Building Information Modeling for Highway Bridge Projects

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Building information modeling (BIM) is a technology used to deliver infrastructure projects with digital media, known as digital delivery. As the architecture and building construction industries have made extensive use of BIM in project delivery for many years, the transportation industry now recognizes its many benefits. As a result, the application of BIM to highway infrastructure is growing in prominence both in the United States and internationally.

BIM can greatly improve collaboration among bridge designers, fabricators, and construction staff and is envisioned to improve data and design-model management throughout the life cycle of each bridge asset. The Federal Highway Administration (FHWA) conducted a research project to address two specific challenges related to digital delivery: technical needs to manage the new digital processes and media, and standardizing the content and format of the digital data. A case study of a bridge project delivered digitally using BIM-based media for the contract document was also conducted as part of this research project. The information presented in this article is from the project's final report, *Demonstration of Bridge Project Delivery Using BIM* (FHWA-HIF-21-031).[1]

Background

For the past century, information flow has been through the use of two-dimensional (2-D) plans, which were usually developed using drafting standards to ensure a consistent, predictable, repeatable, and reliable presentation of the design specifications for construction. One of the primary industry goals of nonbinding and voluntary data standards is to be able to use BIM to replace 2-D plans with three-dimensional (3-D) digital information that has the same standards of accessibility, repeatability, and universal accessibility.

BIM has matured in the architecture and buildings domain and has been adopted widely following a series of major standardization milestones. Data standards for buildings are based on the Industry Foundation Class (IFC) data schema and exchange file format. For many years the lack of data standards for transportation assets limited the application of BIM. In 2019, the American Association of State Highway and Transportation Officials (AASHTO) passed a resolution titled "Adoption of Industry Foundation Classes (IFC) Schema as the Standard Data Schema for the Exchange of Electronic Engineering Data,"[2] which recognized IFC schema as the national standard for transportation projects.

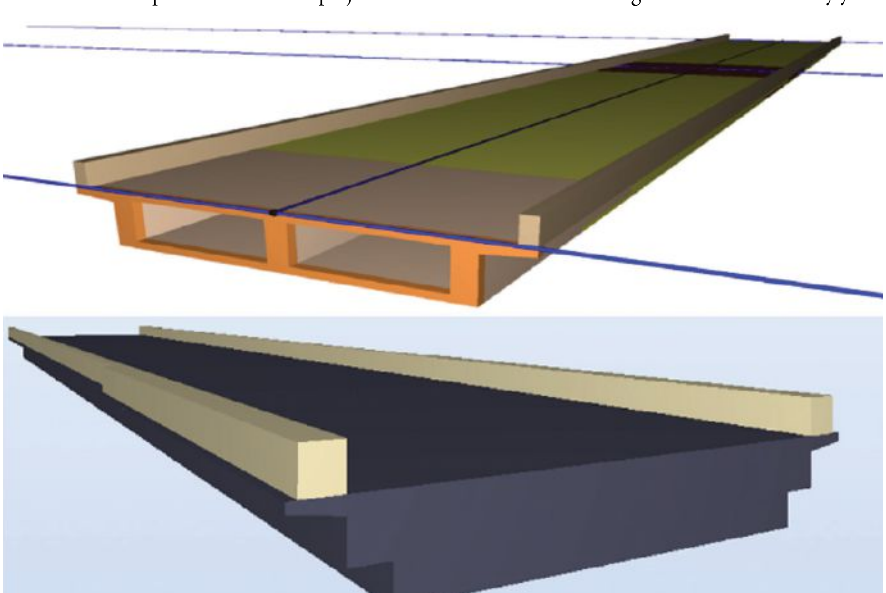
The objectives of the FHWA research project described here were to support the state highway agencies that are advancing digital delivery for bridges and to apply and document the effectiveness of the "IFC Bridge Design to Construction Information Exchange (U.S.),"[3] which is a model view definition that expresses the bridge information necessary for construction.

