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A New Solution for an Old Problem

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An innovative use of anchor blocks and tiebacks may solve a landslide condition on a steep roadside slope in Tennessee.

Much of the historic road over the Cumberland Gap in the tristate area of Tennessee, Virginia, and Kentucky follows the original wagon road blazed by Daniel Boone in 1775. As the population of the region grew, the demand for road improvements became a constant. By 1973, relocation of the road was authorized through a tunnel. The connection to US 25E through the new tunnel required a cloverleaf with ramp to US 58. Construction of the ramp began in May 1990. Planned excavation was to cut as deep as 24 meters (80 feet) into Poor Valley ridge, creating a significant potential for landslides.

This view of the construction site from the interchange shows the concrete barriers and fence that were installed to prevent debris from entering the roadway below.

(EFLHD) designed a solution for this slope failure condition by reviewing data from past slides and obtaining supplemental subsurface information. "The result was an innovative solution that conformed to stringent aesthetic requirements," says Acting Superintendent Mary Collier of the Cumberland Gap National Historical Park.

Past Slide History

When originally designing the ramp, the highway planners reduced the cut slopes for the US 58 ramp from 1:1 (horizontal to vertical) to 2:1. Prior to the start of construction, the engineers installed slope indicator devices and groundwater monitoring wells to monitor the potential for slides as the excavation progressed.

When the cut was nearly 18 meters (60 feet) deep, a heavy rainfall caused a small slide near the base of the excavated slope. The monitoring data indicated a relatively shallow slide involving the soil overburden and the brown shale strata (the Upper Rockwood Formation) just beneath the soil layer. A few months later, in 1991, EFLHD decided to flatten the slope further to 3:1 and continue the cut. Further flattening of the slope to negate the sliding potential was not possible because of right-of-way restrictions.

In January 1992, after another extended rainfall, a much larger slide occurred, near the base of the excavated slope and midway along the proposed ramp. This slide was estimated at 53,550-plus cubic meters (70,000-plus cubic yards).

After a review of several options, EFLHD decided to install a 290-meter (950-foot)-long soil nail wall consisting of a 305-centimeter (12-inch)-thick shotcrete wall with internal drainage and high-strength steel anchor bars drilled and grouted into rock for lateral support. Shotcrete is a sprayed-on concrete layer that can be applied to near-vertical surfaces to act as a supporting wall in conjunction with rockbolt reinforcement.

The engineers designed the shotcrete wall to bear on the stable gray shale (Lower Rockwood). They also modified the slopes above and below the wall. The shotcrete wall supported the soil and the Upper Rockwood strata, which were cut on a 2.5:1 slope. Below the wall, EFLHD excavated the slope down to the Lower Rockwood. Construction of the soil nail wall was completed in October 1992, and it effectively eliminated the problem of the unstable lower slides.

EFLHD performed annual inspections after installation of the soil nail wall. An inspection in April 1997, after very heavy rainfall, revealed the beginnings of a new slide near the top of the cut slope. As a result, EFLHD began monitoring the slope and soil nail wall at a number of locations.

This new slide developed over an area extending from the top of the cut slope down to the north end of the soil nail wall, affecting a portion of the upper (nonstructural) soil nail wall. The slide extended northward over to the US 25E cut slope, representing a section of the cut slope not supported by the soil nail wall.

Movement of the slide at the intersection of the US 25E and US 58 cut slopes caused sandstone boulders to spill continually onto the US 25E eastbound roadway. EFLHD quickly protected against falling boulders by installing Jersey barriers along the roadway shoulder and partway up the slope along a bench.

The New Slide Was Moving In Two Directions

During subsequent monitoring from 1997-1999, a scarp face (a cliff caused by soil displacement) developed at an elevation of 493 meters (1,615 feet), facing toward the US 58 ramp. The scarp face was 76 meters (250 feet) long and up to 2.4 meters (8 feet) high. A similar but shorter scarp face developed along the toe of the slide at US 25E, caused by soil and boulders pushed over the steep slope.

In addition, an earth ripple 0.9 meters (3 feet) high was prominent along the US 58 ramp and the US 25E toe of the slide at an elevation 479 meters (1,570 feet). The earth ripple also affected a nonstructural section of the soil nail wall by spalling off a large portion of shotcrete. Slope monitoring data revealed continuous slide movements accelerating during the spring, tapering off in the drier late summer and fall months.

