

Stone arch bridges in Fujian, China

Z. Ou

Department of Civil Engineering, Fujian University Of Technology, Fuzhou, China

B. Chen

College of Civil Engineering, Fuzhou University, Fuzhou, China

ABSTRACT: A historic review with some typical examples shows that stone arch bridge has long history and high techniques have been achieved in Fujian Province, China. From statistics it is found that more than half of the bridges in local highways are stone arch bridges, which still take an important role in the road system. More than half of them were built in 1960s and 1970s, 71.1% of them have a length short than 30m, 73% of them can not satisfy the present design live load. These bridges are in different service levels now by aging. Though many ancient stone arch bridges are still in service and can withstand loads much greater than those travelling over them when they were built. However, all of them required proper maintenance and many of them need repair or reinforcement in time.

1 HISTORIC REVIEW

Fujian Province is situated along China's south-eastern coast, occupies an area of 121, 400 square kilometres, with a population of 34.71 millions (March 2001). Fujian is known as "south-east mountainous state" for it has about 80% mountainous terrain. Roads often have to cross over rivers, streams or ditches in the stone rich area, resulting numerous stone arch bridges have been built through the history.

The extant oldest stone arch bridge is the Long-quan Bridge, located in Fuzhou, built in 710 for a road to a temple (Fig. 1). The bridge was made just of a curved stone without abutment or pier. The stone has a length of 3.3m, width of 1.1m and depth of 0.3m.

Another famous ancient stone arch bridge is Jin-ao Bridge (Fig. 2), also located in Fuzhou to a temple, built in Wu Dynasty (907 ~ 959) and rebuilt many times in history. The extant bridge was rebuilt in 1763 (Lin 2004).



Figure 1: Long-quan Bridge.



Figure 2: Jin-ao Bridge.

Fujian ancient stone arch bridges have achieved high prestige in China for thin ring stone arch bridge. Xiao Bridge built in 1470 (Fig. 3) has a clear span of 7.2m, but the arch rib is just 20cm in depth, only half depth of a normal arch. The bridge located in a main street of Fuzhou city, after about 600 years, still can withstand its self-weight and the present-day traffic, much heavier than envisaged when they were built.

Gao-po Bridge is another thin ring stone arch bridge, located in Yongding, built in 1477 and rebuilt in 1775 (Fig. 4). The bridge is 60m in length with the span of the arch measuring 20m with a width of 7.5m in deck. The semicircular arch has 15m in rise and is composed of strip stone without adhesive material, only 60cm in depth. As a part of a local road, the bridge withstands current traffic loads much greater than the travelling over it when it was built.

These thin ring stone arch bridges are filled spandrel arches. The space between the deck and the arch were not filled with earth retained by side walls, but with strip stones or aggregates. These filled materials were bonded together by a special adhesive material, which may be a compound of black sugar and a special cooked rice etc, because there was no cement at that time. No spandrel side walls were needed for these arch bridges. The collaboration of the spandrel fillings to the arch ring can increase its useful ring depth, allow for large carrying capacity on very small depth arch rings.



Figure 3: Xiao Bridge.



Figure 4: Gao-po Bridge.

There are many stone arch bridges with several spans still existing. The largest one is the Yong-an Bridge in Wuping (Fig. 5). Its first construction time is not clear now. It was rebuilt in 1824 and 1884. The total length of the bridge is 114m. It has 7 piers and 8 spans with a normal span of 10.9m and width of 3.7m. The piers and arch rings were made of strip stones.



(a) Full view of the bridge.



(b) Local view of the pier.

Figure 5 : Yong-an Bridge.

Many ancient stone arch bridges are covered with houses. Fig. 6 is one of the lounge stone arch bridges—Shuang-hong Bridge with a sharp diversion in the pier facing the stream direction. The houses on the bridge serve as not only resting place for travelers but also a public place for villagers talking, trading and religion activities. The Gu-cuo Bridge in Jiangle shown

in Fig. 7 is a stone arch bridge of about 400 years with a beautiful lounge, harmonic to its environment.



Figure 6 : Shuang-hong Bridge.



Figure 7 :Gu-cuo Bridge.

