

Repair and strengthening of two-way curved arch bridge

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ABSTRACT: Many two-way curved arch bridges have been built in 1960s and 1970s in China, because this bridge type was material saving and easy constructed. However, the technical condition of the majority of two-way curved arch bridges still in service today is very poor and requires maintenance, repair and strengthening. The typical damages of them are material degradation due to ageing, displacement of foundations, both longitudinal and transverse cracks in the arch ribs, etc. In this paper, the general situation of this bridge in service is concerned and repair and strengthening measures of an example bridge is dealt with.

A three- dimension finite element model of the bridge was built to analyse and assess the structural performance. The bridge was repaired and strengthened by enlarging the spring cross-section, casting concrete on top of the crown to increase the rib height, using carbon fiber reinforced plastics layer to strengthen the arch crown area.

1 INTRODUCTION

In Chinese highways, many two-way curved arch bridges have been built in 1960s and 1970s, because this bridge type was material saving and easy constructed in the years. However, the technical condition of the majority of two-way curved arch bridges still in service today is very poor. The problem is confronted with whether to be backouted and rebuilt or requires maintenance, repair and strengthening. Building new bridges needs numinous fund. The highway traffic will be intermitted, influencing the peoples living around the bridges. So it is important to find some suitable strengthening methods to fulfill the capacity of old two-way curved arch bridges.

The typical damages of two-way curved arch bridges in China are material degradation due to ageing, displacement of foundations, both longitudinal and transverse cracks in the arch ribs and lateral connections, etc. The repair methods are strengthening the arch ribs and the lateral beams, except for the maintenance of substructure. The main strengthening methods are applied in China as below:

(1) Strengthening of arch ribs: Steel plates or carbon fiber reinforced plastics(CFRP) layers are attached to strengthen the arch ribs. The steel bars and concrete is used to enlarge the area of arch ribs. Increasing the numbers of arch ribs or changing the arch ribs into box section are other methods adopted.

(2) Lateral contact strengthening: Enlarging the lateral affiliation beams with concrete, increasing their numbers, changing the lateral beams into whole cross beams, and thickening the arch slabs are applied to strengthen the lateral contact.

(3) Other repair methods: Changing axis line or compress line of arch bridge, or changing structural system are last took if the above methods cannot serve the problem.

2 REPAIR AND STRENGTHENING METHODS OF AN EXAMPLE TWO-WAY CURVED ARCH BRIDGE

2.1 *An example Bridge*

One two-way curved arch bridge was built in 1970 and lies in Luoyuan, Fujian province, the spans are $7.9+8\times 22+6.1$ meters, 203 meters total length, 7.6meters width. It is consist of 7 reinforced concrete arch ribs and 6 arch waves. The designed load was vehicle- 13(old Chinese Bridge Design Standards). Figure 1 shows the sketch of whole bridge.

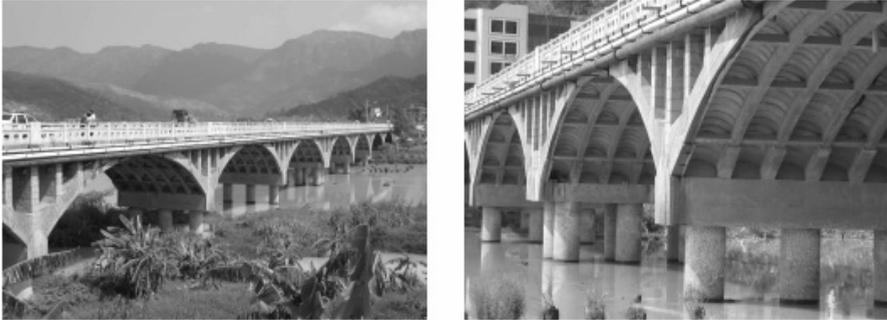


Figure 1: The Example Two-Way Curved Arch Bridge.

