STREAMLINING STEEL BRIDGE AND ARCH ERECTION THROUGH BRIM AND 3D INTEGRATED MODELING FOR THE I-59/20 BRIDGE REPLACEMENT

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BIOGRAPHY

Patrick Noble, PE, SE, is a Bridge Engineer with the Tallahassee office of FINLEY Engineering Group. He graduated from Texas A&M University in College Station, TX with a Bachelor and Masters degree in Civil/Structural Engineering. Patrick has over seven years of steel design experience, specializing in complex steel bridge design and construction engineering for the past four years. His steel bridge project experience ranges from steel plate and box girder design to steel tied arch construction engineering for the US-98 Bridge Replacement in Pensacola Bay, Florida. Patrick served as the Bridge Engineer responsible for the construction engineering of the I-59/20 McFarland Boulevard Bridge Replacement Project in Tuscaloosa, AL.

SUMMARY

Due to recent advances in structural analysis and CAD software, Bridge Information Modeling (BrIM) has become a popular tool for structural engineers to link structural analysis and CAD production. Integrating analysis and CAD production through BrIM allows the engineer to streamline their workflow to increase productivity and quality of the final product for the client. BrIM techniques and 3D Integrated Modeling are also beneficial to the construction engineer, especially in the case of complex bridge projects, providing a modern tool for clear communication to the Contractor regarding issues that may arise during construction and for clarity on the installation of temporary works items. A brief introduction to the FINLEY Engineering Group's workflow for BrIM projects, as well as its implementation on the I-59/20 McFarland Boulevard Bridge Replacement project in Tuscaloosa, Alabama, is presented.

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1.0 The I-59/20 McFarland Bridge Replacement

The new I-59/20 Bridge over McFarland Boulevard in Tuscaloosa, Alabama, is composed of two trapezoidal-box steel suspension arches supporting seven steel box girders with a cast in place concrete deck spanning 250 feet. A grillage of 13 partial depth plate girder transverse floor beams, spanning the full 129 foot 5 inch transverse width of the deck, distributes the superstructure loads to the arch rib through steel structural strand hanger cables located at the ends of each floor beam. This new steel arch bridge, owned by ALDOT, will replace the existing twin four span mildly reinforced concrete bridges.

The construction of the bridge, by Brasfield & Gorrie, is planned in three phases, enabling traffic to remain open along I-20/59 during erection. Prior to the first phase of construction and transferring load to the steel arches, a semi-permanent intermediate bent was constructed in the median of McFarland Boulevard to support the bridge superstructure in a temporary two span condition. The middle third of the new bridge deck was constructed during the first phase by setting the middle three steel box girders over the intermediate temporary bent and casting the concrete deck between the existing twin concrete bridges. Traffic was then shifted to the newly completed phase as the Northbound existing I-20/59 bridge was demolished. In the second phase of construction, the next two steel box girders were erected and the deck cast where the previous existing bridge stood. The South steel arch was then erected. This process will be repeated in the third phase of construction to demolish the existing Southbound bridge, and erect the final two steel box girders and the North steel arch. After completion of the three phases, the hanger cables will be installed and hydraulic jacks at the temporary intermediate bent will be used to incrementally lower the bridge superstructure and transfer load to the arches through the hanger cables.

For this project, FINLEY is providing construction engineering services including construction analysis, temporary works design, erection engineering, demolition engineering, and construction manual production. By utilizing BrIM and 3D Integrated Modeling techniques, FINLEY streamlined the construction analysis of this complex bridge structure and effectively communicated with the contractor during the construction process. In addition, FINLEY was also able to evaluate the fabricated arch geometry prior to erection using the 3D steel arch models from the BrIM workflow.

