Postprint: Parametric Application of BIM Technology in Yongding River Extra-large Bridge Project

Authors: Li Jiangang, Yang Bing, Xu Zhihong, Yongsheng Li, Wei Li, Li Yi

Date: 2018-07-18T00:00:00+00:00

Abstract

The spatially twisted steel tower of the Yongding River Bridge represents one of the major challenges in the bridge design. Through the introduction of a BIM-enabled three-dimensional parametric design platform, the design challenge of the bridge' s spatially twisted steel tower was successfully resolved by leveraging its parametric surface design capabilities. Concurrently, the "skeleton + template" modeling methodology effectively addressed the collaborative design challenges associated with the bridge' s complex steel structure. The adoption of BIM technology not only established a solid foundation for the successful completion of the bridge design, but also furnished an accurate data model for project implementation, operation, maintenance, and management.

Full Text

The Parametric Application of BIM Technology in the Yongding River Bridge Project

Li Jiangang[1], Yang Bing[1], Xu Zhihong[1], Li Yongsheng[2], Wei Li[2], Li Yi[3]
[1]Beijing General Municipal Engineering Design & Research Institute Co., Ltd., Beijing 100082, China
[2]Beijing City Public Highway Connecting Line Limited Liability Company, Beijing 100161, China
[3]Beijing University of Technology, Beijing 100124, China

Abstract

The spatially twisted steel tower of the Yongding River Bridge represents one of the most significant design challenges for this project. By introducing a BIM-based three-dimensional parametric design platform and leveraging its parametric surface design capabilities, we successfully resolved the design challenges associated with the bridge' s spatially twisted steel tower. Simultaneously, the "skeleton + template" modeling approach effectively addressed the collaborative design challenges for the bridge' s complex steel structure. The adoption of BIM technology not only established a solid foundation for the successful completion of the bridge design but also provided an accurate data model for project implementation, operation, and maintenance.

Keywords: spatially twisted steel tower; BIM technology; parametric design platform; skeleton + template; collaborative design

Introduction

BIM (Building Information Modeling) technology originated from a concept proposed by Dr. Chuck Eastman, a professor in the College of Architecture and Computing at the Georgia Institute of Technology. The concept posits that a building information model encompasses all information, functional requirements, and performance characteristics across different disciplines, integrating all project information—including design, construction, and operation management—into a single building model [1].

The spatially twisted surfaces of the tower column walls along Chang'an Avenue's western extension across the Yongding River present a major design challenge for the bridge. Traditional two-dimensional design methods are no longer adequate for completing the design tasks. Additionally, the bridge involves numerous complex issues such as intricate local joint configurations and detailed structures requiring localized analysis, all of which pose significant technical challenges for conventional approaches. The introduction of BIM technology not only effectively resolves these technical difficulties but also provides a refined data model for later project implementation and maintenance management, substantially improving construction quality and reducing implementation risks.

1 Project Overview

The Yongding River Bridge on Chang' an Avenue' s western extension (Figure 1 [Figure 1: see original paper], units: m) spans the Lianshi Lake section of the Yongding River at an approximately 57° skew angle. The main bridge employs a cable-stayed rigid-frame composite system with a main span of 280 m. The main girder features variable width and height, with a standard segment width of 47 m and a maximum width of approximately 54.9 m. Due to the bridge' s skewed crossing of the river channel, the main tower legs incorporate a 25 m "stride" in the longitudinal direction to meet flood discharge requirements, resulting in an inclined, asymmetric, twisted, variable-section steel box arch-shaped tower column.

The introduction of BIM technology effectively resolved the design and optimization challenges of the steel tower’ s twisted surfaces [2]. Three-dimensional collaborative design significantly reduced the difficulty of designing complex nodes, improved design quality, and established a solid foundation for subsequent project implementation and continued BIM application. Leveraging BIM’ s parametric design capabilities, the project successfully accommodated the complex steel structure design. Figure 2 [Figure 2: see original paper] illustrates the simplified application workflow of BIM parametric design for the Yongding River Bridge project.

