Research on Automatic Parametric Modeling of Railway Bridges Based on BIM Technology

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Abstract. Applying BIM technology to the design of high-speed railway bridge is of great significance for improving the efficiency and quality of bridge design. In order to achieve a fully diversified bridge model construction based on design It is necessary to automatically extract key parameter information for bridge modeling from the design drawings. Taking into full consideration the constraints and correlation relationships between various parameters, a bridge component model library was established using BIM secondary development technology. Multi-parameter control of bridge component model shape. The application examples show that the method proposed in this article can provide a solution for the three-dimensional automation and intelligent modeling from two-dimensional design schemes for high-speed railway bridges.

Keywords: High-speed railway bridge, Building Information Modeling (BIM), Automatic modeling, Parameterization, Intelligent Construction.

1 Introduction

In recent years, BIM technology has been increasingly applied to bridge engineering, promoting digitalization, automation, and intelligent management throughout the infrastructure lifecycle. Jiang et al. [1] proposed a BIM-based parametric modeling method for high-speed continuous beam bridges, establishing parameterized component families and simulating key construction processes to improve modeling efficiency and accuracy. Similarly, Hui et al. [2] developed a parametric design workflow for assembled steel–plate composite beam bridges using Revit and Dynamo, enabling batch parameter input and integration with finite-element analysis.

A comprehensive review on parametric BIM for sustainable bridge engineering highlighted the advantages of rule-based modeling and interoperability through open standards such as IFC [3]. Beyond design, BIM has also been integrated into bridge monitoring and lifecycle management: an integrated BIM methodology for bridge assessment adopted mesh-based models and convolutional neural networks for automated damage detection [4], while digital-twin–BIM systems were applied to synchronize monitoring data and support predictive maintenance [5].

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Recent research also explores combining BIM with extended-reality (XR) technologies to enhance visualization and interaction during design and construction [6], and data-driven BIM frameworks for suspension bridges that enable real-time stability analysis [7]. The BIM technology, as a data-centric and visualization-driven approach, offers great potential for improving the productivity and quality of civil engineering design. It integrates geometric, spatial, and attribute data across disciplines and project phases. However, most existing BIM-based studies on bridge modeling remain limited to isolated structures or manually parameterized components, and they cannot efficiently handle the large-scale automation required for high-speed railway projects. In particular, three technical challenges remain insufficiently addressed:

(1) the automatic extraction of geometric and positioning parameters from traditional two-dimensional design drawings;

(2) the integration and automated assembly of diverse bridge components along continuous railway alignments; and

(3) the unified management of parametric and spatial data to ensure consistency across different bridge types and project stages.

To overcome these limitations, this paper proposes an automated parametric modeling framework for high-speed railway bridges based on BIM technology, which enables efficient parameter extraction, component modeling, and alignment-based automatic assembly.

2 Bridge Location Information Acquision

The positioning information for bridge modeling mainly comes from design drawings. There are two positioning criteria for bridge models: the centerline of the line is the positioning criteria for the bridge in the world coordinate system, and the pile number is the positioning criteria for the component in the relative coordinate system of the model. Among them, the starting point of the centerline of the line corresponds to the coordinate origin of the bridge model. The two positioning criteria jointly determine the spatial position of the bridge model. For bridge component models such as piers and abutments, during assembly, not only should they be translated according to the pile number, but also the tangent direction should be calculated based on their position for rotation, and the elevation should be adjusted according to the layout plan.

2.1 Location Information of Centerline

In the BIM modeling process of bridges, the centerline of the line can play a role in constraining the spatial position of components and bridges, ensuring that each component of the bridge can be correctly laid out along the centerline of the line. The following methods can be used to extract the three-dimensional spatial information of the centerline of the route. The steps are as follows:

Set the coordinate set of the centerline plane in the drawing as:

$$Pt = \sum_{i=1}^{n} P_m(x_i, y_i) \tag{1}$$

The starting mileage of the route plan is l_0, corresponding to coordinate points (x_1, y_1). The mileage of other coordinate points can be obtained by calculating the distance from the previous coordinate point, plus the mileage of the previous coordinate point. The calculation is as follows:

$$l_i = \sqrt{(x_i - x_{i-1})^2 + (y_i - y_{i-1})^2} + l_{i-1} \tag{2}$$

Then, the following calculation results:

$$Pt_{new} = \sum_{i=1}^{n} P_m(x_i, y_i, l_i) \tag{3}$$

From the longitudinal section design drawing, extract the centerline coordinate set:

$$Zt = \sum_{i=1}^{n} P_z(x_i, y_i) \tag{4}$$

where x_i and y_i represent mileage and elevation, respectively.