2.0 The FINLEY BrIM Workflow

Traditional construction engineering project workflows begin with the creation of the analysis model for the bridge, followed by verification of the bridge structure, design of temporary works, and concluding with drawing production. This uncoupled workflow requires repetitive and cumbersome inputs by the bridge engineer to define the bridge geometry, section properties, and temporary works details into multiple structure analyses and CAD softwares to complete the project deliverables. The repetitive nature and unintegrated structure of this workflow often results in a loss of quality and inaccuracies in the design and drawing production, which can create cost increases and schedule over runs for the client. FINLEY has developed a BrIM workflow which utilizes SOFiSTiK, a structural analysis software, and the Autodesk suite of CAD software to integrate the analysis and CAD production processes, effectively mitigating the difficulties of an unstructured workflow. The three phases of the FINLEY BrIM workflow are to Input the Global CAD Geometry, Development of the Analysis, Construction and Temporary Works Models, and the Generation of the Integrated 3D Bridge Models. These three phases effectively utilize the analysis and CAD software to provide engineers with the ability to collaborate and integrate bridge information throughout the workflow process. Through implementation of the

BrIM workflow, FINLEY has been able to increase quality, production of deliverables, and provide the ability to store bridge data within a single location.

3.0 FINLEY BrIM Workflow Implementation for the McFarland Project

In the first phase of the FINLEY BrIM workflow, the project team had to clearly define the construction stage from which the global CAD geometry would be created. Since the global bridge and temporary works geometry are coupled through the integrated workflow, the engineer must decide whether the geometry of the bridge should be in the final state at the end of construction or cambered for a particular construction stage. This distinction is important since the temporary works drawings are developed directly from the analysis model geometry. If using the cambered geometry in the analysis models, adjustments are required to the temporary works geometry during drawing production. However, if the bridge is modeled in its final state at the end of construction, careful consideration has to be made when finalizing the temporary works elevations to ensure the proper cambered elevation of the supported structure is taken into account.

For the McFarland project, the final bridge geometry at the end of construction was used to develop the global CAD geometry (Figure 1). This allowed the team to develop the analysis model in tandem with the girder and arch shop drawing creation by the steel detailer, enabling the construction engineer to verify the girder and arch camber prior to the shop drawings being finalized. Through this process, the girder camber was modified from the contract plans to account for the twist of the exterior girders, which occurs when the superstructure is transferred to the arches in the girder fabrication. Using the bridge geometry at the end of construction also simplified the 3D modeling requirements, as each girder had significantly different cambers ranging from six to twelve inches due to the bridge superstructure girders acting as a grillage between the abutments and arches. Additionally, direct modeling of the contract plan geometry allowed the engineer to quickly model the complex structure within the CAD environment. This included the full 3D geometry for the 3D analysis by modeling the steel box girders with shell elements for the bottom flange and webs, and beam elements for the top flanges. Beam elements were used to model the girder top flange lateral bracing and internal cross frames, as well as the steel arches and temporary works elements. Shell elements were used to model the concrete deck.

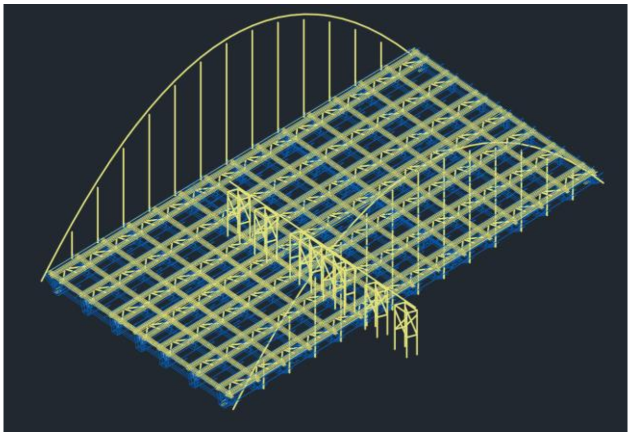

Figure 1: Global CAD Geometry

For phase 2 of the FINLEY BrIM workflow, the analysis model was created by importing the global CAD geometry into the structural analysis software SOFiSTiK through SOFiPLUS, a pre-processing software from SODiSTiK based within AutoCAD (Figure 2). After completion of the bridge geometry elements, construction staged analysis was completed in SOFiSTiK per the contract plan sequence with additional modifications required per the contractor’s means and methods in order to verify the structure’s capacity at various stages of construction. This included an application of live load effects in accordance with AASHTO design specifications in order to verify the steel box girders in the temporary two span condition and to determine the proper design forces for the semi-permanent interior bent.

