AEG Outstanding Environmental & Engineering Geologic Project Award

Paw Paw Slope Stabilization — Chesapeake & Ohio Canal National Historical Park

National Park Service – Joseph Reed, PE, CFM; Susannah Noppenberger
Drill Tech Drilling & Shoring – Bob Stier; Jason Reinhardt, PE
Brierley Associates – Nick Strater, PG; Devon Switser
Gannett Fleming / TranSystems – Andrew Li, PE, CCM

Project Design-Build Team

National Park Service — Owner / Project Management
Drill Tech Drilling & Shoring — Prime Contractor
Brierley Associates — Engineer of Record
Gannett Fleming — Construction Management/Inspection

History of Project Need & Background

Originally constructed 1828–1850, the Chesapeake & Ohio (C&O) Canal was one of the first large-scale civil works projects funded by the U.S. government, with supplemental funds from Maryland and Virginia. The canal's navigational system stretched along the Potomac River for 184.5 miles from Washington, DC, to Cumberland, MD. The C&O Canal's navigational system was primarily comprised of locally sourced materials such as stone, earth, timber, mortar, and brick. Collectively, the C&O Canal's navigational system was comprised of 74 lift locks, seven dams, over 168 culverts, and 1 wooden and 11 stone aqueducts, which traversed along its course with an overall change in elevation of 605 feet, and included one tunnel (Paw Paw Tunnel) that carried the canal through a mountain.

The Paw Paw Tunnel was constructed by the C&O Canal Company in lieu of building over 6.7 miles of canal along the Potomac River (referred to as the Paw Paw Bends). This shortened the river route through the Paw Paw Bends of the Potomac River to 1.5 miles via an alternative inland route. The tunnel is approximately 3,118 linear feet (LF) long and 25 feet wide, is composed of over six million bricks (which serve as a liner), and includes open cuts through the interbedded shale and siltstone on both sides of the approaches to the tunnel entrances. Although it was originally anticipated to take only two years to construct this section of the canal, because of labor shortages, outbreaks of disease, work stoppages, and the arduous nature of the work, the project took 14 years (1836–1850). This excavation through the project area was made through the Tunnel Hill Ridge and valley of Mill Run (a stream that still conveys water through the cut in the form of waterfalls). After the full section of canal through the project area was opened to Cumberland in 1850, the canal remained operational for 74 years until 1924.

Today, the Paw Paw Slope Stabilization Project is located in one of the most remote portions of the C&O Canal National Historical Park, approximately 155 river miles upstream of Washington, DC, in Oldtown, MD. The C&O Canal National Historical Park is a U.S. Department of Interior, National Park Service (NPS) unit. Figure 1 shows a map of the region and local project area.

There is a rich history of rock fall and slope instability within the cut on the downstream approach to the tunnel. This is due to a combination of site-specific geology, gravity, weathering of the rock over time, freeze–thaw activity from water intrusion, and other drivers. Multiple rockslide events have occurred since the canal's completion in 1850, with the largest and most recent slide occurring in May 2016. Prior to the current project, multiple ad hoc efforts were completed over the last decade or so as interim risk reduction measures, including one constructed in 2013 and another between 2017 and 2019. The 2013 effort included installing a short length of rockfall barrier fence in Rock

