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Application Strategy of Composite Steel Composite Beams in Bridge Design

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Abstract: The combined prefabricated steel-hybrid stacked girder structure is very common in modern bridge design. An actual bridge engineering design project is taken as an example in this paper to analyze the application strategy of this structure, encompassing overall design strategy, structural design strategy, and structural calculation strategy. The aim is to offer insights that can enhance the quality of bridge design.

Keywords: Prefabrication; Steel-hybrid stacked girder; Bridge design; Structural design and calculation

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1. Introduction

When designing a combined prefabricated steel-hybrid stacked girder structure, the designer must fully understand its design significance and challenges. They should integrate this understanding with the actual conditions of the bridge engineering project, implement reasonable technical measures in the design process, and ensure effective quality control. This ensures that the structural design meets the practical requirements of bridge construction and application, thereby promoting the positive development of the bridge engineering industry.

2. Project overview

The bridge project examined in this paper is a power plant bridge with a total width of 23.5m and four main bridge spans. The tower bridge is a concrete cable tower, standing around 990m tall, with the main beam being an I-section steel longitudinal beam. The longitudinal bridge sits directly beneath the intersection of the carriageway and the sidewalk, 28m high, with a transverse center distance of 255m. Its pier foundations are located behind the navigational wall and made of cast-in-place concrete. Due to its considerable height and the elevated longitudinal plane of the route, connecting it smoothly to both sides of the approach road is challenging. Opting for an all-steel box beam structure would raise project costs. After considering all factors, the designer chose to use a steel-hybrid stacked girder structure.

2. Significance of combined prefabricated steel-hybrid stacked beams in bridge design

2.1. Basic overview of prefabricated steel-hybrid laminated beams

The composite steel beam structure is a cross-sectional stress structure composed of a steel main beam and concrete formwork. This design enhances the steel beam's flexural performance and the concrete's compression performance, substantially boosting the overall strength and load-bearing capacity of the bridge. As a result, the bridge's service life is prolonged [1]. This type of bridge structure is widely favored in modern bridge engineering due to its simplicity, high construction efficiency, strong adaptability, and ease of operation and maintenance.

2.2. Significance of combined prefabricated steel-hybrid stacked girders

In the context of the current bridge project, the combined prefabricated steel-hybrid stacked girders hold significant design implications, including the following aspects: (1) By implementing a well-thought-out design for these structures, it becomes possible to ensure that their strength and load-bearing capacity align with the actual requirements of the bridge project, thereby maximizing quality and safety [2]. (2) A rational structural design can simplify the construction process of such bridge structures, enhancing construction efficiency and reducing construction costs. (3) Furthermore, a well-planned design for these structures can improve the durability of bridge projects, enhance their practicality, and extend their overall service life. With these advantages, this kind of bridge structure has been increasingly favored in modern bridge engineering design [3].

2.3. Difficulties in designing combined prefabricated steel-hybrid stacked girders

Currently, the design challenges associated with this type of bridge structure primarily revolve around the following aspects: (1) The layered arrangement of steel and concrete within the structure introduces complexity to its stress distribution. The magnitude of stress and the occurrence of slippage can significantly impact structural integrity and safety. Consequently, designers must focus on the rational design of connectors and shear members to address this issue effectively [4]. (2) While this structure is typically suitable for single-span simply supported bridges, its application in continuous bridges requires careful consideration, particularly in the negative moment region. Adjusting the cross-section appropriately is essential to prevent cracking. (3) Due to its lighter weight compared to traditional bridge structures, this type of bridge can serve as a transverse articulated structure in small steel box girders. When dealing with large transverse widths, designers must meticulously assess the transverse stability and reliability of connections to ensure the overall quality and safety of the bridge structure [5].

3. Application strategy analysis of combined prefabricated steel-hybrid stacked girders in bridge design

3.1. Overall design strategy

When designing combined prefabricated steel-hybrid stacked girders, the designer must have a comprehensive understanding of the specific construction and application requirements of the bridge project. This includes considering the actual conditions of the construction site and implementing reasonable measures for structural design and construction program design. This ensures that such structures are effectively applied in practice.

In the construction of the combined prefabricated steel mixed stacked girder structure for this bridge project, the main technologies required on-site are reinforcing steel construction and concrete construction. Unlike typical bridge engineering structures, this type of bridge structure involves multiple horizontal levels.

Therefore, smooth construction relies on ensuring effective coordination among all levels [6]. Besides, designers must adjust the construction process based on the actual conditions to effectively address temporary support within the watershed. Additionally, they should leverage the advantages of water transportation at the tail of the bridge. This involves establishing a rational stress structure using large pontoon bridge hoisting construction methods and implementing whole-section hoisting construction of such structures through integral floating transportation methods [7].