Additionally for phase 2 of the FINLEY BrIM workflow, the same global CAD geometry used to develop the analysis model was then used to further develop the temporary works structures and bridge structure in a 3D environment (Figure 3). Cross sections of the arches and temporary works members were lofted over the member center lines taken from the global CAD geometry. Shell elements were thickened to create the final box girder shape. Additional details not included in the global CAD geometry or required for the analysis, such as bearings, abutments, hanger plates, connection plates, etc., were directly modeled in the 3D environment to be included in the final Integrated 3D Bridge Model. Clash detection and clearances between the structural components can be visually inspected directly prior to components being fabricated or erected, since all of the bridge and temporary works elements are modeled in a 3D environment.

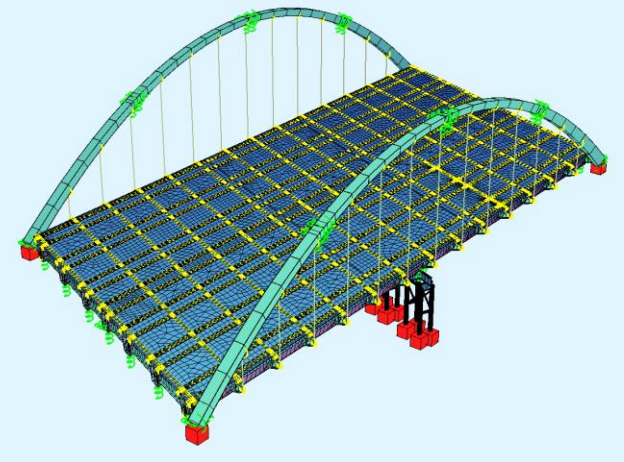

Figure 2: Resulting SOFiSTiK Analysis Model from the Global CAD Geometry

Figure 3: 3D CAD Model of the Temporary Intermediate Bent

Temporary works drawings were then created from the 3D model, allowing for isometric views, as well as traditional plan, elevation, and section views to be included in the drawing production (Figure 4). All views were auto-generated from the 3D model, eliminating the need to generate line by line drawings (Figure 5). The enhanced detail of the drawings allowed the engineer to clearly demonstrate the intent of the temporary works design to the Contractor, the fabrication shop, and the iron worker in the field to fabricate and erect the temporary bent without significant delays.

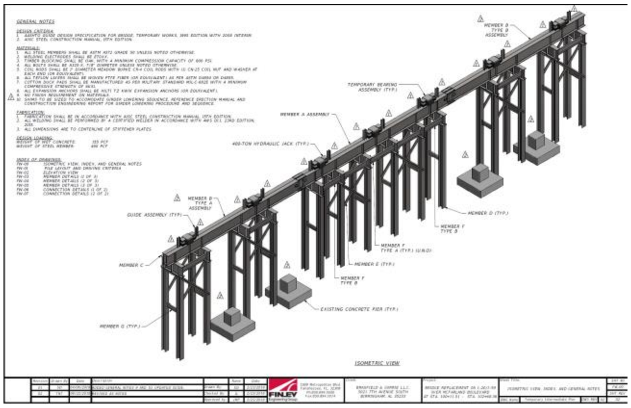

Figure 4: Resulting Drawing Auto-Generated from the 3D CAD Model

Figure 5: Installed Temporary Bent

For phase 3 of the FINLEY BrIM workflow, the final bridge and temporary works 3D models were assembled into the Integrated 3D Bridge Model (Figure 6). This final 3D bridge geometry was used to create isometric and plan views of the construction sequence for the construction manual. Crane operations were also included within the plan views to verify crane placements and boom obstructions for erecting the structural steel. For example, when erecting the structural steel for phase one, the girders were brought to site by truck and positioned on the existing McFarland bridge. A 550 ton crane positioned on McFarland Boulevard reached over the existing bridge to pick the girders and set them on the temporary bent. With the 3D model, the crane position was verified so that the boom would not interfere with the existing bridge railing (Figure 7).