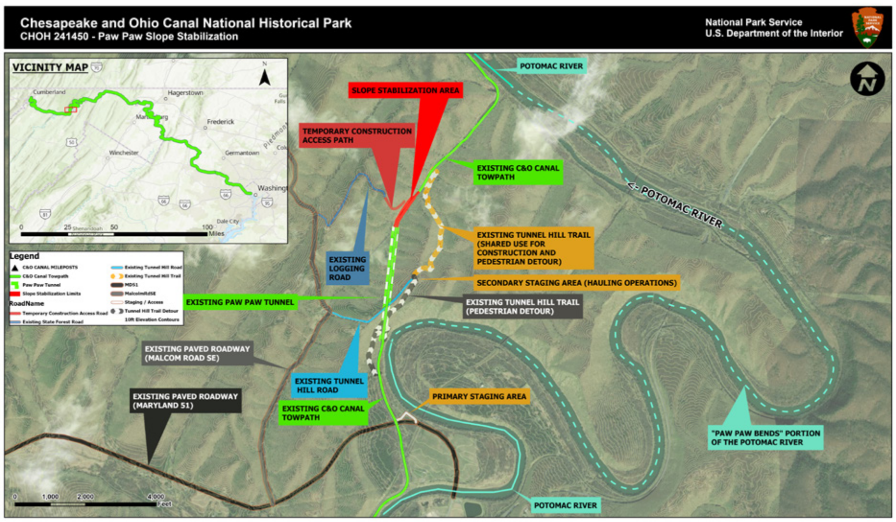


Figure 1, Chesapeake & Ohio Canal National Historical Park regional and local project area map

Figure 2, Paw Paw Tunnel and North Approach through the Deep Cut, 1890

Figure 3, Rock bolting and scaling by NPS in 1950s

Fall (RF) Area 9. The 2017–2019 effort included limited rock scaling, installation of rock bolts, use of precast reinforced concrete shear blocks, draped mesh, and weep drains within RF Areas 2–7. Figure 2 shows the North Portal of the Paw Paw Tunnel through the “open cut” approach, and Figure 3 shows the slope stabilization work in the 1950s. The extent of rockslide that occurred in 2016 is included in Figure 4 and shown in aerial footage in Figure 5. It should be noted that an additional area of potential slope instability was identified by the contractor after initial award of the design-build contract.

The current project was delivered via a design-build contract awarded to Drill Tech Drilling and Shoring, Inc. (DTDS). The engineer of record was Brierley Associates. Construction management and onsite inspection was provided by Gannett Fleming. Overall contract administration was done by the NPS Denver Service Center. The owner is the NPS C&O Canal National Historical Park, which also provided technical services to support the project throughout its life cycle. The design-build construction contract was awarded in September 2020, construction physically began in August 2021, and the towpath (C&O Canal’s primary trail) reopened August 25, 2023. The contractor demobilized after completing all on-site project tasks in late 2023. Total construction cost was approximately $10 million, which was paid for by the NPS Line Item Construction Program.

The Paw Paw Rock Slope Stabilization Project’s components included removal of the existing debris field from the May 2016 rock

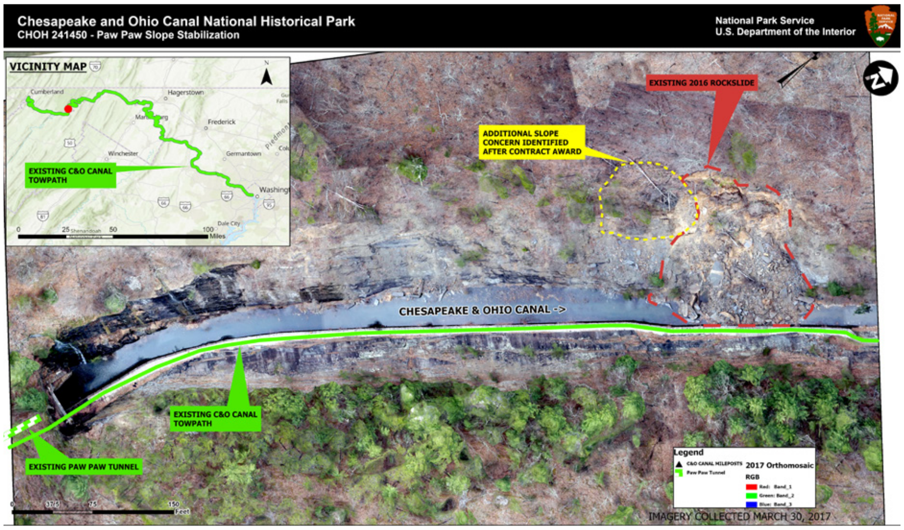


Figure 4, Aerial view of 2016 slope failure (rockslide) and approximate area of additional slope concern