Case Study

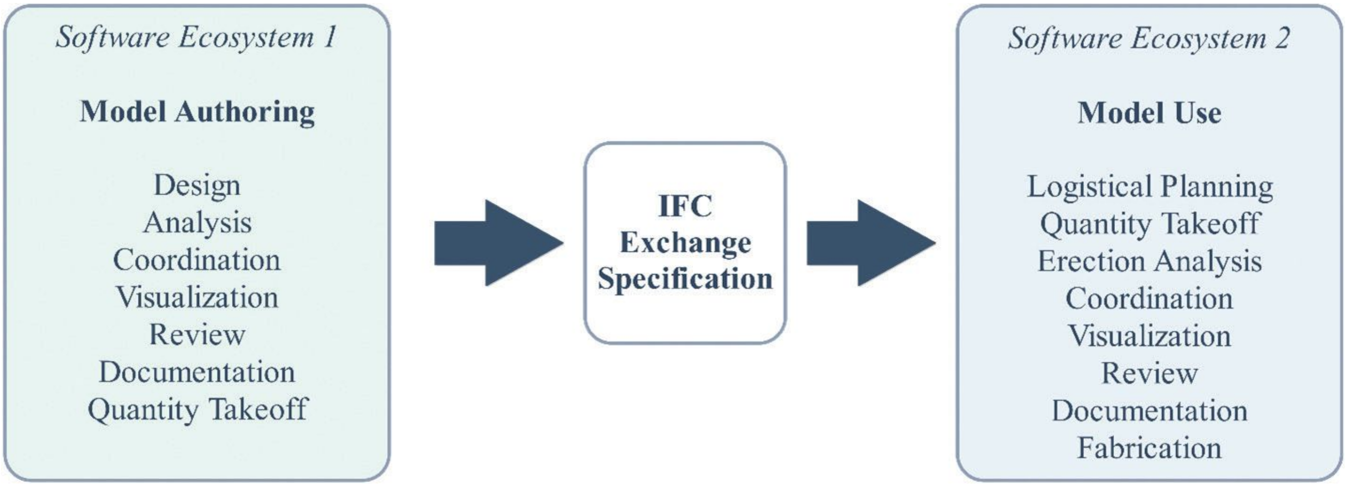
A Utah Department of Transportation (UDOT) project was chosen as the case study for this research. The project, known as the Blackrock project, involved replacing three steel bridges: two parallel bridges that carry Interstate 80 (I-80) over the Union Pacific Railroad, and a bridge that carries State Route 36 over I-80, which was replaced with a prestressed concrete superstructure. UDOT allowed the research team to develop a case study using the project data set to test the IFC exchange specification that had been developed for FHWA.

A utility application was developed in this research that provides access to data stored in AASHTOWare Bridge databases, which can be leveraged by users exporting to design applications and can also accelerate bridge data interoperability with other design, fabrication, and construction software.

Before modeling the case study bridges, data exchange format verification and testing were performed using common industry tools. For the research project, the team used a utility application and accompanying software components that have been created to convert data from AASHTOWare Bridge Design (BrD) and Bridge Rating (BrR) software into IFC format.



Digital rendering of section and abutment elevation of multicell box-girder bridge. All Figures: Federal Highway Administration.



Digital construction information flow. For construction, the owner has more control of how construction information is created and delivered, as represented by the authoring activities on the left. The owner can also influence the way information is exchanged from one software ecosystem to the next (middle). However, the owner cannot control how the contractor and fabricator consume information, which is part of the contractor's means and methods (right).

The Alaska Department of Transportation and Public Facilities and Wisconsin Department of Transportation provided a sample of bridges from their AASHTOWare BrD inventory. These bridges were batch converted to IFC using the exchange utility. By converting these sample bridge models to IFC format, dozens of software viewing applications and toolkits can render the information in three dimensions.

IFC Model of Case Study Bridges

The three new bridges from the UDOT case study were used to further test the IFC exchange specification. The research team used the proprietary 3-D models developed for the bridges as a data set and compared the quality and quantity of information generated by the IFC and proprietary data exchanges. The extent of functionality with IFC-compliant models was investigated. To model the Blackrock project bridges, IFC 4.1 was necessary to capture geometry with dimensions used relative to alignment curves. Custom software functionality was adapted from internal software tools to support modeling of the test bridges using the design information.