Stone arch bridges also been built in personal or public parks. Zhao-jia-bao Bridge (Fig. 8) located in Zhangpu County was completed in 1600, with a combination of stone arch and pillars. It is 22.3m in total length with the span of the largest arch measuring 4.3m. There are two stone arch bridges in the famous public park—West Lake Park in Fuzhou, one with five spans and the other with three spans (Fig. 9).



Figure 8 : Zhao-jia-bao Bridge.



Figure 9: West lake park bridge.

Stone arch bridges had been built in a large amount even in the last century especially in 1960s-1970s under the necessary of highway construction but short of steel and cement and cheap of labours because of the undeveloped industry at that time.

The Yang-kou Bridge (Fig. 10), spanning the Futun River at Shunchang, is the longest stone arch bridge in Fujian province, with the total length of 363m. The structure, which has total width of 6.5m, consists of nine equal spans of 34m, with a relatively low rise of 6.8m. This bridge is built of block-stone, with an arch ring thickness of 90 cm. The highway practically bears on the extrados at the crown, resulting quite slender and graceful structure.



Figure 10: Yang-kou Bridge.

The Jin-shan Bridge (Fig. 11), completed in 1972 and located in Hua-an County, with a span of 99m, is the longest span stone arch bridge in Fujian Province. Its total length is 106.65m. It is a hingeless arch with a ring depth of 200cm.



Figure 11 : Jin-shan Bridge.

From 1980, thank to the policy of reform and opening to the outside world, development of economic improve the structure material supply, various RC, PC, steel and composite bridges have been built in Fujian Province. However, there are still some stone arch bridges built as highway bridges or foot bridges, Fig. 12 and Fig. 13 are two stone bridges designed by the second author of this paper in 1990s in An-xi County and Ming-xi County, respectively.



Figure 12 : Xian-dong Bridge.



Figure 13 : Ri-yue Bridge.

2 STATISTICS ONE THE STONE ARCH BRIDGES IN HIGHWAYS

The Chinese Bridge Management System (CBMS) is used for those bridges in highways (not including expressways) under supervision and management of the Municipal Highway Bureau of Fujian Province. In order to establish this system, a bridge investigation has been carried out and the basic data has been obtained. From CBMS in Fujian Province, there are 1936 stone arch bridges still in service in local highways, accounted for 52% of the total 3729 bridges by the end of 2002 (Zheng R.Q, 2004).

From Fig. 14 it can be found that many stone arch bridges were built in 1960s, 1970s. Statistics shows that 1152 of the bridges in service were built in these two decades, accounted for 60% of the total. The maximum age difference is 227 years between the completed year 1775 of the oldest one Gao-po Bridge (Fig. 4) and the completed year 2002 of the newest bridge Xiaoping II Bridge. The majority of the bridges are 30 to 40 years or older.

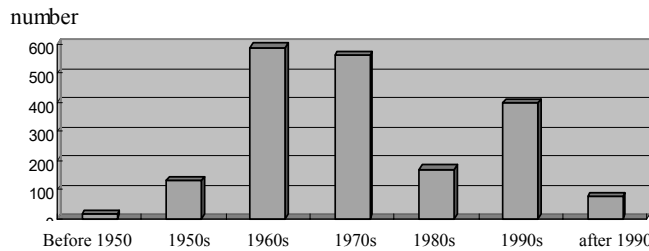


Figure 14 : Year of Construction of stone arch bridges in Fujian Province.

According to Chinese General Code for Design of Highway Bridges and Culverts (JTJ 021-85), highway bridge can be divided into four types as listed in Table 1.

Table 1: Bridge type by length

Bridge Type	Total length L/m	A span L_0 /m
Extra large bridge	$L \geq 500$	$L_0 \geq 100$
Large bridge	$100 \leq L < 500$	$40 \leq L_0 < 100$
Medium bridge	$30 < L < 100$	$20 \leq L_0 < 40$
Small bridge	$8 \leq L \leq 30$	$5 \leq L_0 < 20$

The statistical distribution of the stone arch bridge types is shown in Fig. 15. There is no extra large bridge and only 68 large bridges accounting for 3.5%. Small bridge represents the majority of the stone arch bridges, 1376 bridges (accounting 71.1%) of bridge lengths are short than 30m. There are 493 medium span bridges whose length are between 30 and 100m, 25.4% of the total.