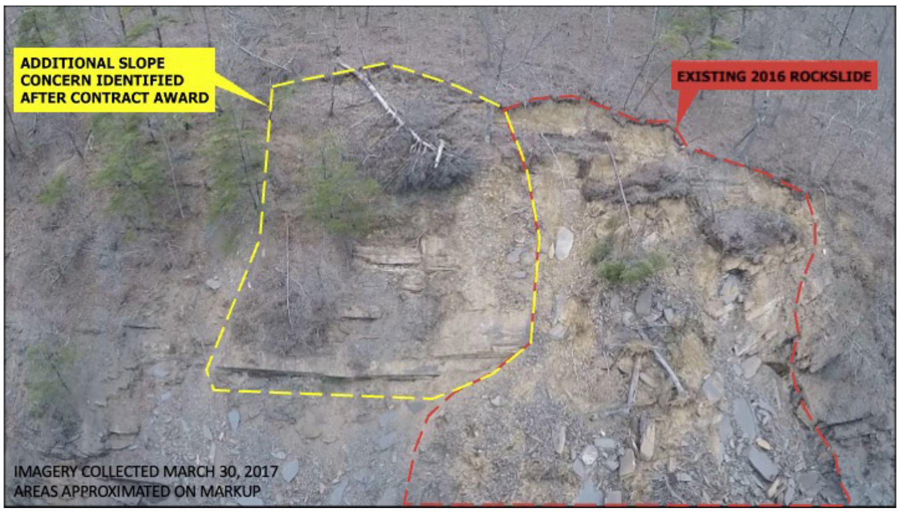


Figure 5, Aerial close-up of 2016 slope failure, northwest slope; approximate area of additional slope concern identified after contract award to the left (south) slide and stabilization of the highest-risk rock slope areas along approximately 1,000 LF of canal, using a combination of rock scaling, rock bolting, pinned mesh, and shear keys (reinforced concrete sculpted shotcrete) by improving drainage (internal rock drains as well as surface drains at the top of bank). The project also included replacement of the wooden boardwalk that carries pedestrian traffic through the canal. These components collectively achieved the project's goals of improving drainage of water through the canal to reduce the freeze–thaw cycling on the historic Paw Paw Tunnel, decreasing the risk of rock fall hazard, improving the safety of tunnel access, enhancing the visitor experience, and maintaining the towpath's (C&O Canal's primary trail system) continuity.

Throughout construction, NPS and its contractors continued to refine the design and construction methods to minimize the impact to the cultural and natural resources that are widespread in this unique area. This included protecting historic structures, minimizing impacts to rare, threatened, and endangered species in a variety of habitats (including the globally rare central Appalachian shale barrens); working to limit visual impacts to the cultural landscape; and ensuring compliance with all applicable laws, regulations, and agency policies. The engineered features were designed and constructed to minimize the visual impact to the cultural landscape by painting hundreds of the newly installed rock bolts and multiple internal rock drains to match the existing geology, coloring installed rock fall mesh to blend with the adjacent rock hues, and sculpting/coloring the 15 shotcrete shear keys to blend in with the adjacent geologic features. This project not only used conventional heavy equipment but also utilized a fleet of articulated dump trucks and had some material deliveries by helicopter. Collectively, the project team delivered a project that will continue to preserve this site for the current and future generations

National and International Significance of the Project

This section of the canal provides unparalleled access to a unique historic engineering marvel (Paw Paw Tunnel) that serves as a focal point of the western portion of the towpath. It is a destination for group biking and camping. This area is also a key field site for the C&O Canal's curriculum-based K–12 Canal Classrooms education program, where park rangers engage thousands of students in experiential learning field trips centered on the historic and natural resources of the canal. The towpath through the tunnel and project area serves a critical link on the 184.5-mile C&O Canal, between Washington, DC, and Cumberland, MD; the 327.5-mile Potomac Heritage National Scenic Trail; the 335-mile Greater Alleghany Passage (GAP); and the 6,800+ mile-long American Discovery Trail. Without the project, the work area would be closed, necessitating an arduous detour that extends 1.5 miles and an elevation change of approximately 400 feet. This region is notorious for having limited communication coverage and difficult rescue capability due to its remoteness. It is estimated that approximately 250,000 annual visitors (many with heavy loaded bicycles) traverse through this area.

Design and Construction Site Geology

The project vicinity is located within the heart of the Valley and Ridge physiographic province. The bedrock in this area includes Ordovician to Mississippian marine and terrestrial sedimentary lithologies that were deposited within the Appalachian Basin and subsequently deformed during the late Paleozoic Allegheny orogeny.

