# THE MOST BEAUTIFUL LIGHT STONE ARCH BRIDGE IN ZHANGJIAJIE CITY OF CHINA

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## SUMMARY

Stone arch bridge is a brilliant pearl of the five thousand years civilization of China. There are more than 70 light stone arch bridges at the Zhangjiajie city which is the world's famous scenic spots. Many important innovations and developments have been achieved in the stone arch bridge technology since 1980. The ribbed slab stone arch bridges have been created based on the new design theory of "plane-hinged" which brings a benefit of saving 30% of the masonry work. It also makes that the traditional stone arch bridges have a brand-new outward appearance. In this paper, a case study of the Guanyin Bridge (the span 4×52 m) is presented. The paper aims at innovation andthe structural characteristics of light stone arch bridge.

**Keywords:** *Light stone arch, ribbed slab arch ring, all open spandrel continuous arch, two plane-hinged arch.*

## 1. INTRODUCTION

China is a large country with long history of application of arch bridge and has achieved high prestige in the world. Because of vast territory with many networks of rivers, the Chinese nation has erected thousands of stone arch bridges. Thousands of ancient stone arch bridges still exist and work nowadays. The Zhaozhou Bridge in Hebei Province was opened in A.D. 606 by mortarless ashlars masonry. The main span of 37.5m was the longest at that time. It has the rise-span ratio of f/l = 1.52, arch ring depth of 1.02m and four symmetric open spandrels. It appeared 1000 more years earlier than in Europe. It is the largest span existing ancient stone arch bridge in the world [1].

In 20th century, the arch bridge still held the leading role with its great variety and large magnitude, especially in country road bridges. Because of cheap cost in labour and material, stone arch bridges were economic to be built for a long time until 1980s. Stone arch bridges were adopted widely in country highways of hilly or mountainous areas in 1950-1970s. In the recent 30 years, despite of the fact that more modern PC girder bridges, cable-stayed bridges and suspension bridges are used as solutions for long span bridges, stone arch bridge is still a structural type of large actuality and application to modern construction technologies in China.

***Fig. 1.*** *Guanyin Bridge in Zhangjiajie.*

We have built more than 70 light stone arch bridges in Zhangjiajie city of China. We also have made many new achievements which will be introduced briefly in this paper. The Guanyin Bridge that is the most beautiful light stone arch bridge of Hunan Province in China will be discussed in detail. (Fig.1, Fig. 2)

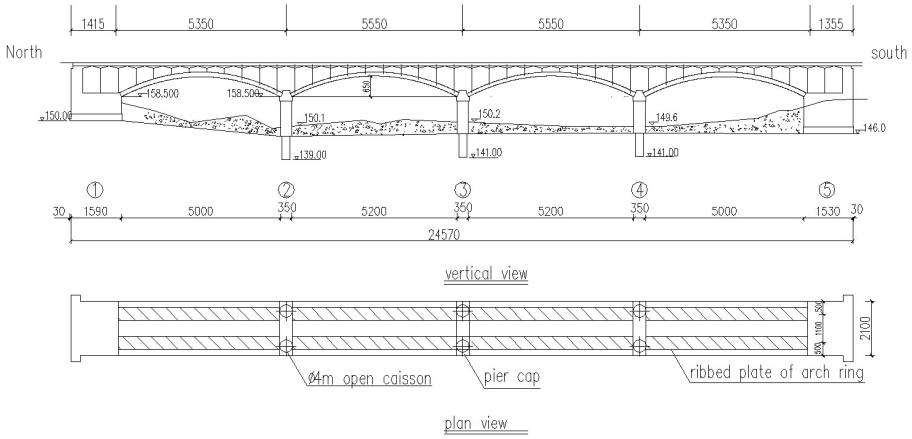



***Fig. 2.*** *Layout of Guanyin Bridge.*

## 2. SOME INNOVATION AND STRUCTURAL CHARACTERISTICS OF GUANYIN BRIDGE

### 2.1. Hollow pier with open caisson [2]

The traditional foundation of stone arch bridge is stone or masonry piers with spread foundation. It has huge volume and large area of water resistance. The innovation way is to use large diameter open caisson through the gravel layer. When the open caisson embed into impervious red sandstone, the large diameter hand-excavated pile was constructed. The foundation of Guanyin Bride was composed of three parts that is pile, open caisson and hollow pier. The pier diameter is 3.5 meters. The open caisson diameter 4 meters. The hand-excavated pile diameter is 2.5 meters. The masonry volume of

combined foundation decreased about 50% of lower part of the structure. The method of Guanyin Bridge was rapidly generalized around Hunan Province. The Yuanshui Bridge in Taoyuan with main span of 100, that hand-excavated pile diameter is 6 meters.