2.1 Preliminary Design Phase

During the preliminary design phase, architects employed Rhino software for bridge landscape design, utilizing three-dimensional conceptual models to conduct site environment analysis, lighting analysis, and nighttime illumination studies to optimize the bridge’ s aesthetic scheme and enhance its overall visual impact (Figure 3 [Figure 3: see original paper]).

2.2 Collaborative Parametric Design

Due to the spatially twisted geometry of the Yongding River Bridge’ s tower column walls, traditional two-dimensional design methods proved inadequate for the main tower design. After evaluation, the CATIA three-dimensional design platform was selected for its powerful surface design capabilities. CATIA offers robust functionality not only in surface modeling but also in parametric collaborative design, large-scale assembly, knowledge engineering, and finite element analysis [3].

2.2.1 Collaborative Design

Collaborative design encompasses both internal and external collaboration. Internal collaboration includes simultaneous collaboration within the same discipline, collaboration across different disciplines during the same period, and coordination across different design phases. For the Yongding River Bridge project, internal collaboration was relatively straightforward, primarily involving coordination between road and bridge disciplines, with the road discipline providing three-dimensional road centerlines and terrain conditions. The primary challenge focused on collaborative design of complex steel structural details within the bridge discipline itself, which was effectively addressed using CATIA’ s “skeleton + template” modeling technology [4].

The entire bridge skeleton is shown in Figure 4 [Figure 4: see original paper]. The bridge skeleton enables macro-level control of the overall design, driving adaptive adjustments of attached bridge components for rapid modification. Following skeleton definition, the overall structure requires functional partitioning and decomposition to facilitate detailed design through divide-and-conquer strategies. Based on the bridge’ s characteristics, the main components were divided as shown in Figure 5 [Figure 5: see original paper]. This decomposition broke the bridge into several major collaborative design components, which were further subdivided down to individual parts. Pre-split components were first associated through assembly conditions, enabling independent design of individual parts while maintaining coordination. Alternatively, components could be designed separately and assembled later.

The further subdivision of the low tower structural components is illustrated in Figure 6 [Figure 6: see original paper]. Beyond internal collaboration, extensive external collaborative design work was required, including landscape lighting, inspection equipment, dehumidification systems, and other ancillary facilities. Figure 7 [Figure 7: see original paper] shows a local three-dimensional collaborative design result for the dehumidification system. Collaborative design effectively resolved potential issues such as conflicts, omissions, collisions, and deficiencies, improving overall design quality and reducing implementation risks.

2.2.2 Steel Tower Spatial Twisted Plate Design

The most significant design challenge involved the steel tower' s spatially twisted wall plates. The design needed to generate surfaces matching the architect' s vision while considering fabrication and manufacturing requirements to ensure constructability. Integrating manufacturing constraints into the early design phase represented a critical challenge.

CATIA' s parametric surface generation offers multiple methods: sweep, fill, bridge, extrude, and revolve. For this project, ruled sweep surfaces were selected after comparing various approaches, offering two primary advantages. First, for irregular spatial curves, ruled sweep surfaces produce favorable Gaussian curvature distributions, facilitating surface development during fabrication and enabling precise control of segment forming. Second, besides two guide curves, ruled sweep surfaces incorporate a spine as a control element. The sweep line between guide surfaces remains perpendicular to the spine, allowing segment division ports perpendicular to the spine to maintain straight edges, which simplifies precision control during segment erection.

The bridge tower features an inclined elliptical arch shape, with tower legs transitioning from rectangular sections at the base to parallelogram sections (with an acute angle of 66°) at the top, creating spatially twisted wall plates. During design, tower wall plates were generated through ruled sweeping using tower auxiliary axes and plate edge lines (Figure 8 [Figure 8: see original paper]).

2.2.3 Parametric Design

Parametric design is a fundamental capability of BIM three-dimensional design software, enabling convenient adaptive adjustments through parameter modifications without redesign, thereby improving modification efficiency. During the Yongding River Bridge design process, frequently used and special parameters were standardized, including plate thickness, stiffener height, and hole dimensions. Parameters were categorized by major component, with control parameters established for each. For example, high tower component parameters (Figure 9 [Figure 9: see original paper]) included flange plate parameters, web plate parameters, tower base reinforcement parameters, anchor zone parameters, and diaphragm parameters, facilitating subsequent adjustments.