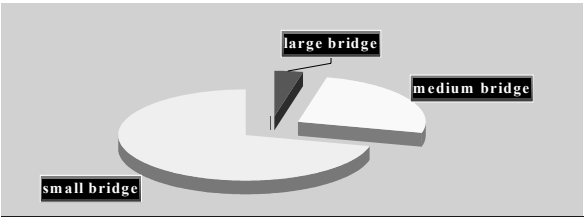


Figure 15 : Types of stone arch bridges.

In Chinese old General Code for Design of Highway Bridges and Culverts (JTJ 021-85), there are four levels of design traffic loads: truck-extra 20 and trailer-120; truck-20 and trailer-100; truck-15 and trailer-80; as well as truck-10, track-50.

According to statistic (Fig. 16), there is no bridge designed in the truck-extra 20, trailer-120; among the 1936 highway stone arch bridges in service, only 528 bridges can service for the load standard of truck-20, trailer-100, accounting for 27%; 815 bridges are designed to meet truck-15, trailer-80, accounting for 42%; 593 bridges' design load is equal or even under truck-10, track-50.

In the new General Code for Design of Highway Bridges and Culverts (JTG D60-2004), Highway I and Highway II are employed as the two design live loads, in which both the design lane loading and design truck loading are used instead of only truck loading in the old one. The live load level of Highway I and Highway II correspond to the original truck-extra 20 and truck-20, respectively. Therefore, only 27% of the existing stone arch bridges in Fujian Province can

meet the requirement of the new Chinese design code TG D60-2004 (most of them were built after 1990), 73% can not satisfy the present design live loads.

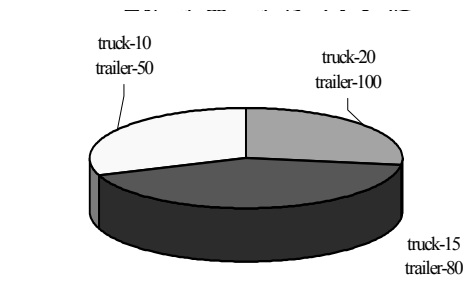


Figure 16: Proportion of load levels of stone arch bridges in Fujian.

3 CURRENT SITUATION AND ASSESSMENT

Stone arch bridge is a kind of structure which is by nature strong. From the previous introduction, it can be seen that many ancient stone arch bridges are still in service and can practically withstand loads much greater than those travelling over them when they were built, which shows that they have inherent reserve strength. After strengthening or reinforcing, they can even have an imaginable carrying capacity. Jiangkou Bridge is an example.

Jiang-kou Bridge in Putian, Fujian, is a multi-span circular arc arch which is divided into two bridges by an isle in the center of the river. These two bridges have 10 and 8 arches with a span about 10m, in which the maximum are 10.3m and 11.7m, respectively. The main arch ring is made up of grouted roughly squared stone whose depth is 40cm. There are vertical cracks on one abutment and a 1.5cm width crack in one main arch ring. A spandrel arch crosses each pier with a span of 2.5m. The clear width of the bridge deck is 4m.

A main transformer with 50 thousand kV which is carried by TG2000 tractor and SGT17.15 slab trailer should go across the bridge. The weight of tractor is 31.4t and that of trailer and transformer is 110t, which obviously exceed the original design live load, i.e., Vehicle-13 (t), Track-60 (t).

In order to pass this heavy traffic load safely, the spandrel arches are filled with stone to form a filled spandrel arch and consolidating the span which had cracks by using scaffolding. Utilizing load optimization concept to arrange the automobile team, the 50MVA main transformer past through the bridge successfully, as shown in Fig. 17 (Zheng Z 2004).



Figure 17: 50MVA main transformer past through the Jiang-kou Bridge.

Although stone arch bridge is a bridge type has much greater resistant capacity and requires very little maintenance compared to other bridge types, however, as time goes by, these bridges are in different service levels now by aging.