### 2.2. Ribbed slab stone arch bridge

The main arch ring of the traditional stone arch bridge is rectangular cross-section slab. It has large volume and heavy work of arch construction. The ribbed slab stone arch bridge was built firstly in Huaihua Region, Hunan Province, in 1978. It kept the traditional slab as the bottom part of the ring with ribs as its upper part which will be laid after the ring been completed. This cross-section provides a much larger rigidity and rubble stone laid with micro-aggregate concrete may be applied. During designing with the new method mentioned above it is seen that the buttress above the ring bears vertical load mainly and required somewhat small rigidity only. Its thickness could be reduced about on half as to 0.4~0.5 m, and the aim of lightening be realized. The masonry work of the superstructure could be saved 30%. Its cost is also saved 32%. About 200 such lightening stone arch bridges have been built in our nation.

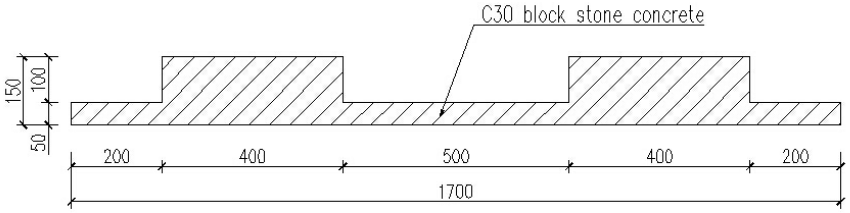



***Fig. 3.*** *Cross-section of main arch ring, Guanyin Bridge.*

The main arch height of the Guanyin Bridge is 1.5 meters. (Fig.3) The floor height is 0.5 meters. After the floor arch ring closure and concrete strength reached 50%, another masonry rib of 1.0 meters height was constructed. It should be noted that, to reduce the cross-section area of the main arch ring, light superstructure and teamwork should be considered .the teamwork between spandrel arch and main arch ring can reduce the live load stress.

### 2.3. All open spandrel light stone arch

We can get seven innovation by measures and some loading test. (1) The ribbed slab cross-section of the arch ring. (2) The spandrel all-opened with multi-arches through the whole span length. (3) The buttresses of the open spandrels composed by “wide coping on narrow wall”. (4) The substructures by column pier and combined foundation of large diameter piles with variable cross-section (caisson and digging pile). (5) The composite abutment with a front part same as the pier and a back part of hollow box with expanded foundation. (6) Designed by two plate-hinged theory as mentioned below. (7) The arch ring of open spandrel considering the co-operation with its protecting course designed as a triple-plane hinged parabolic arch. A new hybrid generation of stone arch bridge is named the all open spandrel light stone arch bridge. See Fig. 5, 6. It can save 30% masonry work comparing with the traditional ones.

In 1995, the Guanyin Bridge, Zhangjiajie, a 4×52 m ribbed slab stone bridge designed by Hunan Highway Design Company, held a multi-arch spandrel 43×5 m = 215 m, the longest all-open spandrel so far in China (Fig. 4).

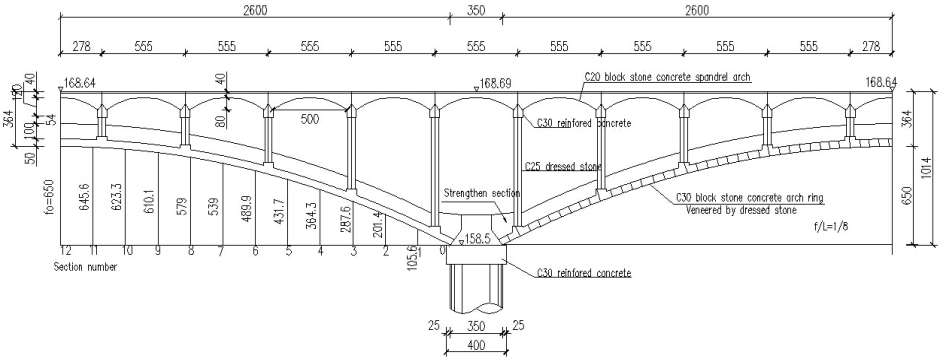
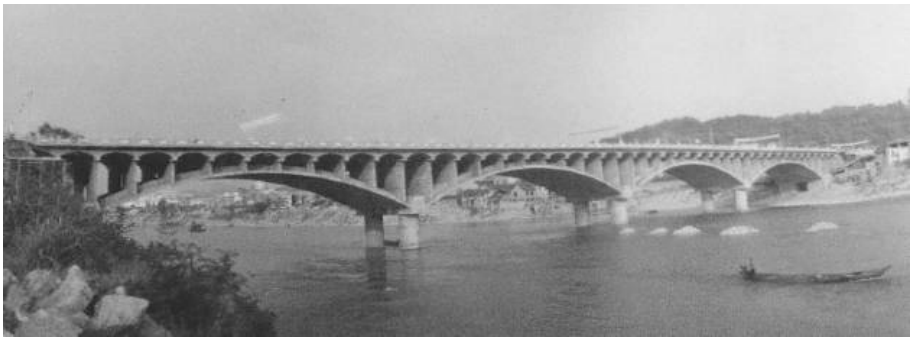


