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DEVELOPMENT, ACTUALITY AND STRENGTHENING OF DOUBLE CURVED ARCH BRIDGE IN CHINA

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Abstract. *Double curved arch bridge was a new type of arch bridges, and was firstly built in Wuxi county, Jiangsu province, China in 1964. It inherited the structural characteristics of masonry arch bridges, and absorbed the advantages of assembled RC bridges at the same time. Its appearance was also national. So it was widely constructed in 1960s and 1970s in China. But to most of existing double curved arch bridges, there are many problems such as low load capacity, bad whole performance, and many cracks on arch rib and arch tile, etc. In this paper, the development of double curved arch bridge in China is briefly reviewed, and several representative double curved arch bridges are introduced. Its strengthening measures are also presented here. Finally, the strengthening and structure analysis of an actual double curved arch bridge are introduced.*

1 INTRODUCTION

Arch bridge is the most prevalent bridge type in China. Approximately 70% of the bridges in China are arch bridge by unofficial static. Double curved arch bridge (Figure 1) was firstly built in China. It reduced the amount of steel bar and did not debase load capacity. Therefore, it was widely constructed in 1960s and 1970s. “Double curved arch” means that the arch rib (lognitudinal) and arch tile (transverse) are all curvilinear. It inherited the structural characteristics of masonry arch bridges and absorbed the advantages of assembled RC bridges at the same time. Its appearance was also national. Since it was widely used, double curved arch bridge was one representative type of masonry bridges in China during that period.

Figure 1: Double curved arch bridge

The construction of double curved arch bridge included two important stages, “divide” and “assemble”. Firstly, the whole structure was divided into parts such as arch rib, arch tile, arch covering and transverse bracing. Then all these parts were assembled into whole. There were not bracket, and ordinary crane was enough during its construction. The detailed construction stages were: a number of prefab arch ribs were supported on abutments firstly and arch ribs were connected by transverse bracing. Transverse bracing and arch ribs composed the arch supporting structure. Then prefab arch tiles were supported on arch ribs. Finally concrete arch covering was poured on arch tiles which acted as form here. Through arch covering, these parts of structure were assembled into whole, and they worked together under the second dead load and live load[1].

At the beginning of double curved arch bridge’s construction, it was designed mainly by experience. But with its development, the size of arch was estimated through experience firstly, and then its loaded performance was analyzed by elastic theory. Finally, its size was corrected according to the result if it was necessary. Because there were not bracket in the construction of double curved arch bridge, and because of its quicker construction and lower cost, it was still built in some area of China in the early of 1990s.

2 DEVELOPMENT

The first double curved arch bridge-East Arch bridge (Figure 2), was built in Wuxi county, Jiangsu province, China in 1964[2]. East Arch bridge was a testing bridge, 13 meters long and 1.5 meters wide. There were three arch ribs and two arch tiles. And only tractor and car was permit to pass. Since the success of East Arch bridge, the design method, structure form, and construction method were improved all the wile. The section of arc rib was changed from rectangle section into inverse T section, H section bending along weakly axis, U section , box section and so on (Figure 3). The number of arch rib and arch tile was gradually decreased in order to enhance the whole performance and improve its loaded property. There were also

only two arch ribs and one arch tile in a double curved arch bridge.

Figure 2: The first double-curved arch bridge-East Arch bridge

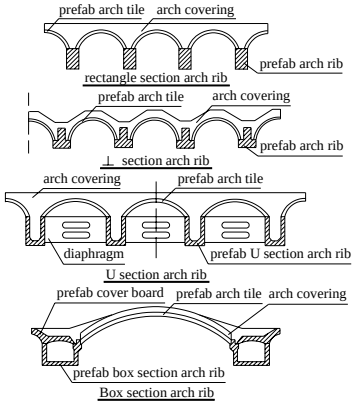

Figure 3: Section of arch rib

Figure 4: Red Star double curved arch bridge

Figure 5: Luoyixi double curved arch bridge

Red Star double curved arch bridge (Figure 4) which spanned a deep valley was built in Zhuzhou city, Hunan province, China in 1967[2]. It was 155.8 meters totally long, 9.2 meters wide, 108.45 meters long main span, and 1/7 rise span ratio. The spandrel arch above arch ribs was three hinged double arch, 24.5 meters long span.

