Research on the Application of Digital Twin in Bridge Cantilever Erection Construction

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Abstract. The implementation of this project aims to explore the specific application of digital twin technology in bridge construction teaching, promote the combination of technology and education, and train talents more suitable for modern engineering needs. This paper explores the application of DT in bridge cantilever construction, using the Yuanjiang Bennett Cable-stayed Bridge as a case study. The 1:100 scale solid model was integrated with a digital building information model (BIM) and a finite element model (FM) from Midas Civil. DIC (Digital Image Correlation) experiments were then performed to observe the deformation of the solid model under stress. The data from the actual model was imported into the finite element model to generate a stress map of the bridge and compared with the DIC data for validation. The results of the study show that the theoretical and actual values are in general agreement. It realizes the process visualization and intelligent monitoring of bridge cantilever erection construction, provides real-time display, monitoring and warning functions, and improves the construction efficiency and safety.

Keywords: Digital Twins, Cantilever erection construction, Bridge engineering

1 Introduction

The bridge cantilever erection construction method is widely recognized in the engineering community for its versatility, simplicity and efficiency[1-2]. It is suitable for a wide range of projects including large-span bridges. Additionally, traffic disruptions are reduced by the minimal support structure and ample clearance beneath the bridge. However, challenges such as assembly inaccuracies and safety issues still remain. So bridge monitoring is crucial to guarantee safety throughout construction.

Digital Twin (DT) technology, an innovative simulation approach, enables real-time data collection, processing, and analysis of objects. It generates a digital replica of an object's entire lifecycle, enabling behavior simulation and prediction. [3-5]

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This paper would take the Yuanjiang Banita cable-stayed Bridge of Huaishaoheng Railway as an example, the entity models are established at a scale of 1:100. By integrating physical assembly models with digital Building Information Modeling (BIM) models and finite element model (FM) by Midas Civil, intelligent monitoring utilizing sensor systems and data acquisition is enabled. Mutual corroboration between the entity and virtual models is completed through experiments.

Current research[6-7] focuses on the application of digital twins in bridge rotation construction and lacks research on combining DT with bridge engineering particularly in cantilever erection assembly construction. Applying DT would enhance construction efficiency, reduce project durations, identify and mitigate potential risks in advance. Moreover, continuous innovation in intelligent construction technologies would be fostered, driving transformation in the industry.

The goal of this study is to deeply explore the application of digital twin technology in the construction of bridge cantilever erection, fill the gap in the existing research, and closely integrate the potential benefits of digital twin with the actual needs of bridge engineering. Through this research, it is expected to provide a new perspective and method for the future development of bridge engineering.

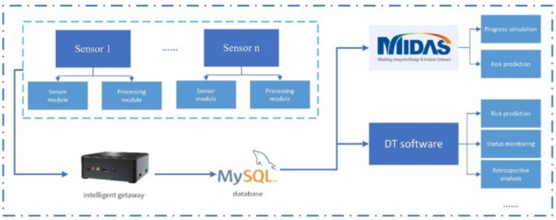
2 Structural Design of Digital Twin

2.1 Programme of Data-Driven

Digital twin technology refers to the full utilization of physical models, sensors, operational history, and other data to simulate processes in multiple aspects, complete mapping in virtual space, and reflect the full lifecycle process of corresponding physical equipment. In order to obtain specific information during the cantilever assembly construction process of the bridge, a series of sensors have been deployed to monitor the actual condition of the bridge. In order to achieve real-time monitoring, early warning, and historical record tracing, a database have been designed to store various information, including sensor data and other on-site information, for experts and the system to access and analyze in the work site. The specific implementation transmission process is as follows.

In the realm of bridge cantilever construction, a multitude of detection data types are involved, encompassing bridge deck displacement sensing, bridge cable force sensing, weather temperature fluctuations, and bridge deck image alterations. Following data acquisition by sensors, these data streams are routed through a wireless communication module to an intelligent gateway, facilitating transmission to a database for update. Finally, the received data drives to perform 3D model simulation and personalized detection, analysis. Processing of key information in bridge construction are achieved through software algorithms for data processing in the database.

