PROJECT

When Engineering Meets Architecture: The Story of the Bend Bridge

by Mario J. Quagliata and Matthew C. Wagner, Colliers Engineering & Design

Metroparks Toledo is reshaping the Toledo, Ohio, riverfront with an exciting vision to develop 300 acres of vibrant green space. As part of its dedication to fostering community connections, Metroparks Toledo is committed to creating dynamic public spaces where visitors can engage with nature and each other. The Glass City Riverwalk will feature more than 5 miles of new mixed-use trails and paths to link communities on both sides of the Maumee River. The $57 million project also includes a wetland walks, a refurbished lighthouse, docks, and natural playgrounds, among other amenities. A standout feature is the new Bend Bridge. This architectural marvel provides pedestrian access from the Glass City Riverwalk to the Martin Luther King Jr. Bridge (MLK Bridge), which crosses the Maumee River and connects to parkland on the east side of the river.

View of the Bend Bridge looking toward the connection at the Martin Luther King Jr.(MLK) Bridge. Photo: Metroparks Toledo.

Superstructure

The project team—consisting of the owner, engineer, architect, and contractor—selected cast-in-place reinforced concrete for its flexibility in shaping complex geometry. The bridge features back-to-back horizontal curves: a tight, 36-ft radius curve followed by a more gradual 290-ft radius curve leading to the MLK Bridge. This distinctive alignment inspired the bridge's nickname, the Bend Bridge.

The structure is 303-ft-long and consists of seven continuous spans, varying from 41 to 55 ft, with one 6-ft cantilever span that abuts the MLK Bridge. The deck provides a 15 ft 9 in. clear width for pedestrians and bicycle users and provides access from the riverfront parkland to the MLK Bridge. The slab superstructure of the Bend Bridge has a curved bottom surface with thickness ranging from 12 in. on the outside to 27 in. at the center. Glass seeding was used on the top surface to enhance aesthetics and recall Toledo's history as the Glass City. To create the glass-seeding finish, the contractor broadcast a mix of tumbled glass (blue, white, and gray colors) on the fresh concrete surface, just after it was finished. The next day, the

profile

BEND BRIDGE, TOLEDO, OHIO

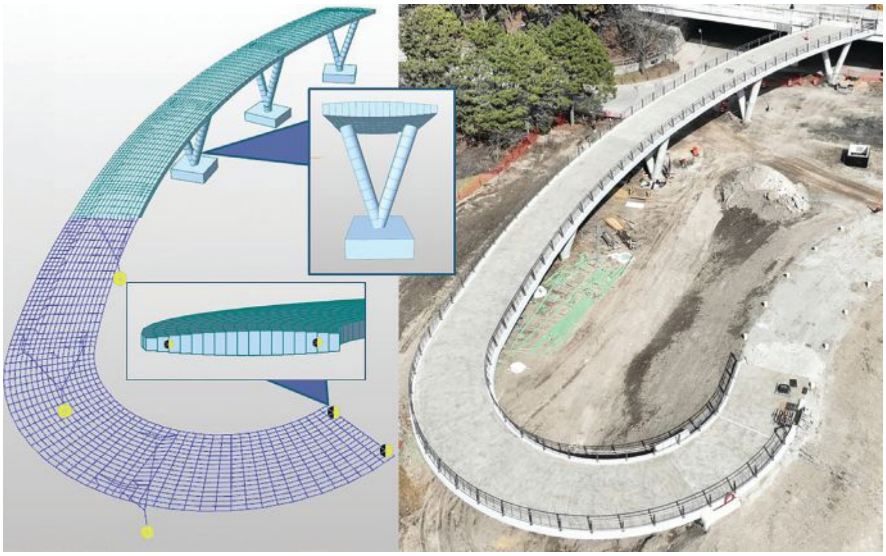
BRIDGE DESIGN ENGINEER: Colliers Engineering & Design, Toledo, Ohio

Other Consultants: Architect: WXY, New York, N.Y.

