Case study of cloud-based parametric workflows for modeling & code checks in bridge rehabilitation

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ABSTRACT: This paper aims to demonstrate how the utilization of OpenBrIM Platform's cloud-based parametric workflows can lead to significant time and cost savings in 3D/FEA modeling and design code checks. The objective of this study is to showcase the benefits of OpenBrIM technology through a rehabilitation project in Florida State. It focuses on highlighting the improved competencies required to build a parametric 3D/FEM model for complex staged deconstruction/reconstruction bridge analysis on the cloud using the OpenBrIM Platform.

1 INTRODUCTION

1.1 *OpenBrIM Platform: Revolutionizing Bridge Engineering*

The OpenBrIM Platform is a cutting-edge software program specifically designed to revolutionize the field of bridge engineering and construction. It offers a comprehensive suite of tools and features that streamline the entire process, from initial design to analysis and code checks. With its cloud-based architecture and parametric modeling capabilities, OpenBrIM Platform empowers engineers and designers to create highly efficient and cost-effective bridge structures.

The program's parametric modeling capabilities are a key highlight. OpenBrIM Platform allows engineers to create 3D models of bridges with interconnected components that can be easily modified and updated. This parametric approach not only saves time but also ensures that design changes can be implemented quickly and accurately, leading to more efficient workflows.

In addition, the OpenBrIM Platform integrates advanced analysis features, including finite element analysis (FEA) and influence surface analysis. These tools enable engineers to simulate and evaluate the structural behavior of bridges under various loading conditions, ensuring their safety and performance.

Furthermore, OpenBrIM Platform incorporates industry-standard design codes and procedures, such as those established by organizations like AASHTO. This ensures that bridge designs comply with regulatory requirements and industry best practices, giving engineers peace of mind that their structures meet the necessary standards.

1.2 *Demonstrating the Power of OpenBrIM Platform: A Case Study of Rehabilitation Project in Florida State*

In this case study, the rehabilitation project in Florida State serves as a prime example to illustrate the tangible benefits of implementing OpenBrIM Platform in a real-world scenario. The project involves the complex staged deconstruction and reconstruction of a bridge, requiring meticulous analysis and design considerations. By utilizing the OpenBrIM Platform, engineers were able to leverage the improved competencies offered by the parametric 3D/FEM modeling capabilities.

2 BRIDGE REHABILITATION PROJECT

The example illustrates a rehabilitation project for a horizontally-curved steel I-girder type bridge in the state of Florida. Typical properties of the bridge are summarized in Table 1. Structural component geometry provided represents the maximum dimensions.

Table 1. Bridge Properties

Bridge Geometry	# of spans	Max. span length	
	8	~173 ft	
Girder Section	Width	Depth	Thickness
Top flange	26"	-	2.25"
Bottom flange	28"	-	2.75"
Web	-	69"	1.00"
Pier Cap Section		Width	Height
		66"	~126"
Pier Column Section		Width	Length
		183"	78"

2.1 *Extend of the Rehabilitation Work*

The rehabilitation project involves the removal of certain superstructure and substructure components to accommodate the widening of adjacent bridges. This section of the paper outlines the primary tasks involved in the deconstruction and reconstruction of both the superstructure and substructure, along with illustrations to enhance the audience's comprehension of the project. Figure 1 presents a typical bridge section that includes existing and removed superstructure units. The dashed lines represent existing parts, while the hatched areas indicate the components to be removed. The solid lines depict newly constructed components, whether temporary or permanent.