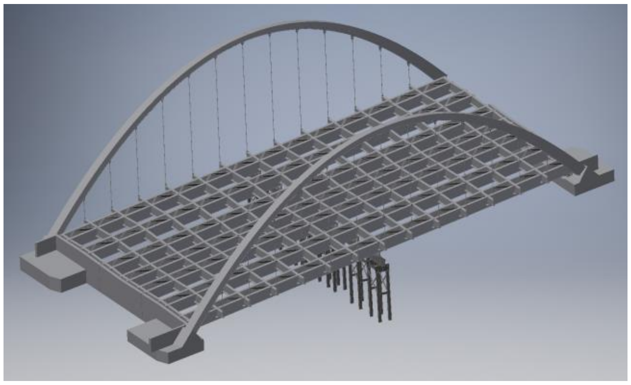

Figure 6: Integrated 3D Bridge Model (Deck Not Shown for Clarity)

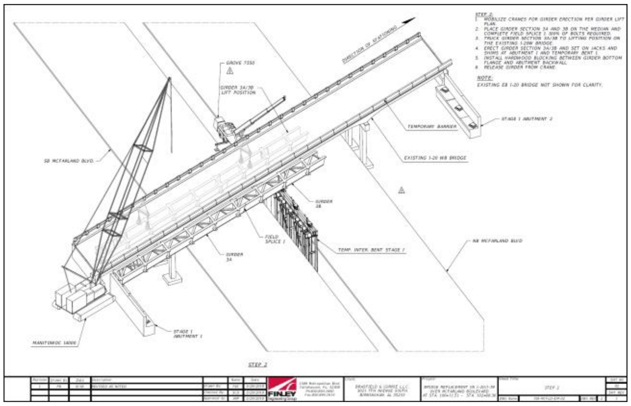

Figure 7: Typical Auto-Generated Erection Sequence Drawing with Crane Placments

4.0 Steel Arch Erection Modified for a Single Weekend Closure

The original arch erection plan called for the four arch field sections to be erected on two 60 foot temporary towers at field splices 1 and 3, and one central 80 foot temporary tower at field splice 2 in the McFarland Boulevard median. However, in order to meet the contractor's means and methods, the contract plan arch erection sequence was modified to complete the arch erection within a single weekend. This minimized the closures of McFarland Boulevard under the arch and eliminated the temporary towers required for the erection, a significant gain in time and cost savings for the Contractor. Prior to erection of the arch in its final location, the first and third welded splices of the four-segment steel arch were performed on the ground with the arch separated in two halves on either side of McFarland Boulevard. The second welded splice was later performed in the air between the two halves once both sections were lifted in place. Both arch halves were perpendicular to the constructed bridge steel girders and were placed on dunnage on their sides to allow for improved access for the welders and UT inspections. A 550-ton crane placed on McFarland Boulevard was used to rotate one of the arch halves from its side to a vertical position once welding was complete (Figure 8). The arch half was then rotated vertically by adjusting the sling lengths above and below the fixed 70 foot long spreader bar until the tip of the arch was in its proper elevation above the bridge deck (Figure 9). Additionally, the angle of the arch baseplate was measured to match the angle of the thrust block. If a discrepancy was seen, the arch position was adjusted by modifying the sling lengths in the rigging. The arch half was swung into its final position and held parallel to the bridge deck by the 550-ton crane (Figure 10). This rotation procedure was repeated with a second 550-ton crane for the second arch half. A strong back, comprised of steel wide flange members, was installed at the arch crown to secure the arch halves together, to ensure continuous arch behavior, and to lock in the arch geometry to allow for the second and final splice to be field welded (Figure 11 and 12). Due to the time constraints for completing the modified arch erection, the strongback was designed to resist the full dead load, uniform temperature, thermal gradient, and inactive construction wind loads of the continuous arch to ensure arch stability and self-supporting behavior without the final welded field splice being completed or continuous crane support.

