Project Report

Research on Key Technologies for the Design of the Pedestrian and Non-Motorized Vehicle Channel of the Zhongxing Bridge

Chunlei Zhang

Shanghai Municipal Engineering Design Institute (Group) Co., Ltd., Shanghai 200092, China.
Correspondence: zhangchunlei5@smedi.com

Abstract: The main bridge of the Zhongxing Bridge is a hybrid girder extradosed cable-stayed bridge with a span arrangement of (64+86) m + 400 m + (86+64) m. A pedestrian and nonmotorized vehicle (hereafter referred to as a "pedestrian/bicycle") crossing channel is designed to traverse the river along the main bridge. In this paper, the design scheme of this pedestrian/bicycle channel is investigated in terms of structural mechanics, structural detailing, economy, and maintenance. The design scheme features a vertical separation of vehicle and pedestrian/bicycle traffic, in which the pedestrian/bicycle system is located outside the webs of the box girder. To decouple the structural connection between the main bridge and the pedestrian/bicycle channel, thereby reducing the effect of the main bridge forces on the channel structure, longitudinal and transverse expansion joints were installed and the installation sequence of the channel was optimized. A computational analysis was performed using the finite element software Midas Civil. The results indicate that the previously mentioned methods can significantly reduce structural stress. Furthermore, analyses of pedestrian comfort and the structural performance of the pedestrian staircase were conducted. The results indicate that this pedestrian/bicycle channel can satisfy both static and dynamic requirements.

Keywords: pedestrian/bicycle crossing channel; setting of expansion joints; installation sequence; pedestrian staircase; static analysis; pedestrian comfort

Citation: Zhang, C. Research on Key Technologies for the Design of the Pedestrian and Non-Motorized Vehicle Channel of the Zhongxing Bridge. *Prestress Technology* **2026**, *1*, 94-106. https://doi.org/10.59238/j.pt.20251107002

Received: 07/11/2025
Accepted: 30/12/2025
Published: 30/03/2026

Publisher's Note: Prestress technology stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.

1 Introduction

With urban development, an increasing number of river-crossing bridges have been constructed. The widespread acceptance of green and low-carbon travel has created a substantial demand for pedestrian and nonmotorized vehicle (hereafter referred to as "pedestrian/bicycle") river crossings. The integration of pedestrian/bicycle channels with vehicular bridges for river crossing has rapidly increased because of its advantages, including land conservation, cost savings, and ease of traffic management. Researchers have conducted extensive studies on this crossing method, resulting in the construction of numerous such bridges.

Based on different slopes of the vehicular approach bridges, Zhang et al. [1] classified the configurations of pedestrian/bicycle channels into three types: on both sides of the vehicular lanes, beneath the vehicular lanes, and via separate ramps or stairways onto the bridge. Qiu [2] classified the setting methods into truss girder structures, cantilever structures, and suspended structures according to their structural forms. The Songpu Bridge is a double-deck steel truss girder bridge; its lower deck, originally designed for railway use, was converted to a pedestrian/bicycle deck during renovation. This bridge has an integral orthotropic steel deck supported by bearings on the lower cross-beams of the main trusses [3]. The pedestrian walkway of the Chongqing Jiayue Bridge is located beneath the cantilever slabs of the girder and uses a steel suspension system. The primary structure consists of hanging plates, suspenders, anchor rods, longitudinal and transverse steel beams, steel deck panels, and steel railings [4]. With respect to the Wusongjiang Bridge, a steel main girder for the pedestrian/bicycle bridge is suspended beneath the main span of the main bridge using flexible hangers, which are connected to the lower edge of the concrete box girder of the main bridge [5]. The lower-level pedestrian/bicycle channel of the Yangzhou Wanfu Bridge uses a composite girder deck system that is based on steel tie rods, with longitudinal and transverse stability cables added to increase stiffness [6]. The Fengcheng Ziyun Bridge has a pedestrian/bicycle channel suspended via vertical rods from the transverse beams of the superstructure, and its main bridge is a self-anchored suspension bridge [7].

Analysis of completed pedestrian/bicycle river-crossing bridges reveals that the majority of non-truss structures use a configuration suspended beneath the main bridge, whereas cantilevered solutions from the main bridge are less common. Furthermore, the main girders employing the cantilever approach are typically constructed of concrete. In contrast, the Zhongxing Bridge is a river-crossing structure with a pedestrian/bicycle channel cantilevered from a steel main girder. The structural configuration and mechanical behavior of this bridge are distinct from those of typical pedestrian/bicycle channels.

2 Project Background

The Zhongxing Bridge is an extradosed cable-stayed bridge that crosses the Yongjiang River in Ningbo. This bridge is designed in accordance with the standards for an urban arterial road, with a design speed of 60 km/h. The main bridge has a 400-meter central span that crosses the river in a single area. The span arrangement is (64+86) m + 400 m + (86+64) m, and the general layout is shown in Figure 1.

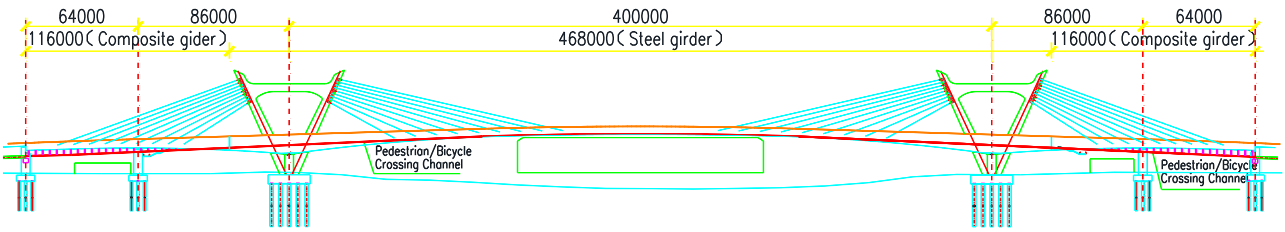


Figure 1 General layout of the Zhongxing Bridge (unit: mm)

The main bridge has a total width of 29 meters. The pedestrian and bicycle lane is positioned at the lower edge of the main girder. The pedestrian/bicycle lane is 5.5 meters wide in each direction and consists of a 3.75-meter-wide nonmotorized vehicle lane and a 1.75-meter-wide sidewalk (including railings). The bridge cross-section is shown in detail in Figure 2.