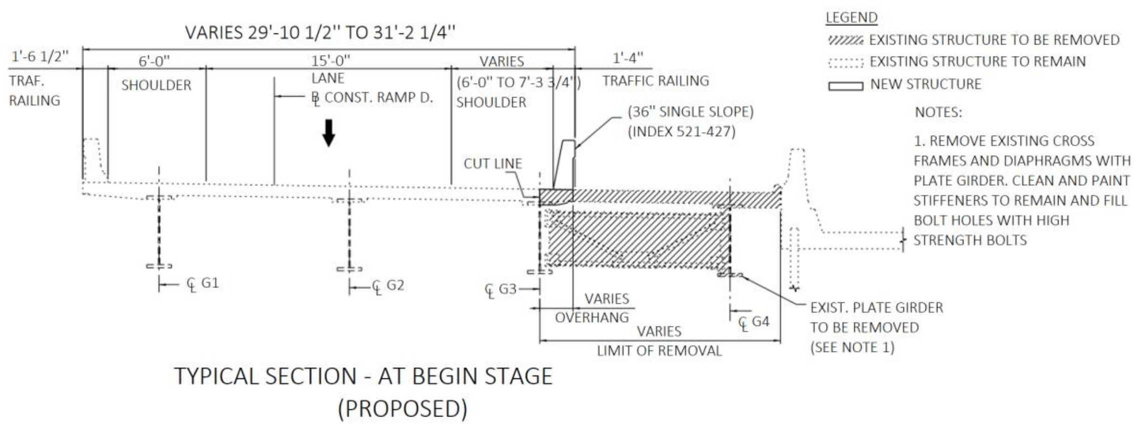

Figure 1. Typical (proposed) bridge superstructure section

The proposed removal of the right-hand side girder, cross frames, diaphragms, part of the deck and traffic railing is through the first five spans of interest in the longitudinal direction. Construction /deconstruction works within first two span will be called as Unit 1, and the ones in the adjacent three spans as Unit 2. During partial superstructure removal of Unit 1, type K concrete traffic barriers are positioned as free stand to channel traffic to a single-lane. To protect motorists from drop-off hazards is the other reason for the temporary traffic barriers.

Substructure of the partially removed superstructure is also modified extensively. Supplemental concrete columns with prestressing and footing extensions are constructed with prestressing while part of pier cap being cut. Additional substructure construction is also required to offset imbalance loads on columns and piles from partial superstructure removal. In Figure 2, representative substructure works are shown for the Unit 1.

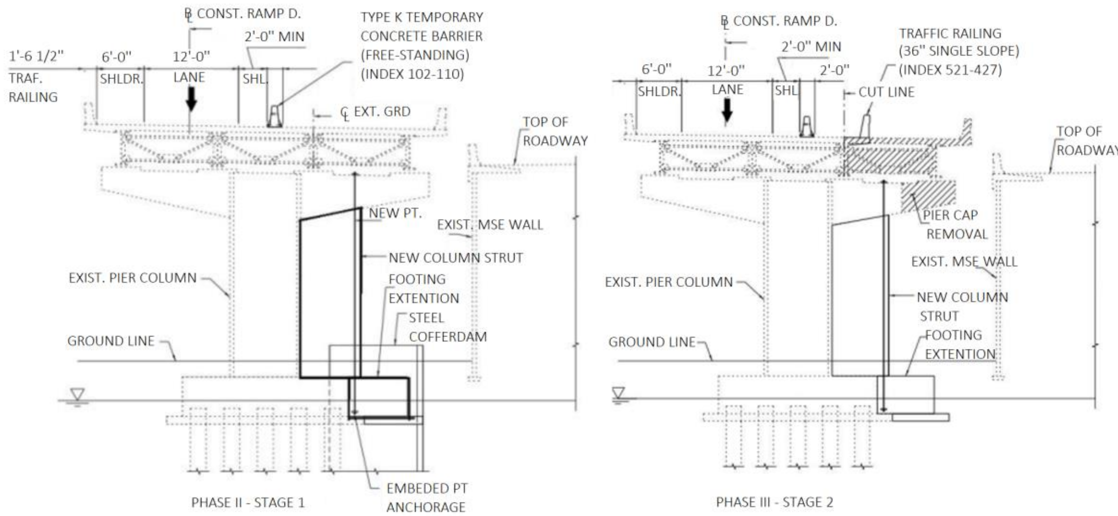

Figure 2. Representative (proposed) bridge substructure works for the Unit 1

Regarding proceeding works for Unit 1, removal of the pier cap and corresponding superstructure components is followed by the new construction of a new deck overhang and traffic railing. Additionally, a new pilaster is constructed at the rehabilitated pier, and a transition traffic railing is needed between the newly constructed traffic railing and the existing one at the adjacent span. Once the rehabilitated bridge part is available, the new lane transition can be stripped and the adjacent lanes reconfigured. Next, pier protection barriers, transitions, curbs at the pier, and the widened intersection are constructed. Finally, the temporary type K traffic barrier is removed.

