Study on the wooden arch structure of Gansu Weiyuan Baling Gallery Bridge

Enyong Wang
Lanzhou City University, Lanzhou, China

Jie Liu and Yuxia Hu
Shanghai JiaoTong University, Shanghai ,China

Yurong Hao and Xingjia Chong
Lanzhou City University, Lanzhou, China

ABSTRACT: This paper makes a research on the wooden arch structure of Gansu Weiyuan Baling Gallery Bridge and tries to find out the rationality of inclined overlapped cantilever beam towards the arch top of the bridge on loading and the approximate rational arch axis. The relation between the approximate rational arch axis and the approximate compress line of dead load is discussed, and some suggestions about how to achieve a reasonable arch axis for the bridge are given.

In 2009, Enyong Wang studied the development of Gansu Weiyuan Baling wooden gallery bridge， which argued that it plays an important part in the development of our wooden gallery bridge. This article focuses on the mechanics of the Baling wooden gallery bridge.

1 BALING WOODEN GALLERY BRIDGE'S STRUCTURE

The wooden arch structure of the stacked beam-arch bridge, firstly founded in A. D. 1032-1033, is totally unique in the history of bridges. The invention of stacked beam-arch structure is intersecting with large wooden crossbar, creating a construction technology with shorter span of timber to build a larger bridge.

Gansu Weiyuan Baling Wooden Gallery Bridge (Fig.1) originated from Lanzhou Wo (grip) Bridge (Fig.2). 40 meters long from the north to the south, 15.4 meters high, 4.8m wide, the entire bridge with the arch 29.5 meters is divided into 13 sections, with 46 columns altogether. The deck and the bottom side of the bridge are 5 layers with 10 thick logs at each side from the pier to the bottom of the cross-strait successive delivery level, which is parabola-like. There are two sideways at each side of the corridor, which is equipped with banister handrail. Bridge's top is a roof shape that cornices picked pavilion. Being a delicate spectacular wood structure, it has become a famous attraction at Wei-shui River.

Figure 1: Weiyuan Baling Gallery Bridge

Figure 2: Lanzhou Wo Gallery Bridge

Baling Gallery Bridge is a tilted stacked girder arch bridge with a more beautiful shape than the Flat stacked Girder Arch Bridge of Muli (Fig.3), whose carrying capacity is stronger, and flood discharging capacity is better.

Figure 3: Structure of Flat Stacked Girder Arch Bridge of Muli in Sichuan Province, China.

2 MECHANICAL ANALYSIS OF BALING GALLERY BRIDGE

Baling Gallery Bridge's Structure is shown in Fig.4. The upper and lower (layer) beams are interspersed by cross beams (a, b, c, d, e points as shown in fig. 4), which plays a supportive role and passes the burden of the upper beams to the lower ones.

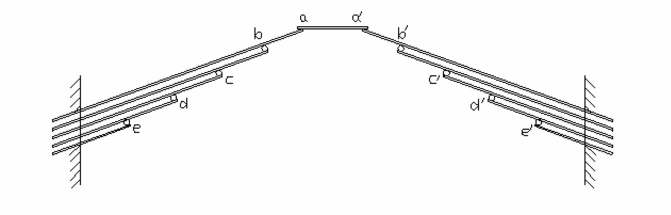

Figure 4: Structure of Oblique Stacked Beam Arch Bridge of Baling

Stressed components of the bridge are shown in Fig.5. As can be seen from Fig.5, each inclined beam of it is cantilever beam. The beam on the top bear firstly the load N from simple beam, and N can be decomposed into contributing Nt along the axis and Nn perpendicular to the beam. Nt makes the beam compressed, and Nn the beam bent. The contributing force is definitely smaller than the original N. Or, the Force N has already been partially converted to the pressure along the axial direction. This is the first reason that oblique stacked beam-arch bridge is more scientifical and rational than the flat stacked beam-arch bridge. We all know that logs not only have good bending ability, but also have a strong compression capability. This inclined arrangement also makes full use of peculiarity of logs as anisotropic materials. Its lower oblique beams have given their additional supportive forces P1, which makes deformation greatly reduced, and carrying capacity better. P1 is actually passing it to the upper start of the lower beams.

Following the process, lower beams are only subjected to bending force P1、P2、P3、P4、P5. This is the transfer route for loading. The statics problem of oblique cantilever beam is a statically indeterminate problem, and additional equations to be solved need looking for deformation of the coordination of conditions, which can probably be concluded: P5> P4> P3> P2> P1>N_n, namely the bending force gradually is increased. As a result, P5 is actually greatest.

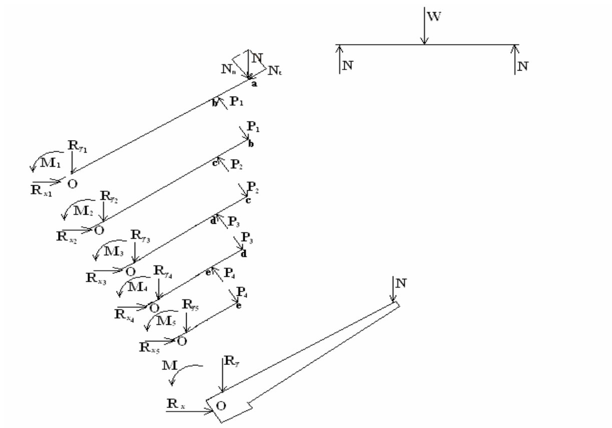

Figure 5: Components Subjected to Loads of Oblique Stacked Beam Arch Bridge of Baling

To some extent, half of the arch serves as an equal strength cantilever beam shown in the lower part of Fig.5, which is very similar to the structure of modern trucks' leaf springs. What's more, this stacked structure of the simulated equal strength cantilever beam shape can strengthen the ability to fight a shock of the load of the bridge.

