Design and Construction

Application and Practice of Ground-free Lightweight Formwork Support System for High Pier Bent Caps

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Abstract: With the increasing urbanization in China, the scale of urban elevated bridge construction continues to expand. Conventional ground-supported formwork systems face significant challenges in the construction of high-pier, large-span prestressed bent caps. These traditional systems, characterized by large site occupancy and high material consumption, often lead to low construction efficiency. Particularly in space-constrained urban centers, their bulky support structures severely disrupt surrounding traffic and fail to meet urban bridge construction demands. In this paper, a lightweight, ground-free formwork support system for high-pier bent caps is systematically investigated. By employing novel materials and structural forms, such as acrylonitrile-styrene-acrylate (ASA) polymer-reinforced alloy formwork and ground-free steel supports, the system achieves lightweight, modular, and green construction. It innovatively addresses multiple technical difficulties inherent in traditional methods, significantly reduces carbon emissions during construction, improves material reusability, and embodies the concept of sustainable construction. Engineering practices in typical projects, including Wenzhou Wenrui Avenue, Hangzhou Shidai Avenue, and Ningbo Jiulong Avenue, have demonstrated the marked effectiveness of this system. It has significant advantages in terms of construction efficiency, cost control, resource conservation, and environmental impact, indicating substantial potential for broader application.

Keywords: high-pier prestressed bent caps; lightweight formwork support; ground-free construction; ASA polymer formwork; prefabrication technology

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1 Introduction

The continuous advancement of urbanization in China has led to a surge in traffic volume, making the construction of elevated bridges critical for optimizing urban traffic structures and enhancing travel efficiency [1]. In the design and construction of elevated bridges, sufficient consideration must be given to the rational reservation and unimpeded flow of the space beneath the bridge, in addition to meeting the required bridge deck width. Consequently, long-cantilever prestressed concrete bent caps, which can effectively improve the utilization efficiency of the underbridge space, have been widely adopted in practical engineering [2].

The primary function of the formwork support system in bent cap construction is to transfer construction loads, provide a stable platform for concrete pouring, and ensure accurate positioning and construction stability of the bent cap. Traditional ground-supported systems, such as cup-lock and disk-lock scaffolding, are increasingly failing to meet the demands of municipal bridge projects in land-constrained areas because of their large site footprint, substantial material consumption, and low construction efficiency. Against this backdrop, lightweight, ground-free, tall formwork support systems for bent caps have emerged and attracted significant attention in practical applications [3,4]. This system abandons the ground-supported approach and is particularly suitable for typical scenarios such as high piers and long-span prestressed bent caps. It not only enables rapid assembly and disassembly of the bent cap formwork but also minimizes the impact of construction on surrounding road traffic, offering a more sustainable solution for municipal road and bridge construction [5,6].

Lightweight design aims to reduce structural self-weight while ensuring load-bearing capacity through the optimization of material properties and structural layout. In bridge construction, lightweight design can significantly increase construction efficiency and reduce material and building costs [7,8]. Within the context of Industry 4.0 and the "dual carbon" goals, lightweight design has become a crucial direction for the optimization of engineering structures [9]. Through structural optimization, cross-sectional innovation, and the introduction of lightweight yet high-strength materials such as polymers and high-performance composites, researchers have continuously advanced the objectives of structural lightweight to pursue greener and more efficient engineering practices [10].

1.1 Technological Evolution of the Bent Cap Formwork Support System

The bent cap formwork support system has undergone three main phases of evolution: from traditional steel tube and coupler scaffolding and cup-lock scaffolding to ground-supported steel supports and then to modular and lightweight designs. It is currently evolving continuously toward "green and low-carbon" solutions and system integration [11-13]. The innovative lightweight, ground-free, tall formwork support system for bent caps employs an acrylonitrile-styrene-acrylate (ASA) polymer formwork and a ground-free steel support system. Through the integrated application of material lightweight, structural prefabrication, and green construction techniques, this system effectively addresses key challenges in the construction of high-pier, large-span bent caps, such as enhancing efficiency, minimizing traffic disruption, and conserving resources. It embodies the advanced trend in current bridge construction technology toward lightweight, efficient, low-carbon, and sustainable development.

1.2 ASA Polymer Formwork

Formwork serves as the critical temporary support for concrete casting, ensuring the precise geometric dimensions and positioning of structural members while they bear various loads during construction. The quality of the formwork directly affects the concrete quality and is a key factor influencing construction efficiency and resource utilization.

The development of formwork materials in China has transitioned from wood and steel to high-performance green materials. In the mid-20th century, wooden formwork was predominant, later gradually being replaced by steel formwork and becoming mainstream [14]. Plywood formwork suffers from issues such as poor surface flatness and insufficient strength. Owing to its significant self-weight and high support requirements, steel formwork limits the efficiency of construction reuse cycles [15]. Driven by the concept of sustainable development, recent years have seen formwork materials expand from wood and steel to lightweight, high-strength options such as alloys and polymer-reinforced alloys, reflecting a development trend toward green and refined solutions.