BIM three-dimensional design platforms typically manage reusable resources through libraries. CATIA’ s parametric resource library utilizes catalog files (.Catalog) for template library management, organizing standard resources that can be instantiated using PowerCopies, UDF features, and document templates. The Yongding River Bridge project developed several versatile templates, including cable anchor zone templates, wall plate stiffener templates, diaphragm templates, tower interior ladder templates, tower maintenance structure templates, tower sealing door templates, and high tower base anchor bolts. These templates were centrally managed through the template library, improving modeling efficiency. Figure 10 [Figure 10: see original paper] shows a UDF feature template instantiation of high tower base anchor bolts.

CATIA also employs document templates, which differ from feature-based templates like PowerCopy or UDF. Document templates operate at the part level (Figure 11 [Figure 11: see original paper]), instantiating parts as basic units. They can attach two-dimensional drawing documents during instantiation, enabling simultaneous generation of three-dimensional models and predefined two-dimensional drawings, significantly simplifying drawing generation for regular structures.

2.2.4 Parametric Simulation Analysis

The twisted variation of the tower cross-sections created substantial modeling workload for global bridge calculations. Leveraging the BIM three-dimensional model significantly improved cross-section generation efficiency for analysis. Beyond complex global calculations, numerous local structural analyses were required. For steel structures, local calculations typically employ shell or solid element models, for which the BIM three-dimensional model provided precise geometric models, enhancing modeling efficiency and analysis accuracy [6][7].

Given the tower’ s spatially twisted arch structure, the relationship between cable anchor zones and tower web plates was highly complex, differing considerably from conventional cable-stayed bridges. To investigate the mechanical behavior of tower cable anchor zones, CATIA’ s integrated analysis platform was used to generate a local solid finite element mesh model associated with the three-dimensional model (Figure 12 [Figure 12: see original paper]). The associated finite element model under the BIM platform enabled automatic updating of mesh models and boundary conditions, facilitating convenient parametric sensitivity analysis and improving local model calculation efficiency.

Figure 13 [Figure 13: see original paper] presents sensitivity analysis results for web plate thickness and stiffener thickness in the tower cable anchor zone. Under given cable forces, parametric component models enabled convenient sensitivity factor analysis, visually determining parameter influence effects to guide optimization of anchor zone structural design.

Beyond collaborative parametric design, extensive work was performed using the CATIA platform, including collision detection and two-dimensional drawing generation (particularly for expressing curved plates), fully leveraging BIM technology' s design advantages.

3 Construction Phase Model Utilization

Current IT application environments in construction enterprises primarily revolve around two-dimensional drawings, supporting information expression and engineering applications based on 2D documentation. Since information under two-dimensional drawings is discrete and non-associated, construction enterprises must manually establish associations between drawings and related information, resulting in a management mode with low structural organization [8].

The Yongding River Bridge project utilized the parametric design model from the BIM design platform to provide refined data models during construction, facilitating both detailed design development by contractors and enabling 4D progress management, optimization of fabrication processes, and construction organization planning (Figure 14 [Figure 14: see original paper]), thereby shortening construction duration, improving fabrication quality, and reducing costs. Contractors could also use the refined construction BIM model for information-based material management, quality and safety management, and schedule-cost management, effectively enhancing management levels during construction and improving constructability.

Figure 15 [Figure 15: see original paper] shows the actual on-site installation of the #1 segment at the base of the high tower' s north leg, which aligned well with the pre-simulated scheme.

4 Conclusion

Due to the unique and distinctive shape of the Yongding River Bridge' s tower columns, the project adopted an advanced BIM design platform from the early stages to resolve design challenges. The three-dimensional parametric design platform under BIM technology not only solved the curved surface design challenges of the twisted steel tower but also addressed collaborative design difficulties for the bridge' s complex steel structure, ensuring successful design completion while preparing refined data models for later project phases and establishing a solid foundation for deep BIM application.