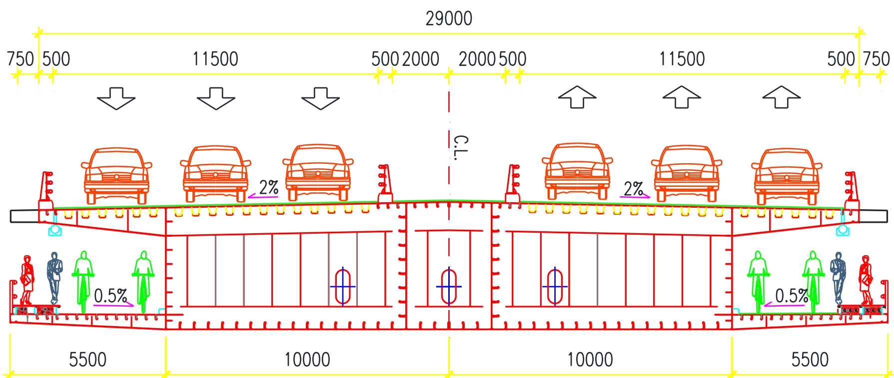


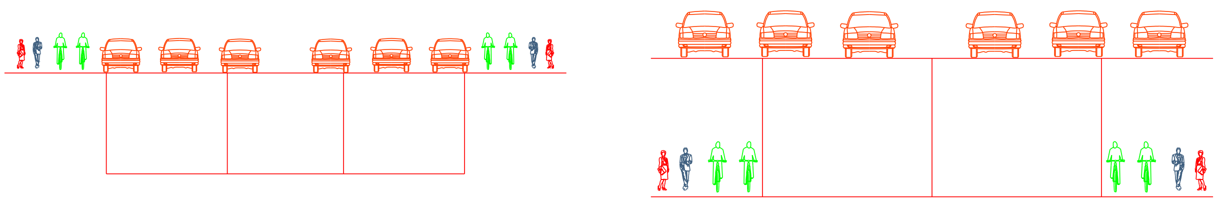
Figure 2 Cross-sectional layout of the Zhongxing Bridge (unit: mm)

The main girder is a hybrid structure. A steel box girder is used in sections of the side spans and over a 468-meter section of the central span, whereas composite girders are employed in other sections. The girder height is 4.5 meters at the mid-span and 10.5 meters at the supports. The main pylon is a steel structure with an inverted V shape. The transverse width of the main pylon is 3.6 meters, and the longitudinal width of the main pylon ranges from 4.0 to 5.7 meters. There are a total of 36 pairs of stay cables, with inclinations ranging from 12.9° to 32.7° [8].

The Zhongxing Bridge is a crucial arterial road that crosses the Yongjiang River and is located between the Qingfeng Bridge upstream and the Changhong Tunnel downstream. Given the inadequate conditions of the existing nonmotorized vehicle crossing facilities, the design of the Zhongxing Bridge must incorporate a function for pedestrian and nonmotorized vehicle crossing.

3 Scheme of the Pedestrian/Bicycle Channel

There are two primary methods for incorporating a pedestrian and bicycle crossing channel on a vehicular bridge: (1) vehicles and pedestrians sharing the same deck level and (2) vertical separation of vehicle and pedestrian traffic [9], as shown in Figure 3.



a) Vehicles and pedestrians sharing the same deck level b) Vertical separation of vehicle and pedestrian traffic

Figure 3 Layout options for pedestrian/bicycle channels on vehicular bridges

The vertically separated design can be further classified based on the location of the pedestrian/bicycle channel: (1) the channel positioned outside the webs of the box girder and (2) the channel positioned inside the box girder chamber.

With respect to bridges with relatively small spans and narrow pedestrian/bicycle channels, a shared-deck-level design is often more appropriate. Although this configuration increases the overall bridge deck area, it provides a simpler structural form, which facilitates design, construction, and future maintenance.

Conversely, the vertically separated design allows for the conservation of bridge space, a reduction in approach span length, and strict traffic segregation. However, the headroom required for the lower level (conventionally designed to be greater than 2.5 m) limits the minimum achievable girder depth. On this basis, the double-deck configuration is generally not economical for bridges with a clear span of less than 50 m.

The Zhongxing Bridge is located within the 60-meter aviation height restriction zone of an airport. This bridge has a V-shaped pylon, and the outward extension of the pylon legs is used to reduce the length of the cable-free zone at mid-span. However, owing to its large main span (400 m), the inclination angle of the outermost stay cables in the mid-span region is very small (12.9°), resulting in a lower load-carrying efficiency for these edge cables. Consequently, the Zhongxing Bridge is designed as an extradosed cable-stayed bridge where the cables and girder work together as a composite system.

Because the main bridge has a single-pylon, central-cable-plane design, its cross-sectional width should not be excessive in terms of structural mechanics. This approach avoids the effects of torsional deformation of the main girder cross-section during construction and operation, which would be difficult to adjust with a single cable plane.

 https://doi.org/10.59238/j.pt.20251107002

If a shared deck-level layout (vehicles and pedestrians on the same plane) was used, the cross-section of the main bridge would be considerably wider. This layout increases the number of webs within the box girder, thereby increasing the difficulty of fabrication, transportation, and installation. In contrast, while the vertically separated layout presents a more complex structural configuration for the pedestrian/bicycle system, it can achieve favorable architectural aesthetics through rational design and landscape optimization.

Furthermore, because pedestrian walkways and nonmotorized vehicle travel (riding/walking) are subject to stricter requirements on longitudinal gradients, a shared-deck-level layout would limit the permissible gradients of both the main bridge and the approach spans. This limitation would likely increase the overall project scale and prove to be less economical. Conversely, the vertically separated layout allows the pedestrian/bicycle channel to cross the river along the main bridge and then use pedestrian stairways to separate and direct pedestrian and bicycle traffic. These stairways, in addition to the accompanying structures for bridge access, can improve the riverside landscape (see Figure 4) and increase economic efficiency.