ASA polymer formwork is produced using ASA resin and nano-calcium as raw materials through a one-step melt coextrusion process. It offers advantages such as low emission, reusability, strong deformation resistance, excellent concrete finishing quality, and low material density [16]. Its demolding process is convenient, allowing for multiple rounds of recycling and reuse. The ASA polymer formwork used in practical engineering is shown in Figure 1, with its cross-sectional diagram presented in Figure 2.

The slopes of the stress–strain curves for the ASA polymer formwork material in the tensile elastic stage and the compressive elastic stage are relatively close, allowing the assumption that its elastic modulus in tension and compression is consistent. According to the elastic modulus values measured under tensile conditions, the elastic modulus of the ASA polymer formwork material is approximately 2,200 MPa. The density of the ASA polymer formwork material is relatively low, ranging from approximately 1,050 to 1,090 kg/m³.

The cost of the ASA polymer formwork is approximately 70% that of reusable steel formwork. However, steel formwork requires rust removal and the application of release agents before use, which affects its construction efficiency and ultimately leads to increased overall cost.

Figure 1 ASA polymer formwork

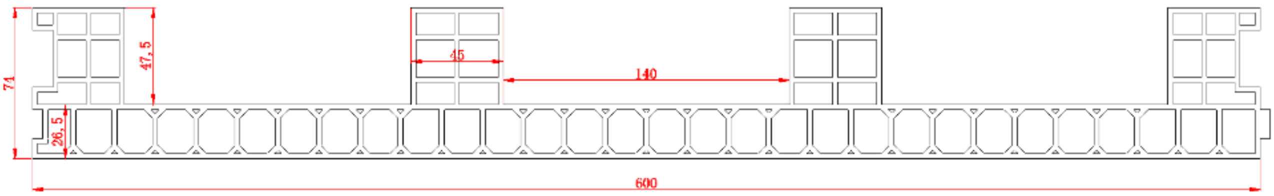

Figure 2 Cross-section of the ASA polymer formwork (unit: mm)

Under the dual carbon strategy, the formwork industry is advancing the standardization, modularization, and enhanced recycling of materials. ASA polymer formwork contributes to resource substitution at the material level through approaches such as “replacing steel with plastics,” significantly reducing carbon emissions and energy consumption [9]. Future efforts may focus on the serialization of the ASA polymer formwork, the synergistic optimization of support systems, and the standardization of construction techniques. This will improve its applicability and economic viability in various scenarios, including the construction of different types of bent caps.

1.3 Ground-free Tall Formwork Support System

The ground-free formwork support system does not rely on ground reactions for load bearing. Instead, it transfers construction loads directly to the bridge piers, as illustrated in Figure 3. The design concept involves preinstalling load-bearing components such as corbels, clamps, steel pin bars, or tie rods onto the piers. A bearing system, composed of structural steel or Bailey beams, is then erected on these supports. Finally, the casting platform is arranged atop this bearing system, thereby eliminating the reliance on ground-supported scaffolding and its constraints on site conditions [17-19]. This system occupies minimal space beneath the bridge, adapts to complex terrain, and offers high recyclability of construction materials. Consequently, it has been widely adopted in environments such as urban elevated bridges, overpasses, and scenarios involving high piers or deep water [20,21].

