Survey and analysis of the main defects in reinforced concrete ribbed arch bridges

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ABSTRACT: Because of those advantages such as simple style, light weight, low demanding for foundation and low cost for construction or maintenance, reinforced concrete ribbed arch bridges are applied widely in China, especially in mountain areas of southwest China. From late 1970's, many RC ribbed arch bridges have been constructed in China, including most of the long span bridges. After many years of operating and service, some defects and damages occur to reinforced concrete ribbed arch bridges. Not only are bridge structural performance and driving comfort reduced, but also does safety risk increase. According to a wide investigation, 100 reinforced concrete ribbed arch bridges are generally surveyed. 49 bridges, which have typical defects in areas of Sichuan, Guangxi and Chongqing, were investigated in detail on site. The defect characteristics and rules are classified and summed up, and, moreover, the reasons for the defects occurrence are analyzed. It is expected to provide scientific, impersonal and rational basis for design, construction, maintenance and rehabilitation of bridges of this style, and lay a foundation for further research work.

1 INTRODUCTION

Because of those advantages such as simple style, light weight, low demanding for foundation and low cost for construction or maintenance, reinforced concrete ribbed arch bridges are applied widely in China, especially in mountain areas of southwest China. From late 1970's, many RC ribbed arch bridges have been constructed in China, including most of the long span bridges.

After many years of operating and service, some defects and damages occur to reinforced concrete ribbed arch bridges. Not only are bridge structural performance and driving comfort reduced, but also does safety risk increase. According to a wide investigation, 100 reinforced concrete ribbed arch bridges are generally surveyed. 49 bridges, which have typical defects in areas of Sichuan, Guangxi and Chongqing, were investigated in detail on site.

The defect characteristics and rules are classified and summed up, and, moreover, the reasons for the defects occurrence are analyzed. It is expected to provide scientific, impersonal and rational basis for design, construction, maintenance and rehabilitation of bridges of this style, and lay a foundation for further research work. The RC ribbed arch bridges in this paper refer to deck RC ribbed arch bridges in particular, not include truss arch bridges, rigid frame arch bridges and double curve bridges.

2 DEVELOPMENT OF RC RIBBED ARCH BRIDGES

In early 20th century, long RC ribbed arch bridges are built abroad. There are some famous bridges such as, Langwieser viaduct for the church, Fig.1, an elegant viaduct in the entire railway network, was built in Switzerland in 1914, with a two rib arch without hinges, with an arch span of 100m and a rise of 42m. Arrabida Arch Bridge, Fig.2, over the Douro River, in Portugal, opened in 1963, has a reinforced concrete arch 270m long, with cross section of three-cell box. Gladesville Bridge in Sydney, Australia, built in 1964, with the span of 304.8m. The arch is made of four ribs of box type cross sections, and ribs are connected longitudinally with concrete. Colorado River Arch Bridge is under construction in United States, with 323m arch span, with twin concrete arch ribs. It will be the first arch structure of this scale to combine a composite steel deck with a segmental concrete arch and spandrels. Some of long span RC ribbed arch bridges abroad are listed in table 1.

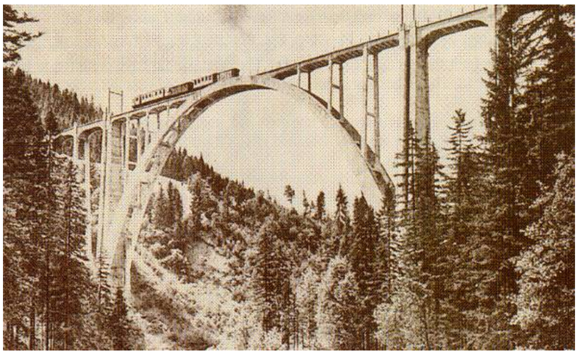

Figure 1 : Langwieser viaduct for the church, Switzerland

Figure 2 : Arrabida Arch Bridge, Portugal

Table 1 : Long span RC ribbed arch bridges outside China

No.	Bridge	year	country	span (m)	Type	Arch ribs
1	Colorado	Under construction	U.S.A	323	Deck open spandrel arch	double single-cell box ribs
2	Gladesvill e	1964	Australia	304.8	Deck open spandrel arch	four box ribs
3	Arrabida	1963	Portugal	270	Deck open spandrel arch	Three-cells box ribs
4	Kyll	1999	Germany	223	Deck open spandrel arch	Double solid ribs
5	Neckar	1977	Germany	154.4	Deck open spandrel arch	double-cells box ribs
6	Caracas	1953	Venezuela	152	Deck open spandrel arch	single-cell box ribs
7	Teufelstal	1938	Germany	138	Deck open spandrel arch	Rectangle ribs
8	Krummba ch	1977	Switzerlan d	124	Deck open spandrel curved arch	Rectangle ribs
9	Fozde Sousa	1952	Portugal	115	Deck open spandrel arch	I-shape ribs
10	Risorgime nto	1911	Italy	100	Deck solid spandrel arch	Box ribs
11	Langwies er	1914	Switzerlan d	100	Deck open spandrel arch	Twin ribs

From late of 1970's, many RC ribbed arch bridges have been constructed in China, including many long span bridges. For example, Laibinmodong Bridges in Guangxi Province, fig.3, has twin double –box ribs, with arch span of 180m, opened in 1998. Chongqing Wenxi Bridge, fig.4, is built in 2001, with 150m arch span. Some of long span RC ribbed arch bridges in China are listed in Table 2.