Louyixi double curved arch bridge (Figure 5) was built above a reservoir in 1974[2]. It was composed of 4 span unsymmetrical double arches (53 meters+116 meters+2×70 meters), 365 meters totally long. Even in low water season, the water was still 15~20 meters deep. The section of arch rib was U section filled with concrete after installation, and the thickness of the slab of U section was only 11 centimeters. Tiny curved slab and RC beam were used as spandrel structure.

Qianhe double curved arch bridge (Figure 6) was the longest span double curved arch bridge in China, which was built in Song county, Henan province in 1968[3]. It was a hingeless arch with variable cross section, 150 meters long clear span, 1/10 rise span ratio, and 182 meters totally long. There were 12 spandrel arches which span was 9 meters long. Because of 29 transverse beams, the whole performance of arch ribs was well.

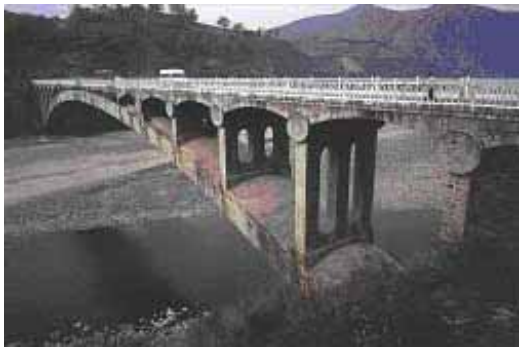

Figure 6: Qianhe double curved arch bridge

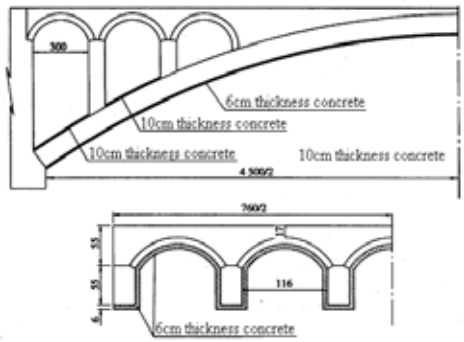

Figure 7: Strengthening design of main arc (cm)

3 ACTUALITY

Up to the present, double curved arch bridge has gone through more than 40 years. Although many factors such as local economy development, social demands and so on, were considered, and advanced techniques and materials were accepted when any double curved arch bridge was built, but with the quick traffic development, the increase of vehicle load and the elevation of vehicle speed in China, there were much obvious limitation such as low design load standard, deficient load capacity, small bridge width. Currently, most of existing double curved arch bridge can not satisfy the increasing traffic, and there are many problems, such as cracks on main arch ring (including lognitudinal cracks on arch tile, cracks on arch rib, cracks on transverse beam, and cracks on the joint between arch rib and arch tile, etc.), cracks on spandrel arch and spandrel wall, leakage of spandrel arch and spandrel wall, distortion and crash of concrete bridge deck, and cracks on piers and abutments, etc.

Remove the old bridge and construct a new bridge can completely solve the problems existing in double curved arch bridge. But the expense is also very high. In fact, the foundation of most double curved arch bridge is well, and it is not necessary to build a new bridge. The load capacity can be heightened through reinforcing, reconstructing and widening the superstructure. It is also a stimulative for the continuable development of bridge construction.

Many scholars have done much research work on strengthening and reconstruction of double curved arch bridge, and a lot of strengthening methods were presented[4,5]. They are summarized as follows:

(1) Strengthening of the whole performance of main arch ring

a. Increased the stiffness of transverse bracing. The transverse beam could be replaced with diaphragm, or increased the number of transverse bracing, so that the transverse whole performance of double curved arch bridge would be strengthened and all the parts of arch would be worked together under load.

b. Enlarged the size of arch rib and arch tile (Figure 7). Firstly, steel bar net were placed around arch rib and arch tile, and then concrete was sprayed on them. So that the load property of arch rib and arch tile would be improved, the integral stiffness and load capacity

would be enhanced.

c. Steel bar net were placed on the negative moment area around springing, and then concrete was poured (Figure 7).

