Case Studies in Welding

Welding plays a crucial role in the success of these two well-known projects. Here's the inside story.

San Francisco-Oakland Bay Bridge

THE REPLACEMENT EAST SPAN OF THE SAN FRANCISCO-OAKLAND BAY BRIDGE NEEDED TO STAND UP TO AN 8.1-MAGNITUDE EARTHQUAKE. AISC-member Trans Bay Steel, Napa, Calif., was selected to fabricate one of the new seismic protection devices for the bridge: a 6.5-ft-diameter hinge system installed at the expansion joints of the bridge's concrete deck segments. Designed to accommodate expansion and contraction caused by temperature changes and motion, one end of the system is fixed, while the other end is clad with stainless steel to allow it to slide within the fixed portion.

Fabricating the A-709 HPS GR 70 steel plate—ranging from 65 to 100 mm thickness—into cylinders and cladding the sliding portion presented multiple challenges. The job specified very tight tolerances, and welding specifications had to meet AWS D1.5:1996 requirements for fracture-critical material.

"This was a completely new design, never built before," says Trans Bay President Bill Kavicky. "We were the first fabricator in the world to attempt forming and rolling this particular grade of material in these thicknesses."

The Fabrication Process

The plate was cut on an ESAB Avenger 2 cutting gantry with a rotating triple-torch oxyfuel bevel cutting head. The bevel head contours the cut to the exact shape needed for a good weld, eliminating some secondary operations and greatly reducing production time.

After the plate was cut, it was formed with Davi plate-forming rolls, specially purchased for this project, on what is believed to be the largest roll forming machine on the West Coast. Once the "can" was formed, the long seam was tack-welded and then moved to welding stations, also from ESAB, where automated subarc (SAW) welding completed the seam. The steel was pre-heated to 140 °C, the internal long seam was welded, and the can was moved to an outside station where the seam was back-gouged and ground smooth to ensure a quality full-penetration weld for the outer seam. The SAW welding procedure included approximately 30 passes for the inside weld and another 30 for the outside weld.

After the cylinders were welded, they were re-rolled to meet the 1 mm to 3 mm tolerance in roundness. Diaphragm plates were welded inside the sliding side to provide extra support for the stainless steel overlay and stiffening where the beam mounts to the concrete structure of the bridge. The fillet welds on these plates were also performed with the subarc process. The final specifications required 80 ksi yield strength, 90 ksi tensile strength, and minimum Charpy impact value of 30 ft-lb at -30 °C.

The cylinders required about 30 passes for the inside weld and about 30 passes for the outside weld.

The cylinders were then moved to a large Betts lathe to be squared off to ensure that they were perfectly perpendicular to the center axis. Each cylinder is 8 to 9 ft. long, and four to eight cylinders were welded together to form each side of the hinge system. The round seams were also welded with the subarc method.

Applying the Overlay

One of the bigger challenges of the project was the need to apply a stainless steel overlay to the sliding section in order to facilitate movement and prevent corrosion. Again, ESAB provided a solution by converting some of Trans Bay's subarc welding equipment for cladding. Instead of welding wire, the cladding head uses a strip electrode 1/16 in. thick and 1½ in wide. Trans Bay used an ESAB stainless steel strip band with a carbon component of 2%, and with 20% chromium and 23% nickel additives. This was partnered with an ESAB 10.05 flux designed to produce a self-releasing slag and optimum bead shape.

ESAB recommended adding a 309 stainless steel underlay that bonds directly to the underlying steel, and a layer of 316 stainless steel was then applied on top of this. The build-up of material is dependent on travel speed, and Trans Bay operated the system at 27 volts and 770-780 amps to create each layer at approximately 3.5 mm thickness. After the cladding, the cylinders were machined down to a total thickness of 5 mm of stainless steel and sanded to a final surface finish of 8 µm.

At the end of the fabrication process, all welds were examined by NDT methods, and were ultrasound- and X-ray-tested. The final weight of a complete hinge system ranged from 75 to 127 tons.

—Sue DiBianca, President, Windhaven Communications, West Falls, N.Y.

