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Rehabilitating Canal Locks

Rehabilitating the C&O Canal Lock Gates

All images by Joshua Coleman unless otherwise noted

1 Masonry walls fully exposed. Fighting mud, debris, and driftwood was a constant struggle during the installation process.

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2 When opened, the lock gates fold into the recess in the masonry wall to avoid possible damage to the sides of the canal boats.

3 Paddle valves located at the bottom of the lock gates are mounted within the frame openings with close tolerances.

THE Chesapeake and Ohio (C&O) Canal runs from Georgetown in Washington, D.C., to Cumberland, Maryland. It was constructed over 22 years, from 1828 to 1850. The canal was in operation from 1831 through 1924, primarily used for hauling coal from western Maryland to Washington, D.C. Over the canal's 184-mile length there are 84 locks raising and lowering canal boats approximately 800 ft. in elevation. The canal business eventually succumbed to the dominating railroad industry and fell into disrepair. In the 1930s, some effort was made by the Civilian Conservation Corps to replace and repair many of the lock gates, using yellow pine coated in creosote instead of the white oak used originally.

In the early 1950s, plans to turn the canal into a highway were famously opposed by Supreme Court Justice William O. Douglas, who hiked the entire length of the canal in 1954. This well-publicized hike brought awareness to the value of the canal as a public space worth protecting. Subsequently, the towpath along the canal was converted into a public hiking trail and designated as a National Park in 1971. Since then, the National Park Service (NPS) has been maintaining and repairing the canal gates. In conjunction with this preservation effort, our company was hired to replace five sets of gates at three separate locks, located in the vicinity of the Great Falls in Potomac, Maryland.

The locks each consist of masonry walls, approximately 100 ft. long, with wooden gates at each end of the lock to control the flow of the water (Fig. 1). The masonry walls are constructed with locally quarried red sandstone, generally measuring 2x3x2 ft. and laid with mortar. The wooden lock gates are opened and closed with a long balance beam which cantilevers away from the gate and can be operated by one person on each side. When the gate panels are open (Fig. 2), they fit into a recess in the masonry wall to prevent interference or contact with the canal boats as they pass through the lock. When the gates are closed, they meet as a miter pointing upstream. The pressure of the water flowing downstream pushes against the gates; consequently, the higher the water level, the tighter the gates get. Paddle valves (Fig. 3) at the bottom of each of the gates are operated with a vertical shaft called the valve stem, which extends to the top of the gate where a handle is rotated by the lock operator to open or close the valve. Opening the valve on the downstream gate lowers the water in the lock, while opening the valve on the upstream gate raises the water in the lock.

The lock gates were made of 12x12 and 10x10 southern yellow pine timbers, connected with mortise and tenon joinery, and were reinforced at some point in their history with through-bolted steel plates. Early photographs of the canal indicate that the steel plates are not part of the original design, though it is hard to determine when this feature was added.

The timbers of the new replacement gates are pressure-treated with chromated copper arsenate, which is a reduction in toxicity from the creosote treatment used previously. Tapered bearing shoulders where the horizontal rails join into the side of each vertical post also feature prominently in the framing details. This tapered shoulder, which is wider on the upstream face, creates an angled surface that resists the force of the water against the rail, without which the tenon would be loaded in the weak axis and at greater risk of failure. The quoin post,[1] or hinge post, is set into a radiused corner in the masonry at the downstream end of the gate recess, allowing the quoin post to rotate as the gate swings. The only attachment points of the lock gates are a cast-iron bearing plate with a 3-in.-diameter pin set into the end grain at the bottom of the quoin post, and a collar around the upper end of the post that is anchored into the top of the masonry wall (Fig. 4). The bearing pin at the bottom of the quoin post is not anchored at all, but simply rests on the stone at the bottom of the canal floor, which allows the gates, when closed, to press more tightly into the masonry quoin. The collar at the top can be tightened or loosened by adjusting metal shims as needed.

Though the tops of the gates are at the same elevation, the upstream lock gates are typically about 10 ft. tall and the downstream lock gates are approximately 18 ft. tall. The downstream gate extends deeper into the water to accommodate the change in elevation through the lock. The difference between these two gate heights determines the corresponding changes in elevation at each lock, which average about 8 ft. The floor of the lock was originally built with several layers of timbers and planking at the depth of the downstream gate and steps up to the shallower depth just downstream from the upper gate. Some of the floors we encountered were made from the original planking, though most had been replaced with concrete slabs.