Most of the stone arch bridges in Fujian Province can be considered substandard in one or another: functionally obsolete, structurally deficient or very commonly both. Functionally obsolete generally caused by their dimensions or geometry. These bridges may be candidates for widening programs, reconstruction to modern standards, or replacement.

The current structural conditions of these stone arch bridges vary from good to very bad. The common structurally deficient are as follows: bulging of the spandrel walls, collapsing of the spandrel walls, scouring of the foundations, and the development of longitudinal cracks in the arch barrel, piers and abutments etc. Some of these bridges in a bad condition with a tendency for accelerated deterioration had better be replaced by new bridges. Most of them after reinforcement, strengthen or rehabilitation can be brought up to standards essential to a safe and effective road system.

At the present time, many new technologies have been applied in the reinforcement of stone arch bridges and have achieved obvious effects, such as adding reinforced concrete arch to the stone arch, placing reinforced concrete hoop, and setting pre-stressed anchor and mud pressing etc.

Taking Mao-cuo-xiang Bridge as the example, its reinforcement is introduced. It is located in 316 National Highway, completed in 1994. It is 8.5m wide, has a main span of 13 m, a rise of 6.8m. The arch ring has a depth of 60 cm.

According to visual inspection in the spot, the foundation of piers and abutments is steady in the Mao-cuo-xiang Bridge, but cracks appeared in the arch ring and water infiltrated here and there, the deck pavement has fractures and cracks. The main arch ring was enforced by adding an reinforced concrete arch under the original arch ring. The bridge under and after reinforcement is shown in Fig. 18.



(a) Under reinforcement



(b) After reinforcement

Figure 18 : Mao-cuo-xiang Bridge.

4 SUGGESTION FOR FUTURE MAINTENANCE ISSUES

At the end of 2002, the highways in Fujian Province have a total length of 54,155 km, in which 582km are expressways, 279km are first-grade highways, 5,573km are second-grade highways, 3,600km are forth-grade highways, 12,935km are non-graded highways. The density of highways is 44.6km/100s.k, ranking the top tenth of the whole country. The present highways are consisted of 5 national highways (G104、G205、G316、G324、G319), 17 provincial main highways (5,522km) and country highways (12,578km) .

In the expressways and first-grade highways as well as most of the second-grade highways built in the last decade, there are few stone arch bridges. However, in many local highways stone arch bridge is still a notable group of structure and still takes an important role in the road systems in spite of their advanced age. However, long service time and poor conditions and traffic increasing made more and more harm to these extant stone arch bridges. Though an investigation has been carried out by Municipal Highway Bureau of Fujian Province, however the current inspection is limited to visual inspection except geodetic and simple tests for those bridges in bad conditions. Therefore a further and detail inspections for each bridge should be conducted to obtain their fundamental qualitative information. After that an overall study on evalu-

ating these bridges to know their maintenance requirement, a plan of systematic maintenance and rehabilitation should be made and carried out.

Highway maintenance fund should be improved. More money and manpower should put on inspections on stone arch bridges, including routine inspections, periodical inspections and special inspections. For those stone arch bridges in bad conditions by the investigation, they had better be reinforced or rebuilt in time. If it is not possible to do that immediately for short of investment, they should be monitored by setting up permanent observation points for pursuing their deterioration. Meanwhile, traffic load and speed should be limited and controlled in a reasonable range to prevent vehicle accidents and bridge damages.

On the other hand, it is seen that after decades of service, most of these bridges have a comparatively stable foundation, and stone arch bridges themselves have inherent reserve strength. The maintenance and repair experiences on stone arch bridges should be summarized to make remedial efforts for most of the bridge in good or medium conditions range from relative minor repairs and protective measures to major reconstructions and replacement in the future.

Experiments show that proper maintenance and early reinforcement measures can maintain or improve bridge service level effectively and more than one third of the fund will be saved. Therefore in maintenance of bridges, reinforcement must be taken into account firstly while reconstruction acts as secondary measure. And respective long-term and medium-term plans must be made and carried out step by step to improve the whole service levels of these existing highway stone arch bridges in Fujian Province.

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