Maintaining a level spreader bar and the CG of the load under the crane boom tip was essential to ensure arch stability throughout all stages of the rotation procedure. This condition requires modifying the sling lengths while the rigging is under load. The variation in length of the upper sling ranges from approximately 9 inches to 5 feet, the lower sling from the spreader bar to the low side of the arch, closest to the base plate, lengthens by approximately 18 feet during the rotation procedure, and the lower sling from the spreader to the arch closest to the crown shortens by approximately 14 feet. 50-tonne chain pneumatic air hoists in series with fixed slings were chosen for this particular rigging configuration as the air hoists could easily accommodate the varying sling lengths within the limited time available for the arch erection (Figure 9). Two-way slings were also utilized below the spreader bar to the arch to provide rotational stability of the arch and allow for the arch to be manipulated in the air when aligning the bolts at the thrust block. Clamp beams were used to attach the rigging lines to the steel arch halves. These clamp beams were located along the length of the arch in order to maintain vertical camber requirements with respect to the contract plan sequence to within acceptable tolerances, while also limiting rotation of the arch ends to allow for proper alignment with the second arch half.

Figure 8: Rotating Arch Section 3 and 4 from Its Side to a Vertical Position

Figure 9: Raising the Arch Tip of Sections 3 and 4 to the Required Elevation by Modifying Sling Lengths with Air Hoists

Figure 10: Swing Arch Sections 1 and 2 Into Position

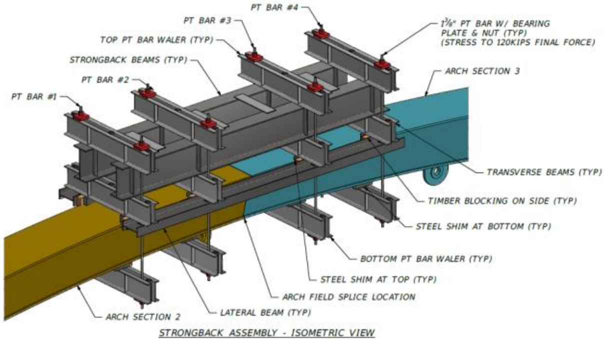

Figure 11: Auto-Generated Strong Back Drawing from the Integrated 3D Model

Figure 12: Strong Back in Position as Field Welding Begins

5.0 Evaluation of the Fabricated Arch Geometry Using Lidar

Prior to performing the first and third field welds on the ground to create the two arch halves, the fabricated arch geometry was evaluated by completing a Lidar scan of the preassembled arches. The full Lidar 3D model was imported directly into the Integrated 3D Bridge model to compare the fabricated arch geometry to the contract plan requirements (Figure 13). This allowed for the fabricated arch geometry to be easily compared to the plan dimensions as all the bridge components were located in one model space.

For typical bridge projects, the geometry of the fabricated steel section is essentially unknown until the steel is erected. This can cause delays in the field during erection due to unforeseen complications regarding steel fit up during erection. By coupling the 3D Integrated Bridge Model with the arch Lidar scan, all project stakeholders can evaluate the bridge geometry prior to erection. This allows for the Contractor and Erection Engineer to plan ahead for any previously unknown complications, as the fabricated geometry can easily be manipulated in a 3D environment per the chosen erection scheme. Additionally, the Lidar geometry provides a more accurate representation of the fabricated shape over traditional survey methods by eliminating any surveyor errors, and by completing a highly realistic and accurate reproduction of the field geometry in a matter of hours. This is especially beneficial for complex structures, such as the steel trapezoidal arch, that are difficult to survey by the nature of their shape. The evaluation of the as-built geometry can be enhanced by also including the as-built substructure in the Lidar scans so that a true as-built geometry of the entire project can be evaluated in a 3D environment.

Figure 13: Lidar Arch Scans Placed in the Integrated 3D Model to Evaluate the Fabricated Shape

6.0 Conclusions

FINLEY's implementation of the BrIM workflow for the construction engineering of the McFarland Boulevard Bridge Replacement project allowed for the project team to develop a complex steel bridge structure with relative ease in an integrated 3D CAD environment. This allowed for the project team to advance modeling of the structure in collaboration with the shop drawing production to verify and incorporate any proposed modifications to the girder camber by the contractor. The 3D Integrated Bridge Model has allowed for the construction engineer to clearly communicate the construction sequence, as well as temporary works designs, through concise and accurate isometric representations to supplement traditional plan, elevation, and section drawings. Further implementation of BrIM techniques through the utilization of Lidar scans of the fabricated arches was beneficial for the contractor to plan ahead for unforeseen complications in the arch erection. This allowed for a reduction of schedule impacts and costs for the contractor to streamline the arch erection sequence.