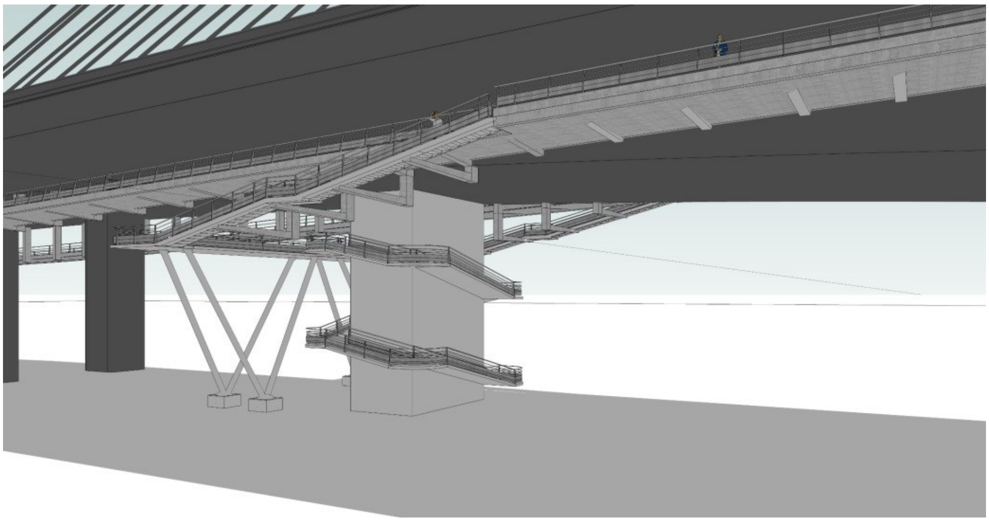


Figure 4 Schematic of the pedestrian stairways and access structures of the Zhongxing bridge

Implementing the vertically separated layout results in a reduced width and fewer cells in the box section of the main girder, which facilitates maintenance and repair work during subsequently stages. Furthermore, this layout allows for the formulation of distinct maintenance strategies that are adapted specifically to the vehicular and pedestrian/bicycle systems, resulting in a more rational and comprehensive maintenance plan overall.

Based on the analyses of structural mechanics, detailed design, economic efficiency, and maintenance considerations presented above, the scheme that incorporates vertical separation of vehicle and pedestrian/bicycle traffic is more suitable for the pedestrian and nonmotorized vehicle channel of the Zhongxing Bridge.

The aesthetic appeal of the structural form is a major factor that must be carefully considered during the design process of the Zhongxing Bridge, which is an urban river-crossing bridge. Simultaneously, the pedestrian experience during the crossing requires that significant attention be given to the design of the pedestrian and bicycle channel. However, if the pedestrian/bicycle system was placed inside the box girder chamber, pedestrians would be unable to appreciate the river scenery. Additionally, the interior of the enclosed box can have poor lighting, severely hindering the crossing experience.

In contrast, locating the pedestrian/bicycle system outside the webs of the box girder effectively addresses these issues. Therefore, this externally mounted configuration was selected for the Zhongxing Bridge channel. By incorporating architectural treatments on the side and top surfaces of the channel (such as suspended aluminum panels), complementing them with features such as light strips, and combining these with railings and a sidewalk paved with preservative-treated timber, a favorable aesthetic outcome can be achieved (see Figure 5).

Figure 5 Rendering of the pedestrian and bicycle channel of the Zhongxing Bridge

4 Key Technologies and Mechanical Analysis for the Design of the Pedestrian/Bicycle Channel

The pedestrian/bicycle channel of the Zhongxing Bridge is divided into four structural zones: the standard cantilever section of the main span and sections of the side spans; Transition Section A, where the cantilever root is located at the web edge; Transition Section B, where the cantilever root is located inside the web; and the hanger section (Figure 6). The width of the pedestrian/bicycle channel of the standard section is 5.5 m, which decreases to 4.0 m on the side span after traffic diversion via the pedestrian stairway system. The channel structure has 12-mm-thick bridge deck panels that are laid on transverse cantilever beams (Figure 7).

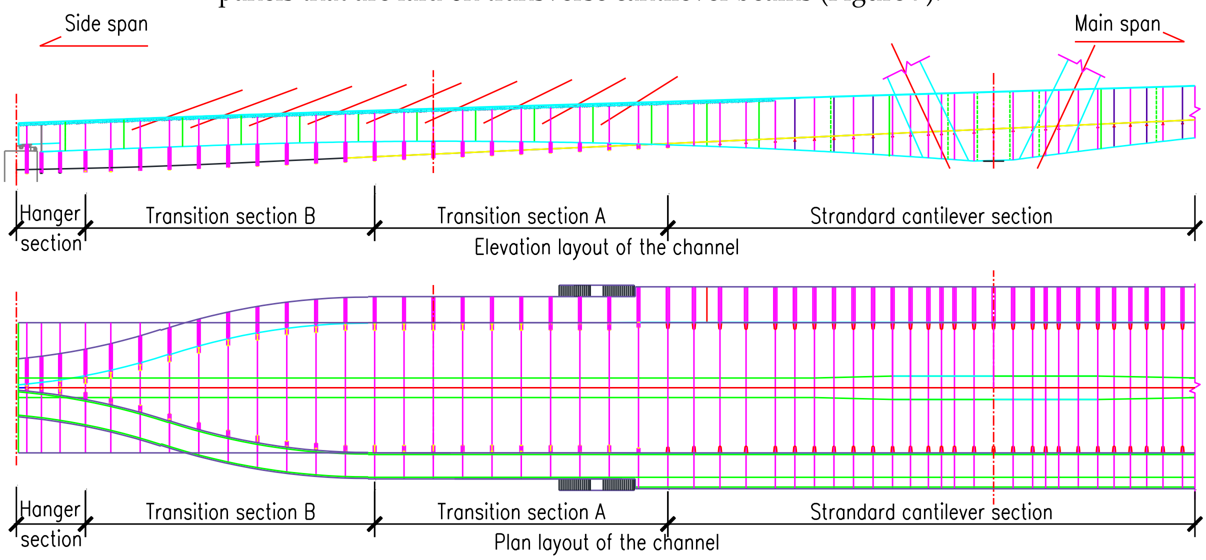


Figure 6 Elevation and plan of the pedestrian/bicycle channel of the Zhongxing Bridge