Figure 3 : Laibinmodong Bridge in Guangxi

Figure 4 : Chongqing Wenxi Bridge

Table 2 : Long span RC ribbed arch bridges in China

No.	bridge	year	Province	span（m）	type	Arch ribs
1	Laipinmodong Bridge	1998	Guangxi	180	Deck open spandrel arch	Double-boxes ribs
2	Wenxi Bridge	2001	Chongqing	150	Deck open spandrel arch	Double-boxes ribs
3	Pingguoleigan Bridge	1995	Guangxi	140	Deck open spandrel arch	double single-cell box ribs
4	Huangmadu Qu river Bridge	2000	Sichuan	140	Deck open spandrel arch	Twin double-boxes ribs
5	Wusheng Jialing River Bridge	1994	Sichuan	130	Deck open spandrel arch	Double-boxes ribs
6	Muxiexi Bridge	2001	Chongqing	130	Deck open spandrel arch	Double-boxes ribs
7	Nibaxi Bridge	2001	Chongqing	130	Deck open spandrel arch	Double-boxes ribs
8	Xiaojiaba Bridge	1999	Sichuan	120	Deck open spandrel arch	Twin double-boxes ribs
9	Longdongbei Bridge	1999	Sichuan	120	Deck open spandrel arch	Twin double-boxes ribs
10	Tiane Hongshui River Bridge	1989	Guangxi	120	Deck open spandrel arch	double single-cell box ribs
11	No.2 Hechuan Fujiang Bridge	1996	Chongqing	120	Deck open spandrel arch	Double-boxes ribs

3 DEFECTS SURVEY OF RC RIBBED ARCH BRIDGES IN CHINA

One hundred existing reinforced concrete ribbed arch bridges are surveyed generally for structural type, parameters and service status. Based on it, 49 bridges of this style build in various time, place and environment, are investigated in detail on site, which have typical defects in areas of Sichuan, Guangxi and Chongqing. The structural parameters, defect characteristics, video and photo information are recorded. According to that information, the disease characteristics and rules are classified and summed up.

3.1 Typical diseases of arch ribs

(1) The overall stiffness of ribs is weak, and load cracks accrued in the bottom of spring and vault;

(2) The concrete of hinge joints between ribs is not dense, or transverse connections is unreliable, resulting in asymmetry deformation of arch ribs and shear cracks appeared on transverse beam under heavy or one side loads;

(3) The pouring of concrete of ribs or transverse beams are not so good, that apparent quality defects have revealed, such as cellular surface, holes and steel bars exposed and corrosion;

(4) Deformation of steel members inside concrete is inconsistent with concrete leading to longitudinal cracks along top and bottom of arch ribs;

(5) The concrete between rib segments or new and old structures are not dense，and brings to cracks of concrete joints, steel members exposed and corrosion.

Figure 5 : Cracks and peeling of concrete on arch

Figure 6 : Broken arch ribs

Figure 7 : Water seeping on ribs

Figure 8 : cracks and water seeping on springing

3.2 Typical diseases of spandrel construction

(1) There are horizontal cracks on midspan of deck slab and longitudinal cracks along prestressed tendons, because of small deck section, low stiffness, thin protect thickness, and not dense concrete;

(2) Joint between deck slabs are damaged, then sudden deflection of slab happens under traffic loads. Especially damages occur generally on bridge deck slab, which is placed transversally, such as slab working separately, cracking and broken;

(3) Pillars on the arch are installed with error, such as eccentricity and incline. The pouring of concrete of pillars and bent cap are not so good, that apparent quality defects have revealed, such as peeling, holes and steel bars exposed and corrosion;

(4) Asymmetry deformation of arch ribs leads to shear cracks on the connection with pillars and bent cap. The bend cracks appear on bent cap in positive moment area in midspan and minus moment area on the top of pillars.

