Journal of Architectural Research and Development, 2023, Volume 7, Issue 2
http://ojs.bbwpublisher.com/index.php/JARD
ISSN Online: 2208-3537
ISSN Print: 2208-3529

# Design Technology of Continuous Beam-Arch Combination Bridges

**Maozhao Yang***

China Merchants Chongqing Communications Technology Research & Design Institute Co., Ltd., Chongqing 400067, China

***Corresponding author:** Maozhao Yang, 86547186@qq.com

**Abstract:** In this paper, a research was conducted on the design technology of continuous beam-arch composite bridges. A brief introduction is given on the of continuous beam-arch composite bridges, its basic mechanical characteristics is analyzed, and three aspects of design technology is studied, which are rise-span ratio, stiffness ratio, and bridge deck cracking. This article acts as a reference for relevant design units in China to improve the design of continuous beam-arch combination bridges.

**Keywords:** Continuous beam-arch combination; Bridge design; Analysis of rise-span ratio; Bridge deck cracking

## 1. Introduction

Continuous beam-arch combination is a bridge type that is increasing in popularity in China because it is consumable-saving, adaptable to various soft soils, low in height, and diversified construction methods. Some examples of continuous beam-arch combination bridges are Xibao Bridge (completed in 2011), the Xianyang West Interchange Special Bridge, and the Guangyuan Jialing River Bridge (completed in 2012), and many more. In road and bridge engineering, the application of continuous beam-arch combination bridges is constantly increasing, and the development of transportation has also resulted in more requirements for the quality of bridges. Therefore, it is important to conduct further research on bridge design to promote the development of the transportation industry.

## 2. Overview of continuous beam-arch combination bridges

The components of a continuous beam-arch combination bridges include beams, suspenders, bridge deck systems, arch ribs, and tie beams. Each component is crucial, interdependent during the assembly stage to create beautiful and durable bridge. Among them, the arch rib of the bridge is mainly responsible for load bearing, the bridge beam is responsible for the thrust of the arch end of the prestressed beam load, the suspender and the bridge deck are responsible for the pressure bearing of the bridge in the application stage, and the bridge arch is the most important pressure bearing part. Stability directly affects the overall safety and lifespan of the entire continuous beam-arch composite bridge [1]. In recent years, with the emergence of new materials and technologies in the field of road and bridge engineering, the slenderness ratio of the arch ribs of continuous beam-arch composite bridges has been greatly enhanced. The bridges can be designed with or without wind braces, which puts strict requirements on the stability and reliability of arch ribs [2].

## 3. General mechanical characteristics of continuous beam-arch combination bridges

The continuous beam-arch combination is composed of three parts: partial components, load-bearing components, and mechanical transmission components. It belongs to a very classic ternary structure bridge. The overall structure of the bridge is stable and has a long service life [3]. Among the three major components, the arch ribs and tie beams are the main load-bearing components; the main components for live load distribution are scales and bridge decks; and suspenders and columns are mainly responsible for mechanical transmission [4]. Among them, the tie beam is not only the main live load distribution structure, but also an important load-bearing member, which will bear the most force. The continuous beam-arch combination bridge is highly similar to the continuous beam in terms of external support system. and the support part only generates vertical reaction force. Based on this feature, the force characteristics of the continuous beam can be clearly understood. Therefore, continuous beam-arch combination bridges have the following mechanical characteristics [5]. In the internal structure of the bridge, the load pressure between the arch and the beam will that balance out each other. In the external structure of the bridge, the load force will be transformed into another form of energy. The total bending moment of the beam section can be converted into the force performance of arch compression and beam tension, which can maximize the stability of the bridge after it is put into operation [6].

## 4. Design technology of continuous beam-arch combination bridges

The key elements in the design of continuous beam-arch combination bridges are the rise-span ratio, stiffness ratio, and bridge deck cracking analysis.

### 4.1. Rise-span ratio

The rise-span ratio directly affects the arch rib, the internal force value of the tie beam, and the construction method of the continuous beam-arch combination bridge. When the rise-span ratio decreases, the ratio of horizontal force and vertical force of arch rib will increase accordingly. At the same time, due to the shrinkage and creep effect of concrete and changes in temperature, the additional stress will increase as the rise-span ratio decreases. Therefore, during the design of continuous beam-arch composite bridges, it is necessary to select a reasonable value for the rise-span ratio. **Table 1** shows the internal forces of the center girder and arch under different rise-span ratios:

