Research and Application of Fair-Faced Concrete Construction Technology for Three-Dimensional Curved Cantilever Structures (Postprint)

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Abstract

To address the issue that traditional plywood cannot shape spatially irregular concrete structures, this paper proposes the "construction technology of fair-faced concrete for three-dimensional curved cantilever structures." In this construction technology, the formwork adopts a "steel panel" + "steel keel" support system to resist deformation during construction. For the irregular variations in the normal direction of the curved surface, a steel panel cutting and assembling process is employed. Computer three-dimensional models are utilized for the detailed design, layout, and fabrication of the steel keel framework, enabling the T-shaped steel keel framework to accurately simulate irregular variations along the length direction. The drainage holes inherent in the framework are fully utilized to reinforce the entire formwork support system, ensuring a smooth structural contour curve and meeting the high-standard requirements for the visual appearance of fair-faced concrete.

Full Text

Research and Application of Fair-Faced Concrete Construction Technology for Three-Dimensional Curved Cantilever Structures

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Abstract

To address the limitation of traditional plywood in shaping spatially complex concrete structures, this paper proposes a "fair-faced concrete construction

technology for three-dimensional curved cantilever structures." This technology employs a "steel panel + steel keel" support system to resist deformation during construction. For irregular variations along the surface normal direction, steel panel cutting and assembly techniques are utilized. Computer three-dimensional modeling is adopted for the detailed design and fabrication of the structural steel keel, enabling T-shaped steel keel frameworks to accurately simulate irregular changes along the longitudinal direction. By fully utilizing the drainage holes inherent to the framework itself to reinforce the entire formwork support system, the technology ensures smooth structural contour curves that meet the high-standard aesthetic requirements of fair-faced concrete.

Keywords: Special-shaped structures; Formwork system; Fair-faced concrete; Construction technology

In recent years, building forms have become increasingly complex and architecturally expressive, posing significant construction challenges. The Petal Art Framework Project for the 2014 Qingdao International Horticultural Expo Theme Plaza [Figure 1: see original paper], located in the northwestern section of the Qingdao Horticultural Expo site and covering an area of 40,000 m^2, consists of 20 petal-shaped structures. Among these, nine reinforced concrete petal art frameworks feature spatially irregular cantilevered multi-curved configurations with complex geometries, requiring fair-faced concrete on their interior surfaces. Traditional plywood formwork cannot achieve the smooth transitions required for such irregular frameworks, necessitating rational selection and design of the formwork system along with strict control over fabrication and installation processes. This approach enables effective control over the curvature accuracy of fair-faced concrete arcs and formwork joint misalignment, ensuring concrete casting quality.

Given the project' s unique characteristics and challenges, steel panel cutting and assembly effectively resolve the inability of traditional plywood to shape spatially irregular concrete structures, playing a crucial role in fair-faced concrete formation. For the irregular variations along the framework' s longitudinal direction, detailed design of the framework keel was conducted, with T-shaped steel keels fabricated to simulate these changes.

1 Formwork System Selection and Design

1.1 Construction Process Flow

The construction sequence follows: detailed design drawing development → positioning and layout → main steel keel installation → secondary keel installation → panel installation → steel pipe bracing.

1.2 Computer-Aided Detailed Design of Steel Keel

Before formal installation of the steel keel, the framework drawings must be thoroughly studied. In CAD, the framework is decomposed into segments of 50 cm each. Prior to steel formwork installation, the expansion joint shear wall construction drawings are analyzed, considering both formwork installation and concrete construction techniques to determine the geometric dimensions of the formwork and the length of tie bolts. After determining the steel formwork dimensions, calculations of strength and deflection are performed for the expansion shear wall formwork to establish the thickness of the steel panel, the selection and spacing of back ribs, and the position and diameter of tie bolts. AUTOCAD software is then used to simulate and position the installation, determining the layout drawings as shown in [Figure 2: see original paper]. Following completion of the keel detailed design, mechanical cutting is performed via computer to verify the geometric dimensions of each component, as shown in [Figure 3: see original paper].