 https://doi.org/10.59238/j.pt.20251107002

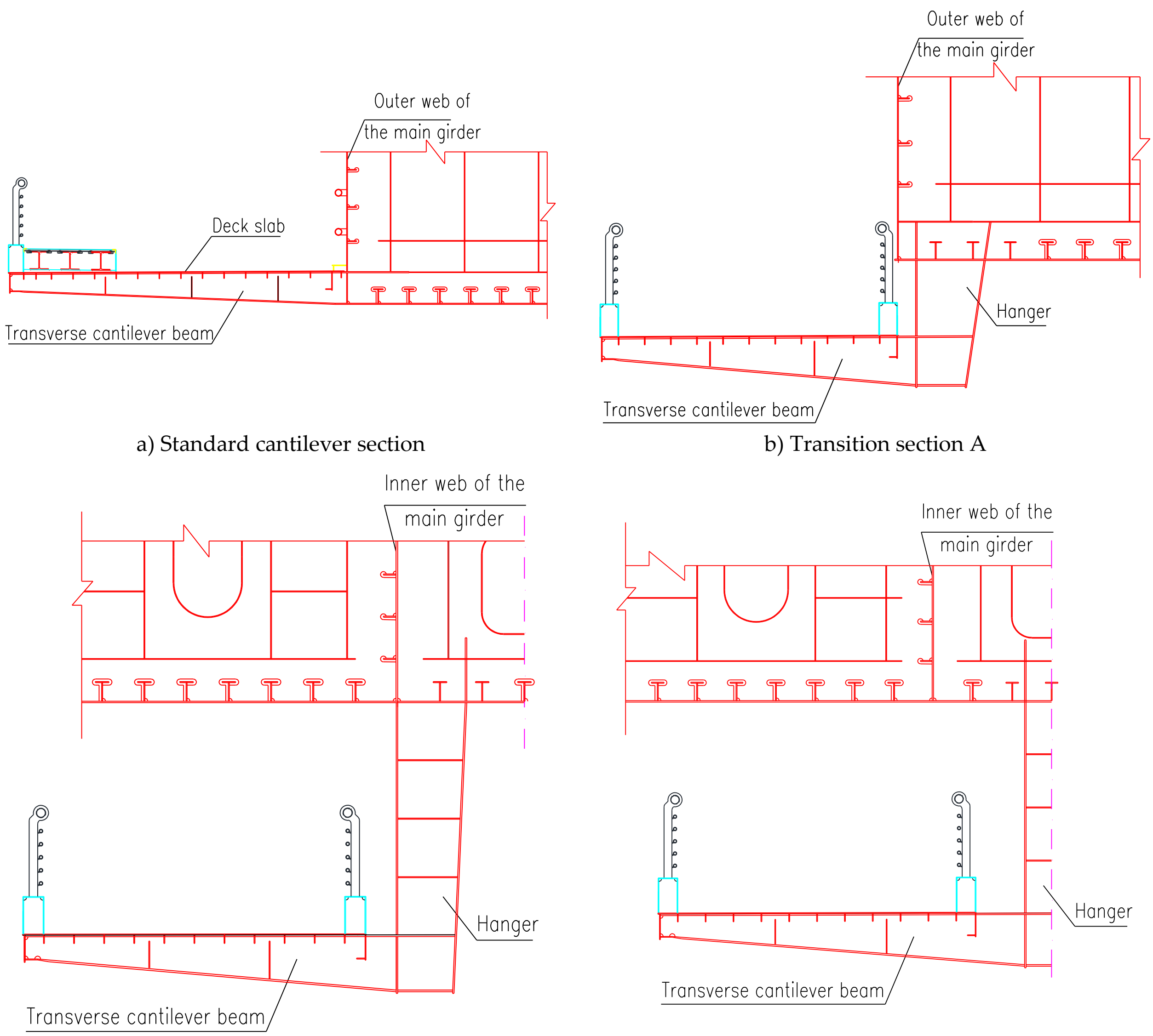


Figure 7 Cross-sectional schematics of the pedestrian/bicycle channel of Zhongxing Bridge

Because the pedestrian/bicycle channel is connected to the main bridge via transverse cantilever beams, the force and deformation of the main bridge under load inevitably affect the channel. Therefore, several approaches were implemented during the design phase to decouple the connection between the pedestrian/bicycle channel and the main bridge structure and ensure the structural safety and mechanical reliability of the channel. Building on the design of the ancillary pedestrian bridge at the Ningbo Waitan Bridge [10], key methods used for the Zhongxing Bridge crossing system include the installation of expansion joints in the deck slab and the optimization of the structural installation sequence. These approaches decrease the effect of the main bridge forces on the structural behavior of the pedestrian/bicycle channel.

4.1 Design of Longitudinal and Transverse Joints in the Pedestrian/Bicycle Channel Deck

The pedestrian/bicycle channel is designed as a structural system borne by transverse cantilever beams. Loads are transferred from the bridge deck slab to these transverse beams, which subsequently transmit the forces to the main bridge. Consequently, the connection between the pedestrian/bicycle channel deck slab and the main bridge is designed as a disconnected and nonwelded interface (see Figure 8) to weaken the structural link between them.