The rock slopes within the work area comprise bedded shale, siltstone, and sandstone of the Upper Devonian Brallier Shale (Formation), which represent submarine turbidity flow deposition. The bedrock has been folded, resulting in an anticlinal structure. The axis of the anticline is located immediately above the north tunnel portal and within the eastern rock slope bordering the work area, and trends approximately northeast–southwest, consistent with the broader Valley and Ridge trends. Flexural slip movement during folding resulted in slickenslided bedding surfaces and a distinct axial cleavage, which trends northeast–southwest and dips at steep angles to the northwest.

Within the work area, the bedding of the bedrock dips to the northwest, which has resulted in planar sliding failure of blocks on the southeast slope. A conjugate joint set dips to the southeast, which encourages planar sliding failure of blocks on the northwest (opposite) slope. This pattern can be seen in Figure 6. This conjugate joint set was determined to be the cause of the 2016 slope failure. In addition, a concentration of cleavage joints results in spalling and toppling failures along the upper portions of the southwest slope and near the tunnel portal.

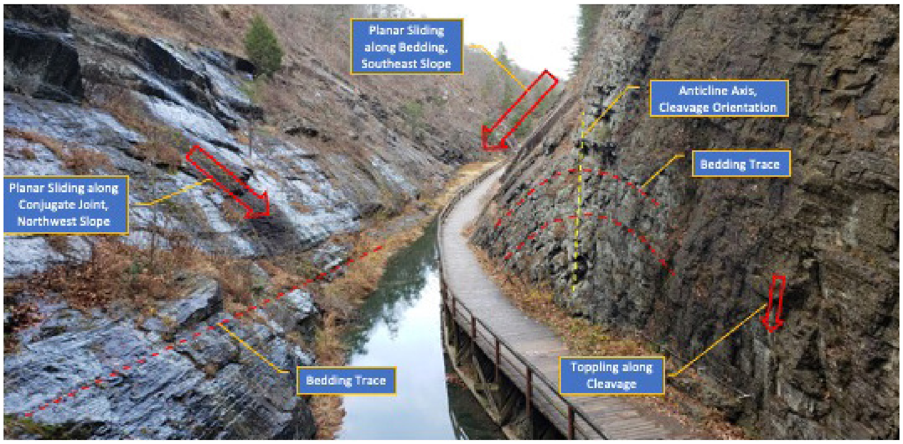


Figure 6, Structural geology and slope failure elements within the canal, facing north (preconstruction).

Schematic Design

The design-build package developed for the original request for proposal was assembled by NPS with the help of consulting services from Vanasse Hangen Brustlin, Inc., and Terracon. The design-build request for proposal package included details developed to the schematic design (SD) level or approximately 30% design level. As part of the SD development, a slope stability risk assessment was developed to prioritize 13 different discrete RF areas within the 1,000-linear-foot-long section of canal on the northwest and southwest slopes within the project area. These RF areas were carried through the subsequent stages of design-construction and used to determine appropriate treatments and prioritizations.

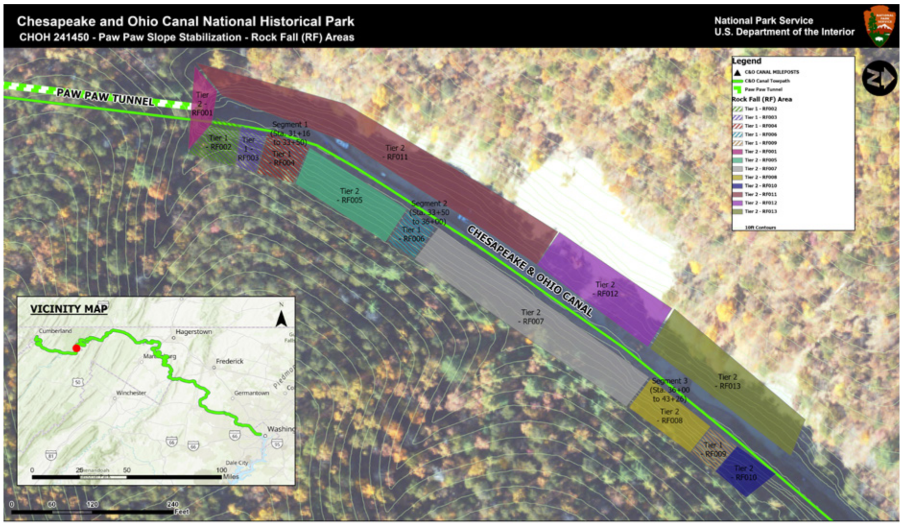


Figure 7, Rock fall areas, as developed in the schematic design used for the design-build request for proposals