BIM Technical Specifications for Bridges

Providing information for consideration when agencies are drafting BIM technical specifications for highway bridges was an additional objective of this research project. The following items should be considered in implementing BIM for bridges:

- Technical specifications for BIM-based design should include determination of BIM-related roles and responsibilities (model/BIM manager, model authors, and third-party users), BIM template files, the construction schedule, details of the information exchanges, and overall BIM data structure.
- Construction specifications should include partnering in BIM projects, which is a structured approach to collaboration and teamwork between contracting parties on a construction project, including the owner, designer, fabricator, and construction engineers; the use of electronic documents with digital signatures; and scope validation such as exchange of information and communication, including BIM-related products, and establishing precedents of the BIM documents among the entire set of bid documents for resolving claims and disputes.

Key Findings and Suggestions

This research project provides resources for state transportation agencies implementing digital delivery of bridge projects by including sample technical specifications, a test of an implementation of the "IFC Bridge Design to Construction Information Exchange (U.S.)" model view definition that provides feedback to national and international efforts, and an AASHTOWare BrD to IFC Exchange Utility, which can be used to convert current BrD files into IFC.

The key findings and suggestions include the following:

- It is currently possible to use digital delivery to construct and fabricate complex workhorse bridges using an approach with proprietary software and user-defined detail annotations and attachments for work-around as needed.
- The AASHTOWare bridge models share a well-designed data model that can be mapped to IFC format for most workhorse bridges.
- The bridges tested for IFC exchange in this research were comprehensively described by the IFC data structures. However, it would be beneficial to refine the "IFC Bridge Design to Construction Information Exchange (U.S.)" model view definition to provide direction on representing provisional data and to provide information for capturing multiple representations of the same component for different uses.
- A BIM object template, which provides a structured approach to providing input to describe and expand digital description and associated software standards, is suggested for further study and development.

Moving Forward with BIM

With today's advanced technology and tools, the traditional practice of sharing project documents via hard-copy plan sets and by PDF and word-processing files from silo to silo through the life cycle of a bridge project is inefficient. With BIM, all project data from planning to decommissioning will be digitally accessible for all involved in planning, building, and maintaining bridges, thereby providing seamless data exchange. State departments of transportation are increasingly recognizing the advantages of implementing BIM to improve efficiency and advance our industry.

References

1. Federal Highway Administration (FHWA). 2021. *Demonstration of Bridge Project Delivery Using BIM*. FHWA-HIF-21-031. Washington, DC: FHWA. https://www.fhwa.dot.gov/bridge/pubs/hif21031.pdf.
2. Association of State Highway and Transportation Officials. 2019. "Adoption of Industry Foundation Classes (IFC) Schema as the Standard Data Schema for the Exchange of Electronic Engineering Data." AR-1-19. https://bit.ly/3E2lmnk.
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Details on Two Upcoming Changes to the *AASHTO LRFD Bridge Design Specifications*: Strut-and-Tie Modeling versus Sectional Design, and Struts Crossing Cold Joints

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My article in the Fall 2021 issue of *ASPIRE*® summarized 11 working agenda items that were approved by the American Association of State Highway and Transportation Officials' (AASHTO's) Committee on Bridges and Structures (COBS) at its summer 2021 meeting. That article provides sufficient explanations for the adopted revisions to the *AASHTO LRFD Bridge Design Specifications*[1] that are limited in scope, but others warrant additional discussion. To that end, my article in the Winter 2022 issue and this article each focus on two of the items in greater detail.

Working Agenda Item 206: Strut-and-Tie Modeling versus Sectional Design

Working agenda item 206 provides clarification to Article 5.7.3.2 regarding what types of loads impose additional demands on stirrups near the supports, and what types of loads directly flow into the supports via the formation of direct struts. Sections near supports are subjected to a complex state of stress influenced by the location (that is, the distance from the support) and the type (concentrated or distributed) of loads. In the absence of a concentrated load within the effective shear depth d_v, and where the reaction force in the direction of the applied shear introduces compression into the end region of a member, the location of the critical section for shear is to be taken at a distance d_v from the internal face of the support, and the shear reinforcement required at the critical section shall be extended to the support. This is because the externally applied uniform loads and the self-weight of the member in the immediate vicinity of the support are directly transferred into the support by a compression strut and do not impose an additional demand on stirrups located within d_v of the support. Loads away from supports create a compression field, and the vertical component of the forces generated in the compression field does introduce an additional demand on stirrups (see Fig. C5.7.3.2-1b in the AASHTO LRFD specifications).