Based on the considerations outlined above, the overall design of this bridge project employed small box girders with an open section as the steel box girder structure, while reinforced concrete members were utilized for the bridge deck. Taking into account the construction needs, application requirements, and site conditions, the designer opted for five girders on the bridge's transverse side, with a girder spacing of 4.8 meters. The top plates of both the steel box girder and the cross girder were designed using a shear nail welded form. The casting of the entire concrete bridge panel was completed at the prefabrication site. After passing inspection, it was transported to the construction site. Subsequently, the construction unit conducted the lifting construction on-site according to the engineering design. Upon completion of the lifting process, the construction unit ensured proper execution of concrete joint construction according to the design requirements for the concrete panel and lateral connections. This approach effectively ensures that the overall design of such a bridge engineering structure meets actual construction and application requirements.

3.2. Structural design strategy

The designer should not only focus on the structural composition and component size parameters but also on the construction design to ensure the usability of such a structure in bridge engineering.

For the main beam section design of the bridge project, the designer opted for shear connectors for the prestressed cast-in concrete bridge panels and open steel box girder structures. The main components of the steel girders include main girders, diaphragm girders, and stiffening ribs. Given that the structure of the bridge project involves a precast concrete box girder, the designer chose to design the steel-hybrid stacked girders as an inverted trapezoidal steel box girder structure to ensure aesthetic coordination in the specific structural design. The box girder design incorporates parameters such as the top width, middle distance, bottom width of the single steel box girder, and the thickness of the roof and bridge panel, which are determined based on the actual circumstances. Additionally, the designer incorporated plate ribs on the top surface of the flange plate above the steel girder for the bridge project's bottom plate and upper web. This allows for the reinforced concrete deck structure and the shear key to be jointly connected, forming an integral whole, with the shear key applied via welded nails. **Table 1** shows the basic design parameters of the combined prefabricated steel-hybrid stacked girder structure of this bridge project.

Table 1. Basic design parameters of the combined prefabricated steel-hybrid stacked girder structure of this bridge project

No.	Parameter	Specification	No.	Parameter	Specification
1	Number of steel beams across the bridge	5	4	Bridge roof thickness	25 mm
2	Design value of steel beam middle distance	4.8 m	5	Bridge panel thickness	0.3 m
3	Bottom width of single steel box girder	2.0 m	6	Shear bonding stud specification	180 mm*23 m

According to the basic design requirements for the combined prefabricated steel-hybrid stacked girders in this bridge project, the welding of the main girder was completed in the factory, ensuring that the welding strength at the interface exceeded that of the parent material. The pure steel section on the pedestal was tied together with the bridge deck plate. After tying the hoop reinforcement and longitudinal steel reinforcement together, the staff took reasonable measures to address them based on the actual situation to ensure that the steel section was properly tied to the bridge deck plate. If the steel beam size was too large and there were numerous longitudinal steel bars in the column structure, these bars were cut off as needed during construction. They were then securely linked with steel bar connectors or steel beam flange plates before concrete could be poured. To ensure that the concrete was poured properly and improve overall construction quality and safety, a stable platform was set up to provide sufficient support. Once the structural strength of the concrete bridge deck plate met design standards, the construction unit lifted off the pedestal and transported it to the site [9]. After lifting into place, the construction unit strictly adhered to the engineering design when connecting the steel crossbeam. Wet joints on the horizontal side were treated with concrete pouring to support the second phase of dead load for the bridge structure, ultimately forming a safe and stable overall bridge structure.

3.3. Structural calculation

Structural calculation was also a key aspect of the specific design of this project. In this project, the designer mainly adopted the following two calculation strategies.

The first strategy involves basic assumptions. In the design of this stacked beam structure, the designer primarily opted for the elastic calculation method, assuming that steel and concrete are materials with linear elasticity. When calculating the ultimate load-carrying capacity, the designer focused on calculating the stress value at the edge of the cross-section to align with the material's design strength standard. According to the elastic calculation method, when determining the flexural capacity of the stacked girder structure, the following assumptions were made: (1) Steel and concrete materials were assumed to be perfectly elastic, exhibiting a clear linear relationship between stress and strain. (2) The cross-section of the stacked girder structure was assumed to conform to a flat cross-section assumption. (3) The connection between steel reinforcement and the concrete bridge panels was assumed to be very strong, with no possibility of parallel slip [10].

Secondly, the calculation results were analyzed. In this project, the designer primarily used the beam lattice method to establish its structural modeling and obtained its structural calculation results through this model. They could only proceed with the construction of such bridge engineering structures if the structural stress, flexural resistance, and shear resistance of such composite beams were up to engineering standards. **Table 2** shows the durability stress calculation results of the combined prefabricated steel-hybrid stacked girder structure of this bridge project.