(2) Mending of the cracks on spandrel arch and spandrel wall

For the cracks on spandrel arch and spandrel wall whose width were more than 0.5 millimeter, the measure that use concrete mortar to pour into crack under high pressure, could be accepted.

(3) Disposal of bridge deck

Since the thickness of bridge deck of most existing old double curved arch bridge could not satisfy the presented load standard, all the bridge deck was completely removed. Sometimes, parts of backfill on main arch ring were also removed to reduce deadweight. Then new RC bridge deck was poured. So that driving status was improved and the integrity of arch bridge was enhanced.

(4) Mending of the cracks on pier

For the cracks on pier, the mending measure that use epoxy resin concrete mortar to pour into crack under high pressure, was frequently accepted. Steel hoop and anchoring were also used.

Although all of these measures could reinforce old double curved arch bridge and properly increased its load capacity, the increased degree was limited. They did not essentially change the section property of structure such as bending stiffness and torsional stiffness.

In the following text, a new strengthening method is introduced, based on Guokeng double curved arch bridge, located in Zhangzhou city, Fujian province, China. The essential of the method is to change the ringent section into a box section, so that the section property is totally changed, and the load capacity of bridge will be greatly increased. It is a beneficial attempt for similar problems.

4 NEW STRENGTHENING METHOD

Guokeng double curved arch bridge (Figure 8) was composed by 7 hollow catenary double curved arches (3×75m+4×45m), and was built in 1974[3]. Concrete solid pier, U shape abutment, sunk caisson foundation, and spread foundation were used. It was 468.51 meters totally long and 11 meters wide. The load standard was Qi-13, Tou-60 (bridge design load standard in China). It has been 30 years since it was built. And there were many cracks on arch rib, arch tile, spandrel pillar, pier and abutment. The owner of the bridge

Figure 8: Guokeng double curved arch bridge

required that the load standard must be advanced to Qi-15, Gua-80 after replacement. So the above ordinary replacement methods were not feasible. Considering the condition, a new strengthening method is presented here. The ringent section is changed into a box section (Figure 9). The bending stiffness and torsional stiffness are increased, and the load transverse distribution of live load is more symmetrical, so that the load capacity is greatly increased.

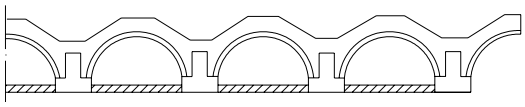

Figure 9: Cross section after strengthening

In order to validate the feasibility of the method presented above, the box arch structure and the old arch structure are analyzed respectively using the software ~ bridge doctor. The load standard is Qi-15, Gua-80. Due to the length restraint of this paper, only the results of the 75 meters span double curved arch are presented. Under the worst load combination, the maximal and minimal principal stresses of each section of the old arch structure and the box arch structure are showed respectively in Figures 10 and 11, and the maximal and minimal component stresses of the bottom of each section of the old arch structure and the box arch structure are showed respectively in Figures 12 and 13.

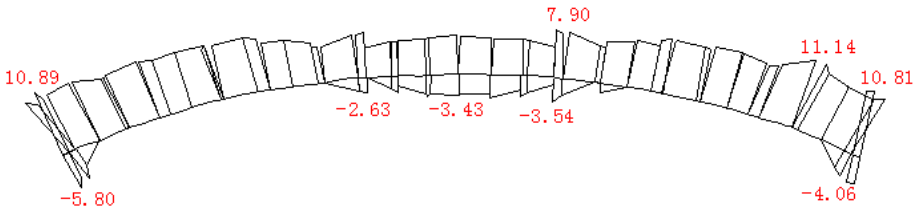

Figure 10: Maximal and minimal principal stresses of each section of old arch structure (Mpa)