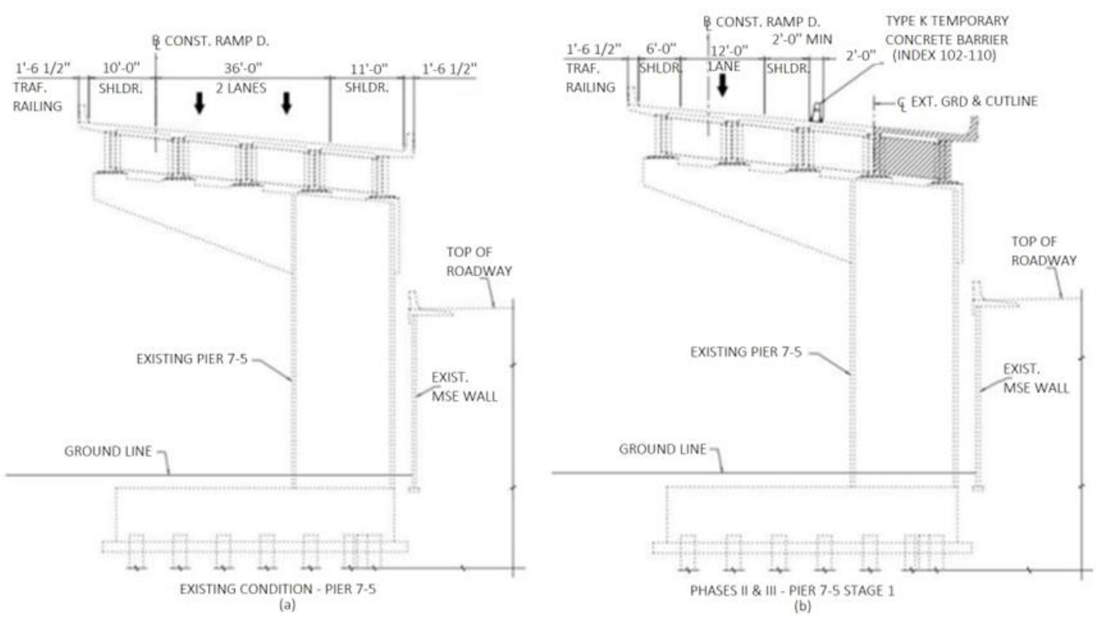

Figure 3. Unit 2, existing situation (a) and removal of the superstructure (b)

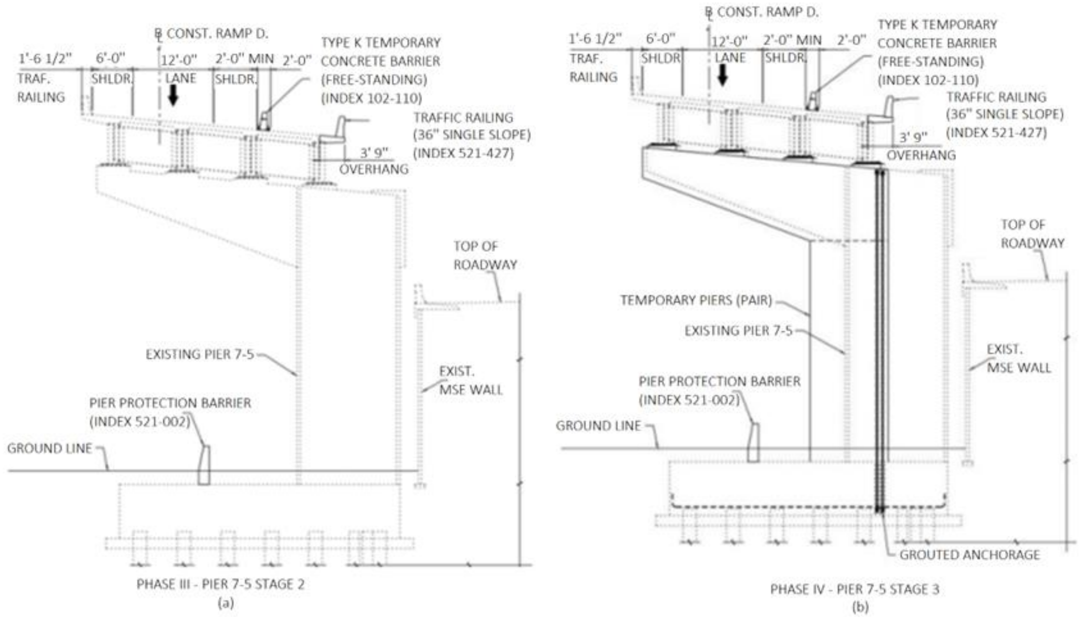

Figure 4. Unit 2, newly constructed superstructure (a) and temporary piers (b)

The particular work for demolish and new construction of Unit 2 is also distinctive. The pier linking the fourth and fifth span under consideration is exposed to modification. For the removal of Unit 2 substructure, temporary C-shaped piers are constructed each side of the pier on top of the existing footing. Via jacking, the support is transferred to the new temporary bearings. Figure 3 and Figure 4 clarifies the steps followed in superstructure removal process and temporary substructure construction and temporary load transfer for Unit 2.

