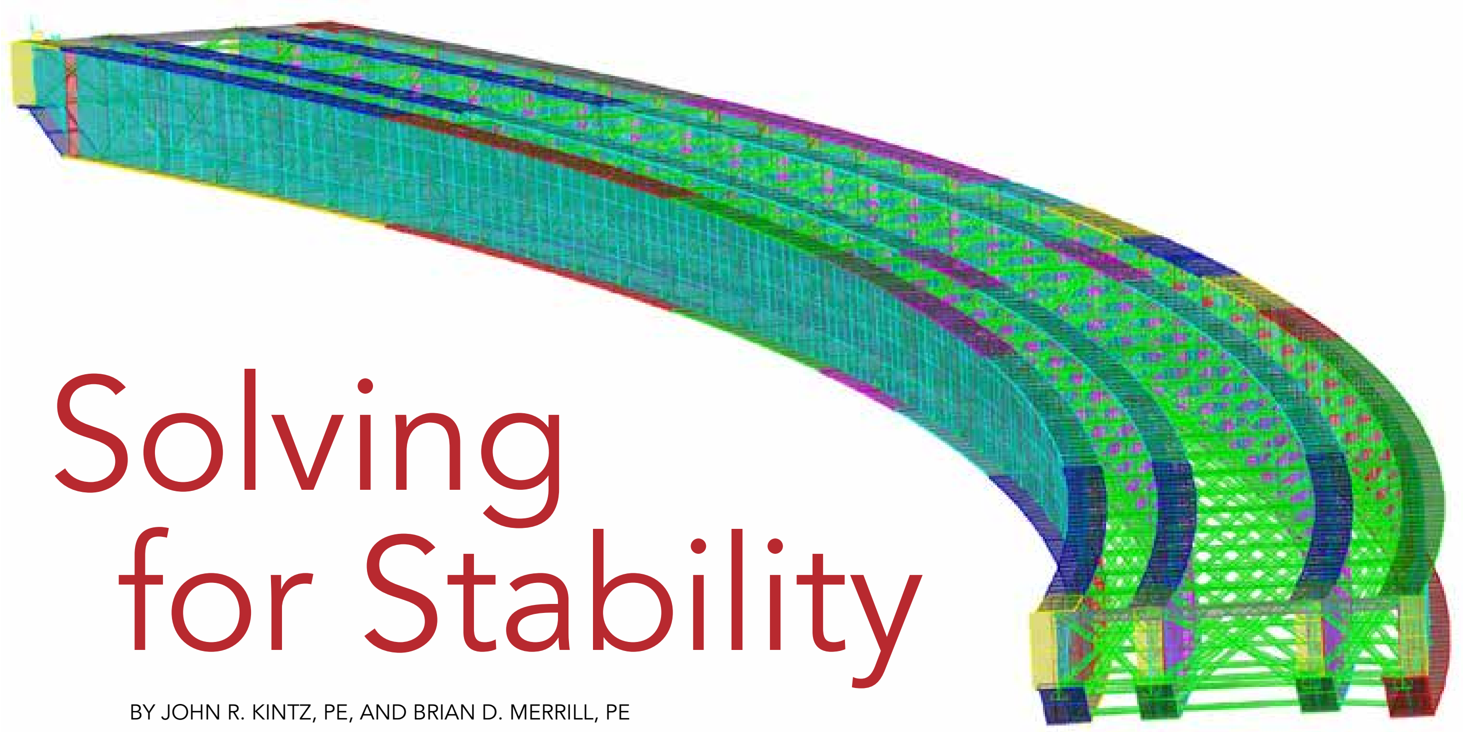
Recognizing and accommodating field constraints
in bridge design.



Solving for Stability

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MODERN CODES and more advanced analysis tools have helped designers confidently create longer, more slender, and more complex steel bridge structures.

When developing a signature bridge or a bridge located in a high-visibility area, this often means longer spans, unique geometries, and an increased consideration of aesthetics. These bridge designs are often analyzed in the completed condition using commercial finite element software, supplementing model results with design code provisions to verify the adequacy of the structure and its components. However, understanding the proper application of these resources and anticipating the construction methods employed is a crucial part often overlooked in design.