Detailed Design

The design-build phase of the project was awarded to DTDS in September 2020, and following an intensive site reconnaissance, Brierley developed a slope remediation design that would include a combination of scaling (rock removal), pattern and spot bolts, pinned mesh, water features (internal drains and surface swale improvements), and anchored shear buttresses. A distinct remediation approach was developed for each RF zone, specific to the surface morphology, structural geology, and previous slope behavior in that area.

Following an extensive scaling program and removal of the 2016 slide debris, isolated rock blocks would be supported by spot anchors, whereas laterally extensive rock slabs would be addressed through application of a pattern anchor system. In each case, the anchor design was developed to accommodate the block or slab size and slope geometry, and localized testing of anchors was completed to confirm capacity. For areas where upslope anchor installation might be problematic, anchored shotcrete shear buttresses were designed to provide supplemental support of both blocks and slabs. Rock drains were included in the remedial design to reduce hydrostatic loading of the rock mass.

A pinned mesh concept was developed for the upper portions of the southwest slope, and for a near-vertical section of the rock slope adjacent to the north tunnel portal, where pedestrians often stop for photographs or rest after completing the tunnel hike on the wooden boardwalk below. The mesh was intended to reduce rockfall potential caused by spalling and toppling of smaller blocks along the pervasive cleavage joints exposed in this area.

During initial site reconnaissance, an active rockslide was identified to the immediate south-southwest of the 2016 failure (Figures 4 & 5). The active slide was estimated to be about 125 feet (measured along slope) by 65 feet (measured up- and downslope) in plan dimensions, and approximately 5–10 feet thick. The upslope limit of the active slide was defined by a tension crack and down drop scarp, and field measurements suggested that this mass already slid downslope by about 1–3 feet. Given its size and degree of apparent movement, in-place stabilization of the active rockslide mass was not considered practical, safe, or cost-effective, and a plan for removal was developed.

Preconstruction Activities

DTDS could not start construction until the entire design was completed by Brierley Associates and environmental permits from Maryland Department of the Environment and U.S. Army Corps of Engineers were obtained by DTDS with the assistance of KCI Technologies, Inc. DTDS also performed additional slope monitoring of the active slide area during the design and permit acquisition phases.

Preservation of existing historic features throughout the project site were critical to all parties. Sauls Seismic, LLC, performed preconstruction assessment of all existing historic features along the existing 3,118-foot-long Paw Paw Tunnel, the approximate 4 miles of canal towpath, and Tunnel Hill Trail. Seismographs were installed at each of the Paw Paw Tunnel portals and at the midway point of the tunnel. The solar-powered seismographs continually monitored vibration and air overpressure to ensure the construction operations did not impact the integrity of the brick-lined Paw Paw Tunnel and associated portals. Automated alerts were disseminated via email if vibrations and/or air overpressure were detected above the thresholds of concern.

Rock Scaling

The project required over 110,000 square feet (SF) of rock slope scaling, the removal of 5,000 SF of preexisting draped mesh, and the removal of trees and vegetation. All scaling and removals were completed via rope access utilizing Society of Professional Rope Access Technician (SPRAT)–certified workers. The contractor estimated approximately 500 cubic yards (CY) of rock was removed from the slopes during the scaling process. The scaled material was removed from the site during the removal of the existing (2016 slide) slide material, which was estimated by DTDS at approximately 2,900 CY.