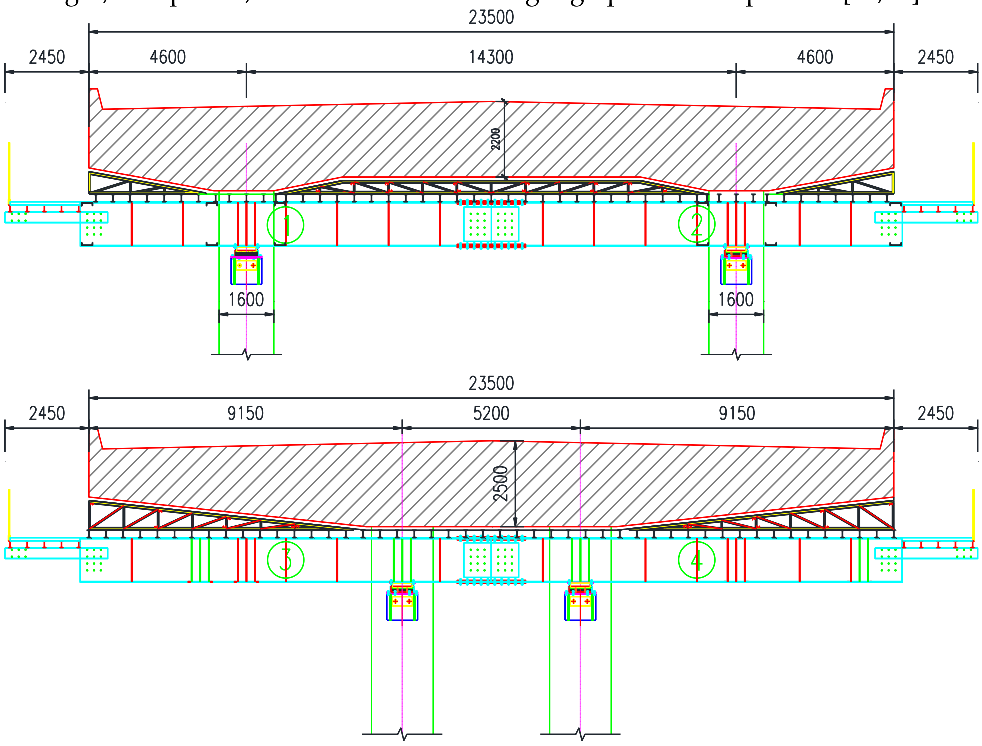

Figure 3 Schematic diagram of the ground-free steel support (unit: mm)

With advancements in construction technology, ground-free support systems for bent caps have evolved from simple early platforms using clamps or steel rods into multiple forms that offer high load-bearing capacity, stability, and versatility. The following are several commonly used ground-free support systems in engineering.

(1) **Pin Bar-distribution Beam System**: In this system, preformed holes are provided in the bridge piers into which high-strength steel pin bars (shear pins) are inserted to serve as the primary load-bearing points. Structural steel distribution beams are then erected on these pins to support the formwork and construction loads [18,20,22,23]. In analytical models, the contact between the pin bar and the pre-formed hole in the pier is often simplified as ideal. However, in practice, owing to installation clearances and component deformation, the contact stress on the hole wall is often unevenly distributed, which can lead to localized stress concentrations and potential concrete failure at the contact area with the pier.

(2) **Pin Bar–truss Composite System**: In this system, pin bars are combined with a truss structure to form a stable load-bearing system [4,19,24]. The truss efficiently distributes loads and transfers forces to the pier structure through the pin bar connections, offering excellent overall stiffness and spanning capability. It is particularly suitable for the construction of long-cantilever prestressed bent caps. During the engineering design phase, spatial modeling and analysis are typically conducted using finite element software such as Midas Civil. This

involves calculating member forces and deformations under multiple load case combinations to verify structural strength and stability.

(3) **Corbelled Bracket System**: In this system, corbels are installed onto the pier shaft. Bailey beams or large structural steel sections are then placed on these corbels to form a load-bearing platform, offering advantages such as convenient installation and good economic efficiency [25,26]. Corbels can be categorized into pre-embedded and posttensioned types. The former offers better integrity and higher load-bearing capacity, while the latter is installed by tensioning using precision-rolled threaded steel bars, offering flexibility and adjustability and causing less damage to the pier shaft. The design of corbelled brackets requires precise calculation of loads and eccentricity effects. Finite element simulation software is employed to conduct stress analysis on the corbels, Bailey beams, and connectors to ensure safe and reliable force transfer [27].

(4) **Clamp-type Ground-free Support System**: In this system, clamps fixed onto the pier columns are used as the ultimate load-bearing components, relying on the frictional force generated by the pretension of high-strength bolts to sustain the loads [28]. To enhance safety, a combination of upper and lower clamps connected by support rods is typically used to form an integrated load-bearing system.

By transferring construction loads to the permanent structure, ground-free support systems fundamentally eliminate the reliance on the ground-bearing capacity and extensive site preparation required by full-framed scaffolding. Owing to the significant reduction in ground-supported components, these systems can markedly minimize disruption to traffic beneath the bridge. Consequently, they are especially suitable for construction in city centers or along busy traffic corridors. Furthermore, these systems demonstrate clear advantages in economic aspects such as assembly/disassembly efficiency and material reusability, aligning with the current development requirements for green construction, energy savings, and consumption reduction.

2 Engineering Applications

2.1 Application of the Ground-free Support System for Bent Caps in Section 2 of Phase I, Wenrui Avenue Project

The total length of Section 2, Phase I, of the Wenrui Avenue project is 2,170 m. The construction of the mainline elevated bridge is coordinated with the Wenzhou Metropolitan Railway Line S3, involving a total of 71 mainline bent caps and 39 ramp bent caps. The pier columns generally exceed 20 m in height, with the maximum reaching 26 m, classifying them as high-pier structures. This imposes significant demands on the safety and adaptability of the support system.

The width of the construction site is essentially consistent with the width of the urban expressway bent caps. Employing the traditional full-framed scaffolding method for formwork erection and concrete pouring after pier completion would have required an extensive ground footprint. This would have led to the interruption of longitudinal traffic beneath the bridge and subsequently affected the construction sequence of adjacent bent caps, thereby constraining the overall project progress. To overcome this challenge, the project ultimately adopted a ground-free formwork support system for the bent caps, anchoring the formwork system directly to the top of the piers, which effectively avoided occupation of the space below the bridge.