This study utilizes a SQL Server database as a data transmission intermediary, establishing a "bridge_info" table to store pertinent data regarding bridge cantilever construction including bridge deck displacement sensing, bridge cable force, weather temperature changes, and bridge deck image alterations, which are crucial for construction safety warnings. Additionally, a "construction_info" table records bridge structure details, materials utilization, responsible personnel lists, and construction dates, facilitating retrospective analysis of bridge progress and quality monitoring. The data stream transmission mechanism diagram of the system is shown in Fig.1 below.[8]



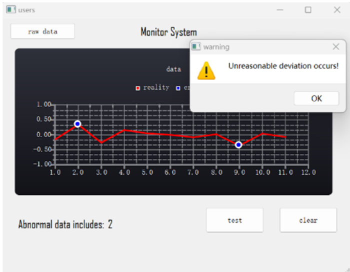


Fig. 1. Flow chart of data exchange mechanism

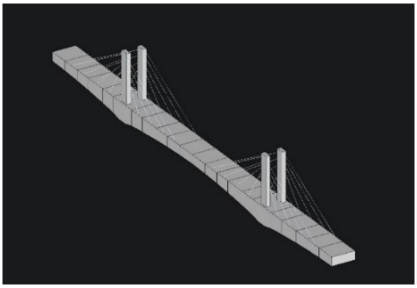
Fig. 2. Error report

When there is a problem with the associated data simulation, there will be a program error reported in Fig. 2.

2.2 Construction of Bridge-To-Body Digital Twin

2.2.1 Building Information Modeling (BIM) Models.

Starting from the actual project, the BIM visual 3D model established is shown in Fig. 3. During the construction phase, digital twin would be combined with BIM modeling to simulate the execution of the cantilever assembly construction process and predict possible problems or risks. By simulating and optimizing the construction process, project efficiency can be improved, costs can be reduced and construction safety can be ensured.



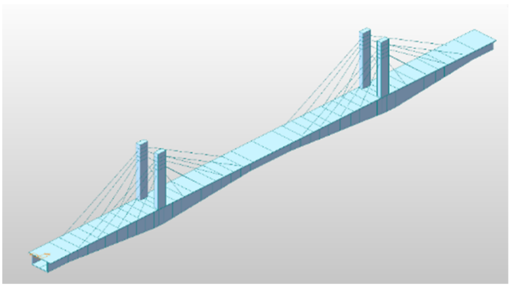


Fig. 3. BIM model of the bridge

Fig. 4. FM mode of the bridge

2.2.2 Finite Element Model (FM) by Midas Civil.

Based on the actual project, the Midas finite element model is established which is shown in Fig.4. Through the simulation of the load situation, the force situation of each bridge section can be analyzed and compared with the subsequent actual load test of the actual reduced model. The combination of finite element model and digital twin thus can monitor structural changes during construction and timely adjustment of the construction program in real time to ensure the integrity and safety of the bridge structure. Through the finite element analysis, the parameter matrix in the original database is called to constrain the finite element model. And the finite element model is analyzed and solved, and finally the digital twin database is established.

The combination of Midas finite element model and digital twin is based on the overall consideration of bridge structure safety, construction process monitoring and data accuracy. This method not only provides a scientific analysis tool for the project, but also lays a solid foundation for the subsequent maintenance management.

2.3 Entity Model Testing

In this study, an assembled model was carefully constructed with the scale of 1:100 and the use of Tilia wood material. And the properties of wood are shown in Table 1, which ensures the high stability and accuracy of the model in the simulation process.

Tilia wood has good stability and toughness. Compared with other woods, Tilia wood is not easy to crack, deformation, and can effectively resist the influence of the external environment. The decision to choose Tilia wood as the modeling material was based on its superior physical properties and ease of processing, ensuring the stability and accuracy of the model in support of the overall objective of this study.

Table 1. Properties of the timber.

Indicator	Elastic modulus (GPa)	Poisson's ratio	Compressive Strength (MPa)
Data	11	0.2	9.8

In the process of making the model, the CAD software is first used to draw the accurate graphics of each part, and then the precise cutting is carried out on the Tilia wood according to these graphics. After that, through the meticulous assembly process, each interface can achieve the effect of seamless stitching. In order to simulate the process of lengthening the bridge body in cantilever construction, a wooden box substructure composed of four pieces of wood is designed. And strong magnets are attached to the connecting surface of the box to simulate the connection effect in actual construction. In addition, iron wire is used for connection to simulate the role of cable.

3 Results

In order to further observe the deformation of solid model under stress, DIC experiment (Digital Image Correlation) was carried out. The shadowgraph of the solid model taken by DIC is shown in Fig.5. In the experiment, the load weight on the model is gradually increased, and the deformation data of the model is accurately recorded and analyzed with the help of advanced equipment.