Rock Anchors

Once scaling was completed in each of the designated RF areas, the installation of pattern and spot anchors began. The majority of the pattern anchors consisted of 8-foot-long #10 galvanized threaded steel bars placed on an 8-foot x 8-foot pattern. While the design called for resin encapsulation of the bolts, some of the anchors required cement encapsulation because of the weathered nature of the bedrock. Spot anchors consisted of 10- to 20-foot-long #10 galvanized threaded bars. It was originally envisioned that the rock bolts would be installed utilizing a Pegasus Drill staged at the bottom of the canal. However, because of the unforeseen active slide that had to be removed, the only area that was able to utilize the Pegasus Drill was RF011. The majority of the anchors were installed utilizing wagon drills with rope access and rope access drill technicians (Figure 8). In all, DTDS installed over 10,000 LF of anchors.

Rockfall Protection Mesh

The design-build contract originally envisioned RF protection mesh in the areas downstream of the North Portal in RF04—RF08 and not directly adjacent to the historic portal of the Paw Paw Tunnel. After detailed analysis by Brierley Associates, it was determined that additional RF protection mesh would be required in RF02 and RF03, directly above the boardwalk carrying the C&O Canal towpath and adjacent to the Paw Paw Tunnel North Portal. Elevations of the bottom of the RF mesh were carefully coordinated to try to limit accessibility for unauthorized climbing by park visitors, while balancing the need to mitigate the potential for spalling rock to endanger the traveling public. A Geobrugg Tecco® mesh was utilized and powder coated in a hue to blend into the existing rock face geology in order to minimize the visual impact. Over 30,000 SF of Tecco® mesh was installed between RF002 and RF08, also by rope access drill technicians (Figure 9).

Slide Removal

The design-build contract required the removal and stabilization of the 2016 rockslide in area RF012, estimated at an area of approximately 7,000 SF and having an in-place volume of about 2,600 CY. Once the slide material was removed, spot and pattern rock anchors would be installed for long-term stabilization. However, removal of the 2016 rockslide was complicated by the discovery of the active slide to the south (Figures 4 & 5). Because of safety concerns, the active slide was monitored for movement using an array of survey targets. As noted, because of its size and unstable nature, the active slide needed to be removed. A supplemental survey completed by DTDS determined that the

Figure 8, Rock anchor installation by rope access and wagon drill, typical

Figure 9, Placement of pinned Geobrugg Tecco® mesh

2016 and active slide had a combined area of approximately 27,000 SF, and that 10,000 CY of in situ material would need to be removed.

Initially it was decided that the safest and quickest way to remove the active slide was through blasting, and a detailed drill-and-blast plan was developed by DTDS and Beckley Drilling and Blasting (BDB). This would involve drilling a series of blast holes upslope of the active slide, parallel to and below the estimated slide failure plane. A new access path was pioneered into this area by DTDS in cooperation with NPS and the State of Maryland by using a portion of an existing logging road through Green Ridge State Forest and NPS lands (see Figures 1 & 10). To facilitate access, materials were also mobilized by helicopter to provide the necessary erosion and sediment controls in the canal. Because of the presence of natural resources, ground disturbance was limited and a temporary mulch access roadway installed, which was removed at the end of the project. Once the mulch road was installed, BDB mobilized and began drilling. Unfortunately, the drill holes encountered zones of poor-quality rock and soil-filled layers and would not remain open, and the plan to complete the blasting was abandoned.

In close coordination with Brierely, NPS, and DTDS, it was decided to mechanically remove the active slide material rock utilizing hydraulic excavators and breakers. To access the active slide from the north, switchbacks were installed within RF13 utilizing existing scaled/fallen rock to allow the excavators to reach the upper limits of the slide (Figure 11). This work became the critical path of the project and extended the schedule.

The rock was downsized with breakers so that it could be transported up Tunnel Hill Trail, utilizing three Hydrema 912 off-road dump trucks. Tunnel Hill Trail is an existing historic haul road that dates back to the tunnel and canal's original construction era. It has a width of about 9 feet and the Hydremas have a width of 8 feet, 4 inches—making the trip time consuming and precarious. Multiple measures to mitigate damage to the existing historic features along the roadway were implemented, including bridging over historic stone retaining walls and using crane mats to distribute wheel loads on the haul route. The rock was then transferred to a secondary staging area near the intersection of Tunnel Hill Trail and Tunnel Hill Road (see Figure 1) and loaded into standard dump trucks for removal to an offsite location. In all, DTDS estimated that about 13,000 CY of rock was removed from the slide area, downsized, and removed from the site.