All ground-free supports throughout the project utilized a welded H-beam corbelled bracket system, as shown in Figure 4. By combining welded H-beam main girders with corbel structures, various support configurations adaptable to different spans and cantilever lengths were constructed. The construction sequence for the steel ground-free supports in the Wenrui Avenue project is illustrated in Figure 5.

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Figure 4 Bent cap formwork support construction for the Wenrui Avenue project

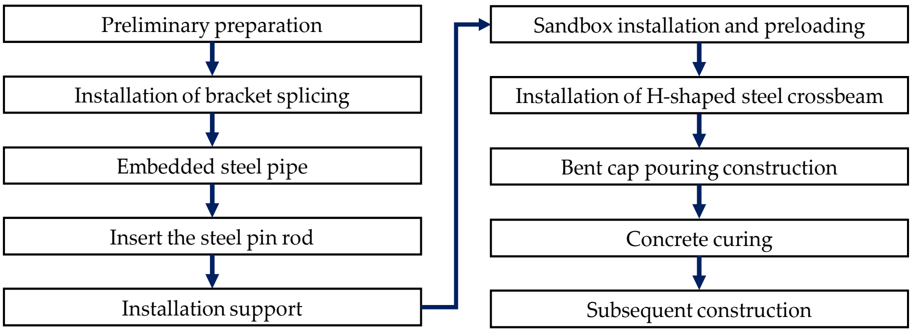

Figure 5 Flowchart for the ground-free support construction of Wenrui Avenue bent caps

During construction, a preloading test was conducted on the support system, with real-time monitoring of stress and deformation. The preloading test was performed using concrete blocks and sandbags, as shown in Figure 6. The total stacking load for the preloading test was set at 1.1 times the total construction load of the bent cap. The first support of each type scheduled for construction was selected as the test subject. The preloading procedure employed graded loading and unloading, conducted in three stages: 60%, 80%, and 100% of the target load value. The deformation values at the measurement points under each load level were recorded during the test. The results indicated that the support system exhibited controlled deformation and a reasonable stress distribution under loading, satisfying all the construction requirements.

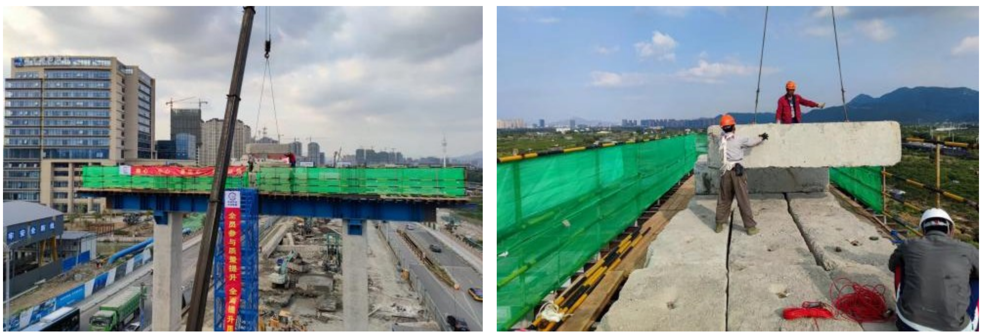

Figure 6 Preloading test of the ground-free support on Wenrui Avenue

2.2 *Application of the Ground-free Support System for Bent Caps on Hangzhou Shidai Avenue*

The Shidai Avenue South Extension Project (from the Ring Expressway to the Middle Ring Road Section) is located in Xiaoshan District, Hangzhou. The bent cap works for this project cover the elevated mainline from chainage K0+000 to the north approach of Yupu Bridge (Piers 1 to 55), from the south approach of Yupu Bridge to the railway-affected section at K7+157 (Piers 78 to 222), and from K8+217 to K11+047 (Piers 257 to 347), as well as related ramps, totaling 350 bent caps.

In this project, the cantilever ends of some double-column bent caps projected within the limits of the traffic maintenance road, leaving no ground space available for erecting pier-supported brackets or full-framed scaffolding. To overcome this construction constraint, the project adopted a corbelled bracket system, a ground-free support method, for bent cap construction. This effectively avoided interference with the traffic beneath the bridge. The design of the bent cap support is shown in Figure 7.