Once the project was under way, the canal gates were removed from their existing positions by the general contractor, using an excavator, and delivered to our shop in York, Pennsylvania. The gate panels were set up in our yard, measured, and recreated in 3D digital models. In an attempt to anticipate how well the new gates would fit into the existing masonry walls, we decided to hire a 3D laser scanning company to document the existing field conditions. 3D models of the cast-iron gate paddles, frames, and steel connecting plates were also created, using the casting patterns supplied by the NPS from previous repair work. The masonry scans and the digital models of the timber, steel, and cast-iron parts were all integrated to determine the fit and to verify that the gate models were going to seal well with the existing masonry. The goal was not necessarily to make the exact cuts that would be required for a perfect fit, but rather to assure that the overall size and configuration of the new gates could be modified to fit in the field. If the gates were too small, they would have been much more difficult to fix than if they were too big. It was interesting to look at the assembly in the model from inside the stone wall and see the points where the timbers extended into the masonry. In the end, I'm not sure that the 3D laser scanning helped us to be any more accurate since we still had to scribe the quoin posts to fit, but it did give me some peace of mind. Once we were confident of the geometry, shop drawings of each individual gate were generated to indicate the dimensions of every component and then submitted to the general contractor and the NPS for review and approval.

[1] Quoin post: "a corner post," specifically "the vertical member at the hinged end of a gate in a navigation lock," Merriam-Webster.com.

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4 Quoin post set in place with collar strap set in the masonry wall.

Part of our scope was to include the manufacture and installation of the cast-iron frames, paddles, and other miscellaneous parts that we had no prior experience with. The search for a foundry that could handle the small quantities and large sizes that we required proved difficult. Through many cold calls and inquiries, we connected with a foundry that has been in business for generations. As it happens, this particular foundry had already made several of the frames and paddles as extras for a previous order, and they were able to fill our order more quickly than we had originally thought possible.

Unfortunately, the frames and paddles have a left or right orientation for how they swing, and there were too many of one orientation and not enough of the other. This required that some parts had to be melted down and recast into the opposite mold configuration. In the original hardware, the round bolt heads were flat and countersunk to be flush with the plates. The neck of the bolt has a square profile which locks into a square hole in the steel plate to prevent the bolt from turning. The plates themselves were set into the face of the timber gate, resulting in a completely flush installation. When the gates were installed, I noticed that the wooden gunwales of the canal boats would pass directly by the bolt heads, which would most certainly have done some damage had they not been set flush.

Valve stems, extending from the top of the gate to the bottom, where the valves are, were made of solid steel with tapered square ends to match the valve stem handles made with a corresponding socket. This allows the canal operator to open and close the valves at the bottom of the gate while standing at the top.

The hinge post requires a semicircular cross section so that the gate can rotate easily in the masonry quoin. To accomplish this, we laid out the profile at each end of the post; then facets were ripped off with a sawmill and the profile smoothed out with a power planer. A plywood pattern was used as a gauge to determine which areas needed to be reduced. The top two feet of the hinge post is completely round, allowing for the steel collar strap to retain the gate in any position. The ripping, in this case, was done with a circular saw, and the profile of the shape was smoothed in the same manner with the power planer.

5 Installation of lock gates with heavy equipment.

6 Quoin post viewed from above shows the fit of the rounded shape into the masonry.

The miter posts, where the two gates meet, were also ripped at the sawmill with the calculated miter angle. This angle was later adjusted in the field once both gates were seated and swung closed. The thickness of the gates tapers from 12 in. at the hinge post to 10 in. at the miter post, which meant that all of the horizontal 12x12 timber rails had to be ripped on the sawmill. We were thankful to have a great sawmill operator who was able to cut all the various rips and tapers. The horizontal rails connect to the vertical posts using 3-in.-thick tenons which seemed unnaturally huge until the whole assembly was put together. The massive proportions of the gate seemed to correlate well with the large joinery. The panel of the gate itself is created using 2x8 boards, oriented diagonally for lateral bracing and seated in rabbets along the edges of the posts and rails. The effect, much like the bolt heads, was a clean, flush face on the canal side of the gate, to prevent damage to the passing canal boats.

Once all the timber parts were cut in the shop, the steel parts were milled, and the cast parts were poured and coated with an extremely durable epoxy paint, it was time to put the entire assembly together. The width of each gate is approximately 10 ft., allowing for pre-assembly in the shop and delivery to the jobsite as a wide load. This gave us the time needed to fuss and finesse the gate panels in the protection of our shop. We assembled the panels on massive sawhorses with the boat-side up so that we could lay the 2x8 panel boards in from the topside. We intentionally left two boards un-nailed so that we could temporarily pop them out to attach rigging during installation. The boards were nailed in with 40d cut nails, which are best driven with a 5-lb. sledgehammer. We found that predrilling helped prevent splitting of the boards, as the nails were located relatively close to their ends.

The boards were oriented diagonally, as originally designed, to create additional stiffness, with each board acting in compression to help support the gate's massive weight. Opposing panels have the diagonal orientation sloping toward the hinge posts, creating a chevron pattern that is both functional and attractive.

Acquiring the material for the panel boards was exceptionally difficult, since the specification required the stock to be entirely free of sapwood. Apparently, this is not a specification that mills typically sort for, so it was necessary to pay extra for the mill workers to sort through their inventory to provide this. This detail was specified in the original 1830s material lists that I discovered in a document republished in the 1960s. The timber suppliers argued that this step was unnecessary since everything was pressure-treated, but we were nonetheless obligated to meet the specifications. Time may tell whether this extra precaution is worth the cost, as several gates recently slated for rehabilitation do not have the same heartwood requirements. It will be interesting to see if there is a long-term difference in performance.

