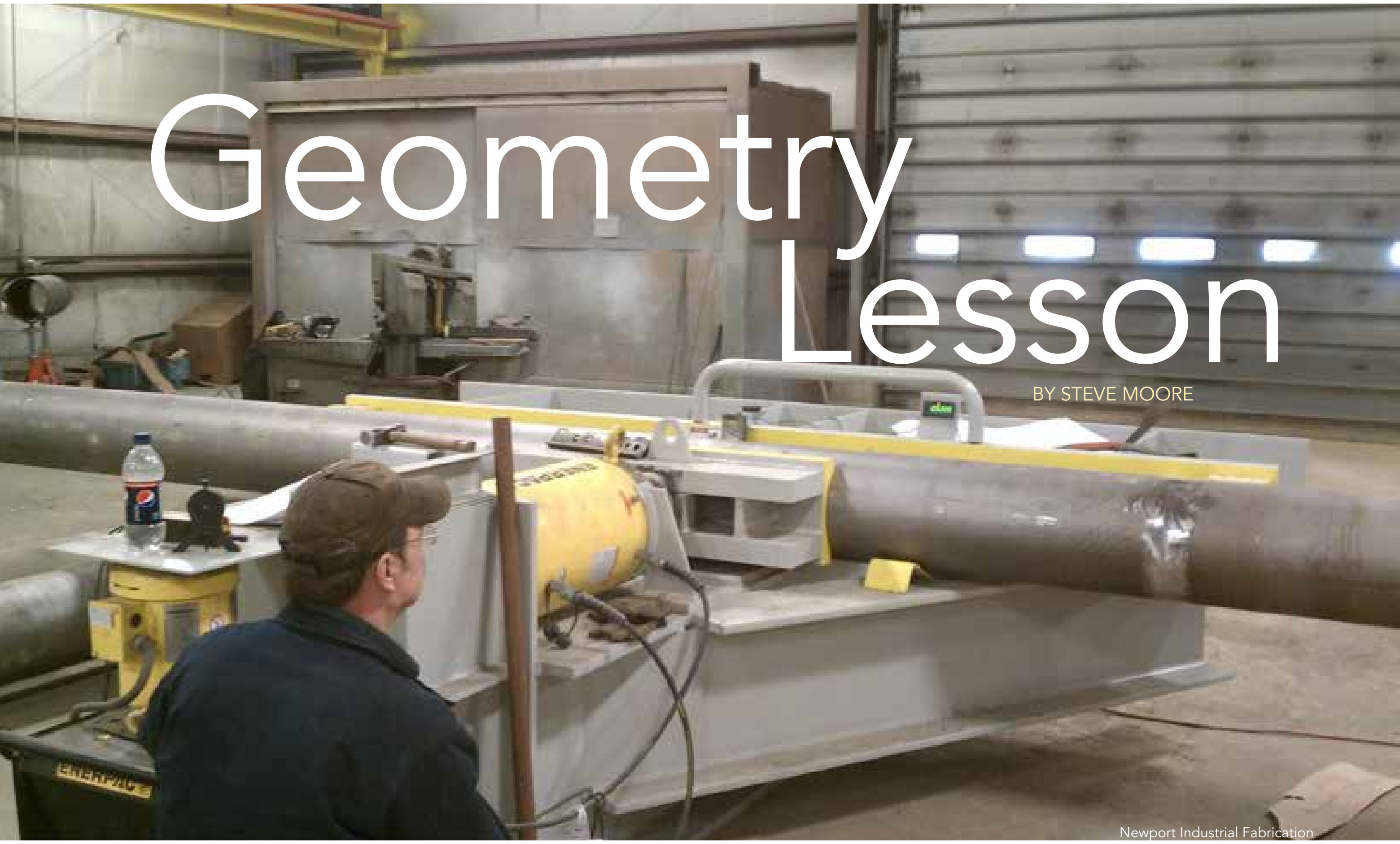
Complex geometry and an equally complex site drove the design of a new pedestrian bridge project in Boston.



Geometry Lesson

BY STEVE MOORE

Newport Industrial Fabrication

THE NORTH BANK BRIDGE takes quite the winding path.

Built to connect isolated sections of Boston's pedestrian park system, the bridge was faced with a number of geometric constraints that forced it to snake over, under and through a maze of existing facilities along the north bank of the Charles River, including a commuter rail yard, the Leonard P. Zakim Bunker Hill Memorial Bridge, a historic building, two highway ramps and a boat ramp.

The 10-ft-wide bridge, which spans nearly 700 ft and provides a bike and pedestrian connection between Cambridge and Charleston, Mass.—both of which are across the Charles from Boston—was conceived in conjunction with the massive Central Artery/Tunnel Project. Funded by the American Recovery and Reinvestment Act (ARRA) and administered by the Massachusetts Department of Transportation (MassDOT), it would be one of the most geometrically complex structures associated with that project. The resulting design consisted of pipe trusses whose deck chords would follow the general S-shaped centerline, while its outer chord undulated above and below the deck, creating a structure with the appearance of a bent strand of DNA. The general contractor, Barletta Heavy Division, chose Newport Industrial Fabrication as the fabricator and Saugus Construction as the erector, and the team retained Civil Geometrics to handle the project's challenging geometry.

Before fabrication could begin, the structure's exact geometry had to be defined mathematically. The basic shape had been provided by the structural designer (Ammann and Whitney) as a series of work point coordinates, but a number of details had to be refined in order to develop complete shop drawings. The team developed a CAD model that respected the design intent while considering issues related to materials use, ease of fabrication, welding codes and the erection process. When finished, this model would drive every aspect of fabrication and erection of the structure.