Table 2. Calculation results of durability stress of the combined prefabricated steel-hybrid stacked girder structure of the bridge project

No.	Item	Allowable parameters	Calculation parameters	Surplus	Calculation results
1	Stress of upper edge of steel beam	206.2 MPa	151.8 MPa	26.38%	Up to standard
2	Stress of lower edge of steel beam	206.2 MPa	184 MPa	10.77%	Up to standard
3	Stress of upper edge of bridge panel	16.1 MPa	10.6 MPa	34.16%	Up to standard
4	Stress of lower edge of bridge panel	16.1 MPa	5.7 MPa	64.60%	Up to standard

Based on the calculation results, it is clear that the combined prefabricated steel-hybrid girder structure designed in this project exhibited excellent stress performance, robust structural rigidity, and commendable fatigue resistance. Additionally, under this stacked girder structure mode, the overall concrete deck consistently remained in a pressurized state, effectively preventing the occurrence of parallel slip issues, and thereby enhancing its durability.

4. Design quality enhancement strategy

In modern bridge engineering, to enhance the design quality and optimize the application effectiveness of composite steel composite beam structures, design units, and personnel can employ the following strategies:

(1) Focusing on ensuring effective connections between section steel, steel plate, and concrete panels. Utilizing embedded or combined connectors, and conducting reasonable calculations of shear resistance at connection points while verifying the bearing capacity of each common section.

(2) Tailoring the section design of these structures to meet overall stiffness, strength, bearing capacity, and resistance requirements in line with actual engineering standards and application needs.

(3) Emphasizing the overall system design of such structures to enhance stability. This can be achieved by adjusting transverse support spacing, designing straight large bending moment planes, and integrating tensile reinforcement bars and supports.

(4) Implementing comprehensive construction control design for bridge structures, considering span layout, construction technology, lifting point location, section selection, and beam height control in line with project construction needs and on-site conditions.

(5) Utilizing advanced finite element analysis software and Building Information Modeling (BIM) technology in structural design to ensure a more scientific and rational approach. This integration can effectively improve design quality and streamline the design process, contributing to the advancement of the modern bridge engineering industry.

5. Conclusion

The combined prefabricated steel-hybrid stacked girders serve as the fundamental structure in numerous contemporary bridge projects. While this structure offers several advantages, its stress state complexity, particularly influenced by negative bending moments and ultimate partial loads, poses challenges. Therefore, in specific designs, designers must incorporate practical considerations and implement a rational approach to structural parameters and construction design. This encompasses overall engineering design, structural design, and structural calculation. By doing so, the inherent advantages of such bridge structures can be fully harnessed, ensuring construction quality aligns with actual application requirements while enhancing safety and durability.

Disclosure statement

The author declares no conflict of interest.

References

[1] Zhou F, 2020, Application of Combined Assembled Steel-Mixed Stacked Girders in Bridge Design. Modern Transportation Technology, 2020(4): 49–52.

[2] Liu Y, 2015, Research on the Application of Steel-Concrete Laminated Plate Combination Beams in the Structural Transition Layer of Commercial and Residential Buildings in Small and Medium Towns, dissertation, Shantou University.
[3] Cao B, 2020, Research on Key Technology of Large-Span Steel-Hybrid Stacked Girder Self-Anchored Suspension Bridge Construction, Zhengzhou University.
[4] Zhao L, Zheng K, 2022, Design Method and New Structural Form of Steel-Concrete Combined Girder Bridge. Sichuan Architecture, 42(5): 141–144.
[5] Wang Q, 2023, Design of Cast-In-Place Prestressed Box Girder Scheme for Steel-Hybrid Composite Girder Bridge on Ramp 1 of Pingwu Hub D. Science and Technology Information, 21(16): 138–141.
[6] Ren W, Zhao Q, Cao Q, 2022, Research on the Rationality of the Design of Steel-Mixed Girder Bridge with Work-Type Section. Journal of Xinxiang College, 39(3): 60–64.
[7] Liao C,2022, Optimization of Structural Design Parameters of Steel-Mixed Girder Bridges. Western Transportation Science and Technology, 2022(9): 105–107.
[8] Dai C, 2023, Discussion on Bridge Design Principles and Technical Approaches to Bridge Reinforcement. Science and Technology Innovation, 2023(4): 125–128.
[9] Zhang Y, 2022, Study on Load Lifting and Seismic Strengthening Technology of Steel-Hybrid Stacked Continuous Girder Bridges. Engineering Construction and Design, 2022(14): 147–149.
[10] Liu X, Li X, Chen H, 2022, Structural Design Index and Cost Analysis of Steel-Mixed Combination Girder Bridge. Urban Road and Bridge and Flood Control, 2022(11): 98–100.

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