Figure 10, Aerial via of temporary access path installation during helicopter material deliveries

Figure 11, Establishment of switchbacks and removal of additional slope concern area and 2016 rockslide

Since the through-traffic on the towpath had to be maintained continually, DTDS had to ensure the traveling public was kept safe, which required maintaining trail detours and establishing shuttles. During hauling operations, hikers and bikers were held at the top and bottom of Tunnel Hill Trail until it could be determined the haul trucks were not operating. While hauling was underway, DTDS provided a shuttle service using specially equipped side-by-side utility task vehicles (UTVs) that allowed for bikes to be transported with the hikers and bikers. When hauling was not underway, park visitors were directed to use the Tunnel Hill Detour, which was originally established for the 2017–2019 project and entails traveling approximately 1.5 miles with an elevation change of approximately 400 feet.

Shear Blocks

The lateral and upslope extent of the exposed rock slabs within RF11 necessitated the installation of shear blocks to provide additional support. The original schematic design included in the request for proposal envisioned large, discrete cast-in-place steel-reinforced concrete wedges spaced at regular intervals. DTDS submitted a request to use hand sculpted shotcrete along the entire length of each proposed shear block location, and a full-scale mock-up was created at the DTDS laydown area. The approved shear block concept included rock anchors installed at the toe of the slabs, along with rebar, welded wire mesh, and drainboard to reduce the buildup of hydrostatic pressures.

Once it was determined that the sculpted shotcrete shear blocks could be utilized, an additional mockup was constructed whereby NPS personnel could observe the appearance of the finished product. A water-based stain was used to result in hues that, in combination with the sculpting, blended so well into the adjacent geology that some visitors to the site had difficulty identifying the locations of the newly installed shear blocks. The sculpted and stained shotcrete was utilized on the remainder of the shear blocks with great success, minimizing the impact to the cultural landscape. A comparison of the appearance approximately one week after initial staining to that with approximately 11 months of weathering/patina is included in Figure 12.

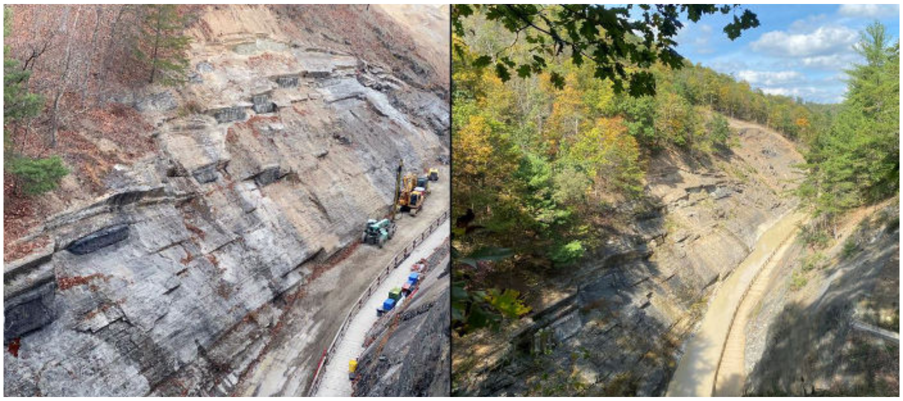


Figure 12, Finished shear blocks, one week following initial staining in November 2022 (left) and after 11 months of weathering/patina (right)

Boardwalk

The design-build contract called for the demolition and reinstallation of an approximately 700-foot-long wooden boardwalk connecting the portal of the tunnel to the rock towpath to the north of the site. Boardwalk construction occurred at the end of the project, once stabilization of the adjacent slopes was completed. The boardwalk design met the most recent codes and standards, most notably installing the vertical support posts on 8-foot centers with proper cross-and-angle braces. Greenway Bridge Company, the boardwalk subcontractor, was required to cut each of the deck boards within a tight tolerance to match the uneven rock face along the length of the boardwalk (Figure 13). Close coordination and adaptative design were required to avoid damaging the historic features that were to remain; including the rope burns in the rock face and the historic remnant of the towpath that was recovered at the southern end of the boardwalk. The final boardwalk construction was completed with no quality issues and to the satisfaction of the entire team.