As one of the earliest municipal engineering projects in China to directly adopt

BIM technology for forward design, the Yongding River Bridge project achieved favorable results across preliminary planning, design, and construction phases. The project has now entered the intensive steel structure fabrication and erection phase for the superstructure, with all processes proceeding in an orderly manner. On November 1, 2017, the installation of the #1 segment at the base of the high tower' s north leg was successfully completed. The project owner, Beijing City Public Highway Connecting Line Limited Liability Company, is actively coordinating with future maintenance units to prepare for operation and maintenance management, aiming to inherit the technical advantages from early project phases and extend BIM technology into the O&M stage. This will enable true full lifecycle management based on BIM technology for the Yongding River Bridge project, accumulating valuable experience for BIM technology promotion in municipal engineering.

References

[1] BIM Engineering Technical Personnel Professional Skills Training Editorial Committee. *BIM Technology Introduction* [M]. Beijing: China Architecture & Building Press, 2017.

[2] Li Jiangang, Zhang Tao, Yang Bing, Li Yi, Wang Lei. Optimal Design and 2D Expression of Steel Tower Twisted Plate Based on CATIA [J]. *Special Structures*, 2017(5): 100-103.

[2] Li Jiangang, Zhang Tao, Yang Bing, Li Yi, Wang Lei. Optimal Design and 2D Expression of Steel Tower Twisted Plate Based on CATIA [J]. *Special Structures*, 2017(5): 100-103.

[3] BIM Engineering Technical Personnel Professional Skills Training Editorial Committee. *BIM Application Case Analysis* [M]. Beijing: China Architecture & Building Press, 2017.

[4] Li Jiangang, Zhang Tao, Li Yi, Wu Wei, Ning Xiaoxu. Engineering Application of "Skeleton + Template" Technology Based on Irregular Shaped Steel Pylon Cable Bridge [J]. *Special Structures*, 2017(6): 88-92.

[4] Li Jiangang, Zhang Tao, Li Yi, Wu Wei, Ning Xiaoxu. Engineering Application of "Skeleton + Template" Technology Based on Irregular Shaped Steel Pylon Cable Bridge [J]. *Special Structures*, 2017(6): 88-92.

[5] Tsinghua University BIM Research Group, isBIM Company BIM Research Group. *Design Enterprise BIM Implementation Standard Guide* [M]. Beijing: China Architecture & Building Press, 2013.

[6] Li Jiangang, Yang Bing, Wang Lei. Optimizing Analysis on the Diaphragm Plate Opening Hole Shape for the Deformed Steel Tower of Cable-stayed Bridge [J]. *Special Structures*, 2016(5): 18-22.

[6] Li Jiangang, Yang Bing, Wang Lei. Optimizing Analysis on the Diaphragm Plate Opening Hole Shape for the Deformed Steel Tower of Cable-stayed Bridge

[J]. *Special Structures*, 2016(5): 18-22.

[7] Li Jiangang, Ning Xiaoxu, Wang Lei. Influence Analysis on the Diaphragm Plate Opening Ratio for the Deformed Steel Tower of Cable-stayed Bridge [J]. *Special Structures*, 2016(6): 61-65.

[7] Li Jiangang, Ning Xiaoxu, Wang Lei. Influence Analysis on the Diaphragm Plate Opening Ratio for the Deformed Steel Tower of Cable-stayed Bridge [J]. *Special Structures*, 2016(6): 61-65.

[8] Li Yungui, He Guanpei, Qiu Kuining. *Construction BIM Application Guide for Building Engineering (2nd Edition)* [M]. Beijing: China Architecture & Building Press, 2017.

First Author:

Name: Li Jiangang
Affiliation: Beijing General Municipal Engineering Design & Research Institute Co., Ltd.
Date of Birth: November 1979
Native Place: Hanshou County, Hunan Province
Title: Senior Engineer
Degree: Master of Engineering
Research Interests: Bridge and tunnel design, BIM technology application in three-dimensional design
Correspondence Address: Building 3, No. 32 Xizhimen North Street, Haidian District, Beijing
Postal Code: 100082
Telephone: 13522263868
E-mail: lijiangang_1@sohu.com