Research on Force Comparison of a Heterotypic Stay Cable Arch Bridge Based on Single-Beam and Beam-Grid Models

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Abstract. This article uses a four-span continuous spatially slanting heterotypic stay cable arch bridge as the background, and establishes finite element models of the main girder using both a single-beam model and a beam-grid model. The calculation results of the two models show that there are certain differences in the deformation and stress of the main girder and arch ribs, but these differences are not significant. Similar projects can refer to the analytical results described in this paper and, considering the actual conditions of bridge engineering, choose and establish appropriate models.

Keywords: Heterotypic Stay Cable; Construction Scheme; Simulation Analysis; Asymmetric Support.

1 Introduction

Bridges, as a vital part of transportation infrastructure, play an indispensable role in the distribution of goods and the rapid economic development. Historically, numerous bridge structures have been rapidly constructed[1]. Conducting simulation and analysis of bridge quality during construction and operational phases has become crucial in the bridge industry. The single beam method and grid beam method are commonly used simulation techniques[2].The grid beam method distributes effects realistically to each web plate, closer to real-world conditions. While the single beam method is efficient and widely used in engineering [3], it overlooks load distribution on web plates and shear lag effects, leading to discrepancies in simulations of bridges with wide spans and small curve radii. Therefore, investigating whether the differences between the single beam method and grid beam method significantly impact calculation results is meaningful. This study uses the Echeng City Bridge, an irregular truss arch bridge in Huizhou City, as a case study, employing both methods for finite element modeling and conducting comparative analysis of their results. The aim is to identify disparities between the two methods, offering insights for bridge design and monitoring.

W. Guo et al. (eds.), *Proceedings of the 3rd International Conference on Green Building, Civil Engineering and Smart City (GBCESC 2024)*, Advances in Engineering Research 264,
https://doi.org/10.2991/978-94-6463-728-1_36

2 Engineering Overview

The main span of the Echeng Bridge is 460 meters long. It is a continuous skewed-space irregular tied-arch bridge with four spans, utilizing a steel beam-steel arch structural form.The bridge layout diagram of the main span is shown in Figure 1.

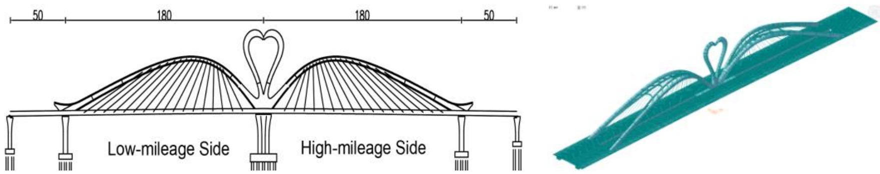

Fig. 1. Bridge Layout Diagram

3 Finite Element Model Establishment

This article takes the main bridge of The Echeng Bridge as a case study, and establishes separate finite element models based on the software Midas Civil using the single-beam method and the grid beam method. In these models, beam elements are used to simulate the main beam, arch ribs, and bridge towers, while cable elements are used to simulate suspenders and tension rods.

Rigid connections are employed for the connections between the main beam and arch ribs, tension rods and arch ribs, main and secondary arch ribs, suspenders and main beam, and suspenders and arch ribs within elastic connections.

3.1 Single Beam Method Calculation Model

When the span width of the box girder is small, the transverse bending moment and torsional effects on the main beam under load are minimal [4]. The loads acting on the model include the bridge self-weight, anchor box weight, phase II permanent load, and cable forces. The anchor box load is applied to the suspension rod elements and the connection points of the main beam, while the phase II permanent load is distributed according to the design drawings on the main beam. The overall bridge model is established based on the single beam method, consisting of 1298 elements and 1230 nodes, as shown in Figure 2.

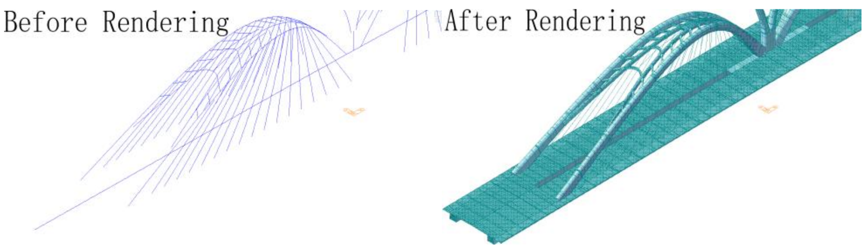

Fig. 2. Single Beam Model Structural Diagram

3.2 Grid Beam Method Calculation Model

The core idea of the grid beam method is to use an equivalent planar or spatial framework to simulate the main beam, concentrating the bending and torsional stiffness distributed across each segment of the main beam into nearby equivalent grid beams[5].The longitudinal beams have three main types of cross-sections, while the transverse beams have two main types of cross-sections. Taking into account shear lag, the cross-sections are divided into beam grids as shown in Figure 3.Phase II permanent loads are distributed across the longitudinal beams based on the area proportion of the divided sections. The bridge's overall model is established based on the grid beam method, consisting of 2373 elements and 2151 nodes, as illustrated in Figure 4.

