's spring and crown were measured when one or two loading vehicles pass through the bridge with different speeds. At the mid-span of the bridge deck pass over the obstacle (the obstacle is a wood block with 2.5m length and a segment of triangle cross section whose bottom is 80cm and height is 7cm.; the bridge has various response when the vehicles pass through the bridge in all kinds of service condition, and the single heavy vehicles pass through the bridge with the different speed, we can evaluate whether the biggest dynamic strain, stress and deflection.

Structure can also be analyzed by applying the structure dynamic model to check whether there are defects:

- For 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 with different speeds. Meanwhile structure can be analyzed by the structure dynamic model simulation calculation.
- For measuring the natural vibration behaviors of the bridge, such as the vibration frequency, vibrative mode and damping ratio of the bridge. Ambient vibration test has been carried out.

The main result of the dynamic load test

Table 4. 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 ($\mu\varepsilon$)
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

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 change 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.

The maximum synthesizing displacement of the deck is 3mm in the moving loads test (the truck speed is 50 km/hr). The synthesize 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.

The ambient vibration test has been carried out by CRAS system, results of the main span is as follow:

Table 5. The ambient vibration test results of the main span.

Model number	Modal frequency（Hz）			Vibration direction	Ratio of the relative damping（%）
	Test result	Theoretical model I	Theoretical model II		
1	0.996	0.87	0.89	vertical	7.843
2	1.387	1.306	1.415	torsion	5.634
3	1.543	1.626	1.484	vertical	5.063

RESULT ANALYSIS

1. From the contrasting datum of Table 2 and Table 3, we can know that the bending deflection and stresses of control sections of main arch are well coincide with theoretical values. The bending deflection and stresses also meet the requirements in "China Standard of Road Engineering Quality Evaluation"[4] under test loads. That is to say both of the rigid and strength of this bridge meets the design requirements and at the same time verifies the exactness of the calculating model.

2. From test datum in Table 3, 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 be met the requirements with certain safety reserve.

3. Although the strain position was tried to keep 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 the smoothness of floor to avoid too hard dynamic impacting. And emergency braking can be avoided when automobile is running at high speed.

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 rational formed, reliable structured with good rigid, strength and stability. It is a kind of better bridge structure form which is worth spreading.

REFERENCES

1. Zhongchu Tian, Donghuang Yan and Deliang Chen,"Report of Testing analysis and Study of the Xiaowan Arch Bridge across the Lancang river in the Yunnan province of China", Changsha University of Science and Technology, April, 2003.(Chinese).
2. The design blueprint of the Xiaowan Arch Bridge about steel box handle- basket by Yunnan Highway Survey and Design Institute. Jan. 2002 (Chinese).
3. Donghuan Yan, Zhongchu Tian and Xuewen Li "Application of computer program to calculation of bridge's structure", Hunan University Publishing, Feb.1999. (Chinese).
4. "China Standard of Road Engineering Quality Evaluation (JTJ071-98)", the People's Communications Publishing, July,1999 (Chinese).
5. "Test Method of Large-span Bridge", the People's Communications Publishing, July,1982 (Chinese).