Figure 9 : pillars on the arch installed with error

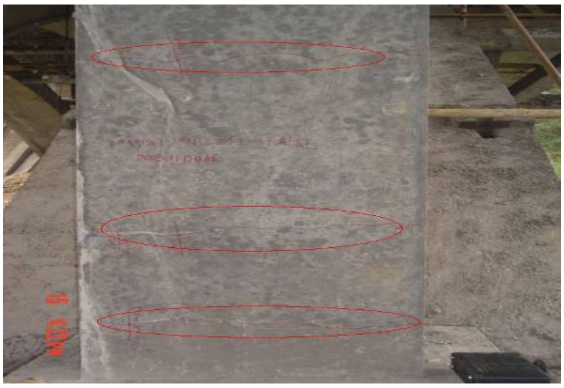

Figure 10 : horizontal cracks on pilars

3.3 Typical diseases of skewback, abutments and foundation

(1) Asymmetry deformation of arch ribs or sedimentation of foundation leads to cracks and crushing on skewback and foundation;

(2) The concrete of foundation cracks, seep water and expose steel bars, because of wash out and erode or poor construction quality;

(3) sidewalls and conical slope swell, crack and sink after absorbing water for the reason of drain destroy, compacting shortage or poor masonry quality.

Figure 11: cracks and water seeping on skewback

Figure 12: sink and crush on conical slope

3.4 Other typical diseases

(1) Unequally force leads to rubber bearing slope, distortion and cracks. Some of bearings are dislocation,moved and lose even;

(2) Diseases on deck pavement are ubiquitous, such as cracks along deck slabs, continuous deck area on simple- supporting structure, and abrasion or crush close to expansion joint;

(3) Some of RC ribbed arch bridges vibrates obviously, especially when heavy traffic load pass.

Figure 13 : Bearing dislocation

Figure 14 : Deck crush close to expansion joint

4 ANALYSIS ON REASONS OF DISEASES

The working status of R.C. ribbed arch bridges connected closely with every aspect of design, construction, maintenance or management. The reasons of diseases are analyzed from these aspects as followed.

4.1 Reasons of design

Some of arch bridges, especial old bridges conform to old version standard with low load rank. Not giving full consideration to durability, not evaluating development speed of traffic correctly or limited by cost, security capacity of rigidity and intensity of bridge design is low. For this reason, bridges have light weight, small rigidity and week transverse connection, which cannot meet the growing need of traffic load. From the investigation data, diseases appeared commonly on highway bridges with light structure.

Old design of arch brigs adopts 2D beam models, with simplifying 3D problem as 2D problem with method of transverse distribution of load. If there is a great deal of difference between calculation model and practical structure, improper structure and steel bars arrangement designed. Insufficient consideration for different quality of construction control results in low capacity of protection layer thickness of steel bar. Not exact calculation of foundation deflection and continuous arch effect, and unsuitable choice for safety factor reduce safety capacity and durability of arch bridges.

Bridge deck slab with transversal placed are not reasonable. All deck slabs hold loads together with post-poured joints, and post-poured joint is destroyed easily when heavy load passed and slabs sudden deflect frequently. Therefore, deck slabs hold load separately resulting in diseases growing of slabs after joints invalid. Moreover, traffic loads transfer from deck to pillars and arches finally.

4.2 Reasons of construction

The working status of arch bridges is closely related with construction management, technology and quality control. Some problems lead to internal damages and hidden dangers for safety, such as followed: The quality of raw material is not good. Construction sequence and schedule are not reasonable. The technique of concrete pouring, curing, and mold removal is not suitable. Joints concrete between rib segments is not dense. Protection layer thickness of steel bar or steel frame is too thin or too thick. prefabricated components are installed error. Temporary support is removed too early. In addition, deformation of template or support is excessive.

4.3 Reasons of maintenance

Maintenance for bridges are not received enough attention yet. Maintenance after disease appeared even deteriorated are cost more and effect worse than preventive maintenance. Moreover, due to shortage of technician and funds, maintenance works mostly aim at members on the top of deck, such as deck pavement, water pipes and rails. The members under deck are ignored sometimes, so diseases on major structure found and dealt with not in time. Because of that, diseases grow and bring to other disease, even collapse. And not reasonable strengthen measure may result in new diseases happened, because of former structure destroyed and self weight increased.

4.4 Reasons of management

Management department supervise not strictly for traffic limitation in weight, speed and wide, so that bridges are overloaded. Frequent overloads make bridges in status of high stress, and safety capacity and durability reduced. Furthermore overloading brings about arch ribs large distortion, transverse beam cracks, wholeness disrupted, and structure destroyed.

Some of signs for navigation or traffic are not so clear that boats and cars crash to bridges. The crash accident leads to cracks and even collapse if seriously.

5 CONCLUSION

Based on general survey on 100 reinforced concrete ribbed arch bridges, 49 bridges from those with typical defects in areas of Sichuan, Guangxi and Chongqing, were investigated in detail on site. The firsthand information about defects is acquired, and meanwhile their characteristics and rules are classified and summed up. After that, reasons for defects occurrence are analyzed from aspects of design, construction, maintenance and management. The analysis result is expected to provide scientific, objective basis for improvement of design and construction for new bridges, and maintenance and rehabilitation for old bridges.

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