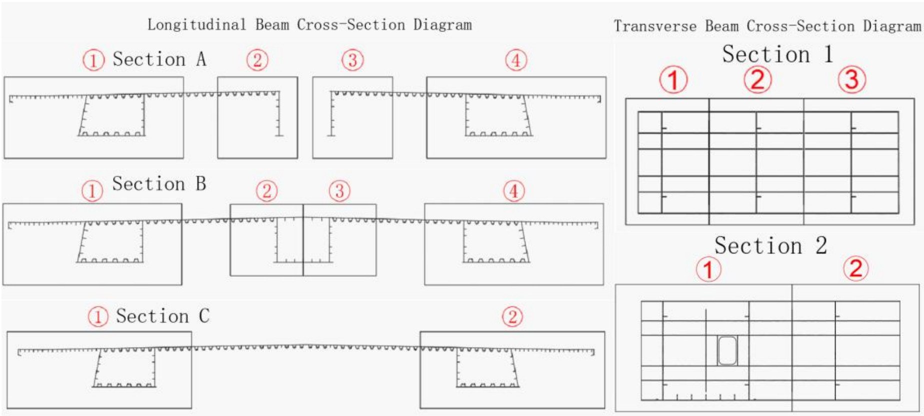

Fig. 3. Beam Grid Model Section Diagram

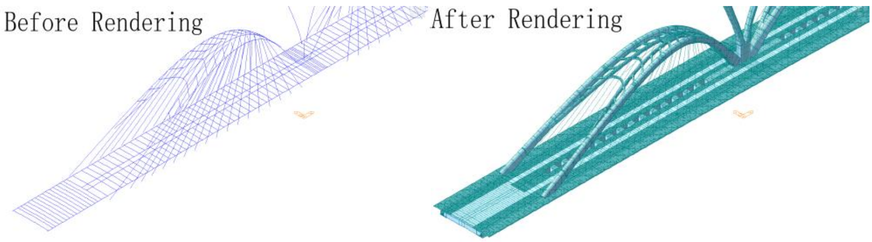

Fig. 4. Grid Beam Model Structural Diagram

4 Comparison of Model Analysis Results

The deformation of the main girder and arch ribs is primarily influenced by their self-weight and the tension in the cables. The overall deformations after analyzing finite element models using the single beam method and the grid beam method are shown in Figures 5 and 6.

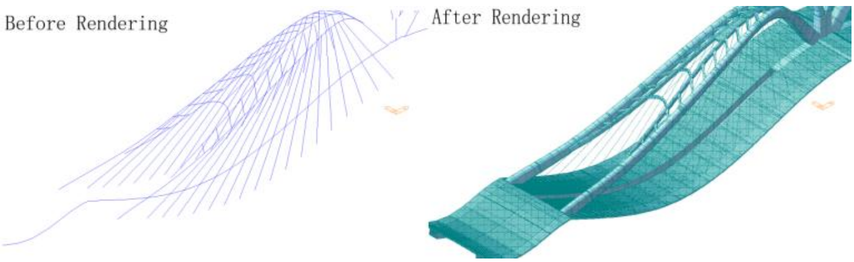

Fig. 5. Deformation Diagram of the Single Beam Model

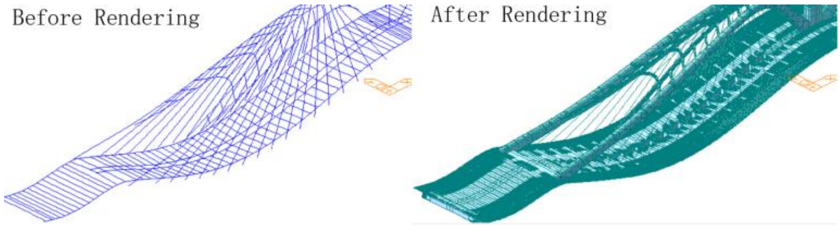

Fig. 6. Deformation Diagram of the Grid Beam Model

4.1 Main Beam Deformation

The Bridge deformations directly reflect changes and responses of the structure under load, which are crucial for ensuring the safety and reliability of bridge structures [6]. Points are selected from the downstream end of the short span of 10 single beam models and connected elastically with suspenders. These points are numbered sequentially from the center to the edge of the bridge as points 1 to 10. Deformation comparisons are made between corresponding points 1 to 10 in the main beam of the grid beam model, with results shown in Table 1. It can be seen that the stress difference between the external longitudinal beams in the single beam model and the grid beam model is relatively small, while the difference with the internal longitudinal beams is relatively large.