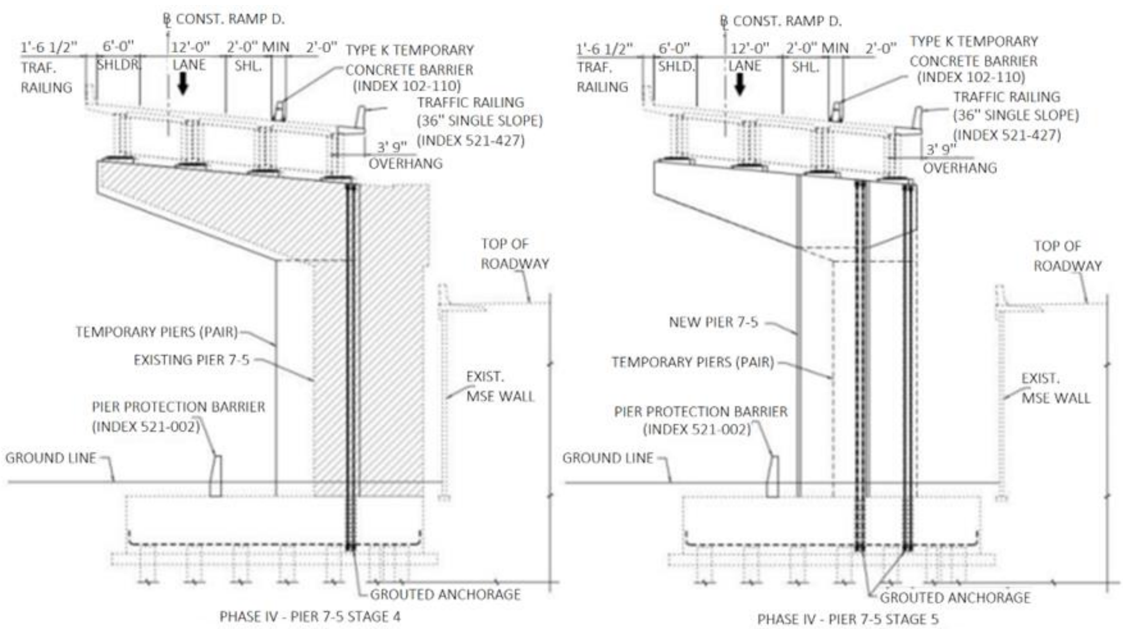

Figure 5. Unit 2, removal of existing substructure (a) and new piers (b)

Figure 5(a) provides a visual representation of the existing structure to be removed and the newly constructed structure with temporary piers. The next step involves the demolition of the existing pier column and pier cap located between the temporary C-shaped piers.

After the removal of the existing pier cap and pier column shown in Figure 5(a), a new asymmetric hammerhead pier was constructed between the temporary C-shaped piers, as shown in Figure 5(b). The support was transferred to new permanent bearings of the newly constructed asymmetric hammerhead pier cap using jacking. Finally, the temporary C-shaped piers were demolished, resulting in the final situation as visualized in Figure 6.

