Lessons Learned in the Field

Understanding Distortion is a Never Ending Challenge

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The Project

My company was asked to fabricate sixteen catcher beams to be installed on the Commodore Barry Bridge outside Philadelphia. In the event that the main pins that carry the deck of the bridge should ever break, these beams are designed to "catch" the deck and keep the bridge from plunging into the water. The creation and installation of the catcher beams was part of a retrofit project on the bridge, which was built in 1974 and is owned by the Delaware Port Authority. The project was completed in November, 2002.

Background

The steel selected for the catcher beam project, a 2 in. [50 mm] thick A710 Grade A Class 3 material, was chosen for its high Charpy value, 60 ft-lbs [80 J] at minus 80°F [minus 62°C]. When I tried to develop a history of the A710 steel, information was very limited. I could not find that it had ever been used on a bridge anywhere in the United States. The U.S. Navy had used A710 in the past, but had a history of it cracking at thicknesses greater than 1 in. [25 mm].

The structure of each catcher beam consisted of a box with two flanges 2-1/2 in. thick by 17 in. [65 mm by 430 mm] wide and two webs that were 2 in. thick by 18 in. high [50 mm by 460 mm]. The outside corner welds were 1-3/8 in. [35 mm] partial joint penetration (PJP) groove welds, with an inside corner weld of 3/8 in. [9.5 mm]. This of course was only on the bottom flange, which could be welded inside. Once the cap was put on, welding was restricted to the outside, dictating PJP groove welds only.

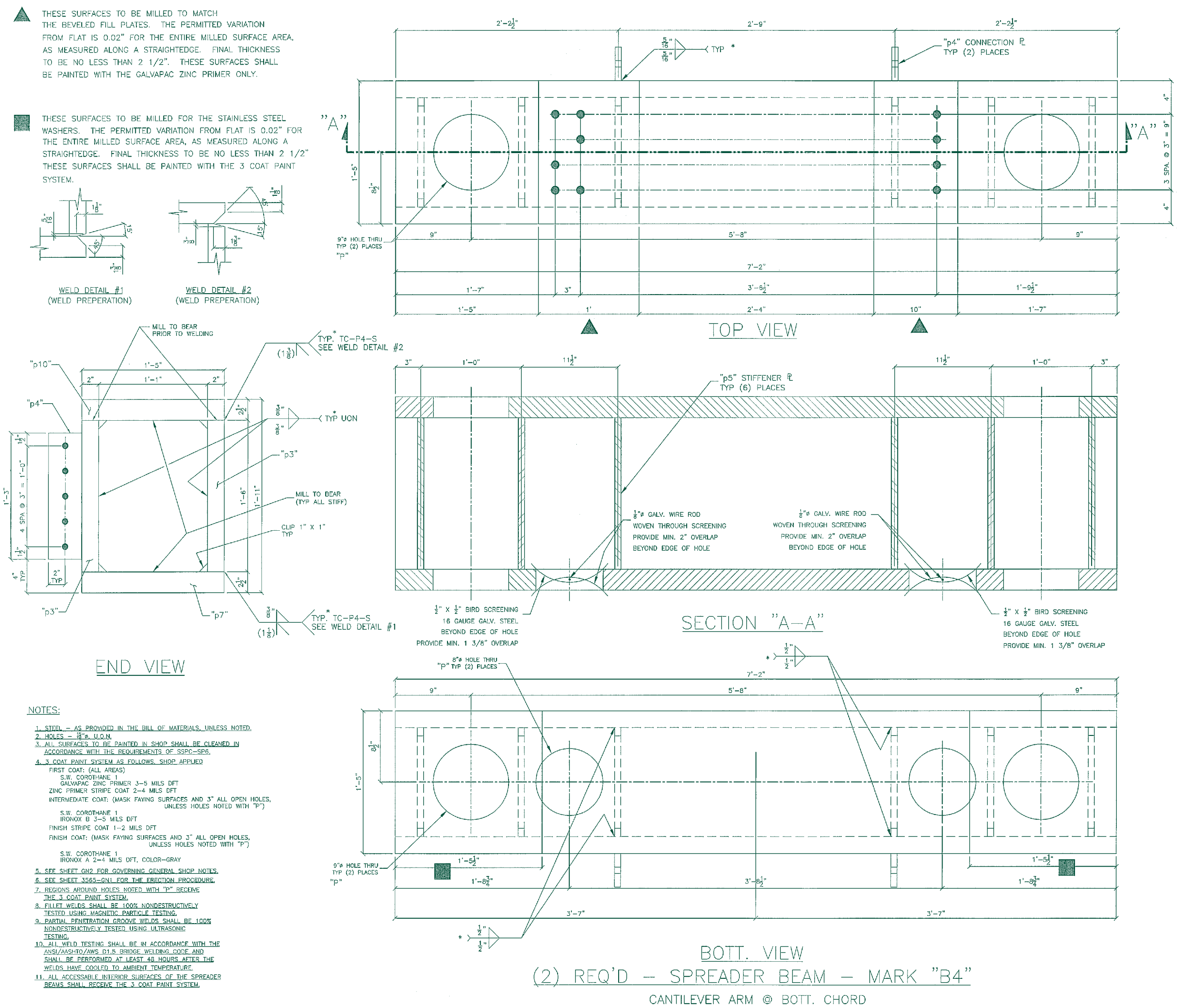
The Initial Challenge

With this very limited information, I put together a game plan according to which we would preheat and rotate this assembly after it was tacked up. We built a preheating station in which the part could be heated and rotated. It became known as the "rotisserie." We brought the beam up to 400°F [200°C], let it soak for one hour at that temperature, then let the weldment cool down to 350˚F [175˚C], before welding the first root pass on the two bottom outside partial joint penetration groove welds. After that, the spreader beam was taken out of the rotisserie, and we ran the two inside 3/8 in. [9.5 mm] fillet welds. The temperature was still maintained at 350°F until the completion of the 3/8 in. fillet. Then the assembly was allowed to cool down to room temperature.

