Bridge Maintenance, Safety, Management, Digitalization and Sustainability – Jensen, Frangopol & Schmidt (eds)
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BIM-data of baseline digital twins for a new bridge maintenance system

C.S. Shim, G.T. Roh, D.H. Kang & J.W. Park
Chung-Ang University, Seoul, South Korea

ABSTRACT: With the growing deterioration of bridge structures in traffic networks, there is an urgent need for a reliable method to assess and predict bridge performance using diverse data sources. Building Information Modeling (BIM), currently being implemented in new construction projects, holds promise for providing crucial information to establish a maintenance baseline model by collecting and consolidating data from design to construction phases. However, the maintenance of existing bridges is hindered by a reliance on document-oriented information and the lack of effective integration of individual data within current bridge management systems (BMS) and information systems for inspection and repair records. To overcome these limitations, this paper aims to define key management factors and deliver a baseline digital twin model at the completion stage for maintaining existing girder-bridges. Additionally, inspection and maintenance history data generated during the maintenance stage are incorporated into the digital twin model. The paper presents the definition of BIM data for constructing a baseline digital twin specifically for common types of girder-bridges and demonstrates its functional implementation. A data-driven information delivery is presented for a typical prestressed concrete girder bridge. The effectiveness of the proposed approach is evaluated through actual examples of existing bridges.

1 INTRODUCTION

The increasing proportion of aging bridge structures emphasizes the urgent need for an appropriate maintenance plan and reliable method to assess and predict bridge performance using diverse data sources. Building Information Modeling (BIM), currently being implemented in new construction projects, holds promise for providing crucial information to establish a maintenance baseline model by collecting and consolidating data from design to construction phases. However, the maintenance of existing bridges is hindered by a reliance on document-oriented information and the lack of effective integration of individual data within current bridge management systems (BMS) and information systems for inspection and repair records. A system based on the concept of digital twins, which involves expanding this idea to introduce 3D models and related data into maintenance management systems, has been proposed (Jeon et al. 2023). In this process, a high-reliability, integrated data-driven information delivery system is required from design to operation [2]. To progress from the member-level data through the entire life cycle of a bridge using the data-driven system, a data management regime and optimization process are required. Data becomes the minimum unit of information required for business units and each stage, and utilizing this, digital models and updates in various aspects are carried out.

To overcome and satisfy these limitations and requirements, this paper aims to define key management factors and deliver a baseline digital twin model at the completion stage for maintaining existing girder-bridges from member unit to bridge system. Additionally, inspection and maintenance history data generated during the maintenance stage are incorporated

DOI: 10.1201/9781003483755-238

into the digital twin model. The paper presents the definition of BIM data for constructing a baseline digital twin specifically for common types of girder-bridges and demonstrates its functional implementation. A data-driven information delivery is presented for a typical pre-stressed concrete girder bridge. The effectiveness of the proposed approach is evaluated through actual examples of existing bridges.

2 DEFINITION OF DATA

The scope of BIM data extends from the member level that makes up the bridge to the system level. Depending on the life-cycle of the bridge, the data is segmented by a member, and accordingly, updates or exchanges of each piece of information take place. For flexible information exchange and optimization, it is essential to structure key information at each stage. And, to effectively utilize standardized data, pre-agreed data definitions between designers, fabricators, and assemblers must allow for seamless information exchange. The data for components is broadly categorized into geometry, material, performance, and external conditions (alignment, climatic conditions, fabrication, and construction-related schedules, etc.). Each piece of information is interlinked and dependent on data from the planning or design stages onward. Once such a system and procedures are established, the optimization of the data system occurs, ultimately enabling the utilization of accumulated data in the stages of sharing and maintenance. This leads to the establishment of a Digital Twin Model system for evaluation and prediction. Figure 1 illustrates the data flow of prestressed girders and the corresponding BIM model updated by this information.