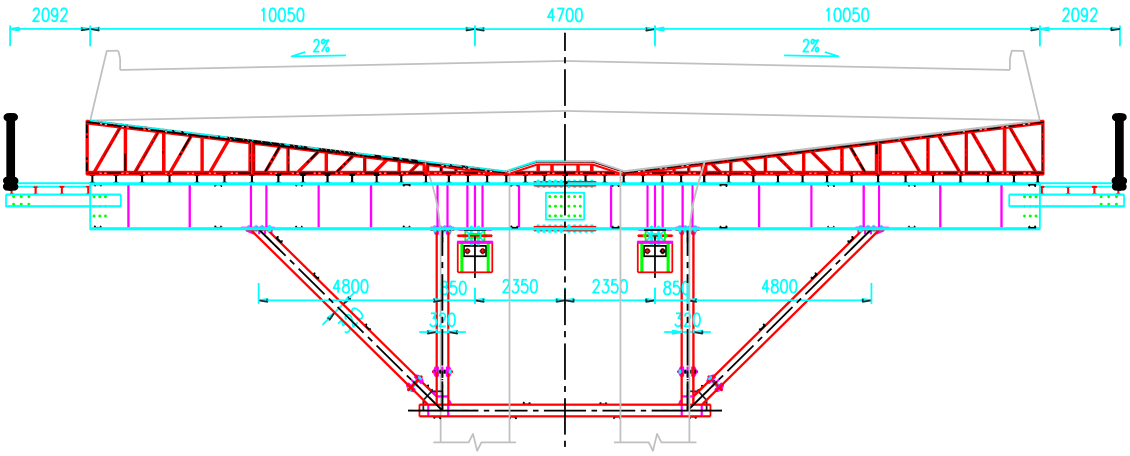

Figure 7 Design of the double-column bent cap ground-free support for Hangzhou Shidai Avenue (unit: mm)

Figure 8 Space beneath the bridge is utilized for social vehicle passage during the construction of the ground-free support system

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The construction sequence was as follows: construction preparation → pre-embedding of steel pipes during column casting → insertion of high-strength pin bars → installation of steel corbels → placement of sand jacks or precision-cast unloading blocks → erection of steel cross beams and intergirder bracing → laying of distribution beams → installation of the bent cap bottom formwork system → concluding with the casting of the main bent cap structure. By utilizing ground-free supports, the space beneath the bridge, which would otherwise have been obstructed, remained available for public vehicle traffic, as shown in Figure 8.

2.3 *Application of the Ground-free Support System for Bent Caps in Section III, Ningbo Jiulong Avenue*

Section III of the Ningbo Jiulong Avenue Expressway Project has a total length of 1,265 m. It is a coconstruction project involving an urban elevated road and Metro Line 10, comprising a total of 109 bent caps (including cross beams). The structural types encompass various forms, such as single-column, double-column, triple-column, and quadruple-column piers, with a predominance of long-cantilever, large-span prestressed bent caps. These complex engineering conditions impose high demands on bent cap construction technology.

Figure 9 Section III of the Ningbo Jiulong Avenue project

If the bent cap construction had employed the full-framed ground-supported scaffolding method, the erected scaffolding would have occupied a substantial amount of space beneath the bridge. This would have led to the interruption of construction access routes, severely impacting material logistics and the work on adjacent piers. Furthermore, the installation and dismantling cycle for ground-supported scaffolding is lengthy, making it difficult to meet the tight schedule requirements of the Section III Jiulong Avenue project, which is being constructed concurrently with the metro rail line. Consequently, the bent cap construction ultimately adopted a combined formwork support system integrating the corbelled bracket system—a tall, ground-free support (Figure 10)—with an ASA polymer formwork. The practical application of this combined structure of ground-free support and ASA polymer formwork is shown in Figure 11.

Building upon the research and experience from the Wenrui Avenue and Shidai Avenue projects, this project carried out specialized designs tailored to the different bent cap forms. The resulting combined formwork support system features standardization and reusability. The construction sequence was as follows: preliminary preparation → pre-embedding of climbing cones during column casting → installation of climbing cone bolts → placement of sand jacks → installation of H-beam cross girders and intergirder bracing → installation of distribution beams and chamfer brackets → placement of timber battens and formwork → construction of the main bent cap structure.

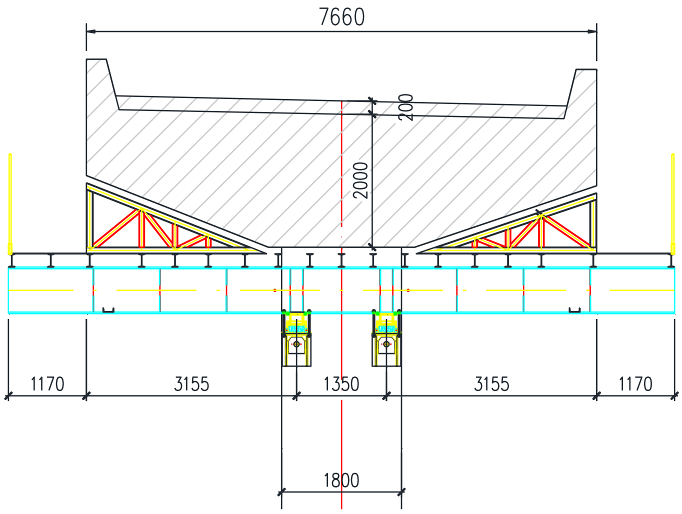

Figure 10 Ground-free support for a bent cap in the Jiulong Avenue project (unit: mm)