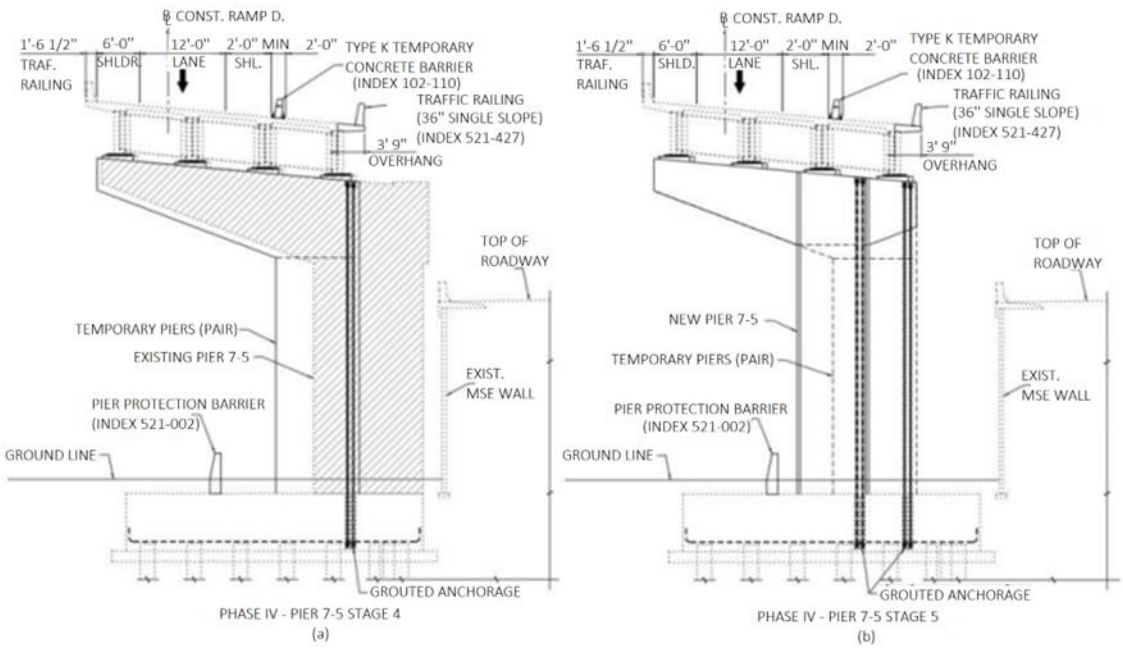

Figure 6. Unit 2, removal of temporary substructure (a) and final condition (b)

3 PARAMETRIC BRIDGE WORKFLOW ON BROWSER

In this part of the paper, some of the main components of OpenBrIM Platform's parametric bridge workflow that provided exclusive advantages in the project are presented broadly, including: i) 3D/FEA modeling, ii) staged construction/deconstruction analysis, iii) 3D influence surface live load analysis, iv) code checks, and v) state amendments.

3.1 *3D/FEA modeling*

The OpenBrIM Platform played a crucial role in the success of the bridge rehabilitation project. This cloud-based platform, accessible via a browser, enabled the team to model the bridge parametrically using a standard steel I-girder bridge workflow template. This efficient workflow relied on a predefined library of engineering components that were parametrically related to each other, allowing for fast and accurate 3D modeling.

To meet the project's tight schedule, the team also developed and integrated non-standard, project-specific bridge components into the workflow. All information was fully integrated on the browser, including the finite element analysis (FEA) definition of the bridge, which enabled the use of the same model for analysis, design, and code check procedures for each state of the structure. The benefits of this approach were numerous, including faster modeling and analysis, greater accuracy, and improved collaboration between team members.

Figure 7 shows a snapshot of the modeled information on the OpenBrIM Platform App, while Figure 8 provides a simultaneous output of the mathematical representation of the bridge.

Figure 7. 3D model representation of the bridge on the OpenBrIM Platform

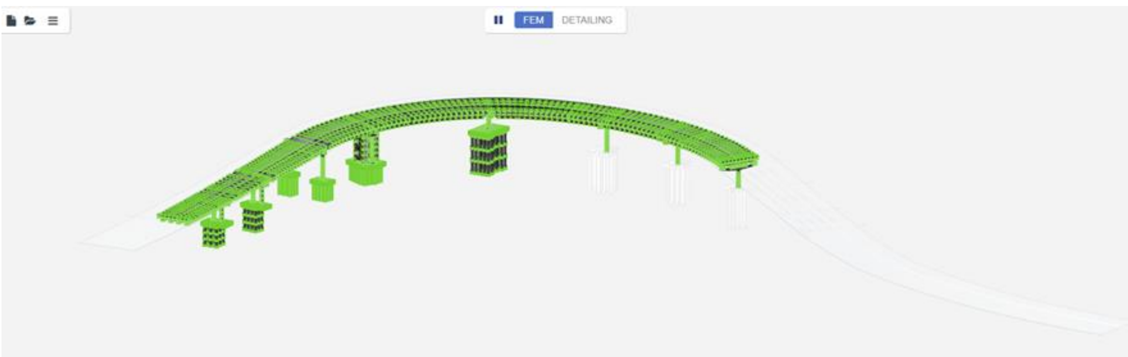

Figure 8. FEA model generated automatically once the 3D model is generated

3.2 *Staged construction/deconstruction analysis*

In the case of this project, the staged construction and deconstruction analysis was crucial. OpenBrIM Platform's staged construction/deconstruction analysis allowed the engineers to break down the 96 stages of the complex construction process and analyze each stage in detail. This enabled them to identify potential issues such as structural instability, material failure, or safety hazards, and optimize the process to mitigate these risks. By using the OpenBrIM Platform's advanced analysis tools and parametric modeling capabilities, the engineers were able to simulate various scenarios and evaluate the impact of different design choices on the construction process. The staged construction and deconstruction analysis also allowed the engineers to develop a detailed sequence of construction and deconstruction steps with corresponding limit states and structural state, ensuring that each phase of the process was executed efficiently and code-compliant.

