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A Review of the Key Points in the Design of Small-Radius Curved Ramp Bridges

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Abstract: This article explores the fundamentals of small-radius curved ramp bridges. It covers the selection of box girder spans, support methods, and forms, along with design optimization techniques for this type of bridge structure. The purpose of this paper is to provide robust support for enhancing the design quality of these bridges and ensuring their efficacy in real-world applications.

Keywords: Bridge design; Small-radius curve ramp; Box girder span; Support method; Support form

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1. Introduction

When designing a small-radius curved ramp bridge, its stress characteristics should first be clarified. Then, its box girder span and support can be designed accordingly. Lastly, its design should be further optimized through in-depth research based on actual engineering practices. In this way, the quality of the design can be improved and the requirements are met.

2. Stress characteristics of small radius curved ramp bridges

The main stress characteristics of small radius curved ramp bridges include the following: (1) The stress on the inner and outer sides is not uniform. The torque on this structure causes problems such as the inner beam unloading and the outer beam overloading, resulting in uneven stress on the inner and outer sides. (2) These bridges also suffer from flexural deformation. Under the superposition of twisting and bending, this type of bridge has greater deflection deformation than a straight bridge with the same span. (3) The structure is subject to transverse horizontal forces due to factors such as the horizontal centrifugal force experienced when a car is in motion, longitudinal horizontal forces resulting from temperature changes, and those arising from concrete shrinkage and creep. These forces act laterally, potentially affecting the stability and integrity of the structure. 4) Under a bending moment, the total cross-sectional stress of this type of bridge structure will be greater than that of a straight bridge, making it more prone to deformation at the cross-section.

3. Key points in the design of small radius curved ramp bridges

Since the structure of a small-radius curved ramp bridge is significantly different from traditional straight bridges, its stress conditions are more complex, making quality control more difficult. Therefore, when designing such bridges, designers should take into account their characteristics [1]. The key points in designing this type of bridge project include several aspects: the selection of the span of the box girder, the selection of the support method, and the design of the support. Through proper selection of design contents and design methods, the quality of the design can be ensured. **Figure 1** is a schematic diagram of the overall structure of a small radius curved ramp bridge project (unit: m):

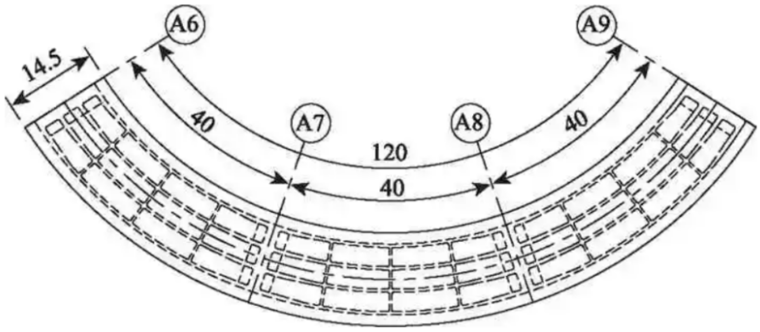

Figure 1. Schematic diagram of the overall structure of a small radius curved ramp bridge project

Below is an outline of the basic design points of the small radius curved ramp bridge.

(1) Selection of box girder span

The selection of a box girder span is crucial in designing a small-radius curved ramp bridge. Normally, such a structure's bending moment stiffness ratio will directly impact the structure's stress and deformation. If the bending stiffness is relatively high, the torque deformation caused by the curvature factor will also be relatively large [2]. Therefore, when designing this type of bridge structure, designers need to minimize its bending stiffness and improve its torsional stiffness while effectively controlling its vertical deformation.

To achieve this goal, the box section of the box girder should have a larger torsional moment and a smaller height. Generally, the span-to-beam height ratio should be around 18:1. Under certain conditions, the ratio of span3-to-beam height might need to be adjusted to 22:1. In this way, the span of the box girder can be adapted to the overall structure, thereby effectively avoiding deformation problems caused by the unreasonable span of the box girder and achieving reasonable savings in construction costs.

(2) Reasonable selection of support methods

In the structural design of small-radius curved ramp bridges, if different support methods are selected, the effects on the internal forces in the upper and lower structures will also greatly differ [3]. There are two main types of supports for this type of bridge structure: torsional support and point hinge support. The main components of these supports are usually basin rubber bearings or plate rubber bearings.

The type of support should be selected based on the structural parts of the bridge and actual working conditions. (i) Torsion supports are usually preferred in designing the ends of continuous beams to ensure higher lateral torque performance and lateral stability of the main beam. (ii) Either a torsion support or a point hinge support can be adopted for the middle part of a curved bridge. Most component supports should use round plate or basin rubber bearings to effectively accommodate the lateral deformations of the main beam [4]. (iii) When designing a tall single-column mid-pier structure, it is important to consider implementing a pier-beam consolidation structure based on the specific situation. This approach effectively utilizes the bridge's flexibility, meeting deformation requirements while saving costs during construction.

(3) Layout of the support structures

The layout of the support structures is also important in designing small-radius curved ramp bridges to ensure their functionality, stability, and safety [5]. Support layouts for bridges commonly fall into three main types: all supports arranged as torsion-resistant supports, end supports as torsion supports with the middle support as a single pivot hinge support, and end supports as torsion supports with the middle support as a combination of single pivot hinge and torsion supports. Regardless of the chosen support form, designers must ensure that the lower piers are appropriately matched to maintain the overall bridge's support effectiveness.