Figure 11 Schematic diagram of the combination of ground-free support and polymer formwork for Jiulong Avenue

3 Calculation for the Ground-Free Support of Bent Caps

The calculation for the ground-free support of bent caps is illustrated using the double-column Pier 18 on the main line of the Wenrui Avenue project as an example. The length of the bent cap is 23.5 m, the maximum depth is 2.2 m, and the maximum width is 3.1 m. Longitudinal and cross-sectional views of the bent cap support are shown in Figure 12. The ground-free support employs WH 1,300×600×18×32 mm welded H-beams as the main girders and I22 I-beams as the distribution beams.

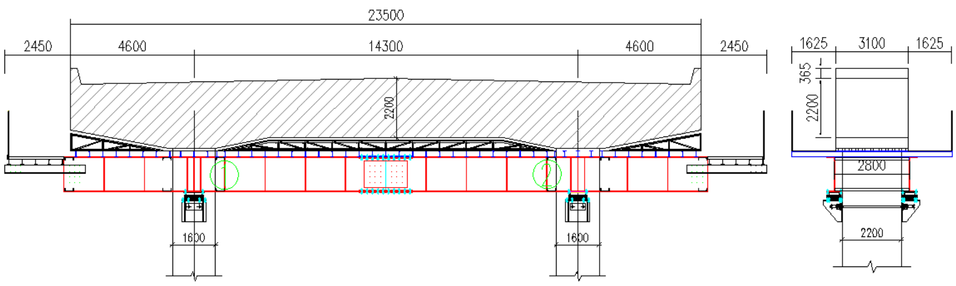

Figure 12 Longitudinal and cross-sectional views of the bent cap support (unit: mm)

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3.1 Loads

In accordance with the Technical Specifications for Construction of Highway Bridges and Culverts (JTG/T 3650—2020) and the Technical Regulations for Safety of Scaffolding and Support Construction in Highway Engineering (JT/T 1516—2024), the main loads on the support and their characteristic values are as follows:

① Self-weight of the formwork and support: The unit weight of the formwork structure is assumed to be 1.5 kN/m³. The self-weight of the support is automatically calculated by the software.

② Weights of freshly placed concrete, reinforcement, prestressing tendons, or other concrete structures: Calculated separately based on the varying depth of the bent cap. The unit weight of the reinforced concrete is assumed to be 26 kN/m³.

③ Load from construction personnel, equipment, and materials: 3.0 kN/m².

④ Vibration load induced during concrete compaction: 2.0 kN/m².

The load combinations for different verification purposes are as follows:

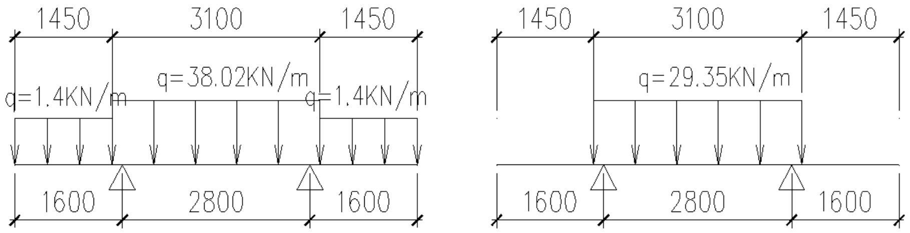
For the strength calculation: 1.3 × (①+②) + 1.5 × (③+④);

For the stiffness check: 1.0 × (①+②).

3.2 Calculation of the I-beam Distribution Beams for the Support

The support distribution beams employ I22A I-beams with a length of 6 m and a spacing of 500 mm. The central portion of the beams carries the load from the bent cap, while the sections on both sides, corresponding to access walkways, bear the construction live load. The maximum depth of the bent cap concrete is taken as 2.2 m.

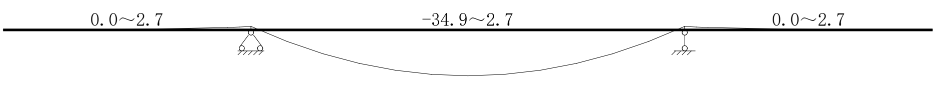
A simplified structural model (free-body diagram) of the I-beam distribution beams is presented in Figures 13 and 14.