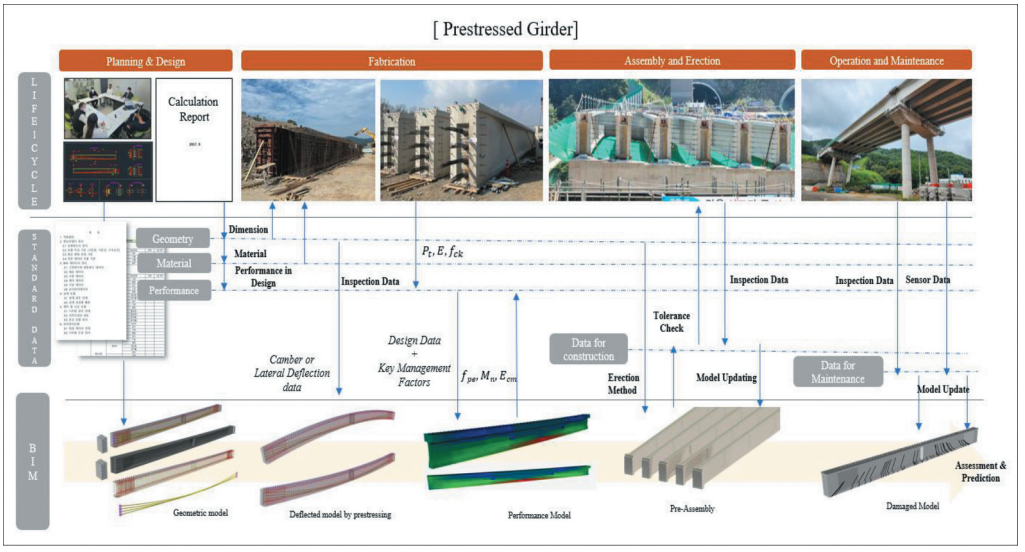


Figure 1. Data and model updating flow during the life-cycle of the prestressed girder.

The Digital Engineering Model, defined by applying data at each stage from the existing 3D geometric model, allows for a comprehensive examination of Design for Manufacture and Assembly (DfMA). This involves performance evaluation at the member level, consideration of information updates during fabrication and assembly stages, and application and evaluation in the design phase, all through the utilization of data and models. Additionally, it enables advanced checking of assembly for connection joints through pre-assembly simulation

of precast or prefabrication components, facilitating the early identification of assembly collisions. Once a system is established through data and data-based Digital Engineering Models (DEM) from the assembly stage to the as-built phase, the entire process's information and framework are managed as a baseline digital twin.

The baseline digital twin model is bifurcated into two branches for structural assessment during the operation and maintenance stages. Integrated information from these branches is utilized for evaluation and prediction. One branch comprises member force-related information for assessing the performance of components or bridges, while the other involves condition assessment by inputting or managing inspection data via the bridge maintenance management system.

To assess the strength and condition of structures, key management factors at the component level are necessary from the design stage. For instance, in the case of a girder bridge, structural components include girders and deck plates in the superstructure, and piers and abutments in the substructure. Updates for each component's key factors are based on information entered throughout the lifecycle. In the case of prestressed girders, during the design phase, factors such as geometric dimension section, concrete compressive strength, prestress material, and tension force are determined based on specifications for bending and shear strength. In the fabrication and as-built stages, actual values obtained from material tests, such as concrete compressive strength and elastic modulus related to the properties of materials, and the actual tension force specified in the tension report may differ from the design values, leading to inevitable variations in component strength.

Additionally, for prestressed concrete members, it is necessary to include data elements representing behaviors with time-dependent characteristics, such as relaxation, creep, and shrinkage, to accurately evaluate the performance of the structural member. However, determining precise values for these variables is challenging. Therefore, a stepwise management approach is adopted, using deflection values of members or strain data through sensors as indirect data. To achieve this, factor settings for component strength assessment are required, and these factors are continuously updated based on the input data. For prestressed girders, proposed key management factors include effective prestress stress (f_{ps}) and concrete elastic modulus (E_{cm}). The information input and updated throughout the lifecycle of the prestressed girder are presented in Table 1.