For the entire arch, because its arch feet are thrust, from the mechanical sense, it is an approximation of the mechanics arch. We know that arch has better mechanical properties than the flat beam. Moment on the arch cross-section is less than the corresponding simple beam. It can carry a larger payload. The polyline composited from the various stacked beams contact points of e, d, c, b, a and its symmetrical points can be seen as the approximation axis of the arch, just like a Chinese character "八 " (means eight), as shown in Fig.6.

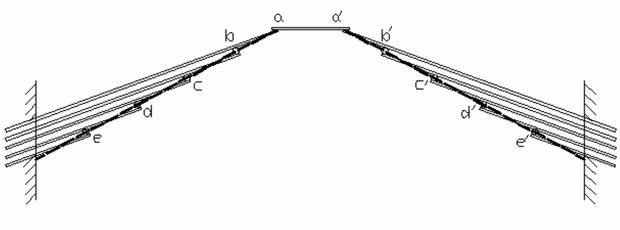

Figure 6: The Arch Axis of Oblique Stacked Beam Arch Bridge of Baling

Moreover, the arch can also be approximated as a three-hinged arch. Under the action of full cross-uniform load (bridge jammed with people), the reasonable arch axis (no moment) of three-hinged arch is a parabola. This approximation arch axis is closer to the parabola axis. In the boundary of Jiangsu and Zhejiang Province, China, the structure of existing wood arch bridge with arcade is basically splay arching structure (like the Chinese character 八), as is shown in Fig.7. Therefore, this is a major reason that Baling gallery bridges can be retained.

By adjusting the length of the logs standing out on each layer, we can make the connection point become a parabola, so we can get the best structure and shape of the oblique stacked beam arch bridge.

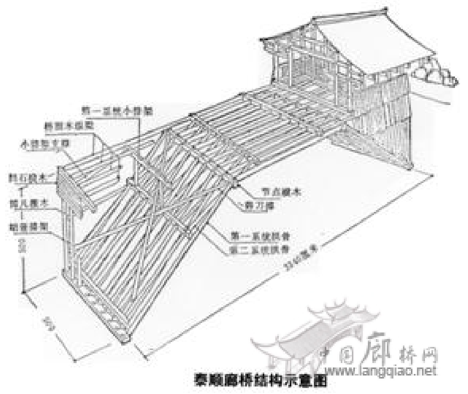

Figure 7: Diagram of the Structure of Taishun Gallery Bridge

3 OTHER PROBLEMS

The problem of contact force between the stacked beams still remains. If we find a linear contact between the upper and lower logs of the Baling Bridge, there will be a force distribution problem between the two beams. Huang Zhi-qiang analyzed it with Krylov Function, and two analytical displacement solutions and rule of distributed force between them are obtained.

As to the problem of internal stress in stacked beam, Li Xiu-lian analyzed theoretically and experimentally the stress distribution of the beam and the composite beams made up of the same materials and the experimental result further proved that the stress distribution is right. Zheng, et al. set up a model of laminated flexuous beams with rectangular cross section by taking advantage of Winkle's foundation assumption method and electric testing technique. The investigation of identical laminated beam, either free of wedges or tightened with two wedges through the interface, is carried out for the stress distribution, inner forces and load-carrying ability both theoretically and experimentally. Both theoretical analysis and experimental results show that, under the same external loading condition, internal stress in laminated beam reaches the largest level; the stress in laminated beam tightened with wedges ranks second and the stress in a beam as a whole of the same dimension the smallest.

Of course, the arch structure of the Baling Bridge is not yet an authentic arch. Even the Bian–jing Hongqiao in "Qingming Riverside" is only an improved version of the inclined cantilever of Baling wooden arch structure, which is an wooden arch structure weaved by simple beams. Actually, logs of such kind of anisotropic materials are not ideal for a real arch structure.

REFERENCES

Wang En-yong, 2009. Speaking from the Gansu Weiyuan Baling Gallery Bridge. Proceeding of the Third China International Symposium on the Roofed Bridges of Wooden Arch Structure in Pingnan County, p.214--220. 2009,10. Fujian China.

Huang Zhi-qiang, 1997. Contact Force Solution of Bending about Finite Length Congruent Form Beam, Journal of Wuhan Institute of Chemical Technology, p.75-77.1997,3.

Li Xiu-lian, 2002. Stress analysis of combination beams, Journal of Qinghai University, p.28-30.2002,8.

Zheng Bi-yu,Wang She, Zhang Ya-ting ,Li Xin-bo,2006. Stress analysis and experiment of laminated beams, Journal of Chang'an University (Natural Science Edition), p.62-65.2006,9.

Jia You-quan , 1984. Experiments of mechanics of materials.Beijing; Higher Education Press.

Liu Hong-wen, 1992. Mechanics of materials: first half .Beijing: Higher Education Press.

Sun Jian-guo,2004. Analysis and experiment of laminated beams.Mechanics in Engineering, p.74-76.2004, 26(4).