Over and Above

Removing a steel column and replacing it with a one-of-a-kind steel arch created open space for newer, larger equipment.

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THE FABRICATION OF EVERY CHEMICAL VESSEL BEGINS WITH CUTTING PLATES, so a CNC plasma arc metal cutting machine is one of the most important pieces of equipment in Eastman Chemical Company's principal metal shop. In early 2005, the company's old CNC machine was worn and breaking down often, threatening to shut the Kingsport, Tenn. shop down. Eastman needed a new CNC machine, but the model they wanted to buy would not fit in the existing building without the removal of one of the building's main steel columns.

The column in question, a W21×111, supported three large bridge cranes and the building's high and low roof—a total design load of over 200,000 lb. To allow the lower segment of the column to be removed, Eastman engineers designed a tubular steel arch to carry the concentrated load.

Existing Structure

The 1940s-era shop is steel-framed with concrete roof slabs on high and low roof sections. The roof section in the center of the building, where the shop's larger cranes are operated, is 56' high. This section is flanked on both sides by 30' roof sections. In the 47'-wide center aisle, a 25-ton crane and 10-ton crane run on girders supported on the top of a series of W21×111 columns spaced 20' over the length of the building.

The shop is 156' wide and has been expanded over the years to its present 400' length. As the plant has grown, space has been exhausted—the building is boxed in and cannot increase in size.

The old CNC machine's position prevented the cranes from accessing the entire length of the burning bed, but the new machine would not fit in this location. A W21 column had to be removed and rotated to provide crane access.

Analysis and Design

Engineers determined an arch structure would allow for the removal of the column. It would provide strength and stiffness, as well as a "doorway" to open up the required floor area. The exact dimensions needed for the new plasma arc machine were obtained, and a scale drawing was made to determine the dimensions needed for the arch.

The arch was designed as a fabricated-in-place box section built of ASTM A36 steel plates welded together. The arch would span 40' and would receive a point load at its 18'-high crown. The crown would be 21" wide by 32" deep to carry heavy bending moments. The arch would have tapered legs, which would be 21" square at the bottom.

A STAAD model was prepared and loads were calculated so the arch would be strong and stiff enough to limit deflections. Preliminary plate thicknesses were determined by using the limiting width thickness ratios from AISC's *Specification for Structural Steel*

The lower portion of an existing column, shown in the photo on the left, was removed and replaced with an arched steel box member fabricated from ASTM A36 steel plate. The "flanges" of the box are ⅝" plate, while the "webs" are ½" plate.

Buildings for both flanges and webs of box sections. This yielded thicknesses of ½" for the webs and ⅝" for the flanges. A Visual Basic computer program was written to quickly calculate the section properties of the box sections, making it quicker and easier to find the properties of the tapered leg.

Hand drawings were imported into Bentley Systems' MicroStation. The top and bottom surfaces of the arch were placed on circular arcs of two different radii, which created the varying depth from the bottom of the legs to the crown for the arch's tapered legs.

Once the analysis was complete, engineers had to decide how the horizontal thrust loads of the arch would be carried. The arch's location in the shop made it impossible to dig into the floor deep enough to put in adequate concrete foundations to carry the thrust. The only alternative was to tie the legs together with a steel plate, embedded in the floor to prevent it from becoming a tripping hazard. A ¾"-thick tension plate was used, which was wide enough to fit between flanges of the W21 columns to allow for bevel welds. A slot was chipped in the floor to accept the plate.

A STAAD model of two of the building's bays was created and included the arch and all of the structural steel framing, roof steel, and crane girders. The loads from the cranes were placed on the girders according to the wheel spacing. Maximum roof dead and live loads were included, as well as wall loads. The analysis indicated that the maximum deflection would be approximately 0.26". Stresses were well within what was allowable. Reduction in member sizes was not considered because this deflection was considered to be the maximum.

At the crown of the arch, the top and bottom flange plates were extended into and between the flanges of the W21 column.

Construction

The top of the arch was laterally braced by a roof-framing truss a few feet above the crown. The arch legs abut the adjacent W21 columns approximately 3.5' above the floor to provide the space needed for the new machine. The lower portion of the columns had to be boxed in, and the arch section had to be carried to the other side of these members to prevent weak axis bending of the columns. New base plates were added under these extensions.

The floor was removed and the spread footings exposed to prepare for the foundation loads under the new base plates on the outside of the arch's legs. The footings rest on hard soil about 6' under the floor. A new pier was placed under each leg to carry the concentrated loads to the footings. The new base plates and boxed legs were built on the piers, with a gap under the base plates that was later grouted.

A slot was then chipped in the floor and the tension plate was welded. The curved web plates on one side of the arch were placed first. The plates were trimmed to fit exactly between the flanges of the columns and then welded. The bottom flange plates were then bent and welded in pieces, with full-penetration splicing as needed. After the web plates for the arch's other side were added, welders made interior welds from the inside of the incomplete arch before the top flange plates were placed. At the crown of the arch, the top and bottom flange plates were extended into and between the flanges of the W21 column. This created a joint similar to a dovetail, which made the splice especially strong. After the top plates were welded, the arch was finished.

Construction of the arch was completed in August 2005. The column was burned off and removed, transferring its load to the arch. A deflection of just over .25" was measured, which was within the range of what had been expected, but the crane load was not yet on the arch.

Load Testing

A procedure was developed to test the arch with the cranes fully loaded. The load of the 10-ton crane was moved over the arch, and 1⁄16" of additional deflection was measured. The fully loaded 25-ton crane was then moved over the arch, keeping the 10-ton crane as close as possible. No additional movement was detected. Next, the loaded 5-ton crane was moved over the arch and all three cranes were positioned adjacent to it, with the heaviest one positioned closest. Again, additional movement was not detected. This completed the test, proving the arch to be strong and robust.

The initial deflections were believed to have been caused by flexure and the closure of gaps and clearances, after which additional loads were being carried predominantly by axial stress. The inability to detect further movement from the crane loads may have been due to inaccuracies in measuring methods; however, footing and soil pressure calculations showed the movements were safe for the additional loads due to conservatism in the original design. MSC

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Engineering Software

STAAD Pro
MicroStation