Ultimately, to assess the bridge system after the As-built stage, a system-level analytical model consisting of key factors of components is constructed. Based on data from field load tests conducted on the actual bridge, the lateral load distribution ratio is updated. Subsequently, a system is established to evaluate the member forces using standardized inputs in the common domain.

Table 1. Data definition for prestressed girder during its life-cycle

	Geometry Data	Material	Schedule(Date)	External Condition	Performance
Design	Dimension	F_{ck}, E_{cm}, f_{ps}, E_s	-	Bridge Alignment Humidity Temperature	M_{n_design} V_{n_design}
Fabrication	Deflection	F_{cm}, E_{cm}, $f_{first\ tension}$	Concrete casting(Date) 1st Prestressing(Date)	Humidity Temperature	$M_{n_fabrication}$ $V_{n_fabrication}$
Assembly	Deflection Inspection Data	F_{cm}, E_{cm}, $f_{second\ tension}$	Erection(Date) Deck(Date) 2st Prestressing(Date) Continuous(Date) Superimposed(Date)	Relative Location Humidity Temperature Support Condition	$M_{n_assembly}$ $V_{n_assembly}$

3 BRIDGE MANAGEMENT SYSTEM

When data, including design stage to construction stage information for each structural component of a bridge, is transferred to the Bridge Management System (BMS), maintenance procedures based on Building Information Modeling (BIM) are implemented in earnest. Periodically conducted public damage assessments and records of restoration are documented through various methods such as data, images, 2D inspection drawings, etc. This information is loaded or mapped onto the maintenance system, and it is visualized as shown in Figure 2. Damage information is typically mapped on a face-unit basis on the drawing of the structure and managed. However, the existing mapping approach, where image storage is designated as the management unit at the face-unit level, imposes challenges regarding storage space for the entity responsible for structure management. Damage information is managed as data before the mapping input stage, and since this data allows for individualized progress verification through shape modeling or numerical visualization methods, management through damage vectorization is possible rather than using the conventional mapping approach (Shim et al. 2019).

A sophisticated code system tailored for assessing bridge damages streamlines the automated compilation and quantification of defect data. Utilizing diverse image sources obtained from Unmanned Aerial Vehicles (UAVs) and Ground Penetrating Radar (GPR), in conjunction with damage maps, various image mapping techniques were employed with distinct approaches to visually represent the scrutinized data (Shim et al. 2019). The amassed inspection data and damage records for each bridge component can be systematically gathered, providing a robust foundation for informed decision-making. By harnessing federated data, digital twin models can be meticulously crafted for both individual bridge members and entire bridges (Jeon et al. 2024). These digital twin models, rooted in accumulated data, can effectively manage key performance indicators, enhancing the overall monitoring and assessment of bridge integrity.