The monitoring performed during the 2-year period indicated that the soil nail wall was functioning satisfactorily and was not affected (other than superficially) by the upper slide. However, EFLHD was concerned that a potentially catastrophic slide could occur in the weak Upper Rockwood Formation. EFLHD engaged a consultant to provide a solution.

The consultant's team plotted groundwater and inclinometer records to estimate the slide geometry and contributing factors. They performed laboratory direct shear tests on soil and rock samples to estimate the shear strengths. Then they defined the sliding surface using slope monitoring, topographic, and boring data.

The next step was estimating slope stability using a computer program developed by Purdue University for wedge, circular, and noncircular analyses. In all cases, the factors of safety were at or less than 1.0 when saturated groundwater conditions existed at the site. The factors of safety were substantially greater than 1.0 when conditions were dry.

The plotted slope data confirmed these results since the slide was active during periods of wet weather, gradually slowing and ceasing during dry periods. With the mechanics of the slide ascertained, the next step was to examine various support options for stabilizing the slope.

This close-up shows the damage to the existing soil nail wall caused by the slide.

Earth Support Options

Strategies for repair came under a number of constraints imposed by the National Park Service, owner of the site. Most important were maintenance of the visual aesthetics and minimal disturbance of the tree line above the scarp. The goal was to preserve the viewscape from The Pinnacle, a prominent observation point overlooking the Cumberland Gap. Another constraint was limited access to the site since the Park Service would not allow cutting of access roads up the slope to the slide area, necessitating using an existing unpaved haul road along the tree line.

EFLHD reviewed various options. One was multiple concrete-filled caissons either cantilevered into the rock or held by tieback anchors (steel rods or cables grouted into rock). Other options included another soil nail wall or a rock buttress. A fourth possibility was concrete anchor blocks placed on the slope with tieback anchors drilled into the Lower Rockwood. "The first three alternatives, although removal and disposal," says Don Miller, project delivery engineer.

The fourth alternative had significant advantages. The anchor blocks could be buried below the ground surface so they would not be visible. Installation would require relatively light equipment, and the anchor blocks could be precast offsite to minimize the onsite storage and work area. The cost would be comparable with other methods, the anchor blocks could be placed in several rows to distribute the resisting force more evenly, and groundwater flow would not be impeded. Finally, the work could be performed in stages, minimizing the potential to trigger the still-active slide.

Workers are spraying shotcrete for one of the pads.

Design of the Anchor Block System

Computer wedge analyses determined the optimum block size and anchor capacities that would provide a minimum factor of safety of 1.50. The engineers planned a grid of 84 anchor blocks, each 2.4 by 2.4 meters (8 by 8 feet), positioned parallel to the slope with a spacing of approximately two times the width of the anchor blocks in each direction.

The plan called for tiebacks to be drilled into the rock at an incline of 30 degrees from the horizontal. The anchor loads planned for would be able to withstand a worst-case scenario involving the water table at the ground surface, the tiebacks skewed off their planned inclinations, and a wedge of unstable earth.

The contractor is drilling for the ground anchors. Note the anchor block set prior to drilling.

Proof loading an installed ground anchor.

A 45-degree increase in the force component for those anchors located on the northeast (US 25E) side was due to the change in slope direction. However, the anchor forces on that side generally carried less load due to the shallower depth of the slide surface.

As mentioned, EFLHD specified that the anchor blocks should be precast rigid footings fabricated offsite. The need to haul them into position on the slope using a temporary access road imposed a size and weight limitation. To permit easiest handling, EFLHD selected a 136-megapascal (300-kip) load capacity anchor block and tieback arrangement.

The engineers estimated that the anchor should develop load capacity when the tiebacks were drilled 9 meters (30 feet) into the Lower Rockwood. The intent also was to seat the blocks on a 152-millimeter (6-inch)-thick shotcrete leveling surface to minimize disturbance to the possibly uneven bearing surface.

Constructability and the Bidding Process

When bidding the contract, EFLHD considered a number of constructability issues. One was site access for equipment and materials, given the steepness of the slope, the length of the temporary access road, and the weight of the prefabricated anchor blocks. Another issue was safety while working on a slope with an active slide mass. A third concern was whether the contractor would be able to stabilize the slide within a single season, given the number of anchors that could be placed at any one time. To continue work into the winter and spring (the wettest times of year) risked failure before completion.