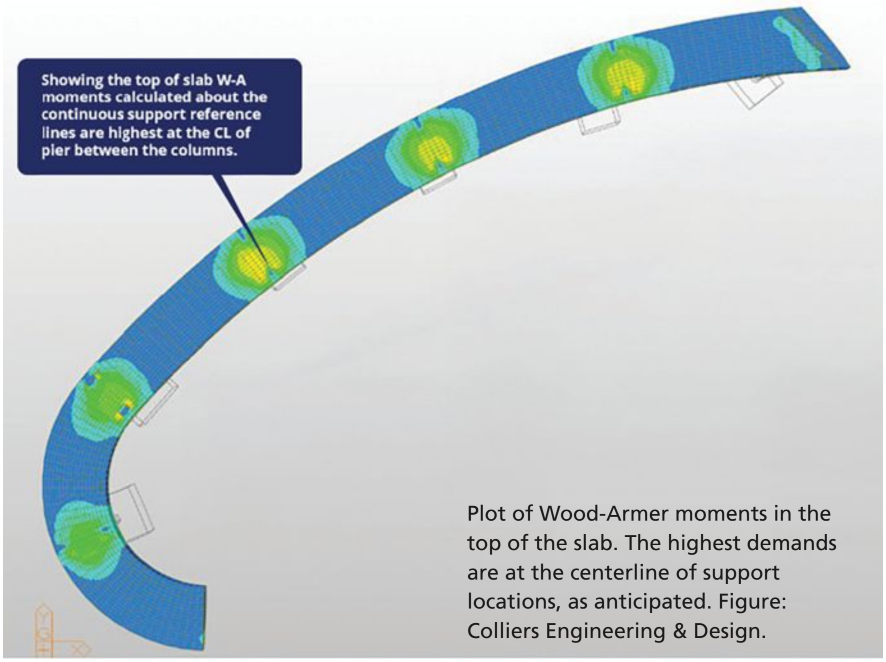
PRIME CONTRACTOR: Kokosing Construction, Westerville, Ohio

CONCRETE SUPPLIER: Kuhlman Corporation, Toledo, Ohio

OTHER MATERIAL SUPPLIERS: Custom metal formwork (piers): CFC Manufacturing, Carbondale, Pa.; custom foam inserts (piers): Global Foams, Dayton, Ohio; reinforcing bar supplier: CMC Rebar, Muncie, Ind.; reinforcing bar installer: Flatrock Bridge Group, Maumee, Ohio; stainless steel railing: Forms+Surfaces, Pittsburgh, Pa.



Three-dimensional finite element mesh (left); an aerial view of the actual bridge layout (right); and model renderings of the V-shaped piers and curved slab superstructure (inset). Figures and Photo: Metroparks Toledo.



Plot of Wood-Armer moments in the top of the slab. The highest demands are at the centerline of support locations, as anticipated. Figure: Colliers Engineering & Design.

contractor power-washed the surface to remove the paste from the glass. This treatment, which was used on the deck surface and on all the path sidewalks in the park, gives the concrete a pop of color and an interesting look. Stainless steel hand railings are mounted on 1 ft wide × 6 in. tall concrete curbs that also house conduit for embedded LED lighting. A 1-in.-wide open joint with a sliding cover plate at the MLK Bridge interface allows independent movement between the two structures while providing compliance with the Americans with Disabilities Act accessibility requirements.

Substructures

The project team collaboratively designed the piers to serve both structural and architectural roles. Cylindrical or flared columns were initially considered for simplicity, but the project architect proposed a V-shaped pier design with varying oval cross sections to provide a more distinctive sculptural form. The legs range in transverse width from 3 ft at the base to about 4 ft at the top and are 2½ ft wide in the longitudinal direction.

The contractor developed custom forms with foam inserts at the base to create a smooth saddle (or fillet) where the legs converge. The bridge design team ran preliminary analyses, which confirmed that the elements would withstand the anticipated applied loads and internal forces. The piers are fully integral with the superstructure. Advanced analysis and design were required to produce the visually seamless form. The piers vary between 10 and 22 ft in height, with grouped pier heights that allowed the reuse of formwork. Each pier is supported by vertical H-piles driven to bedrock. Compared with battered piles, vertical H-piles provide more lateral flexibility in the foundations, so the superstructure can more easily accommodate creep and shrinkage over the long term.