For steel bridges, particularly plate girder bridges, the most critical structural demands encountered during the design life often occur during erection and deck placement. During this time, the girders do not act compositely with the concrete deck and, depending on construction staging, may not have all bracing installed or full girder line continuity at a given time. The AASHTO *Bridge Design Specifications* and state DOT bridge design manuals dictate that designers select girder geometries to satisfy constructability criteria and run a deck placement analysis on the completed system. Except on exceedingly complex bridges, little consideration is given to erection staging, as this is typically the responsibility of the erector and erection engineer. Regardless, adhering strictly to the design criteria may not mitigate all constructability concerns, and designers must be mindful of site constraints that may require deviation from the assumptions made in their analysis. Conversely, common situations encountered by steel erectors may require analysis methods beyond simplified models. The following case study illustrates a scenario where existing site constraints created a condition different from that assumed in the design and led to significant challenges during construction.

Project Background

The example bridge is a horizontally curved, four-plate-girder direct connector with a roughly 1,600-ft radius of curvature. The steel unit is two-span continuous over radial supports, with centerline span lengths of 312 ft (Span 3) and 294 ft (Span 4) for a total length of 606 ft. The inner three girders along the curve have a constant web depth of 9 ft, 5 in., while the exterior girder has a web depth of 10 ft. The interior bent has a post-tensioned concrete bent cap on a radial alignment that is cast integrally with the plate girders, and the column is positioned between two existing bridges carrying mainline highway traffic in each direction below. The minimum design vertical under-clearance is 16 ft, 9 in., and the mainline bridges below are skewed 67° relative to the interior bent cap.

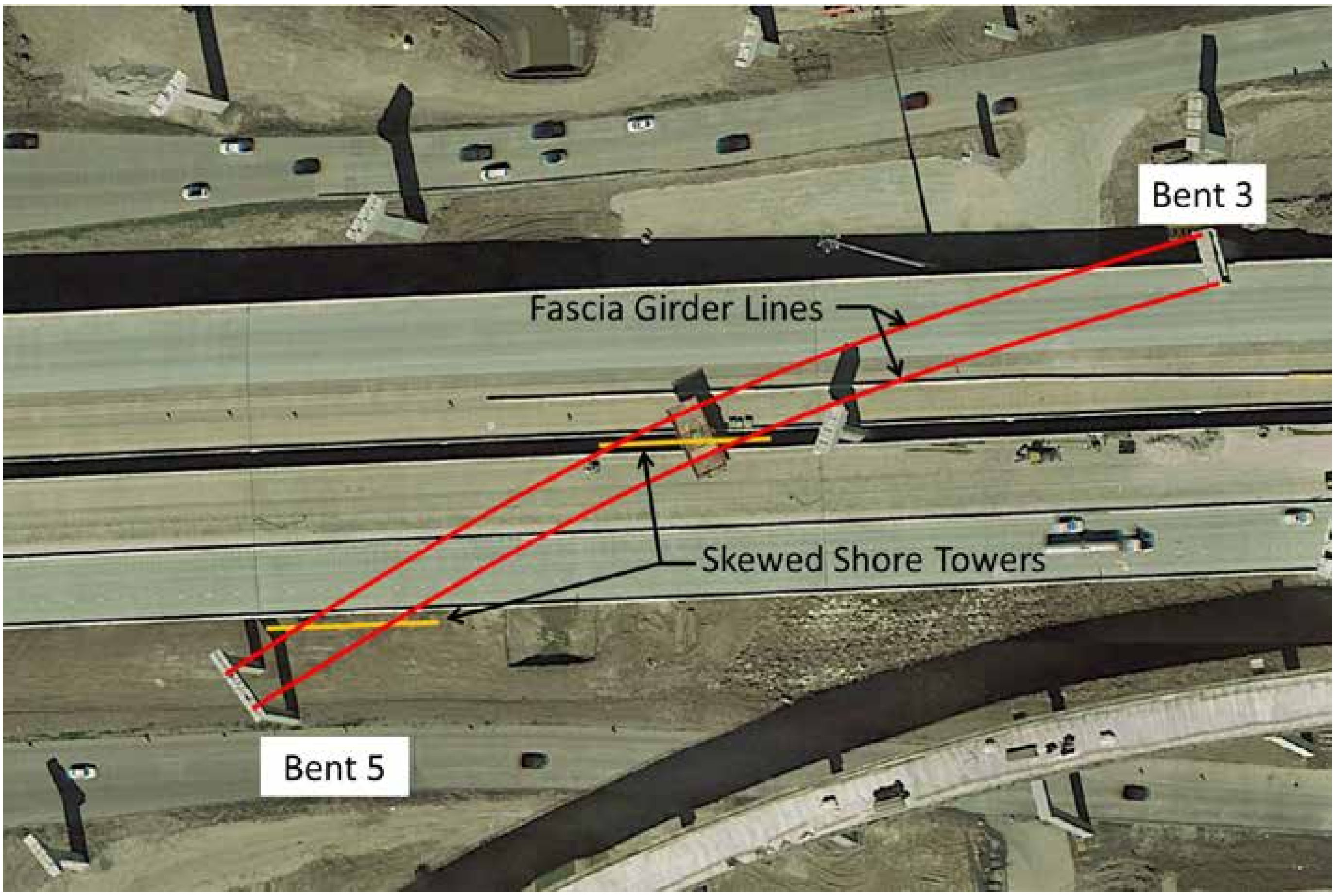
opposite page: A 3D model of the horizontally curved, four-plate-girder direct connector (with a roughly 1,600-ft radius of curvature).