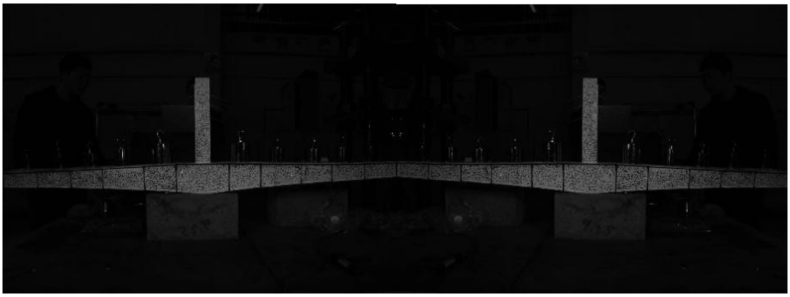


Fig. 5. Shadowgraph of the Solid Model

Finally, the data of weight loads and bridge self-weight from the actual model is imported into the finite element model and solved. Then the stress diagram of the bridge shown in Fig.6 is received.

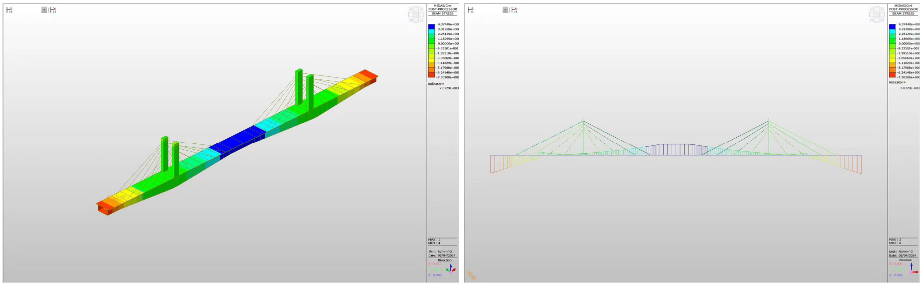


Fig. 6. Stress diagrams of bridge

By analyzing the finite model data in comparison with the DIC data, the results are basically the same. Some of the theoretical values deviate from the actual values by about 10% because the parts of the solid model are connected by magnets and are susceptible to external impacts and other factors.

4 Conclusion

This paper uses real bridge construction as its background and integrates digital twin technology with traditional bridge monitoring methods. This system achieves visualization and intelligent monitoring of the bridge Cantilever Erection Construction process and key information. Through the integration of digital twin technology with the system enables real-time display, monitoring, and warning during the construction.

The integration of digital twin technology with traditional bridge monitoring methods presents a transformative opportunity for the construction industry. By enabling real-time visualization and intelligent monitoring of the cantilever erection construction process, this system enhances safety, efficiency and decision-making capabilities. However, addressing the financial, technical, and educational challenges associated with its implementation is essential for maximizing its potential. Future research should focus on developing cost-effective solutions, improving system interoperability, and fostering a skilled workforce to ensure that the benefits of digital twin technology can be fully realized in the field of bridge construction.

References

1. Linhui, K. Keke, Y.(2020) Bridge engineering cantilever bridge construction technology [J]. Chinese Science and Technology Journal Database (Citation Edition) Engineering Techbology,5:0109-0112. https://qikan.cqvip.com/Qikan/Article/Detail?id=1000003416306
2. Jianghua, Y. (2023) Research on Construction Technology of Cantilever Assembly Method for Urban Elevated Bridges. ELECTRIC POWER ENGINEERING TECHNOLOGY, 22:59-61. https://qikan.cqvip.com/Qikan/Article/Detail?id=7111494634
3. Zhang, Y. (2024) Digital Twin: Architectures, Networks, and Applications. Springer Cham. Berlin. https://doi.org/10.1007/978-3-031-51819-5
4. Lin, K. Zheng, J. Lu, X. (2024) Digital twin and its applications in civil engineering:Review and outlook. Journal of Harbin Institute of Technology,56(1):1-16. https://www.engineeringvillage.com/app/doc/?docid=cpx_M1d76817218d18fe6c0fM71381017816545&usageOrigin=share
5. Soheil,S. Kostas,A. Newton,L. (2022) Digital Twin Technology: Fundamentals and Applications. Springer Cham. Berlin. https://link.springer.com/book/9783031677779
6. Liu, Y. Xu, F. Yang, Z. Deng, Y. Wang, X. (2023). Research on the Application of Digital Twin in Bridge Rotation Construction. Proceedings - 2023 6th International Conference on Computer Network, Electronic and Automation(ICCNEA), Xi'an, pp. 419-423, doi: 10.1109/ICCNEA60107.2023.00094.
7. Aija Z. (2020) Research on BIM-based construction monitoring program design and monitoring management of bridge transitions across high speed railways doi: 10.27414/d.cnki.gxnju.2020.001489
8. Haifan JIANG, Guofu DING, Tong XIAO. (2022) Digital Twin Evolution Model and Its Applications in Intelligent Manufacturing. Journal of Southwest Jiaotong University, 57(6):1386-1394. doi: 10.3969/j.issn.0258-2724.20210202