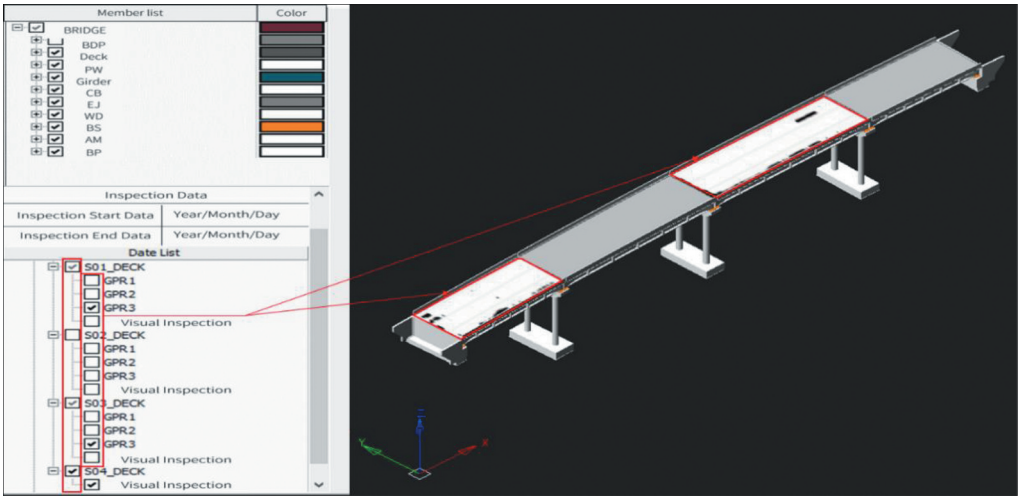


Figure 2. The bridge digital model with mapped damage information in BMS.

4 IMPREMENTATION TO A PRESTRESSED BRIDGE

4.1 *Prestressed concrete girder bridge*

The baseline digital twin concept is currently being applied to an expressway bridge in Korea. The bridge is comprised of prestressed concrete (PSC) girders with span lengths of 35m and 50m. In Figure 3, the bridge layout and the girders before erection on the shoe are illustrated. Steel lateral crossbeams and full-depth precast decks are assembled alongside the PSC girders.

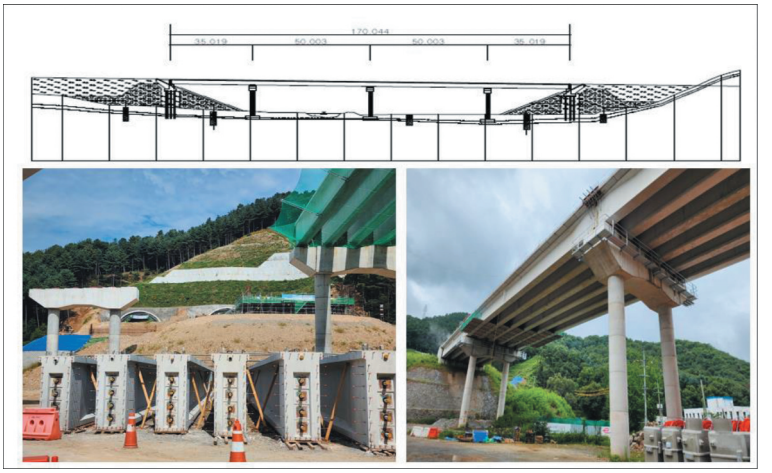


Figure 3. A prefabricated PSC bridge for implementation (In Korea).

In this project, we estimated the displacement of girders during the manufacturing phase through camber measurements. Utilizing the DEM, we predicted the deformations of girders based on camber measurement data over time and construction schedules, estimating concrete elasticity and initial prestress stress. These data can be collected by a common data environment (CDE) in a construction project. Figure 4 illustrates values related to the determination procedure of concrete elasticity and prestress stress after the first tensioning. The initial input concrete elasticity of 33,980 MPa and the initial prestress after short-term losses, such as elastic shrinkage and friction, were 1144 MPa in design phase, showing a significant difference from the values after actual tensioning. These results highlight the dependency of deformations on prestress and concrete properties as well as external influences, with key factors varying among girders within the same span. To construct a baseline digital twin model for the bridge, accurate assessments of material properties from production to hypothesis, and understanding the internal stresses, strengths, and stiffness of the actual components through updates, are essential.