**Table 1.** The internal forces of the center girder and arch under the background of different rise-span ratios

| **Sagittal Ratio** | | **1/6** | **1/5** | **1/4** | **1/3** |
|---|---|---|---|---|---|
| Arch | Axial force | 6578.44 | 5565.85 | 4518.45 | 3412.75 |
| | Bending moment | 91.19 | -386.24 | -289.19 | -428.31 |
| Beam | Axial force | -6574.05 | -5557.30 | -4511.91 | -3404.11 |
| | Bending moment | -1.75 | -83.81 | -127.61 | -68.79 |

For the internal force of the structure under the action of constant load, **Table 1** shows that under the action of the continuous girder-arch composite bridge, the internal force of the structure was affected by the larger rise-span ratio, and the value of the rise-span ratio reduction was related to the axial force of the tie beam and the arch. The variation of rib horizontal thrust had the same range, that is, the range of variation = 92%. As the rise-span ratio decreased, the bending moments of tie beams and arch ribs increased; and the bending moments of tie beams increased then decreased which makes it nonlinear. The reason for this phenomenon is that under the condition of a large rise-span ratio, a small span will cause a large deviation between the reasonable arch axis of the arch rib and the parabola under the action of dead load. After decreasing to a certain value, it will gradually increase again.

In terms of internal force of the structure under live load, the value of internal force of the structure under 1/4 cross-border is assumed to be 1. At this moment, the change of rise-span ratio greatly affected the internal force of the structure under live load. With the change of rise-span ratio, the variation law of the axial force under the action of live load was the same as that of dead load, but the value was larger [7]. When the rise-span ratio decreased, the bending moment decreased then increased, while the bending moment of arch rib decreased.

### 4.2. Stiffness ratio

In terms of stiffness ratio, the balance of the horizontal force of a continuous beam-arch combination bridge depends on the longitudinal beam. The way that the beam and arch at the arch foot are placed on the support in a rigid manner allows the load to be borne by the beam and arch, which reduces requirements for the abutment, thus saving materials to a certain extent. In the continuous beam construction system, the stiffness ratio consists of two parts, that is, the bending stiffness of the arch rib and the stiffness of the beam. Based on the relative values of the two stiffnesses, it is divided into three kinds of stiffness, namely, steel beam with rigid-frame arch, steel beam with flexible arch, and flexible beam with rigid-frame arch. **Table 2** shows the influence of different stiffness ratios on the internal force of the continuous beam-arch composite bridge under dead load:

**Table 2.** Influence of different stiffness ratios on the internal force of continuous beam-arch composite bridge under dead load

| $I_{arch}/I_{beam}$ | | 4 | 3 | 2 | 1 | 1/2 | 1/3 | 1/4 |
|---|---|---|---|---|---|---|---|---|
| Arch | Axial force | 4343.51 | 4355.90 | 4378.39 | 4309.15 | 4279.5 | 4365.66 | 4281.66 |
| | Bending moment | -75.20 | -54.82 | -49.82 | -38.65 | 35.20 | 44.29 | 55.62 |
| Beam | Axial force | -4337.49 | -4349.81 | -4371.14 | -4302.79 | -4273.10 | -4359.25 | -4275.85 |
| | Bending moment | 184.75 | 137.75 | 55.30 | -17.48 | -66.75 | -99.19 | -128.40 |

As shown in **Table 2**, under the action of dead load, when the cross-sectional area of the beam-arch was fixed and the stiffness ratio of the beam-arch was changed, the axial force of the structure was less affected, and the stiffness ratio only affected the distribution of the beam-arch bending moment. With the increase of beam-arch stiffness ratio, the bending moments of tie beams and arch ribs first increased then decreased, but the effect of arch ribs was greater than that of tie beams. When the beam-to-arch ratio was in the range of 0.5–1, the variation of arch rib bending moment had the largest amplitude. When the beam-to-arch ratio was in the range of 1–3, the rate of change of the bending moment of the tie beam reached the maximum, indicating the variation of the stiffness ratio of the beam bending moment in this section had the greatest influence. Therefore, this means that the influence of different stiffness ratios on the internal force of the structure under the action of dead load, the change of the stiffness ratio and the impact on the bending moment of the beam arch depend on the distribution of the bending moment. Besides, with the increase of the stiffness ratio of the arch rib, its bending moment also increased [8]. At the same time, unlike the influence of the stiffness ratio on the bending moment under the action of constant load, the change of the stiffness ratio under the action of constant load is less affected by the bending moment of the tie beam than that of the arch rib. The higher the stiffness ratio, the greater the change in the bending moment. When stiffness ratio range is between 1–2, the arch rib bending moment produced the largest change in curvature.