Fitting the cast-iron paddle valves into their cast-iron frames turned out to be the most challenging aspect of the assembly process. It didn't occur to me to inspect them before we put the whole thing together, but the castings were delivered to us rough, with all the surface inconsistencies from their sand molds preventing a good fit between the valve paddles and frames. Naturally, we had already mounted the frames into the gate panels, so the grinding and fitting process had to be done from underneath the assembled gate panels on a mechanics dolly. In hindsight, we should have done all the grinding and fitting before mounting the valve frames into the gate panels.

While loading the gates onto the delivery truck proved to be a simple operation, moving them into position on site proved to be quite difficult. Since we had last been on site to remove the old gates, the general contractor had completed much of the site work, including the removal of the temporary access to the towpath that we had planned on using. This meant that we now had to transport the assembled gates across a pedestrian bridge which, stout as it was, had not been designed to support the weight of the heavy equipment and the gate panels themselves. Recognizing the challenges of moving the assembled gates across the canal, the contractor developed a plan to build a load-rated bridge using crane mats to span over the existing pedestrian bridge. With access across the canal to the towpath now established, the gate panels were picked up using an excavator and carried down the 12-ft.-wide towpath to their respective locks.

This same towpath is a popular tourist site, offering access to the Great Falls, and remained open throughout the project. This access requirement resulted in the frequent stopping of the heavy equipment

7 Tuning the miter joint between the two gates.

8 The miter sill truss, being cut in place, is anchored to the floor of the lock to help resist the force of the water and to seal the bottom sill of the gates.

9 Completed lock gate in closed position. Gates are operated using balance beams which cantilever beyond the lock into the towpath.

and all associated work, to allow busloads of visitors to pass through the narrow path not blocked by equipment. It was not the most productive part of the process.

When the canal gates arrived at their respective locations, the rigging was adjusted to lift them vertically and then lower them down into the drained lock (Fig. 5). Once lowered into position, the round part of the hinge posts had to be scribed to fit the masonry walls, ensuring the tightest seal possible. Several cycles of marking, hoisting, and removing material with a chainsaw was necessary to ensure a snug fit. In some cases, the stones had heaved so much that a substantial amount of wood had to be removed to get a good fit (Fig. 6). With both gates scribed to fit into their masonry quoins, the miter cuts were then scribed to fit tightly where the panels met. To close miter and improve the fit, a chainsaw was passed from top to bottom between the miter joint of the adjoining panels until the fit was quite close (Fig. 7), and then a power planer was used to smooth the rough sawn surface. Lastly, the miter sill, which is essentially a horizontally oriented truss, bolted to the floor of the lock, had to be cut to size and assembled (Fig. 8). The miter sill maintains a seal to prevent water flowing under the gates. The upper (upstream) chords of the truss need to be well aligned with the miter gates in their closed position.

All field cuts were dressed with a copper-based wood preservative, similar to the chemicals used in the pressure treatment, liberally brushed onto any surfaces that were exposed when the joinery was cut. These trusses were built using pressure-treated 12x12 timbers fixed into place with 2-in.-diameter anchor bolts at 2 ft. on center (Fig. 9).

The process of filling the lock gates required a three-day procedure involving opening overflow gates seven miles upstream to allow the entire lock to fill up. Since this procedure is so time-consuming, and would have required even more work to drain again, we were not able to test the gates one lock at a time, but instead had to complete the work on the five consecutive lock gates before we would know if our work was effective in holding back the water. Somewhat anticlimactically, we were never notified that the canal was being tested. When I called to find out the dates of the test, I was informed that everything was fine, and that the work had passed inspection. Soon after the canal gates were opened, an unexpected storm caused major flooding. A large tree had floated downstream and damaged another pair of gates, a set that we had not yet repaired. Consequently, the locks are still partially drained and not yet open for use.

The opportunity to work with the National Park Service to rehabilitate such an iconic and significant piece of American history has been thoroughly rewarding. The operation of a large, dynamic timber structure through simple mechanics inspires the imagination. Thoughts of putting one's back into pushing the balance beam to close these massive gates is gratifying at a very elemental level. The poetry of the canal and its quiet witness of the passing of time and technology as it slowly drifts back into a natural habitat inspires reflection and perspective that is precious in our busy lives. Using our skills, in much the same manner as was done by the original lock builders nearly 200 years ago, is one reason why we are so passionate about the craft of timber framing. We are grateful to all the members of the organizations who valued this canal enough to help make its rehabilitation possible.

—Joshua Coleman

Joshua Coleman has been timber framing since 1999. He is a project engineer and lead designer for Lancaster County Timber Frames, Inc., as well as a loving husband and father of five great kids.