Figure 9 shows the proposed structural parts to be removed, newly constructed footing extentions and temporary piers modeled in OpenBrIM Platform. Corresponding FEA representation of construction/deconstruction stages in OpenBrIM Platform is presented in Figure 10.

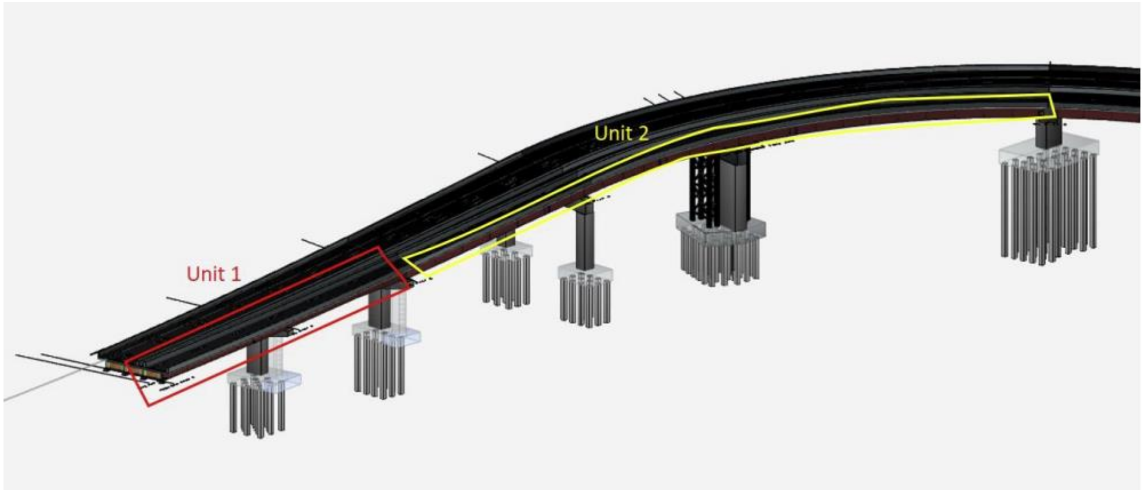

Figure 9. Proposed structures to be constructed/deconstructed, OpenBrIM Platform 3D model

Figure 10. Deconstruction stage of Unit 1 and Unit 2, OpenBrIM Platform FE representation

3.3 *3D influence surface live load analysis*

To assess the structural behavior of the bridge during construction and service phases, 3D influence surface analysis of the OpenBrIM Platform has been utilized. The analysis was conducted in accordance with the AASHTO LRFD Bridge Design Specifications, 9^{th} (AASHTO, 2020). The influence surface analysis provided critical information about the maximum forces and deformations that could occur at any location on the bridge, which helped in designing the temporary structures and in identifying the most critical locations for monitoring during construction.

The live load analysis was conducted for various stages of construction, including the existing, temporary, and final stages, to assess the structural behavior at each stage. Parametric 3D influence surface created automatically for live load analysis and is also capable of simulating braking and centrifugal effects by applying unit forces in longitudinal and transverse directions, respectively. The results of the analysis were presented graphically on the OpenBrIM Platform, which facilitated easy interpretation and communication of the results to the project stakeholders. An example of the graphical representation of the vehicle position producing the specified live load analysis result is shown in Figure 11.