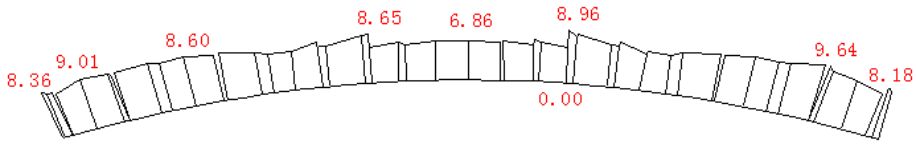

Figure 11: Maximal and minimal principal stresses of each section of box arch structure (Mpa)

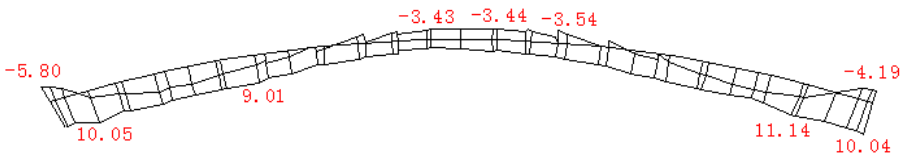

Figure 12: Maximal and minimal component stresses of the bottom of each section of old arch structure (Mpa)

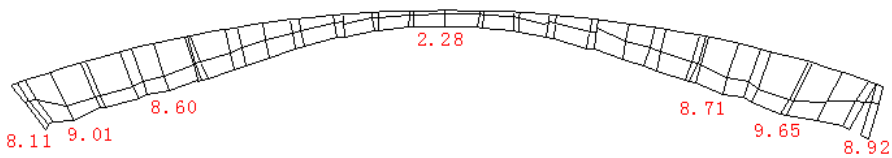

Figure 13: Maximal and minimal component stresses of the bottom of each section of box arch structure (Mpa)

From figures 10 to 13, we know: (1) For the old arch structure, tensile stresses of the cross section in springing and vault are larger than tensile strength value of concrete under the load standard Qi-15, Gua-80, and cracks appear. But for the box arch structure, the load capacity of main arch ring is greatly increased, the load standard Qi-15, Gua-80 can be satisfied, and the stress of any cross section is compressive. The load characteristic of masonry structure is well utilized. (2) For the box arch structure, the top stress decrease and the stress of each cross section is more symmetrical although the dead increase. The reasons are that using box section will improve the whole performance and make the load transverse distribution of live load more symmetrical. (3) The connective strength between arch rib and the concrete should be regarded very weightily in order to ensure the integrity of box section and avoid serious adverse aftereffect.

5 CONCLUSIONS

Although double curved arch bridge is scarcely built in China at present, there are still many existing old double curved arch bridge which have many problems and can not satisfy the load demand. It is necessary to accept some reasonable strengthening measures to exert their potential.

As far as technique, it is feasible to change the ringent section into a box section. By this means, the bending stiffness and torsional stiffness are increased, the load transverse distribution of live load is more uniform, and the whole performance is more rational, so that the load capacity is greatly increased. While considering the economic, it is also reasonable, since the engineer quantity and construction schedule are decreased. Because the strengthening work is under main arch ring, it also do not affect the normal transit of the bridge.

In conclusion, it is a good concept to change section property for the strengthening of thousands of existing old double curved arch bridge in China. Moreover, it also has reference meaning for the strengthening of old bridge used other structure system.

REFERENCES

[1] Fan Li-chu, *Bridge engineering*, Peoples traffic publishing company, China (1987).
[2] Compile Committee of Chinese bridge, *Bridge of China*, Tongji university publishing company, China, and, Architecture and city publishing company, China (1993).
[3] Ministry of Communications of The Peoples Republic of China, *Bridge of China*, Foreign language publishing company, China (2003).
[4] Zan Run-shui, Hu Zhao-fang, and Shuai Chang-bin, *Strengthening techniques of old bridge and example*, Peoples traffic publishing company, China (2002).
[5] Wang Guo-ding, Yuan Hai-qing, and Chen Kai-li, *Inspection and strengthening of bridge*, Peoples traffic publishing company, China (2003).