As a result of these concerns, EFLHD used a two-step process to advertise the project. First, EFLHD asked prospective contractors to provide a history of their experience with this type of construction, how they would meet the National Park Service's aesthetic criteria, and whether they would use the anchor block strategy or submit their own design that would meet all of the salient requirements.

Most of the contractors who expressed interest chose EFLHD's plans for the anchor block system. Two contractors submitted their own designs, which were slight modifications of the same anchor block strategy. The National Park Service and EFLHD selected five contractors to submit final bids.

The second step was the actual bidding. The contractor that won the bid would perform the drilling for the tieback anchors and install them, place the shotcrete leveling pads for the anchor blocks, and repair the existing soil nail wall. Several subcontractors would construct the haul road, do the excavation and backfill, seat the anchor blocks, and place the topsoil after final grading.

The contractor placed fill material over the anchors and is shown restoring the site to its original contours.

Construction

A staging area along the shoulder and ditch of the US 58 ramp followed an existing logging road along the tree line to the slide location. For transporting materials, a track excavator was used to carry the anchor blocks from the staging area to the slide. A track loader also hauled water, aggregate, and cement bags for a portable shotcrete plant. A boom fork transported all of the other materials.

Prior to the start of construction, EFLHD installed concrete Jersey barriers on the affected slope along US 25E. As an additional precaution, the contractor installed a high chain-link fence on top of the barriers. The fence prevented the numerous boulders that were dislodged during construction from overtopping the Jersey barriers and falling onto the road below.

The contractor began work on July 2, 2001, by clearing and grubbing the site. The crew installed erosion-control silt fences and brush barriers around the perimeter of the slide and installed temporary piezometers to measure the water pressure and inclinometers to monitor the slope for movement during construction. Read weekly, the monitors indicated some movement of the slope at times, but the movement was not significant enough to alter the construction process.

Then the crew laid out a grid of 13 columns of anchor blocks in 10 rows on the slope. Using an excavator, the crew cut a bench into the slope and immediately placed the shotcrete leveling pads against the slope. After a shotcrete leveling pad had cured for at least 12 hours, the contractor used an excavator to carry a concrete anchor block up the mountain from the staging area and placed it on its shotcrete pad.

A compressed-air rig drilled holes for the tiebacks, which varied in length from 26 to 32 meters (85 to 105 feet). An excavator and boom fork lowered the tieback tendons into the holes, and the contractor then grouted the tendons and cast grout cubes. After the grout cubes reached the required strength (usually 3 days), the contractor stressed the tiebacks to 100 percent of design load. Typically, little to no movement of the anchor blocks was observed during stressing.

An average of two anchor blocks per day (shotcreting, drilling, grouting, stressing) were completed. Once several of the top rows of tiebacks were stressed, excavation of the row below could begin. This procedure enabled the contractor to work on multiple rows of tiebacks at a time, stair-stepping down the slope.

Due to the unusually dry summer, all the tiebacks were completed by early October 2001. An excavator and a bulldozer recontoured the slope and added topsoil prior to seeding. Three permanent piezometers and inclinometers were installed, and the access road was restored to the original contours—well ahead of schedule.

Postscript

Four months after the construction was complete, a heavy storm dropped 116 millimeters (7 inches) of rain during a 48-hour period. The inclinometers recorded no appreciable movement of the slope. The only visible damage was two minor slides of topsoil, which were quickly repaired.

EFLHD anticipated that construction would be difficult, since the work would be performed on an active slide, near the top of a barely accessible slope, several hundred feet away from level ground, and in a location where any additional loading on the slope could cause catastrophic failure. For these reasons the sequence of placement and installation of the anchor blocks had to be accomplished in a controlled manner. In addition, since the direction of the tieback installation varied with the direction of the slope, the tieback geometry was monitored carefully to ensure that there would be no interference from adjacent installed anchors.

"All of this appears to have been accomplished successfully," says Miller, "judging by the subsequent heavy rainfall and thanks to EFLHD's innovative planning and the contractor's successful carrying out of the plan. The result is a new strategy for stabilizing steep roadside slopes."

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