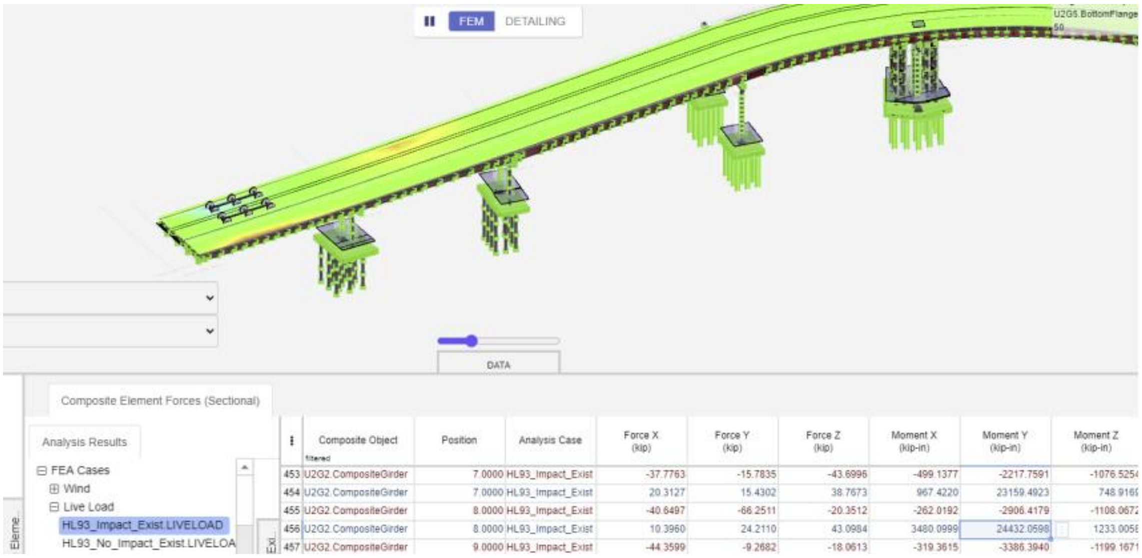

Figure 11. 3D influence surface live load analysis, interpreting results along with vehicle position

3.4 *Code checks*

The parametric bridge workflow allows for all the bridge information to be modeled as design parameters for the code checks. In OpenBrIM Platform, design parameters from bridge components and analysis results are parametrically integrated to each other. The workflow template includes predefined code check procedures that automatically incorporate digitized AASHTO chapters to ensure compliance with design standards.

For this project, both superstructure and substructure code check procedures of OpenBrIM standard steel I girder workflow template are employed. Code check results are reported in two main formats on the cloud: i) a summary of Demand/Capacity values and ii) detailed report. Detailed report transparently reports:

- all the design parameters with the compilations developed by OpenBrIM library developers/structural engineers using core OpenBrIM features (document, table, CADD, graph, and section analysis if needed)
- unfactored/factored analysis results
- design equations used with the reference equation number, the value and explanation of every single term used in the computation

In this project, performed substructure code checks were:

- pier cap code check
- pier column code check
- piled cap code check
- pile capacity check

Superstructure code checks utilized were as follows:

- steel I girder code check
- field splice code check
- cross frame code check
- shear stud code check

3.5 *State amendments*

The OpenBrIM Platform allows for state-specific amendments to be integrated into bridge workflows, in addition to the standard AASHTO design specifications. For this project, one of the state provisions integrated in the workflow is exemplified here.

Florida Department of Transportation (FDOT) requires the maximum service stress in pier columns, pier caps and pile caps under construction loading and Service III limit state to 24 ksi (FDOT, 2022) regardless of the grade of steel used.

Figure 12 shows a section analysis of a pier column, which is a core feature of the detailed code check report. This analysis helps ensure compliance with the Florida Department of Transportation's requirement for maximum service stress in pier columns under certain loading conditions.