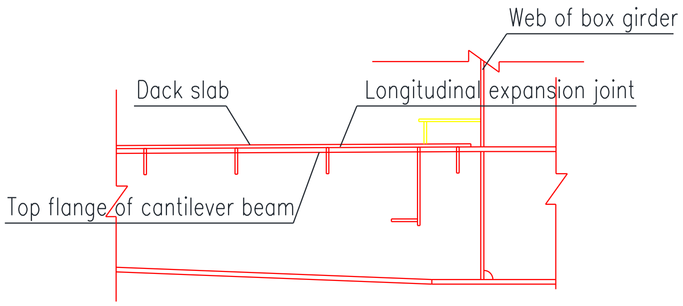


Figure 8 Schematic of the longitudinal joint in the pedestrian/bicycle channel deck slab (view in the transverse direction)

Because the pedestrian/bicycle channel extends over a considerable length of the bridge, transverse joints are installed at approximately 100 m intervals along the longitudinal direction to reduce the effect of both its own thermal forces and the overall forces from the main bridge. Two end plates are provided at each transverse joint location to assist with load transfer (see Figure 9).

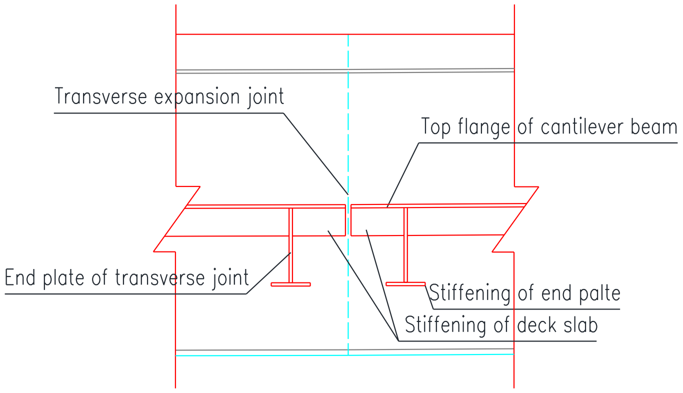


Figure 9 Schematic of the transverse joint in the pedestrian/bicycle channel deck slab (view in the longitudinal direction)

4.2 Installation Sequence Optimization for the Pedestrian/Bicycle Channel Structure

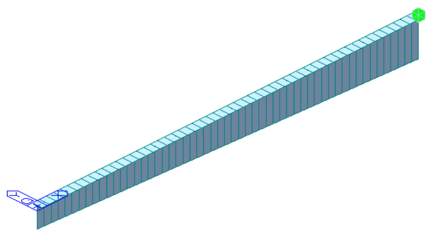
With respect to the side spans of the main bridge of the Zhongxing Bridge, composite girders are constructed using the incremental launching (segment sliding) method, whereas the main girders in the central span are erected by the cantilever method. Because the pedestrian/bicycle channel is connected to the primary structure through welded joints, the channel structure in the mid-span region can be erected concurrently with the main bridge box girder using the cantilever method. With respect to the land-based construction of the pedestrian/bicycle channel in the side spans, two approaches are feasible: erection simultaneously with the main bridge or installation after the closure of the main bridge at mid-span.

To investigate the effects of joint settings and the installation sequence on structural forces, finite element models were established for computational analysis.

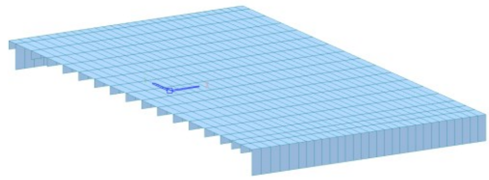
4.3 Analysis of the Effect of Joint Settings and Structural Installation Sequence on the Structural Forces of the Pedestrian/Bicycle Channel

Two loading cases were considered in the local stress analysis of the structure at the transverse joint: Case 1, where the closely spaced transverse beams at the joint are analyzed considering cantilever beam behavior, and Case 2, where the pedestrian/bicycle deck panel is analyzed considering cantilever plate behavior. The computational models and the corresponding results are shown in Figure 10 and Figure 11, respectively.

https://doi.org/10.59238/j.pt.20251107002

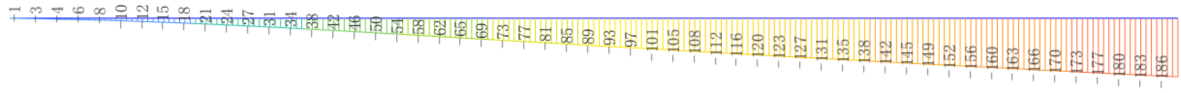


a) Case 1: computation schematic for the closely spaced transverse beams

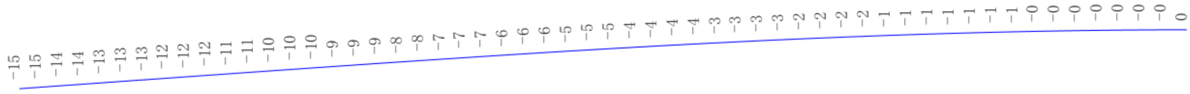


b) Case 2: computation schematic for the cantilever deck panel

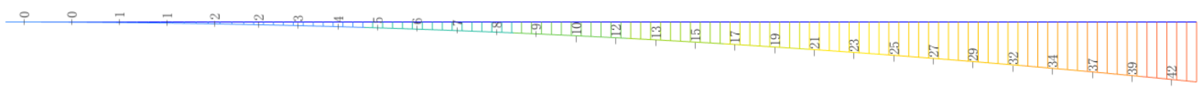
Figure 10 Mechanical analysis of the pedestrian/bicycle channel at the joint



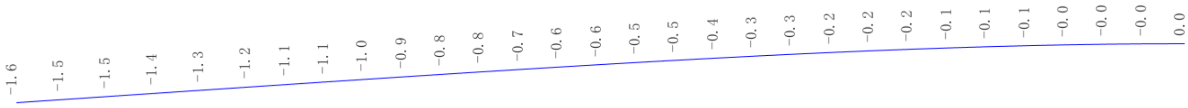
a) Case 1: stress under dead load + full crowd load (unit: MPa)



b) Case 1: displacement under full crowd load (unit: mm)



c) Case 2: stress under dead load (unit: MPa)



d) Case 2: displacement under dead load (unit: mm)

Figure 11 Results of the structural force analysis at the joint

The results of the above analysis reveal that the stress at the root of the cantilever beam in Case 1 is 186 MPa, whereas the stress at the root of the cantilever plate in Case 2 is 42 MPa. The displacement at the free end is 15 mm for Case 1 under the full crowd load and 1.6 mm for Case 2 under the dead load. Both values satisfy the requirements of the relevant design codes.