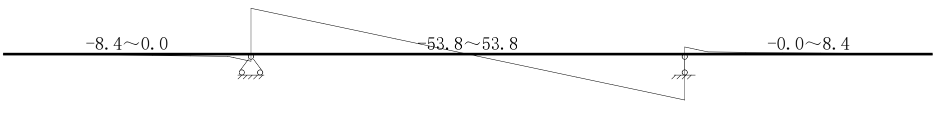
Simplified diagram for strength calculation

Simplified diagram for deformation calculation

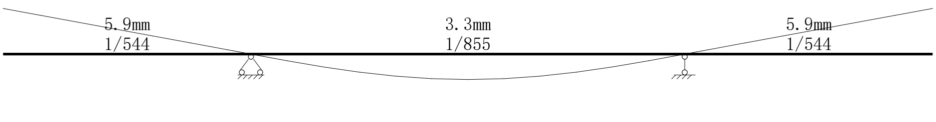
Figure 13 Simplified force diagram of I22A I-beam distribution beams (unit: mm)



a) Bending moment (unit: kN·m)



b)Shear force (unit: kN)



c) Deformation (unit: mm)

Figure 14 Calculation results for I22A I-beam distribution beams

The calculation results are presented in Table 1. The maximum normal stress is $\sigma_{max} = 107.3$ MPa < 215 MPa, and the maximum shear stress is $\tau_{max} = 37.1$ MPa < 125 MPa. The maximum deflection is $f = 5.9$ mm < L/400. All the values meet the code requirements.

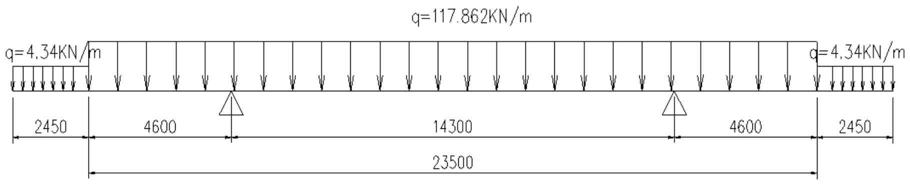
Table 1 Summary of the calculation results for the I-beam distribution beams

Parameter	Calculated Value	Code Limit	Redundancy
Normal Stress σ_{max}	107.3 MPa	215 MPa	1.0
Shear Stressτ_{max}	37.1 MPa	125 MPa	2.37
Deflection f	5.9 mm	8.0 mm	0.36

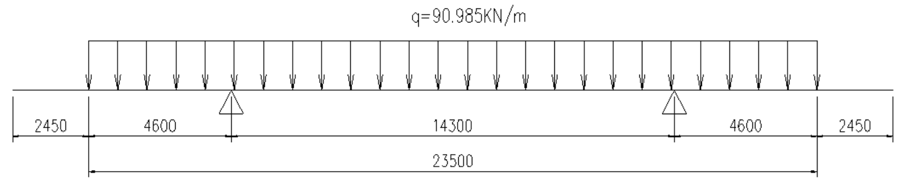
3.3 *Calculation of the I-beam Main Girders for the Support*

The main girders of the support employ WH 1,300×600×18×32 mm welded H-beams made of Q345b steel. As the total load from the bent cap is borne by two main girders, each individual girder is calculated to carry half of the total bent cap load.

A simplified structural model for the main girder calculation is presented in Figures 15 and 16. Given the numerous stiffening plates on the main girder, its self-weight is factored into the calculation with a multiplier of 1.35.

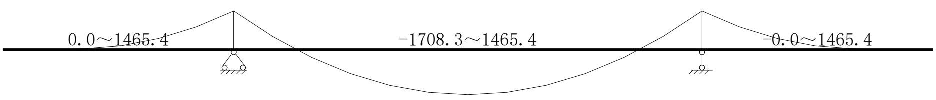


a) Simplified diagram for strength calculation

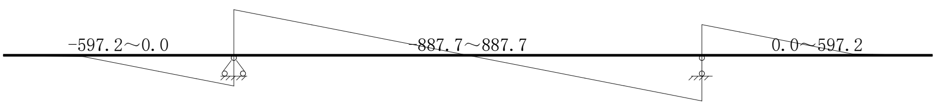


b) Simplified diagram for deformation calculation

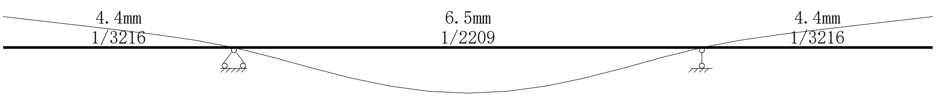
Figure 15 Simplified force diagram of the I-beam main girder (unit: mm)



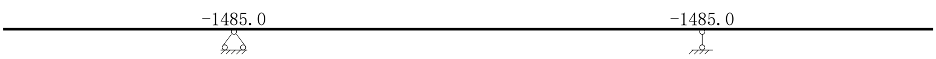
a) Bending moment (unit: kN·m)



b) Shear force (unit: kN)



c) Deformation (unit: mm)



d) Reaction force (kN)

Figure 16 Calculation results for the I22A I-beam main girders

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The calculation results are presented in Table 2. The maximum normal stress is $\sigma_{max} = 57.9\ \text{MPa} < 295\ \text{MPa}$, and the maximum shear stress is $\tau_{max} = 42.1\ \text{MPa} < 170\ \text{MPa}$. The maximum deflection is $f = 6.5\ \text{mm} < \text{L}/400$. All the values meet the code requirements.