1.3 Positioning and Layout

Due to the unique curved geometry of the art framework and its location on sloping terrain with varying cross-sectional elevations, GPS was employed for positioning and layout to ensure accuracy. By establishing points at both ends of the component and at the vertex of the curved section through the drawings, the main keel positions are determined to ensure the final component matches the design.

2 Formwork System Installation

2.1 Main Steel Keel Installation

After fabrication in the factory, the main steel keels are transported to the construction site. Prior to installation, temporary bracing is provided for the main steel keels, with the keel bottom welded to embedded chemical anchors in the foundation, as shown in [Figure 4: see original paper]. Since each steel keel has different dimensions, they are numbered according to the original layout drawings after fabrication to avoid on-site installation sequence errors that would cause deviations from the original design. The position of the main steel keels is verified, and after adjustment, the keel base is connected to the pre-embedded chemical anchors to ensure no displacement occurs during construction. Once the main steel keels are installed, adjacent keels are connected with steel bars or rectangular tubes to guarantee overall stability.

2.2 Secondary Keel Installation

The secondary keels utilize 20\$$\times 20mm \times$\$2 mm thin-walled square steel tubes spaced at 100 mm to prevent deformation of the steel formwork during concrete pouring, with both ends welded to the main steel keels. The top of the thin-walled square steel tubes is flush with the top of the main steel keels to ensure tight contact with the steel panel surface and guarantee integrated load-bearing, as shown in [Figure 5: see original paper].

2.3 Steel Panel Installation

The formwork panels employ 1.5 mm thick steel sheets measuring 1.00 m × 2.00 m, laid in the direction of the keels and spot-welded to the secondary keels on their interior side. Steel panel cutting is performed based on cross-sections at 50 cm intervals to calculate the developed area of the steel formwork. During spot-welding of steel plate joints, proper spacing must be maintained to avoid excessive welding that could cause heat deformation of the steel plates, leading to defects in the final concrete shape. Conversely, excessive spacing may cause grout leakage during pouring. Steel plate joints must have gaps no larger than 1 mm; otherwise, adhesive tape is applied to seal the joints and prevent grout leakage during concrete casting.

2.4 Backside Formwork Installation

After fabrication, backside formwork panels should be immediately numbered to ensure orderly management and proper placement. Since the backside of the framework features undulating elevations, the backside formwork configuration must correspond to these height variations.

2.5 Internal Steel Pipe Bracing

Before erecting the support system, the scaffolding foundation must be leveled, with the compactness of backfill soil beneath the supports meeting code requirements. The support platform must have proper drainage to prevent water accumulation and excessive moisture content variations in the soil. The support system utilizes the drainage holes reserved at the bottom of the framework foundation. Steel pipes are placed at angles consistent with these drainage holes, locked on both interior and exterior sides of the framework with steel pipes and right-angle couplers (quantity determined by calculation). After locking, wooden blocks are inserted to fill gaps between the steel pipes and drainage holes, preventing vertical movement. The main steel keel supports must be tightly braced, with diagonal bracing ensuring accurate force transmission, as detailed in [Figure 6: see original paper].

3 Economic Benefit Analysis

The application of this three-dimensional curved cantilever fair-faced concrete construction technology effectively resolved issues such as prominent concrete joints and misalignment caused by complex structural geometries, achieving aesthetically pleasing and high-quality results. Through detailed design based on construction drawings and computer three-dimensional positioning during fabrication, the main steel keels ensured consistency between the final concrete shape and design intent. This approach establishes a new concept for constructing irregular multi-curved concrete members and provides a reference for future promotion of this construction methodology.

For irregular structures, the steel formwork construction method offers lower material costs compared to new materials such as glass fiber-reinforced plastic 定型化模板. Compared to traditional earthwork formwork and timber formwork, it saves substantial labor. The resulting concrete finish is superior, avoiding the costs associated with subsequent repairs. Additionally, construction duration was shortened, saving labor and equipment rental expenses. The project was completed 40 days ahead of schedule, reducing assembly labor by over 400 workdays. Cost savings include: labor costs: 400 × 260 = 104,000 yuan; equipment rental fees: 5,400 yuan/day × 40 days = 210,000 yuan. Total savings: 104,000 + 210,000 = 314,000 yuan.

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Note: Figure translations are in progress. See original paper for figures.