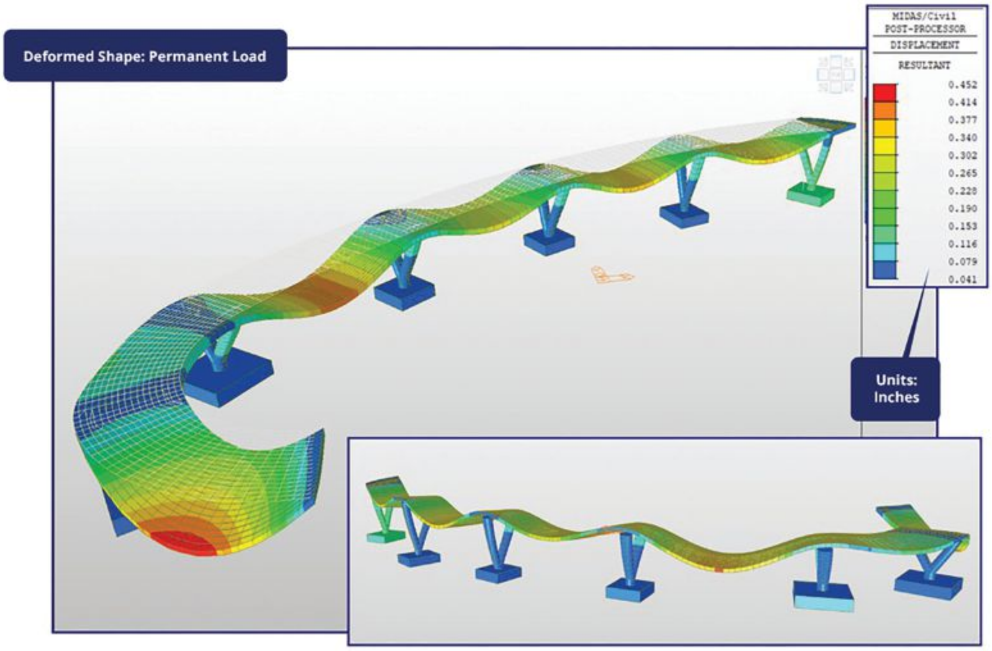
The abutment at the low end of the bridge features a more standard semi-integral design. The abutment is supported on vertical and battered piles, with elastomeric bearing pads supporting and accommodating the movement of the superstructure. The elastomeric bearings sit on top of the abutment beam seat. They are vulcanized to galvanized steel sole plates that are embedded into the superstructure concrete with shear studs. An approach slab and sleeper slab were also used to provide a smooth transition onto the bridge.

METROPARKS TOLEDO, OWNER

BRIDGE DESCRIPTION: 303-ft-long, continuous cast-in-place concrete slab structure supported on six integral V-shaped concrete piers. The bridge has seven 41- to 55-ft-long spans plus a 6-ft cantilever span. The deck provides a 15 ft 9 in. clear width for pedestrians and bicycle users.

STRUCTURAL COMPONENTS: Cast-in-place concrete slab superstructure with a curved bottom surface that varies in thickness from 12 to 27 in. The V-shaped piers vary in height from 13 to 23 ft with oval-shaped legs that vary in width from 3 ft at the bottom to about 4 ft at the top. Each pier is supported on nine vertical HP12x53 H-piles that are driven to bedrock.

BRIDGE CONSTRUCTION COST: $2.6 million total ($475/ft^2)



Plot of exaggerated deflections due to application of permanent loads. Both the pier column and slab formwork elevations were intentionally overbuilt to allow for short- and long-term displacements. Figure: Colliers Engineering & Design.

Funding

The project was primarily funded by a federal Better Utilizing Investments to Leverage Development (BUILD) grant, which was secured for the bridge and the broader riverfront parkland development. The grant was tied to an aggressive timeline to start construction, which added pressure to complete the design phase of the project efficiently. Design was completed in 8 months between January and August 2022.

Analysis and Design

To meet the project's structural and aesthetic goals, the bridge design team developed a detailed finite element analysis (FEA) model to evaluate structural demands and deformations. This approach enabled accurate simulation of complex structural behaviors and facilitated precise reinforcement detailing and construction planning. The modeling began with creating a mesh in computer-aided design software, aligning nodes orthogonally to the bridge's curved centerline to match the direction of primary transverse reinforcement.

Quadrilateral elements were selected for their accuracy and computational efficiency. A critical parameter in model development is the element aspect ratio (AR), and while elements with an AR close to 1 yield high accuracy, they significantly increase computational runtime and complexity, resulting in unnecessary model troubleshooting challenges. The final FEA model consisted of 2506 nodes, 136 beam elements representing structural members such as columns and pile caps, and 2263 shell elements modeling the concrete slab. This complex geometry was managed through 28 analytical domains, each grouping elements by similar local bending axes. These domains were essential for efficiently applying Wood-Armer moment calculations, which were pivotal in the slab reinforcement design. (Those calculations are described in the next section of this article.)