To verify the effect of joint settings and the structural installation sequence on the total forces in the pedestrian/bicycle channel, a general-purpose finite element analysis was conducted using the software Midas Civil. The model comprises a total of 1306 nodes and 1457 elements, including 1385 beam elements, which are used to simulate the main girders, pylons, and pedestrian/bicycle channel structure, and 72 truss elements, which are used to simulate the stay cables. Because the main bridge uses a system in which the pylon is fixed to the girder but separated from the pier, the boundary conditions are simulated by applying vertical (z-direction) and transverse (y-direction) restraints at the main piers, side piers, and auxiliary piers. A longitudinal (x-direction) restraint is applied at one of the main piers. The pedestrian/bicycle channel is connected to the main girder elements via rigid links.

The load cases considered include self-weighting of the structure, foundation displacement effects, prestressing loads, vehicular live loads, pedestrian live loads, wind loads, and thermal actions (uniform temperature changes, solar temperature differences for the main girder, solar temperature differences for the pylon, and temperature differences between the stay cables and the pylon/girder).

The material specifications are as follows: the main girders, pylons, and other primary structural components use Q345q-D steel; the cross-beam at the pylon top uses Q370q-D steel; the pedestrian/bicycle channel and other secondary structures use Q235C steel; the deck slab in the side span composite girders uses C60 concrete; the prestressing strands are Φ_s15.2–5 high-strength low-relaxation strands; and the stay cables are constructed of Φ7 mm hot-dip galvanized-aluminum alloy-coated steel wires with a characteristic tensile strength of 1770 MPa.

Two separate models were established:

Model 1: The pedestrian/bicycle channel is constructed without transverse joints and is erected simultaneously with the main bridge up to its closure.

Model 2: The pedestrian/bicycle channel is constructed with transverse joints, and the side span sections (including hangers and related structures) are installed after the main bridge closure.

The established finite element models are shown in Figure 12.

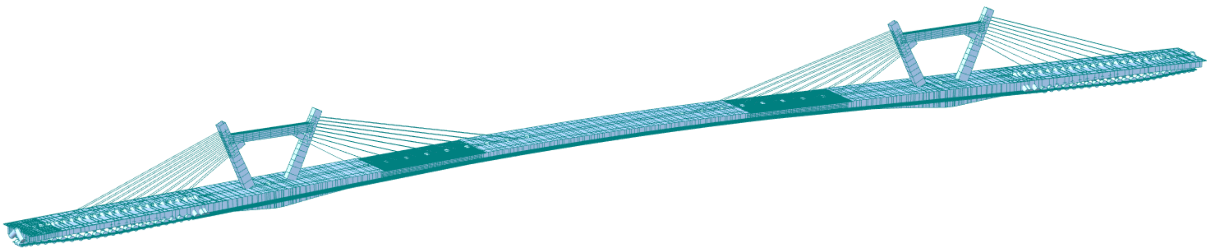


Figure 12 Overall model of the structure with the pedestrian/bicycle channel

The stresses in the pedestrian/bicycle channel structure in the completed bridge state and under live load conditions for the two models are presented in the comparative table below.

Table 1 Maximum stress in the pedestrian/bicycle structure for different computational models (unit: MPa)

Model	**Main Span Cable Zone Max. Stress**			**Side Span Cable Zone Max. Stress**		
	Dead Load	Dead + Live Load	Dead + Live + Temp	Dead Load	Dead + Live Load	Dead + Live + Temp
Model 1	152.4	188.0	202.0	139.2	244.1	334.1
Model 2	152.4	188.0	202.0	108.0	167.4	195.1

As shown in the table above, the structural stresses within the pedestrian/bicycle channel structure (main span cable zone) are equal under both computational models. However, under dead load, the stress in the side span cable zone is greater in Model 1 than in Model 2. With respect to Model 1, the pedestrian/bicycle structure is erected simultaneously with the main bridge. Thus, forces sustained by the main bridge are transferred to the pedestrian/bicycle structure through their connection. In contrast, with respect to the erection method in Model 2, where components such as the hangers for the pedestrian/bicycle structure are installed after the main bridge closure, the channel primarily bears only its self-weight and is not affected by the internal forces of the main bridge structure.

With respect to the side span cable zone structure under a live vehicular load on the main bridge, the forces in Model 2 are also lower than those in Model 1. This finding is attributed to the presence of transverse joints in the pedestrian/bicycle structure, which weakens its connection to the main bridge. Consequently, less force and deformation from the main bridge under a live load is transferred to the pedestrian/bicycle structure.

https://doi.org/10.59238/j.pt.20251107002

If the methods of installing transverse joints and postclosure installation of members are not adopted, the stress in the pedestrian/bicycle channel structure becomes excessively high (with a maximum stress of 334.1 MPa in the side span cable zone) and fails to meet the structural stress requirements. Therefore, employing the construction sequence of installing joints and erecting the pedestrian/bicycle channel after the main bridge closure can effectively reduce its participation in bearing the main bridge loads, thereby decreasing the effect of the main bridge forces and deformations.

5 Pedestrian Comfort Analysis for the Pedestrian/Bicycle Channel

The pedestrian/bicycle channel of the Zhongxing Bridge is a cantilever structure that is relatively lightweight and has low stiffness, rendering it susceptible to various unfavorable vibrations under high-density pedestrian flow. With respect to footbridges, the importance of vibration comfort criteria is unquestionable, because it directly affects both safety and serviceability. Therefore, a dynamic analysis of the channel, a human-induced vibration analysis, and a comfort assessment under pedestrian excitation were conducted.

Through modal analysis, the essential natural frequencies of the pedestrian/bicycle channel were identified as follows: the first vertical bending mode at 0.3604 Hz, the first lateral bending mode at 0.5027 Hz, and the first torsional mode at 1.3360 Hz. A comfort assessment was performed in accordance with the German guideline EN03 (2007) for footbridge design. The analysis indicates that at a maximum crowd density of 1.5 persons/m^2, the maximum vertical acceleration of the girder is 0.378 m/s^2. The maximum accelerations for all the sensitive vibration modes meet the “best” comfort level requirement specified in the guidelines [11].