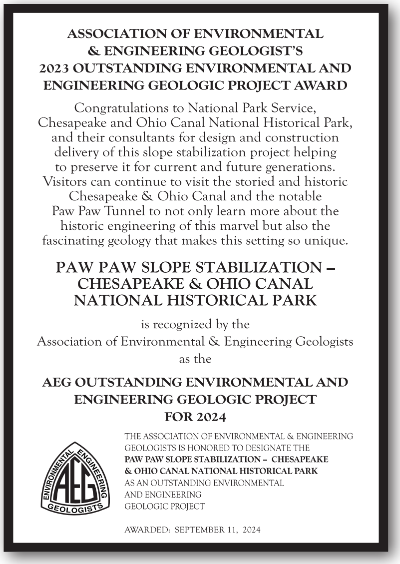
Figure 13, Boardwalk construction

Closing

The Paw Paw Slope Stabilization Project advanced to the point of being able to reopen the park's primary trail system (C&O Canal Towpath/Boardwalk) 1,066 days after award of the design-build contract. Throughout construction the project team had to remain adaptive to the constraints of the project while maintaining a sensitivity and awareness to the natural and cultural resources, as well as the engineering. Overcoming logistical hurdles and technical challenges, and including measures to minimize impacts to the exceptionally rare resources in the project areas; the project team successfully delivered a project to stabilize the slopes on both sides of the canal for the approximately 1,000 LF of the north approach to Paw Paw Tunnel and in doing so preserved it for the current and future generations. Visitors can continue to visit the storied and historic Chesapeake & Ohio Canal and the notable Paw Paw Tunnel to learn more about not only the historic engineering of this marvel but also the fascinating geology that makes this setting so unique. This project exemplifies the potential of the design-build model for sites with challenging and varied conditions. Preconstruction conditions are compared with the postconstruction product in Figures 14–19.

References

Southworth S., Brezinski D., Orndorff R., Repetski, J., and Denenny, D., 2008, *Geology of the Chesapeake and Ohio Canal National Historical Park and Potomac River Corridor, District of Columbia, Maryland, West Virginia, and Virginia.* U.S.G.S Professional Paper 1961.



ASSOCIATION OF ENVIRONMENTAL & ENGINEERING GEOLOGIST'S 2023 OUTSTANDING ENVIRONMENTAL AND ENGINEERING GEOLOGIC PROJECT AWARD

Congratulations to National Park Service, Chesapeake and Ohio Canal National Historical Park, and their consultants for design and construction delivery of this slope stabilization project helping to preserve it for current and future generations. Visitors can continue to visit the storied and historic Chesapeake & Ohio Canal and the notable Paw Paw Tunnel to not only learn more about the historic engineering of this marvel but also the fascinating geology that makes this setting so unique.

PAW PAW SLOPE STABILIZATION – CHESAPEAKE & OHIO CANAL NATIONAL HISTORICAL PARK

is recognized by the
Association of Environmental & Engineering Geologists
as the

AEG OUTSTANDING ENVIRONMENTAL AND ENGINEERING GEOLOGIC PROJECT FOR 2024

THE ASSOCIATION OF ENVIRONMENTAL & ENGINEERING GEOLOGISTS IS HONORED TO DESIGNATE THE **PAW PAW SLOPE STABILIZATION – CHESAPEAKE & OHIO CANAL NATIONAL HISTORICAL PARK** AS AN OUTSTANDING ENVIRONMENTAL AND ENGINEERING GEOLOGIC PROJECT

AWARDED: SEPTEMBER 11, 2024

This project will be presented and awarded at the Annual Meeting during the Opening Session on September 11, 2024, from 10:20am to 11:00am

Figure 14, Paw Paw Slope Stabilization Project—As viewed from above the north portal of Paw Paw Tunnel (November 2020 on left and October 2023 on right)

Figure 15, Paw Paw Slope Stabilization Project – As viewed looking north at the 2016 rockslide (November 2020 on left and October 2023 on right)

Figure 16, Paw Paw Slope Stabilization Project – As viewed looking south at the 2016 rockslide (May 2021 on left and October 2023 on right)

Figure 17, Paw Paw Slope Stabilization Project – As viewed looking south at the 2016 rockslide (November 2020 on left and October 2023 on right)