2.2 *Damages of example two- way curved arch bridge*

The main structural concrete in the bridge is damaged partially. Some steel bars are tarnishing in most arch ribs. The lateral contact beams are damaged in some ways. There are longitudinal cracks in medium arch waves. Net cracks lie on the pavements. The foundations of abutments have somewhat displaced. The cones are damaged by cracks. There are also cracks on the pier copings with some steel bars tarnishing.

The vehicle loading test report of the bridge showed that, the maximum concrete strain and deflation of main arch of tested span exceeded the calculated numerical value. The cracks would expand sequentially under short time load. The performance of crack resistance decreased. The whole strength and the vertical rigid of the bridge also decreased. The lateral relation was weakened. Safety and dual ability of the bridge decreased, and the example bridge could not fulfill the designed command. The report suggested that the load on the bridge should be restricted, and repair methods should be took as quickly as possible.

Figure 2 shows damages of the example bridge. Maintenance of arch ribs and lateral beams were taken several years ago. But the damages still exist.



Figure 2: Damages of the example bridge.

2.3 Damages Causes of the example bridge

There are many reasons and causes of the above damages of the two- ways curved arch bridge.

(1) The monolithic loading capacity decreased. The designed load was vehicle-13, but the real traffic vehicle loads are much stronger than that. The designed load is much lower and not suitable to today's heavy traffic loads.

(2)The designed strength of arch ribs was deficiency: the standard of concrete in construction was lower than today. Though the spring cross- sections were enlarged, their bending strength and rigid are still insufficient. Loading capacity had decreased under the heavy vehicles in long time.

(3)The lateral relation was scarcity: the cross- section of lateral beams was small, and the few number brought on falling short of lateral relation. Longitudinal cracks lied on medium arch waves. The thickness of arch waves was deficiency too, which conduced the inhomogeneity of lateral load distributing, and make for the longitudinal cracks.

(4)The ratio of steel bars was low: the main steel bars were standard I and had low strength in the two- ways curved arch bridges built in 1970s. The diameter was only 14~16mm, it induced the bending strength and loading capacity.

2.4 Repair and strengthening methods

The example bridge could not satisfy the designed capacity demand, not considering the damages of substructure. The repair goat is to meet the designed capacity. The ways below were taken to repair and maintenance. Figure 3 is the sketch map of repair of the example bridge.

(1) Replace new pavement and light filling. Construct new pavement after having fulfilled light material filling on the arch extrados.

(2) Strengthen lateral relation of whole bridge. Using cast- in- place concrete to connect the arch soffit. Increase the height of the arch slab to strengthen the lateral affiliation. Epoxy mortar is used to remedy the cracks of lateral connect beams and arch waves.

(3) Repair main arch ribs. Use epoxy mortar to repair the cracks on the arch ribs. In the area of arch crown the CFRP layers are attached under the arch ribs. The repairing length is about 4 meters. Spring cross- section is filled with reinforced concrete to enlarge the area and strengthen the loading capacity.

(4) Maintenance the damaged piers and abutments.

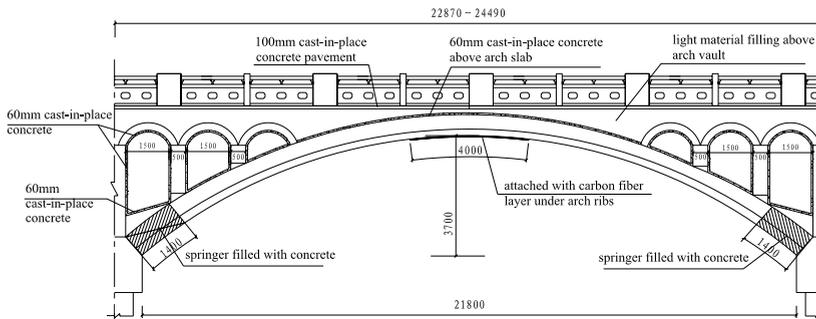


Figure 3: Sketch map of Repair methods of example bridge (mm).