below: Installing a plate girder. The inner three girders along the curve have a constant web depth of 9 ft, 5 in., while the exterior girder has a web depth of 10 ft.

Design vs. Field Conditions

Prior to construction, several key differences between the bridge configuration in the design and the temporary condition before casting the integral bent and bridge deck needed to be considered. The partially erected superstructure provided different bracing, girder line continuity, and global stability behavior than the fully erected system assumed in the design. Temporary shoring was needed for the girders at the interior bent location until the integral cap could be cast and post-tensioned. This shoring was installed at a heavy skew (67°) due to the underlying parallel highway bridges beneath either span. The temporary shoring supports also did not provide the same rotational restraint assumed from the integral bent in the design.

The differences between design and construction resulted in the construction sequence becoming the critical analysis stage for bridge behavior. Per NCHRP Report 725: *Guidelines for Analysis Methods and Construction Engineering of Curved and Skewed Steel Girder Bridges*, the bridge with the severe skew at the temporary interior support, in contrast to the assumed radial support in design, required a more advanced 3D analysis to reasonably predict behavior such as vertical displacements, cross-frame forces, flange lateral bending stresses, and girder layover at the bearings. Traditional analysis methods, such as 1D line, 2D grid, or other simplified analyses, were poor predictors of these items with greater than 30% mean error from actual behavior per the NCHRP report.



A plan schematic of the project, indicating the bridge's path as well as the skewed shoring towers.

Refining the Analysis

Structural engineer Wiss, Janney, Elstner Associates (WJE) developed a 3D finite element model using SAP2000 to analyze critical stages of the proposed construction sequence and examine the behavior of the partially and fully erected superstructure. Analyses showed that the girder deflections in the fully erected system exceeded those assumed in the design. As a result, the limited design underclearance to the highway below was a concern for the owner and engineer of record. Perhaps even more critical was that the model exhibited large vertical deflections (greater than 3 ft) and restraining forces at the end bent for the partially erected superstructure, with all four girders simply supported over the interior shore tower. In addition, cross frames and associated erection bolt connections were also overstressed in this configuration. These findings indicated a stability concern, and it was unlikely that the bridge could be erected in sequence from one end to the other.

In the end, an innovative approach was required to erect the bridge safely and keep girder deflections within acceptable tolerance while accommodating strict limits on lane closures and temporary supports. This involved the partial erection of the superstructure, constructing the integral cap before erecting the remaining girder segments.

The lesson is clear: Getting a good read on existing site conditions, even before a contractor has even bid on the project, can help engineers, contractors, and owners alike construct complex bridges safely and smoothly.

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