2.2 Location Information of Bridge Components

The bridge span annotation information and corresponding mileage information can be extracted from drawings or design achievement databases, and constrained by coordinates, mileage, and other information.

Let the bridge start and end mileage be:

$$Bridge = \sum_{i=1}^{m} (StartLc_i, EndLc_i) \tag{5}$$

where $StartLc_i$ is Starting mileage of the bridge(m), and $EndLc_i$ is the end mileage of the bridge(m).

The centerline coordinates within the bridge are calculated as follows: (1) Based on the bridge start and end mileage and the line centerline mileage (l_i in $LineCorrd$), all line centerline coordinates and mileage data located between the $StartLc_i$ and $EndLc_i$ miles are stored in $BridgeCor_i$, the bridge's line center coordinate set. (2) Since the line center coordinate data $LineCorrd$ is stored at certain intervals, it is necessary to interpolate the bridge Start and End mileages to count their 3D coordinates. Take the starting point mileage calculation as an example, according to the value of $StartLc_i$, two neighboring points $P_1(x_1, y_1, z_1, l_1)$ and $P_2(x_2, y_2, z_2, l_2)$ can be determined in $LineCorrd$ of the line centerline, and the starting point of the bridge,

$StartPt_i$, is located between the points P_1 and P_2, and $StartLc_i \geq l_1$ && $StartLc_i \leq l_2$, which is calculated by interpolation method and added into $BridgeCor_i$ coordinate set. Interpolation method is used to calculate the 3D coordinates of the bridge starting point and add them to the $BridgeCor_i$ coordinate set. The calculation is as follows:

$$StartPt_i(x,y,z) = \begin{cases} x = x_1 + \dfrac{StartLc_i - l_1}{l_2 - l_1}(x_2 - x_1) \\ y = y_1 + \dfrac{StartLc_i - l_1}{l_2 - l_1}(y_2 - y_1) \\ z = z_1 + \dfrac{StartLc_i - l_1}{l_2 - l_1}(z_2 - z_1) \end{cases} \tag{6}$$

And the bridge endpoints are calculated in the same way.

Based on the mileage of each bridge span, determine the two data points at the centerline of the bridge route. Use interpolation calculation method to calculate the *x*, *y*, and *z* of each bridge span according to the mileage, and complete the acquisition of bridge span coordinates. The calculation method is the same as equation (6). Store the calculated information in the bridge coordinate database to effectively manage and call the modeling coordinate information.

3 Bridge Components Modeling

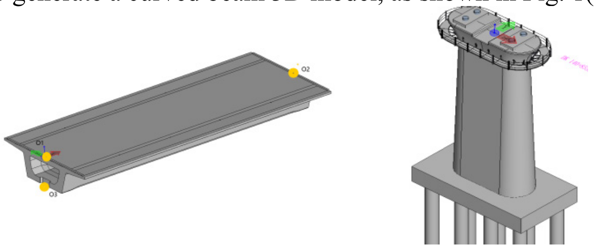
3.1 Development Environment

There are various types of high-speed railway bridges, such as simply supported beam bridges and continuous beam bridges with simple structures, arch bridges with special structures, and various combination bridges. To better meet the diverse modeling needs of bridges, BIM API secondary development technology is adopted to develop bridge modeling programs, and the modeling data can be dynamically adjusted. To better meet the diverse modeling needs of bridges, the proposed system was developed on Bentley MicroStation CONNECT Edition using the MicroStationDGN .NET API for secondary development. The programming was implemented in C# language within Microsoft Visual Studio 2022, enabling direct manipulation of DGN model elements, parameter assignment, and geometric constraint control. Through this environment, bridge component models such as beams, piers, and foundations can be automatically generated and adjusted based on design parameters and alignment data.