In addition, when the area and moment of inertia changed simultaneously, the self-weight of the arch beam changed along with the area and bending resistance, which caused change in axial force of the beam arch, followed by a linear change in the stiffness ratio. When the beam-arch area changed, the beam-arch bending moment decreased with the increase of stiffness ratio. The bending moment of the tie beam was the greatest when the stiffness ratio was 2, and the rate of change of the tie beam bending moment reached the maximum when the stiffness ratio was ¼:1. The minimum bending moment of the arch rib appeared when stiffness ratio = 1, and the change rate of the bending moment is in the range of stiffness ratio 0.5–3. When the stiffness ratio = 1, the beam-arch composite bridge was in its maximum stress state. When the stiffness ratio is < 1, the bending moment of the beam increased as the stiffness ratio gradually decreased. Therefore, the optimal stiffness ratio should be within 0.5–2.

### 4.3. Bridge deck cracking prevention

In the design stage of continuous beam-arch composite bridge, it is necessary to consider the problem of cracking. At present, there are three ways to solve the problem of cracking. The first is to use micro-expansion concrete in the secondary pouring of the bridge deck to form compressive pre-stress in the bridge deck. The second method it to design the bridge in a way that the compressive pre-stress in the bridge deck is lower than the tensile stress of concrete, so as to ensure that no cracks appear or the crack width is reduced after the bridge is completed. The third method is to add fiber materials such as polymer fiber and steel fiber into the concrete to improve its tensile capacity. The fourth method is to use the pre-loading method to reduce the internal tensile stress of the bridge deck concrete to zero or within the allowable range under the action of the second phase of dead load and live load [9]. The four methods have their own advantages and disadvantages. Among them, the first method reduces transverse shrinkage stress, but has minimal effect on the longitudinal shrinkage stress. The second method can make bridge deck cracks more scattered and thinner, but it is not economical and costs a lot [10]. The third method can achieve the purpose of no cracks, but it can only be applied to the bridge deck situation when the main longitudinal beam and arch of the bridge deck are jointly stressed and then poured. The fourth method is effective, but it requires a huge ballast. Therefore, the nature of the bridge project needs to be considered to select the optimal method or a combination of methods, so as to effectively solve the cracking problem of the bridge [11].

## 5. Conclusion

The design of beam-arch combination bridges is highly technical, and there are many influencing factors in the design stage. Therefore, the influence of rise-span ratio and stiffness ratio and the solution for cracking in the later use should be considered in the design stage, so as to effectively improve the design quality and meet the requirements for bridges.

## Disclosure statement

The author declares no conflict of interest.

## References

[1] Gong X, 2022, Research on Construction Monitoring of Downward Continuous Girder-Arch Composite Bridge, dissertation, North University of China.

[2] Liu Z, Lu Z, 2022, Design of Guangyuan Jialing River Bridge on Lanzhou-Chongqing Railway. Low Carbon World, 12(2): 148–150.

[3] Fan Z, Che Z, 2021, The National Railway Administration Issued the Industry Standard “Code for the Design of Concrete Steel Tube Structures for Railway Bridges”. Railway Technical Standards (Chinese

and English), 3(1): 116–118.

[4] Kuang H, 2021, Research on the Application of BIM Technology in the Design of Short-Tower Cable-Stayed Bridges, dissertation, Lanzhou Jiaotong University.

[5] Li C, 2019, Design of Bridges with Special-Shaped Continuous Beam-Arch Composite System. Engineering Construction and Design, 2019(15): 128–130.

[6] Li G, Wang L, Wang J, et al., 2020, Experimental Research on Mechanical Performance of Continuous Beam-arch Composite Steel Bridges. Low Temperature Building Technology, 42(11): 58–61.

[7] Qiao C, 2020, Key Technology of Alignment Control of Curved Continuous Beam-Arch Bridge Structure. Railway Construction Technology, 2020(11): 118–122.

[8] Liu Z, 2020, Research on Key Technologies for the Construction of Rigid Frame Arch Steel Box Continuous Girder Composite Bridge -- Taking Guidan Road Project as an Example, dissertation, South China University of Technology.

[9] Zhang J, Yan A, Guo Y, 2020, Research on Structural Design of Asymmetric Overhead Arch Bridge with a Main Span of 292m. Railway Standard Design, 64(1): 142–146.

[10] Yuan Y, 2020, Research on Visual Construction Control and Maintenance Management of Continuous Beam-Arch Composite Steel Bridge Based on BIM, dissertation, Southeast University.

[11] Chen J, 2022, Continuous Beam-Arch of High-Speed Railway Across the Water Service Area of Beijing-Hangzhou Grand Canal Design. Urban Road Bridge and Flood Control, 2022(05): 85–87.