An important and common question in finite element modeling is "How accurate is accurate enough?" For the Bend Bridge design, targeting an AR of less than 5 struck a practical balance between model accuracy and computational runtime.

Pile foundations and elastomeric bearings were represented through point springs and elastic links. Horizontal stiffness from foundations was captured using springs and was adjusted based on geotechnical data. Substructure components such as columns and pile caps were modeled explicitly as beam elements, whereas elastomeric bearings at abutments were modeled as equivalent springs derived from their physical properties. The deck slab was modeled using shell elements divided transversely into 1-ft-wide strips, which were each assigned an average thickness based on the slab's cross-sectional variation. This method provided an accurate representation of bending and torsional moments in the slab.

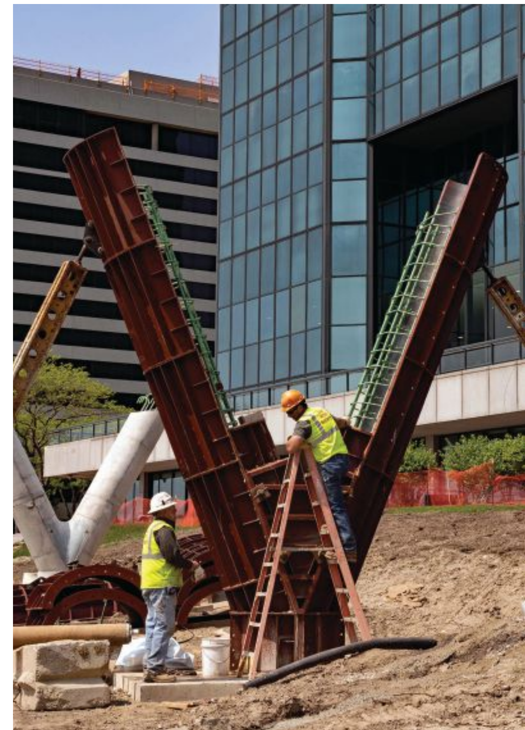
Wood-Armer Method

Given the Bend Bridge's unique curved geometry and V-shaped integral piers, the traditional strip method design approach for the slab would have been inadequate as it would result in underestimating the design stresses. The Wood-Armer method—developed for plate and shell elements—was adopted to accurately capture combined bending and torsional stresses, which are especially prominent near slab edges and support regions. Because traditional, slab strip methods primarily address direct bending moments M_x and M_y but often neglect twisting moments M_{xy}, which occur in plates, such methods may underestimate reinforcement requirements and compromise structural performance.

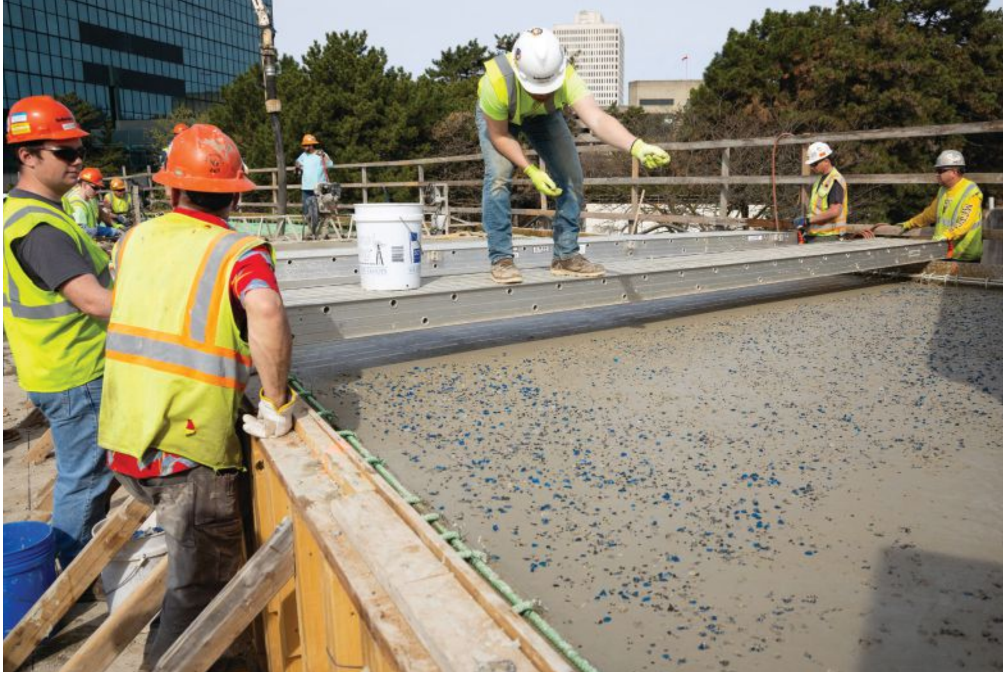
The Wood-Armer equations explicitly account for twisting moments, combining them with direct bending to calculate equivalent reinforcement moments in longitudinal and transverse directions. The Bend Bridge design leveraged analytical domains to ensure that alignment of the reinforcement accurately reflected principal-stress directions.