The zero clearance tolerance proved to be a real challenge

Now the spreader beam was fitted with six internal bearing stiffeners. Both ends of the stiffeners had to have a mill-to-bear fit to each flange, and no weld was initially specified. The mill-to-bear tolerance was zero clearance across the full width of the stiffener. Anticipating that this fit requirement would be difficult to achieve, we fabricated a yoke-type fixture to tightly clamp the stiffener to the flange. The fixture ensured that this fit was maintained before welding began.

Despite the fixturing, the zero clearance tolerance proved to be a real challenge. We would start to weld, and the stiffener would start rising out of the box, creating a 0.015 to 0.020 in. [0.381 to 0.508 mm] gap. We changed the direction of welding, and tried driving the weld in from the outside corner. Ultimately, we ended up running a short 6 in. [150mm] weld, skipping a 6 in. space and completing the joint by using a back-step welding technique to complete the fillet welded joint.



We also used differential preheat to control this dimension. We only preheated the web, with no direct heat applied to the stiffener. The stiffener received its 250°F [120°C] preheat via heat conduction through the web. The 100°F [40°C] differential allowed the web volume to expand to a greater dimension than the stiffener. Then, after welding and overall cooling, the web volume contracted more than the stiffener volume, which drove the stiffener into contact with the bottom flange.

The combination of the welding sequence and the differential preheat were sufficient to get the stiffener into continuous contact with the flange. At this point, one consultant we spoke with about the project remarked, “You might as well be making a Swiss watch out of a steel beam!” It certainly felt that way at times. But our problems still were not over.

Another Problem

The surface of the flange plate wasn’t flat enough for the tolerance. We discovered that the way these plates came from the steel mill, there was a very slight waviness and grooves on the surface of the plate, and that accounted for the 0.015 in. [0.381 mm]. Since the plate surface rolling tolerances exceed 0.015 in., no amount of preheat temperature differential between the web and stiffener could correct the out of tolerance gaps. We went back to the Engineer, who raised the tolerance to 0.010 in. [0.54 mm]. Still, we had rejections. Then the Engineer raised the tolerance to 0.015 in. [0.381 mm]. More rejections. So we ended up receiving permission from the Engineer to weld the bottom of the stiffeners to the flange.

Now, The Top Flange

To control the gap between the stiffener and the top flange, both components were machined in a big planer to a flat and level condition.

On the first spreader beam that was welded, the top flange distorted in a convex direction approximately 0.030 in. [0.76 mm]. To reduce this distortion we used a post heat of 350°F [175°C] for a minimum of 8 hours. The post heat relaxed the welding residual stresses to a point where the flange flattened down to under 0.015 in. [0.381mm].

The other thing I did to control distortion was to build in a 0.010 in. [0.254 mm] gap between the flange and the web, fixing this dimension by using small tack welds. The tacks created a gap which gave room for the shrinkage, to bring the top plate down before it started to distort. Creating this small gap did about as much for us to control distortion as anything. The heat definitely helped flatten the flange out over time, but the small gap gave it some place to go.

Hydrogen Control

The second challenge was to prevent delayed weld cracking by controlling hydrogen in the weld. This was done via two methods:

First, we used a controlled hydrogen process: SAW (Lincoln Mil800-H flux and LS3 wire combination) with diffusible levels between 1.5 to 2 ml/100 grams of weld deposit.

Second, we filled each partial joint penetration groove weld to only half of its depth before rotating to the next joint. Hydrogen takes time to diffuse, and the greater the distance of material through which the hydrogen must travel, the more time will be required. By welding only half the groove depth, the distance for hydrogen to diffuse was reduced. Also, since the whole assembly was maintained at the preheat/ interpass temperature, the rate of hydrogen diffusion was greater. While hydrogen was diffusing from the partically welded joint, another joint was welded.This allowed a minimum of 12 hours for the diffusible hydrogen level to drop even lower. This procedure also balanced some residual stresses, controlling distortion (sweep and camber) of the beam assemblies.

Making a Swiss watch out of a steel beam

Personnel with whom I had spoken at two Navy shipyards described delayed cracking in welds over 1 in. [25 mm]. I believe that if the shipyards had followed the above with proper preheat practices and the use of low to medium restrained joints, weld cracking would have been reduced to an acceptable level.

Conclusion

Despite the demanding conditions, the project was completed successfully. By using principles of distortion control, the displacements were minimized, although the final solution required the application of a fillet weld to overcome all the challenges. A cooperative Engineer and careful planning overcame the dimensional control problems. Selection of the proper materials, control of procedures, and careful preheat and interpass temperature controls overcame any tendencies toward hydrogen cracking. I guess we did make a Swiss watch out of a steel beam.