Grand Canyon Skywalk, Arizona

4,000 FT ABOVE THE COLORADO RIVER, THE NEW GRAND CANYON SKYWALK EXTENDS 65 FT FROM THE CLIFF EDGE OF THE GRAND CANYON AT THE WESTERN RIM. The glass floor and sidewalls of the horseshoe-shaped walkway ensure heart palpitations to anyone vaguely troubled by heights. A 15-second freefall to the canyon floor would span twice the height of the world's tallest skyscraper. A typical day here can see vertical winds of more than 90 miles per hour.

To secure the Skywalk, engineers cantilevered it to the cliff using 94 steel rods that bore 46 ft into the limestone. It is estimated to withstand 71 million lb of weight, roughly equal to 71 fully loaded Boeing 747s. However, operators have limited the maximum occupancy to 120 people.

Engineers for the steel structure and heavy plate shop needed to speed up productivity in their existing submerged arc setup to meet the project's tight timetable. A potential fabricator for the project, AISC-member Mark Steel Corporation, Salt Lake City, had been using a DC submerged arc set-up for jobs of this scope with typical results. But upon discovering the Power Wave AC/DC 1000 from The Lincoln Electric Company, the company learned that a tandem arc setup, one in AC and another in DC, could boost its welding productivity by more than one million pounds of steel for the Skywalk.

With just a few days notice, Mark Steel engineers flew to Lincoln's world headquarters in Cleveland to purchase and train on the new equipment. Training wrapped up in about a day, and the company was then equipped to win the job to fabricate the skywalk's frame and anchor system by demonstrating productivity advantages afforded them by their new technology.

Securing the Structure

The Skywalk's steel anchors were flux-core welded with 5/64 Outershield 70 and 1/16 Outershield 71M with 100% CO_2 shielding gas. The steel sections were 2 in. thick, 8 ft long, 2.5 ft wide, and 4.5 ft deep. Joined to form 46-ft anchors, they are now weighted in cement to secure the structure.

The horseshoe itself was formed from two box girders of A572 grade 50-carbon steel welded with Lincoln's Lincolnweld L-61 wire and 865 flux. The fabrication was performed in accordance with AWS D1.1. The girder sections are 2 in. thick, 6 ft long, and 2.5 ft wide. They were shipped in 40-ft sections and assembled on-site.


APCO Construction

While welding the box girders, productivity gains were captured mostly by the tandem submerged arcs. One AC arc and the other DC, operators used digital push-button controls on the Power Feed 10A to set waveform frequency, balance, and amplitude to obtain the optimal balance between penetration and deposition. Welding waveforms could be adjusted to any frequency between 10 and 100 Hertz with the turn of a knob. This allowed operators to pinpoint maximum productivity and quality for varying materials and jobs.

Embedded software allows opposing arcs to run in tandem without interfering with one another. This translated to a travel speed of 26 to 28 in. per minute. Deposition rates increased from about 28 lb per hour with the lone DC set up to about 55 lb per hour, using 3/16 wire on two arcs. This proved particularly helpful for some of the longer welds, which ran 38 to 40 consecutive ft. (Ultrasonic testing revealed that the project's weld reject rate was less than 2%.)

The shops' fabricators had typically beveled material of this size 30° on each edge to form a combined 60° bevel at the joint. Now with greater penetration abilities, the bevels have been reduced to 22.5° at each edge to form a 45° total wedge.

This narrower gap allowed reduced prep time and grinding with less weld metal required per inch of weld. Overall, Mark Steel saw a productivity gain of 25% to 30% and a corresponding reduction in consumable cost. The company also realized a 10% to 15% reduction in electrical costs using the inverter-based equipment.

The Skywalk is equipped with three 3,200-lb oscillating steel plates inside hollow bridge beams that act as shock absorbers. They move up and down to neutralize vibrations from foot traffic and wind gusts. Set atop the box girders, the walkway itself is constructed of 3-in.-thick heat-strengthened glass.

To meet the tight project deadline, Mark Steel welded around the clock. As such, equipment reliability and technical support were key considerations in the decision to go with brand new and unfamiliar equipment in the eleventh hour. Thanks to the success of the project, Mark Steel plans to incorporate Power Wave equipment more and more in their other projects.

A New Record

In May of 2006, final tests were conducted on the Grand Canyon Skywalk, and the structure passed engineering requirements by 400%. The Skywalk is now the highest man-made structure in the world, built with more than one million pounds of steel. It was designed to withstand an 8.0-magnitude earthquake 50 miles away.

—Tony Noah, Technical Sales Representative, The Lincoln Electric Co. Cleveland