Results from the Wood-Armer analysis provided clearly enveloped demands

Elevation view showing custom forms used to construct the V-shaped piers. Photo: Kokosing Construction.



Elevation view of one of the finished V-shaped piers showing the architectural form, including the smooth fillet area between the column legs. Photo: Colliers Engineering & Design.



Workers perform the first step in creating a glass-seeding finish by applying a mix of tumbled glass (blue, white, and gray colors) on the fresh concrete surface, just after it was finished. The glass seeding enhances the bridge aesthetics and recalls Toledo's history as the Glass City. Photo: Colliers Engineering & Design.

and maximum stresses. Critical areas requiring additional reinforcement were identified by the design team and addressed in the plan details. Slab-to-pier interfaces, which experience significant stress concentrations, received special attention. Elastic links were strategically used to represent the load transfer between the columns and slab nodes without artificially increasing stiffness, thus avoiding locked-in stresses, modeling singularities, or other common inaccuracies that may occur when simplified boundary conditions are used.

Consideration of Time-Dependent Deformations

The analysis also explicitly considered time-dependent deformations—primarily concrete creep and shrinkage—to evaluate long-term structural integrity and inform decisions about reinforcement detailing. Concrete creep, defined as the increase in strain under sustained loading, gradually alters internal stress distributions. Shrinkage results from moisture loss, inducing internal tensile stresses in restrained elements. These phenomena significantly influence long, multispan reinforced concrete structures such as the Bend Bridge, and they could potentially cause distress, increased deflections, and compromised serviceability if ignored. The design team incorporated analyses of both creep and shrinkage, providing accurate predictions of their long-term impact on the structure.

The detailed evaluation of creep and shrinkage used equations from the American Association of State Highway and Transportation Officials' *AASHTO LRFD Bridge Design Specifications*[1] and time-step analysis considering the age of concrete for each component based on the anticipated construction schedule. This evaluation directly influenced key design decisions, including the following:

- Staged construction. The design accounted for phased construction, recognizing time-dependent changes in geometry and stresses with specific temporary shoring requirements incorporated into the contract documents to achieve the desired profile grade.
- Formwork and shoring. The V-shaped columns, which are inherently flexible, were intentionally built slightly higher than final profile elevations to counter anticipated creep- and shrinkage-induced displacements. Although this approach initially seemed counterintuitive, it ensured correct final elevations and improved ride quality.

The analysis results directly informed predictions about both short- and long-term displacements from sustained loads during and after construction. Coordination of these details, including intentional overbuilding of pier column and slab formwork elevations, significantly mitigated field issues, ensuring precise shoring construction, accurate reinforcement placement, and adherence to design tolerances. This approach ultimately will improve ride quality and structural performance throughout the bridge's service life.

Conclusion

The Glass City Riverwalk Bend Bridge exemplifies modern structural analysis and design practices, demonstrating how advanced analytical methods such as finite element modeling and Wood-Armer reinforcement design can effectively facilitate the realization of complex architectural visions. By prioritizing meticulous modeling, precise detailing, and proactive consideration of long-term behavior of the structural material, the team delivered a structure that is functional and durable, and will serve as a striking landmark bridge within the Toledo Metroparks System.

Reference

1. American Association of State Highway and Transportation Officials (AASHTO). 2020. *AASHTO LRFD Bridge Design Specifications*. 9th ed. Washington, DC: AASHTO.

Mario J. Quagliata is regional discipline leader: bridges and structures, and Matthew C. Wagner is geographic discipline leader: bridges and structures for Colliers Engineering & Design in Lansing, Mich.