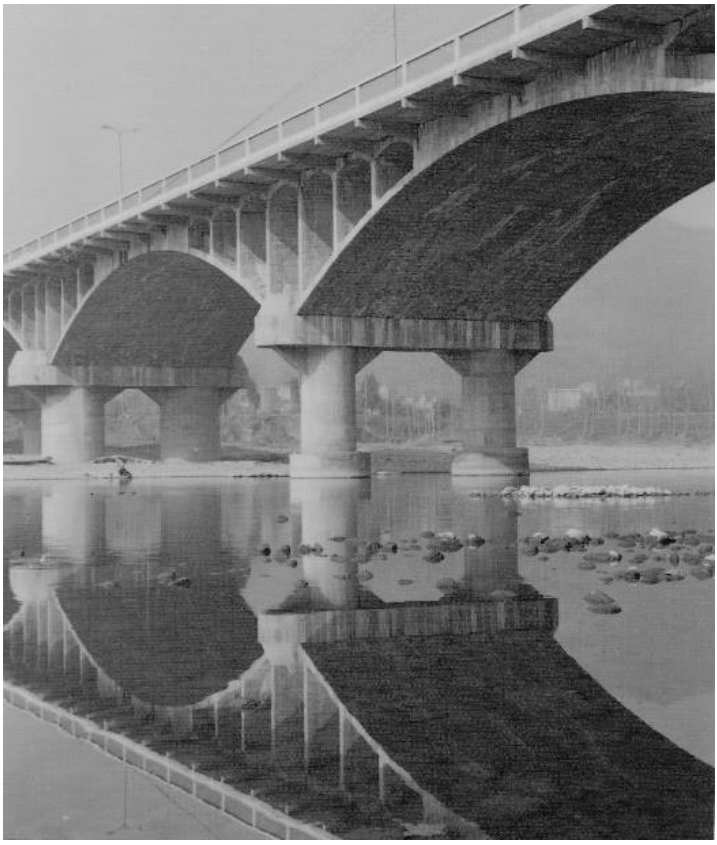

***Fig. 4.*** *All open spandrel light stone arch, Guanyin Bridge.*

In addition, the large diameter digging piles are introduced as twin column pier for Lusiwan Bridge (6×48 m), Zhangjiajie County, which promoted a new type substructure of compositing pile foundation by "caisson (Φ4 m), digging pile (Φ2.5 m). The twin column pier (Φ3.5 m)" had been carried out in Guanyin Bridge (4×51 m). The twin column pier by RC changed the bulky appearance of the substructure of old stone arch bridges. Moreover, in Guanyin Bridge the cantilevered RC coping of the buttress hangs out as well, which results the whole spandrel arches hangs out as well, while the precast foot walk units hang out from the spandrel arch 1m more. (Fig. 5, 6) [3].

***Fig. 5.*** *Guanyin Bridge with coping of buttress, spandrel arch ring cantilevered 2×1 m each, (2Φ3.5 m hollow pier).*



*a) Lusiwan Bridge with cantilevered PRC beam for the deck structure, (2Φ3m-2Φ5m digging pile)*



*b) Guanyin Bridge with precast foot walk until cantilevered 2×1 m from the spandrel arch moreover, (2Φ4 m/2Φ3.5 m caisson digging pile)*

***Fig. 6.*** *The lightening of both substructure and deck structure.*

## 3. ACHIEVEMENTS OF GUANYIN BRIDGE

The Guanyin Bridge adopt all characteristics of light stone arch bridge. There are non-pile cap hollow pier spread foundation, ribbed slab stone arch ring and all open continuous spandrel light stone arch. It can save 30% masonry work comparing with the traditional ones. It represents the highest level of light weight design and construction of Chinese traditional stone arched bridge.

Majestic beauty of Tianmen Mountain and slender light stone arch bridge, is one of the most beautiful scenic spots in Zhangjiajie City. Highway Design Company of Hunan Province and East China Jiaotong University cooperate to design more than 70 ribbed slab light arch bridges in Zhangjiajie. The compilation of 《span 20-80 meters Standard drawing for ribbed slab light arch bridges 》 was accomplished. The software SAB (stone arch bridge) are also developed that aim to structure analysis theory of "plane-hinged". We glade to provide it for your reference design. Through mutual Communication and learning, we believe that Chinese ribbed slab light stone arch bridge, the bright flowers of science and technology, will move toward the world.

## REFERENCES

[1] WANG BO-HUI, *Selection from Wang Bo-hui's paper*, The people's communication press, Beijing, 2004.

[2] SHANG GUAN-XING, Research report of the light stone arch bridge reforms, *Communication of Highway Engineering*, Vol. 31-34, Changsha, 1983.

[3] B.H.WANG, S.D.TANG, G.X.SHANG, *The heritage and development of the stone arch bridge in China*, *6th International conference on arch bridges*, Fuzhou 2010, pp. 234-242.