Bizarre Bends

One of the biggest challenges was determining how to bend the 12-in. hollow structural section (HSS) main chords that trace bizarre corkscrew-like curves in three dimensions. Using custom software provided by Civil Geometrics, these four 700-ft chords were parsed for manageable (10-ft to 40-ft) sections whose local curvature was virtually planar. This allowed these segments to be bent as flat (2D) curves and the desired 3D shape would be achieved by appropriate "timing" of these segments relative to each other. The steel bending was performed by Newport Industrial Fabrication, which actually designed and built its own bending machine. Further work by Civil Geometrics provided curve ordinates for each phase of the bending of the many chord segments. The remaining truss elements (12-in. HSS verticals and 6-in. diagonals) provided an additional challenge

Bending the 12-in. main chords.

requiring the computation of hundreds of parameters defining their geometry. Because of the non-planar nature of the trusses, as many as ten parameters were required to define the "fish-mouthing" of the most complex members, with no two ever being the same. Most challenging were the diagonal braces that overlapped both the main chords and the vertical members. Parameters included length, four intersection angles, three "timing angles" and two offsets relating the diagonals to the verticals. Performing the welding of these joints in a code-compliant manner, while maintaining the geometry, was a technical challenge that required both an in-depth analysis of dihedral angles on a one-off basis and Newport Industrial's highly skilled welders—as well as MHP Systems Engineering, Houston, who acted as the TYK weld consultant. All full-penetration welds were inspected with MT or UT.

Defining the mathematics of the trusses was only the first step in getting the structure's geometry to come together properly. In order to control and monitor this geometry, a method of precise survey control had to be established in the shop. For this purpose, Newport Industrial acquired a high-precision total station. This is a standard piece of survey equipment that combines the ability to measure angles and distances with an onboard computer and the ability to store large amounts of data. Working with Civil Geometrics, Newport established a network of 14 permanent survey targets around the work area. Repeated surveys established the relative positions of these targets to sub-millimeter accuracy, and they became the frame of reference used to lay out and monitor the fabrication process. Resection techniques then allowed the total station to be positioned anywhere on the shop floor and to control the structure's geometry to the high degree of accuracy required.

Pieced Together

For transportation and erection, the bridge was divided into nine separate assemblies, and the fabrication of each of these was performed in three stages. In the first stage, the "north" and "south" truss assemblies were positioned on pipe stands and oriented on the shop floor for convenient access and welding. This required that global coordinates defining the truss geometry undergo a "rigid body transformation" to the preferred shop position and orientation. As fabrication was done with the trusses in an entirely different orientation from what their final position would be, the geometry of each assembly, in the form of X/Y/Z coordinates, had to be manipulated to conform to the shop's frame of reference. Working with Newport's engineers, Civil Geometrics provided the transformed coordinates for each truss position on the shop floor. With this information in hand, the total station could be used to position every component of the trusses to a very high degree of precision and to monitor them as fabrication progressed.

In the second stage, the north and south trusses for each assembly were repositioned so as to relate properly to each other, and the HSS10×6 floor beams were added completing each of the nine assemblies. As in the first stage, a transformed set of coordinates, representing the proper shape of each assembly in this new position, had to be provided.

Steve Moore

The bridge being erected on the north bank of the Charles.

One of many diagonals displaying compound fish-mouthing.

Newport Industrial Fabrication

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The first stage of fabrication, with trusses positioned for ease of access and welding.

Thermal zinc coating being applied at Newport Industrial's coatings facility.

In the third and final fabrication stage, adjacent pairs of assemblies were positioned outside of the shop to ensure their proper relationships. Connections were fine-tuned in this stage and any minor surplus or deficit in length was noted so that adjustments could be made in subsequent assemblies. A final as-built survey of the base plates and critical nodes served to review the geometry achieved and to provide guidance for the erection process.

As with the fabrication of the superstructure, the construction of the abutments and piers that would carry the bridge also had to be controlled closely. As with the survey work in the shop, a frame of reference had to be established that had the geometric integrity demanded by such a project. Working with Civil Geometrics, Barletta's survey team recovered approximately ten existing survey monuments originally provided for the Central Artery/Tunnel project and incorporated these into a local survey network, along with 12 additional points added in stable and convenient locations. Processing the highly redundant survey data then produced a network that could be used to locate all substructure components of the project. Upon completion of this work, a careful as-built survey was performed and compared to the 3D model of the superstructure to ensure that there would be no surprises when it came time to erect the trusses.

Getting There

For trucking, each of the nine sub-assemblies was carefully cross-braced, then split in two lengthwise by cutting all of the HSS floor beams at their midpoints. A total of 18 permit loads delivered these pieces to the job site, where they were reassembled into the original sub-assemblies. To control the erection of certain components, Civil Geometrics performed reverse coordinate transformations of shop as-built geometry back to the project's global coordinate system. This allowed Barletta's surveyors to position those truss ends that were supported on falsework at mid-span locations.

Through careful planning and a lot of intricate engineering and survey work, the North Bank Bridge, which opened this past summer, came together virtually flawlessly and takes its place as a critical link in Boston's pedestrian park system. MSC

Owner
Massachusetts Department of Transportation

Structural Engineer
Ammann and Whitney, Boston

General Contractor
Barletta Heavy Division, Canton, Mass.

Survey/Geometric Design
Civil Geometrics, Bozeman, Mont.

Steel Team

Fabricator
Newport Industrial Fabrication, Newport, Maine (AISC Member/AISC Certified Fabricator/NSBA Member)

Erector
Saugus Construction, Georgetown, Mass. (AISC Member)

Pre-asssembly work in the fabrication shop yard.