3 FINITE ELEMENT CALCULATING ANALYSIS ON EXAMPLE BRIDGE

3.1 Three dimension finite element model

A three dimension finite element model of the bridge was built to analyse and assess the structural performance. Considering the multiple arch function, three spans were took to build

the calculated model(Figure 4). The consist section of arch ribs and arch slabs is especially considered in the model. The arch ribs are rigid with piers. The piles are fixed at the bottom. 3534 nodes and 3950 elements are consisted in the model.

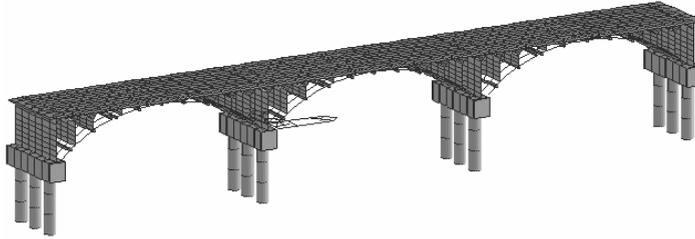


Figure 4: Three dimension finite element model of the bridge.

3.2 Analysis on structural performance before repair

In the model before repair, arch waves are neglected. The calculated result is checked by designed load. Table 1 shows the result of the structural performance before the bridge is repaired.

Table 1: Structural Performance before Repair.

Section	Rib	Axial Force KN	Shearing Force KN	Bending Moment KN. m	Axial Force Resistance KN	Checked Result
Spring	Edge	496.37	-4.92	-290.43	219	Not fulfilled
	Medium	715.15	-19.94	-340.91	512	Not fulfilled
L/4	Edge	238.87	-55.57	126.11	407	Fulfilled
	Medium	371.48	-78.09	140.60	785	Fulfilled
Crown	Edge	229.99	-13.26	146.89	299	Fulfilled
	Medium	344.32	-28.62	196.77	347	Fulfilled

The result of finite element calculating shows that, the loading performance of spring section is not suit to the designed demand before repair.

3.3 Analysis on structural performance after repair

The model is modified by the repair methods. The spring section is enlarged, and the arch slab is thickened. The calculated result is checked by designed load. Table 2 shows the result of the structural performance after the bridge is repaired.

Table 2: Structural Performance after Repair.

Section	Rib	Axial Force KN	Shearing Force KN	Bending Moment KN. m	Axial Force Resistance KN	Checked Result
Spring	Edge	459.69	-8.80	-299.14	738	Fulfilled

	Medium	810.14	-111.18	-632.25	946	Fulfilled
L/4	Edge	222.77	-61.37	109.88	479	Fulfilled
	Medium	357.50	-84.09	125.49	896	Fulfilled
Crown	Edge	216.86	-12.65	143.77	297	Fulfilled
	Medium	328.05	-28.03	194.37	470	Fulfilled

The result of finite element calculating shows that : After repair, the performance of resisting axis forces and bending moment is largely increased, and it can suit the demand of loading capacity. In the area of crown sections, the lateral relation is strengthened. The bridge structure can be loaded in whole system, and is suit to the designed demands.

4 CONCLUSIONS

Attaching CFRP layers under the bottom of crown area of arch ribs, filling concrete into the spring area to enlarge the section, thickening the arch slab, and changing new light material fillings and new pavement are the main repair methods used in the example two- ways curved arch bridge. Having been strengthened and through maintenance, the carrying capacity of the bridge is largely improved. The finite element calculated result shows that:

(1) The loading capacity of spring area would not fulfill the designed demand before repair. But after the spring was filled with concrete, its bearing load capacity became increase and suit to the designed demand.

(2) Thickening the arch slab makes arch waves, arch slab and arch ribs work together to endure the heavy load. They can form consist sections strengthening the lateral connection function.

(3) The CFRP layers used in crown area enhances tensile property and crack resistance.

Together with other maintenance methods the two-ways curved arch bridge becomes to fulfill the designed demand and prolongs service life.

It should be mentioned that, during the construction of repair and maintenance, detail designs and construction methods should be considered. Having served for more than 35years, the example bridge is ageing, it should be especially careful to decrease the dynamic influence. After repair and strengthening, periodic maintenance should be adopted to ensure the whole structure is in good serving state.

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