Table 1. Comparison of Main Beam Deformation Differences

Point	Single Beam Method	Grid Beam Method		Differences (Compared to the Single Beam Method)	
		Outer Longitudinal Beam	Inner Longitudinal Beam	Outer Longitudinal Beam	Inner Longitudinal Beam
1	-106	-116	-124	9%	17%
2	-114	-124	-132	9%	16%
3	-119	-129	-137	8%	15%
4	-119	-128	-136	8%	14%
5	-115	-123	-131	7%	14%
6	-107	-113	-121	6%	13%

7	-94	-98	-106	4%	13%
8	-78	-80	-87	3%	12%
9	-60	-60	-66	0%	10%
10	-39	-38	-41	-3%	5%

4.2 Arch Rib Deformation

Arch rib deformation is crucial for the construction of long-span bridges, guiding the positioning and precasting of arch ribs during bridge construction [7]. Points are selected from the downstream end of the short span of 10 single beam models and connected elastically with suspenders. These points are numbered sequentially from the center to the edge of the bridge as points 1 to 10. Deformation comparisons are made between corresponding points 1 to 10 in the arch ribs of the grid beam model, with results shown in Table 2. It can be seen that they have a relatively small difference in deformation, about 1%.

Table 2. Comparison of Arch Rib Deformation Differences

Point	Single Beam Method	Grid Beam Method	Differences (Compared to the Single Beam Method)
1	-76	-77	1%
2	-85	-86	1%
3	-93	-94	1%
4	-100	-101	1%
5	-107	-108	1%
6	-112	-113	1%
7	-116	-117	1%
8	-118	-119	1%
9	-117	-119	2%
10	-114	-115	1%

4.3 Main Beam Stress

Main beam stress directly reflects the internal material stress state of the main beam structure under load [8]. The main beam stresses from the single beam method and grid beam method finite element models at the downstream end of the short span are shown in Figure 7 to Figure 8 (units: N/mm).

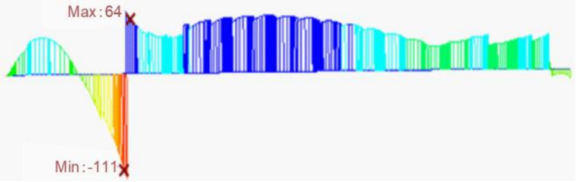

Fig. 7. Stress Diagram of the Single Beam Model

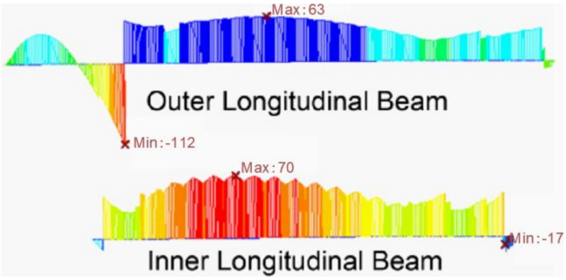

Fig. 8. Stress Diagram of the Grid Beam Model

From Figure 9and Figure 10, it can be observed that the stress variations in the single beam model and the grid beam model are similar.

4.4 Arch Rib Stress

The arch ribs effectively distribute loads and support the bridge deck structure. A comparison of stress in arch ribs using finite element models with the single beam method and the grid beam method is shown in Figure 9 (unit: N/mm).There is minimal difference in arch rib stress between the single beam method and grid beam method, and their overall trends in variation are similar.

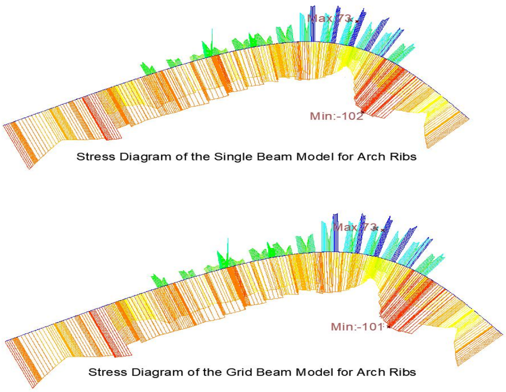

Fig. 9. Comparison of Stress Diagrams

5 Conclusion

Comparing and analyzing the calculation results of this bridge, the following conclusions are drawn:

(1) The overall trends in stress and deformation between the single beam and grid beam models are similar. Differences in results stem from the single beam method neglecting beam stiffness and shear lag, whereas the grid beam model provides a more comprehensive consideration.

(2) The difference between the outer longitudinal beams of the single beam and grid beam models is relatively small compared to the inner longitudinal beams. This is because the outer longitudinal beams are rigidly connected to the suspenders, resembling the stress state of the main beam in the single beam method. In contrast, the connection between the inner and outer longitudinal beams involves limited beam stiffness, resulting in greater deformation and stress in the inner longitudinal beams.

This article aims to provide examples for designers when choosing between the single beam method and grid beam method. Engineers should select the appropriate method based on specific project requirements and actual conditions to ensure the accuracy and reliability of the design.

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