It is important to recognize that loads both near and away from supports introduce stresses in the compression-compression-tension node that forms above the supports, and those stresses should be checked in accordance with the requirements of Article 5.8.2 of the AASHTO LRFD specifications. Alternatively, the complex state of stress that results from the presence of a concentrated force near a support may be accounted for using sectional design models by making conservative assumptions for shear design. In the context of sectional design, calculating capacity and demand at the face of the support conservatively considers the complex state of stress that results from the load introduction into the member near a support.

If there is a concentrated load within d_v of the support, or the reaction force in the direction of the applied shear introduces tension into the end region of a member, the location of the critical section should be at the internal face of the subject support. Accordingly, the design section shear load and shear resistance are to be calculated at the internal face of the support. Furthermore, if the beam-type structural member extends to both sides of the reaction area, the design section on each side of the reaction shall be determined separately based on the loads on each side of the reaction and whether their respective contribution to the total reaction introduces tension or compression into the end region.

Working Agenda Item 215: Struts Crossing Cold Joints

Working agenda item 215 provides new requirements for struts crossing cold joints when designs use the strut-and-tie method. These requirements will avoid unconservative capacity predictions for this situation and bring the AASHTO LRFD specifications into better alignment with international design guidance. Accelerated bridge construction, repair and retrofit of existing bridge structures, foundation retrofits, segmentally constructed bridges, and spliced-girder bridges, as well as other innovative bridge solutions involving complex geometries, result in structural details that contain cold joints. Furthermore, recent events have highlighted the importance of properly checking and detailing cold joints.[2] This technical item was initially discussed in a Concrete Bridge Technology article in the Fall 2020 issue of *ASPIRE*.

Recent events have highlighted the importance of properly checking and detailing cold joints.

Article 5.8.2.2 of the current AASHTO LRFD specifications does not explicitly require that struts crossing cold joints must be checked for shear-friction at that interface. With the upcoming changes to the specifications, this check will become mandatory. This modification will ensure that such cases are checked in design or assessment, or both, and it will help prevent unconservative capacity predictions.

According to the forthcoming AASHTO LRFD specifications, if a D-region is built in stages, the forces imposed by each stage of construction on previously completed portions of the structure are to be carried through appropriate strut-and-tie models. Where a strut passes through a cold joint in the member, the joint shall be investigated to verify that it has sufficient shear-friction capacity. The strut force may be resolved into a normal and shear force at the interface, and the capacity of the interface shall be calculated in accordance with the interface shear resistance requirements of Articles 5.7.4.3 and 5.7.4.4.

In this context, the reader's attention is directed to the discussion in the current commentary to Article 5.7.4.1:

> *Shear displacement along an interface plane may be resisted by cohesion, aggregate interlock, and shear-friction developed by the force in the reinforcement crossing the plane of the interface. Roughness of the shear plane causes interface separation in a direction perpendicular to the interface plane. This separation induces tension in the reinforcement balanced by compressive stresses on the interface surfaces.*
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> *Any reinforcement crossing the interface is subject to the same strain as the designed interface reinforcement. Insufficient anchorage of any reinforcement crossing the interface could result in localized fracture of the surrounding concrete.*

Proportioning, detailing, and anchorage of the reinforcement crossing cold joints are all important to mobilizing the calculated capacity at the cold joint. It is also important to recognize that the cohesion and friction factors listed in Article 5.7.4.4 vary substantially depending on the type and condition of the cold joint interfaces.

Future articles will keep our readership informed about additional upcoming changes to the next edition of the AASHTO LRFD specifications, which is to be published in 2023.

References

1. American Association of State Highway and Transportation Officials (AASHTO). 2020. *AASHTO LRFD Bridge Design Specifications*. 9th ed. Washington, DC: AASHTO.
2. National Transportation Safety Board (NTSB). 2019. *Pedestrian Bridge Collapse Over SW 8th Street, Miami, Florida, March 15, 2018*. Highway Accident Report NTSB/HAR-19/02 PB2019-101363. Washington, DC: NTSB. https://www.ntsb.gov/investigations/AccidentReports/Reports/HAR1902.pdf.