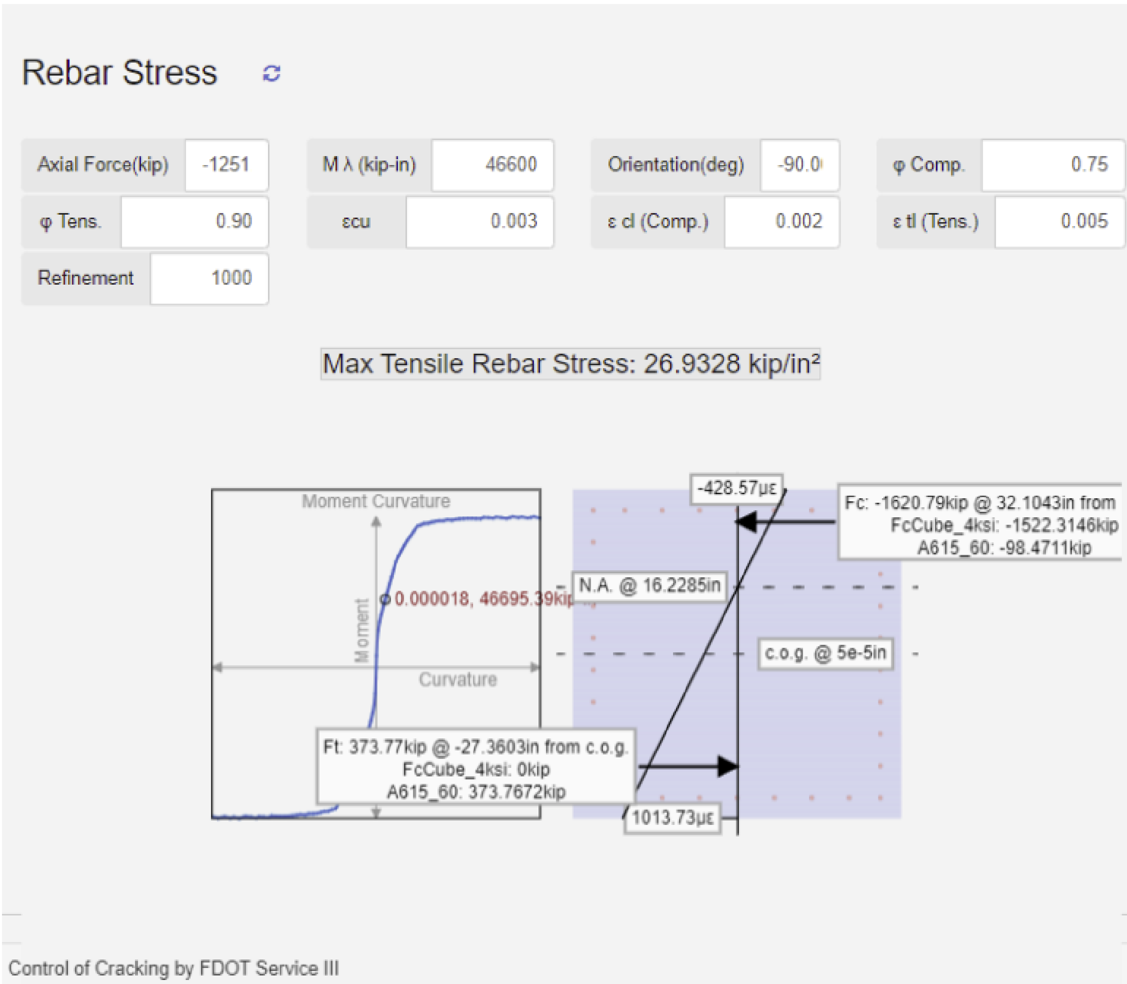

Figure 12. FDOT maximum stress analysis integrated to the OpenBrIM code check detailed report

For one of the pier caps in the project, the maximum tensile rebar stress exceeds the specified conditions. As a result, the pier cap rehabilitation plan has been revised accordingly.

4 CONCLUSION

This paper described the use of OpenBrIM Platform's parametric bridge workflow on a bridge rehabilitation project. The software, which runs on the cloud and is accessible via a browser, enables efficient 3D/FEA modeling, staged construction/deconstruction analysis, 3D influence surface live load analysis, code checks, state amendments and even more functionalities that are beyond the scope of this work.

The OpenBrIM's parametric bridge workflow is based on a standard template for steel I-girder bridges, which includes preloaded components that are parametrically related. This allows for efficient 3D modeling. To meet the specific requirements of the project, non-standard bridge components were developed and integrated into the workflow.

The staged construction and deconstruction analysis on OpenBrIM allowed for the evaluation of loads and stresses on each component of the bridge, as well as the effects of temporary structures used during construction. The FEA capabilities of the platform were used to simulate the behavior of the bridge under various conditions, enabling the refinement of the design and identification of potential failure points. A detailed sequence of construction and deconstruction with 96 steps was developed to ensure that each phase of the process was executed safely. The engineer was able to put his/her effort on interpreting the structural output rather than transforming bridge information from one software to another.

Code checks were performed using the design parameters from bridge components and analysis results, which were parametrically integrated into the OpenBrIM workflow template. Predefined code check procedures being integrated into the standard workflow template enable the efficient reporting of code check results in both summary and detailed formats on the cloud.

Overall, the use of OpenBrIM Platform's parametric bridge workflow minimizes the time spent on modeling bridge information for different purposes and reducing the overall duration of the project.

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