6 Key Joint Design for the Pedestrian Staircase

After it crosses the river along the main bridge, the pedestrian portion of the pedestrian/bicycle channel of the Zhongxing Bridge is directed to the riverside park via pedestrian stairways. Because the design of the stairways must incorporate architectural features in accordance with the landscape requirements for the park, a scheme incorporating steel tubular inclined braces to support the pedestrian platforms was proposed during the design phase. Concurrently, in terms of landscape, the number of columns for the stairways was reduced by having their ends bear directly on the cantilever brackets of the pedestrian/bicycle channel (Figure 13).

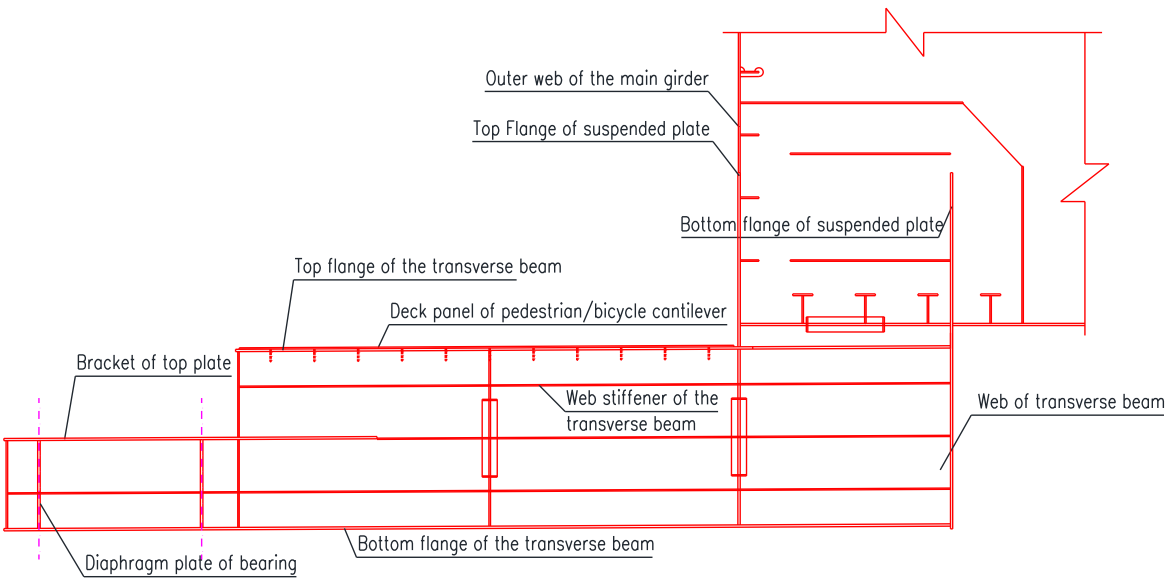


Figure 13 Schematic of the bracket for the pedestrian staircase

Owing to the relatively shallow beam depth, long spans, and comparatively low stiffness of the steel tubular inclined brace support system, conducting static and dynamic analyses of pedestrian stairways and platforms is crucial. A structural computational model was established using the general-purpose finite element software Midas Civil, as shown in Figure 14.

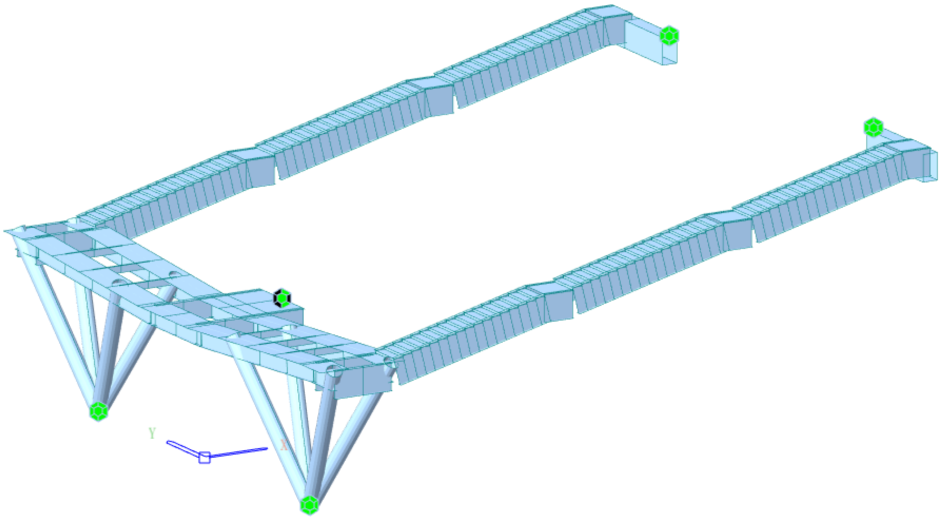


Figure 14 Schematic of the bracket for the pedestrian staircase

The results of the computational analysis revealed that under crowd loading, the stress at the cantilever root of the pedestrian/bicycle channel was 97.7 MPa, the stress in the longitudinal girders of the pedestrian staircase was 146.8 MPa, and the stress in the steel tubular inclined braces was 56.3 MPa. The maximum deflection of the pedestrian staircase under the same load was 37.2 mm. All these values meet the specified design requirements.

Dynamic characteristic analysis of the structure indicated that the natural frequency of its first vertical bending mode is 3.25 Hz. This frequency satisfies the code requirement, which specifies a limiting frequency of 3 Hz for pedestrian bridges to avoid excessive vibration.