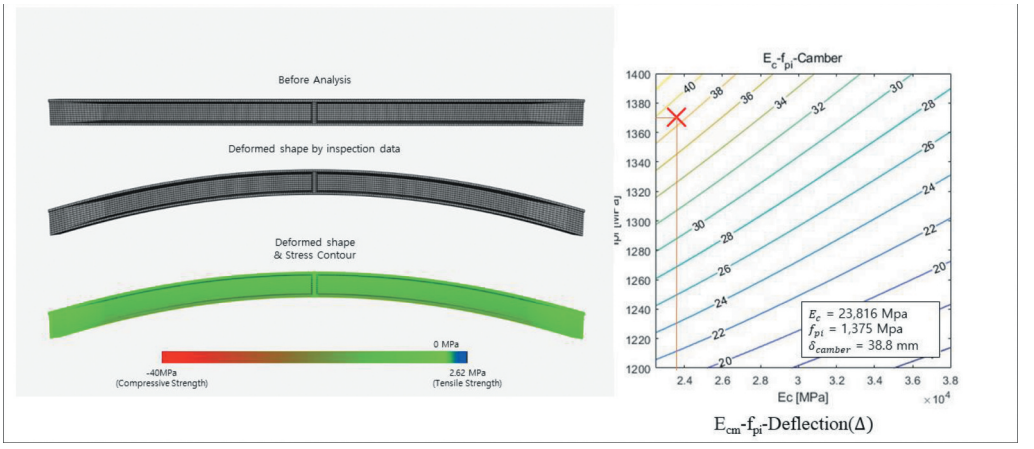


Figure 4. Key management factor of prestressed girder calculated from camber data.

5 CONCLUSION

As the number of aging bridges and the resulting cost of repairs continue to increase, the need for effective maintenance and performance evaluation becomes increasingly important. This

paper contributes to addressing these challenges by proposing a comprehensive definition of Building Information Modeling (BIM) data, establishing the foundation for generating baseline digital twins tailored to the maintenance requirements of common girder-bridges. The significance of a standardized data delivery system for bridges is underscored, particularly emphasizing the critical role of actual data during fabrication and assembly phases to ensure the reliability of baseline models and their as-built data at handover.

Three key points emerge as pivotal in advancing the efficacy of digitalized information delivery in bridge maintenance:

1) Recognizing the pivotal role of consistent data delivery between construction phases, this study emphasizes the necessity for a standardized approach. Notably, the inclusion of actual data during the fabrication and assembly phases is highlighted as crucial for establishing a dependable baseline model and ensuring accurate as-built data during handover.
2) The identification and selection of key indicators emerge as a critical aspect in evaluating the key performance of bridge members. Structural simulations for various scenarios are recommended as a means to comprehensively represent these indicators, providing insights into the diverse conditions and challenges that a bridge may encounter throughout its service life.
3) To facilitate effective data collection from construction projects, the establishment of a collaborative system, such as a Common Data Environment (CDE), is proposed. This collaborative framework can streamline data sharing and communication, fostering a cohesive approach to data collection from various stakeholders involved in the construction process.

In conclusion, the proposed framework not only establishes a robust basis for creating baseline digital twins for girder-bridges but also advocates for a standardized approach to data delivery, the selection of meaningful key indicators, and the implementation of collaborative systems for efficient data collection. These elements collectively contribute to an enhanced understanding of bridge performance and support informed decision-making in the realm of bridge maintenance.

ACKNOWLEDGEMENT

This research was conducted with the support of the "National R&D Project for Smart Construction Technology (RS-2020-KA156007)" funded by the Korea Agency for Infrastructure Technology Advancement under the Ministry of Land, Infrastructure and Transport, and managed by the Korea Expressway Corporation

REFERENCES

Chi-Ho Jeon, Duy-Cuong Nguyen, Gitae Roh & Chang-Su Shim. 2023. Development of BrIM-Based Bridge Maintenance System for Existing Bridges, *Buildings*, 13(9): 2332

Jeon, C.H., Shim, C.S., Lee, Y.H. & Schooling J. 2024, Prescriptive Maintenance of Prestressed Concrete Bridges Considering Digital Twin and Key Performance Indicator. *Engineering Structures*, will be published.

Shim, C. S., Dang, N. S., Lon, S., & Jeon, C. H. 2019. Development of a bridge maintenance system for prestressed concrete bridges using 3D digital twin model. *Structure and Infrastructure Engineering*, *15*(10), 1319–1332.