Table 2 Summary of the calculation results for the I-beam main girders

Parameter	Calculated Value	Code Limit	Redundancy
Normal Stress σ_{max}	57.9 MPa	295 MPa	4.1
Shear Stressτ_{max}	42.1 MPa	170 MPa	3.0
Deflection f	6.5 mm	35.75 mm	4.5

4 Evaluation of Application Effectiveness

A ground-free formwork support system for high-pier bent caps is designed to overcome the drawbacks of traditional high-pier construction methods, such as bulky support systems, long construction cycles, and a heavy reliance on site conditions. By optimizing the load transfer paths and structural details, the system achieves a more streamlined structure and a more rational force distribution.

In practice, the system utilizes shear pin bars combined with corbels as the core support, which is integrated with lightweight polymer formwork. This configuration results in more direct load paths and enhanced structural integrity. The prefabricated construction of the formwork and the standardized design of the support system have significantly improved the efficiency of component transportation and onsite installation.

Taking the construction of a high-pier bent cap in Section III of the Jiulong Avenue project as an example (with a net height of approximately 22.0 m beneath the beam), the steel consumption for the ASA ground-free support portion was only 38.1% of that required for traditional full-framed scaffolding. Field measurements confirmed that the overall construction cycle was reduced from 15 days to 10 days, demonstrating significant advantages [29]. A detailed comparison is presented in Table 3. The formwork maintenance cost is calculated at 20 CNY/m² in this analysis, whereas the corresponding cost for the polymer formwork is negligible.

Table 3 Comparison of Construction Costs between the Support Methods

Indicator	Unit	ASA Ground-Free Support	Conventional Support System	Ratio
Construction Duration	Day	10	15	0.67
Steel Consumption for Support	Ton	25.3	66.5	0.38
Support Cost	CNY	2,277	8,977	0.25
Unit Price of Side Formwork	CNY/m²	9.21	16.67	0.55
Labor and Machinery Cost	CNY	31,000	59,520	0.52
Formwork Maintenance Cost	CNY/m²	0	20	/

In terms of economic benefits, the comprehensive project cost has been controlled effectively through significant reductions in steel consumption, lower transportation frequency, and the elimination of foundation treatment. Statistics from project implementations such as those on Wenrui Avenue, Shidai Avenue, and Jiulong Avenue indicate that adopting the ground-free formwork support system results in an overall project cost of only 52% compared with the conventional approach, with construction cost savings exceeding 19 million CNY. Furthermore, by fully utilizing the space beneath the bridge, expenses related to temporary road relocation and demolition, as well as associated construction measures, are reduced, thereby further decreasing the total project cost.

In terms of social benefits, this system significantly mitigates the impact of bent cap construction on urban traffic. During the construction period, the passage of at least one traffic lane beneath the bridge can be guaranteed, avoiding a complete traffic shutdown for the entire construction duration. The conserved space beneath the bridge allows for more flexible construction sequencing and traffic management arrangements at critical nodes, alleviating the impact of construction on public travel and enhancing the social acceptance of the project.

In conclusion, the lightweight, ground-free formwork support system for high-pier bent caps has significant technical, economic, and social advantages. This provides a new technical pathway for bent cap construction and has substantial potential for broad application and promotion.

5 Conclusions

In this paper, the technical characteristics, structural forms, and engineering application effectiveness of a lightweight, ground-free formwork support system for high-pier bent caps are systematically analyzed, leading to the following conclusions:

(1) Through material improvement and structural optimization, this technical system overcomes the application bottlenecks of ground-supported formwork in the construction of high-pier, large-span bent caps. The ASA polymer formwork achieves the material innovation of “replacing steel with plastics” for the support system. The innovative design of the ground-free support system enables the direct transfer of construction loads to the permanent structure, significantly reducing the dependence on site conditions.

(2) In practical engineering applications, this system has remarkable advantages. In terms of technical performance, notable results are achieved, including an improvement in construction efficiency of more than 30% and a reduction in material usage of approximately 60%. Economically, standardized design and reusable components contribute to lower life-cycle construction costs. In terms of social benefits, it effectively mitigates the impact of urban bridge construction on traffic and the environment.

(3) This technical system not only provides a new solution for high-pier bent cap construction but also promotes technological advancement and industrial upgrading in China's urban bridge construction sector. Its successful implementation offers valuable experience for similar projects and holds significant practical importance for fostering greener and more industrialized development in the construction industry.

With the increasing implementation of the “dual carbon” strategy and the ongoing advancement of construction industrialization, the lightweight, ground-free formwork support technology for high-pier bent caps will play an increasingly important role in a wider range of engineering scenarios, making a positive contribution to enhancing the level of infrastructure development in China.

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