7 Conclusions

This paper presents the design of the pedestrian and nonmotorized vehicle crossing system for the Zhongxing Bridge. Analyses of its structural forces considered the configuration characteristics, joint settings, and construction sequence. A comfort assessment was performed in accordance with the German guideline EN03 (2007) for footbridge design. The design scheme for the key joints of the pedestrian staircase is explained. The main conclusions are as follows:

(1) The main bridge of the Zhongxing Bridge uses a single-pylon, central-cable-plane design, which limits the cross-sectional width to avoid torsional issues during construction and operation that would be difficult to adjust with a single cable plane. A shared deck-level layout (vehicle and pedestrian on the same plane) increases the number of webs in the box girder, complicating fabrication and installation. Furthermore, owing to the stringent requirements on longitudinal gradients for pedestrian and nonmotorized vehicle travel, a shared-deck-level layout would limit the gradients of both the main and approach bridges, likely increasing the overall project scope. In contrast, the vertically separated layout results in a narrower box width, fewer cells, and easier future maintenance. Therefore, considering structural mechanics, detailing, economy,

https://doi.org/10.59238/j.pt.20251107002

and maintenance, a vertically separated layout is recommended for crossing systems.

(2) The pedestrian/bicycle system of the Zhongxing Bridge is divided into four structural forms based on its positional relationship with the main girder. The characteristic feature of the bridge is direct or indirect (via vertical hangers) connection to the main girder through transverse cantilevers. To decrease the effect of the main bridge on the forces within the pedestrian/bicycle system, longitudinal and transverse joints were installed. Furthermore, the hangers for the side span pedestrian/bicycle channel were installed after the main bridge closure was used. Computational results indicate that the maximum stress at the root of the cantilever at the joint is 186 MPa and that the maximum displacement at its free end under full crowd loading is 15 mm. With respect to the side span cable zone structure with both transverse joints and postclosure member installation, the maximum stress under the characteristic combination is 195.1 MPa, which meets the code requirements.

(3) Modal analysis revealed that the vertical bending frequency of the pedestrian/bicycle channel is 0.3604 Hz. A comfort assessment in accordance with the German EN03 guidelines (2007) indicated that under a maximum crowd density of 1.5 persons/m², the maximum vertical acceleration of the girder is 0.378 m/s². The maximum accelerations for all the sensitive vibration modes satisfy the "best" comfort level requirement.

(4) The pedestrian staircase is designed to bear on the cantilever brackets of the pedestrian/bicycle channel. Computational analysis of the staircase and its platform reveals that under crowd loading, the stress at the cantilever root of the pedestrian/bicycle channel is 97.7 MPa, the stress in the longitudinal girders of the staircase is 146.8 MPa, and the stress in the steel tubular inclined braces is 56.3 MPa. The maximum deflection of the staircase under crowd loading is 37.2 mm. The natural frequency of the first vertical bending mode of the staircase is 3.25 Hz, which satisfies the code-specified limit of 3 Hz for pedestrian bridges. Therefore, the pedestrian staircase meets both static and dynamic performance requirements.

Conflict of interest: The author disclosed no relevant relationships.

Data availability statement: The data that support the findings of this study are available from the author, Zhang, upon reasonable request.

Reference

1. Zhang, W.; Huang, Y. Study on Setup Scheme of Pedestrian-non-motorized Vehicle Passage of Urban Trunk Roads for Cross-river Transportation. *Urban Roads Bridges & Flood Control* **2019**, 37-40, doi:10.16799/j.cnki.csdqyfh.2019.01.010.(in Chinese)
2. Qiu, Y. The Design and Construction of Double-deck Bridge for the Separation of Motor Vehicle and Non-motorized Vehicle. *Engineering and Technological Research* **2024**, *9*, 170-172, doi:10.19537/j.cnki.2096-2789.2024.12.055.(in Chinese)
3. Yan, H.; Chen, L.; Shao, C.; Xu, Y. Key Techniques for Design of In-Situ Widening and Reconstruction of Rail-cum-Road Steel Truss Bridge. *Bridge Construction* **2019**, *49*, 91-96, doi:10.3969/j.issn.1003-4722.2019.03.017.(in Chinese)
4. Yang, S.; Xiang, Z.; Zhu, G.; Du, C. Design and Construction Technology of the Underneath Footway of Chongqing Jiayue Bridge. *Chongqing Architecture* **2012**, *11*, 24-26, doi:10.3969/j.issn.1671-9107.2012.06.024.(in Chinese)
5. Wu, G. Research on the Impact of Wusongjiang Bridge Vehicle Incentives on the Comfort of Non-Motorized Pedestrians. *China Municipal Engineering* **2012**, 24-27, doi:10.3969/j.issn.1004-4655.2012.03.009.(in Chinese)
6. Li, C.; Li, W. Research on the Design of Non-Pedestrian Passageways Suspended Under Bridges and Human-Induced Vibration. *China Municipal Engineering* **2020**, 95-97, doi:10.3969/j.issn.1004-4655.2020.04.028.(in Chinese)

7. Yan, X. Design and Research on the Pedestrian and Non-motorized Vehicle System of Ziyun Bridge in Fengcheng City. *Urban Roads Bridges & Flood Control* **2022**, 88-90, doi:10.16799/j.cnki.csdqyfh.2022.02.025.(in Chinese)
8. He, W. Key Design Technologies for the V-Shaped Main Piers of Ningbo Zhongxing Bridge. *China Municipal Engineering* **2022**, 12-16, doi:10.3969/j.issn.1004-4655.2022.02.004.(in Chinese)
9. Hu, F. Nanchang City Chaoyang Bridge Navigation Span Pedestrian and Non-motorized Vehicle Channel Structural Design and Research. *China Municipal Engineering* **2014**, 20-23, doi:10.3969/j.issn.1004-4655.2014.06.007.(in Chinese)
10. Wan, P.; Ma, B. Design of Subsidiary Footbridges of Waitan Bridge in Ningbo. *World Bridges* **2013**, *41*, 5-9, doi:10.3969/j.issn.1671-7767.2013.04.002.(in Chinese)
11. Tongji University. *Ningbo Zhongxing Bridge Pedestrian Comfort Analysis Research Report*; Tongji University: Shanghai, 2016.(in Chinese)

AUTHOR BIOGRAPHIES

Chunlei Zhang

D.Eng. Senior Engineer. Graduated from Tongji University in 2013.

Research Direction： Design and Research in Bridge Engineering.

Email: zhangchunlei5@smedi.com