However, it is no longer common to have double-bearing torsion bearings at both ends and several point hinge bearings in the middle. Therefore, when designing the support layout of such structures, designers usually choose the internal and external eccentric support layout plan. Prestressed steel tendons allow the gradual increase of the torque as the bending radius decreases, so the torque increases as the span increases [6]. To achieve this goal it is essential to consider several aspects when arranging the eccentric bearings at the mid-span of such structures. (i) To prevent lateral load uniformity, the eccentricity of the middle pier can be reasonably set to counter adverse effects caused by the bridge structure. For structures with a bending radius exceeding 130 meters, it is crucial to control the eccentricity within the range of 0.1 to 0.2 meters. (ii) To prevent the prestressed beam torque from affecting the bridge structure, the eccentricity of the mid-span supports can be increased. The total eccentricity of the mid-span supports can be determined based on the total eccentricity and resistance of the bridge, considering the sum of torques during prestressing. Designers may also arrange the mid-span bearings as inner eccentric bearings and outer eccentric bearings, strategically increasing the eccentric distance. This ensures uniform reaction forces from the torsion-resistant double bearings at the bridge ends, with slightly larger reaction forces from the outer bearings if necessary. (iii) To prevent adverse effects such as temperature variations, creep, and uneven torque, a fixed support should be installed at the mid-span of each curved beam structure or a consolidation pier at the mid-span to avoid bridge support slippage. (iv) When the overall stiffness of the bridge structure is low, supports can be strategically arranged at both the inner and outer eccentric parts to mitigate potential issues such as large stress on the inner edge or corner problems under vehicle driving loads [7]. (v) To prevent cracking of the bridge pier's top beam due to excessive reaction force from external bearings and avoid potential traffic accidents, double bearings or consolidated piers can be strategically arranged within the curved box girder structure of such bridge projects. Additionally, prestressed steel tendons should be carefully placed in the beams at the top of the pier, or the density of steel bars at the top should be appropriately increased. **Figure 2** is a schematic diagram of the finite element calculation and analysis model of a small radius curved ramp bridge structure.

Figure 2. Schematic diagram of the finite element calculation and analysis model of a small radius curved ramp bridge structure

In this way, the rationality of the structural support layout of small-radius curved ramp bridges can be ensured, thereby improving the design and construction quality of such bridges and minimizing the risks of accidents and problems caused by poor design.

4. Design optimization of small radius curved ramp bridges

Small radius curved ramp bridge structure exhibits a more complex stress situation. Therefore, compared to traditional straight bridge structures, designing this type of structure is inherently more challenging. To further improve the design of this type of bridge structure and meet its construction, application, and development needs in modern bridge engineering, in-depth research should be conducted on the optimization of its design. With the optimization of its structural design, the overall quality and safety of the project can be improved [8].

Several measures can be taken to optimize the design of such bridge structures. (1) The calculation and analysis of the overall bridge structure should be strengthened. Structural calculation and analysis are an indispensable part of bridge design. Designing such bridges typically involves calculating and analyzing torsional shear stress, torsional warping normal stress, and load forces under normal conditions. To improve the efficiency and accuracy of the calculations, designers can utilize advanced finite element analysis software. By establishing calculation models, importing relevant engineering data, and conducting finite element analysis, various parameters in this type of bridge structure can be accurately analyzed. By doing so, structural optimization can be achieved, ensuring the rationality of design parameters and scientific optimization of the overall bridge engineering structure design. (ii) On-site investigation of the construction site should be carried out. Only by fully understanding the actual conditions at the site and basing the structural design on this information can the overall structure have enough adaptability to meet the real construction and application needs of this type of bridge structure [9]. Therefore, before designing the bridge an on-site investigation of the construction site should be carried out, including items like hydrological conditions, geological conditions, climatic conditions, etc. A comprehensive on-site investigation facilitates material selection, parameter determination, and construction equipment selection. (iii) Utilizing advanced technology for construction and application simulation is essential. After determining its main parameters, simulations of bridge structure construction and application should be carried out to ensure the quality of the design and its practicality [10]. BIM technology enables the simulation of construction and application for the bridge. By importing the designed bridge structure parameters into BIM software, a three-dimensional digital model of the bridge structure can be created. Subsequently, simulated construction and application of small radius curve ramp bridges can be conducted based on this model. This approach facilitates the timely discovery of design flaws, allowing for optimization and prompt adjustments to the design plan. Ultimately, this process enables the reasonable optimization of the design of this type of bridge engineering structure, enhancing its overall design quality.

5. Conclusion

In summary, small-radius curved ramp bridges have become the most typical form of modern bridge engineering structures. These bridges pose unique challenges in design and construction compared to traditional straight bridges. Therefore, it is important for both the teams working on these projects and the designers to focus closely on their design process. They need to understand the most critical design aspects thoroughly. By doing so, they can create practical and sensible designs for these bridges. It is also crucial to adjust plans as necessary based on the circumstances. This ensures that these bridges are well-designed, meet the needs of actual construction, and perform effectively in today's world.

Disclosure statement

The author declares no conflict of interest.

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