3.2 Modeling of Beam Components

By combining component parameters and engineering information, multiple parameters are used to control the model form of components, allowing for the creation of advanced parameterized objects and achieving rapid parameterized modeling of bridge components.

Taking the creation of a simple structural beam model as an example, first create the beam section, input various parameters, and achieve the creation of the outer and inner profiles of the simply supported beam section. Then, using the created beam cross-section as the inner and outer contours, quickly lay out and fuse along the centerline of the route to generate a curved beam 3D model, as shown in Fig. 1(a).



(a)Linear beam model (b) Bridge pier model

Fig. 1. Automatic generation models of bridge components

3.3 Bridge Pier and Foundation Modeling

High speed railway bridges often use circular end plate piers and rectangular plate piers. In addition, there are also styles such as double rectangular column piers, double circular column piers, single circular column piers, and double track circular end hollow piers. The method used for creating bridge piers is similar to that of bridges. The top cap, pier cap, and pile foundation are created using the stretching method, while the pier body is created using a combination of stretching and lofting methods. As shown in Fig. 1(b).

When implementing rapid modeling of bridge components in secondary development, the backend program adds inspection constraints to compare the geometric parameters of the model with the requirements of the drawings, and specifies the range of values for each parameter of the model. Compared to traditional manual modeling, it reduces the error rate and ensures the accuracy of modeling. Based on the positioning data, assemble each component to obtain the model of the entire project.

4 Application Case Study

The bridge project contains a massive number of bridge components, and manually assembling the bridge models is not only time-consuming but also inefficient and prone to errors. After the component models were created, the entire line was assembled automatically using Bentley MicroStation CONNECT Edition as the modeling platform. The program reads the coordinate and attribute data from the bridge database and generates each component instance at its correct spatial location, with posture automatically adjusted according to the line alignment. Using the method proposed in this paper, the BIM modeling of a high-speed railway bridge is carried out, as shown in Fig. 2.

To evaluate the efficiency and accuracy of the proposed method, a comparative experiment was conducted on a 1.5 km segment of a high-speed railway bridge containing 210 structural components. As shown in Table 1， the proposed automated modeling workflow reduced the total modeling time from 9.5 hours (manual) to 1.2 hours (automated), representing an efficiency increase of approximately 87%.

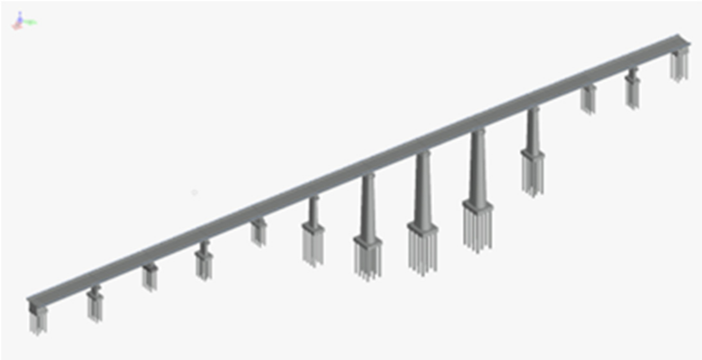


Fig. 2. A model of high-speed railway bridge under construction

Table 1. Comparison and Analysis Table.

Modeling Method	Total Components	Average Time (h)	Efficiency Improvement
Manual Modeling	210	9.5	—
Automated Modeling	210	1.2	+87%

The above results confirm that the proposed automated parametric modeling framework can effectively transform traditional two-dimensional design drawings into three-dimensional BIM models with high precision. Compared with manual modeling, the framework not only accelerates model generation but also minimizes human errors and ensures parameter consistency along long linear infrastructures. This capability is particularly beneficial for large-scale high-speed railway projects that involve repeated bridge structures and complex geometric alignments.

5 Conclusions

This study proposed an automated parametric modeling framework for high-speed railway bridges based on BIM technology. By integrating automatic parameter extraction from design drawings, parametric component library construction, and alignment-driven model assembly, the method enables efficient and accurate generation of large-scale bridge BIM models.

These results confirm that the proposed method effectively addresses the challenges of large-scale automation, consistency, and precision in railway bridge modeling. In future work, we plan to integrate the modeling system with construction simulation and digital twin platforms to further support intelligent design, construction, and maintenance management of high-speed railway infrastructure.

Acknowledgments

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