MICROPILES UNDETECTED: BLUFF STABILIZATION ON THE SEVERN RIVER

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ABSTRACT

One of the main advantages of using micropiles for slope stabilization is that it is possible to conceal the stabilization structure after construction. Natural-looking landscaping is a necessity for private owners along the Chesapeake Bay and its tributaries, who cannot accept stabilization solutions that affect property value or violate requirements of the Bay's "Critical Area" Act and would not be approved by local authorities due to their impact on habitat and aquatic resources. This was the case of a privately-owned property sitting atop a bluff along the Severn River in Maryland. A significant slide occurred on the 60-foot high bluff after a major coastal storm in May 2008. The location of the house and layout of the property prevented large construction equipment from accessing the slope, and it was imperative to stabilize the slope using structures that could be concealed completely after construction. After consideration of various alternatives, a system of micropiles and tiebacks connected through grade beams was selected to provide stability against global failure. In addition, hollow core bar soil nails and flexible facing were used for local stabilization between the grade beams. The end result was a stabilization system that provided an increased factor of safety against global and local instability, allowed enhanced landscaping and grading for improved living space along the bluff, and exceeded the owner's prerequisite for a natural-looking solution. This paper presents a summary of the project, including aspects of the design of the micropiles and their connection to the grade beams. It also discusses construction procedures and presents the results of monitoring efforts performed at the site during and after construction.

INTRODUCTION

The project site is located on the southern shore of the Severn River, approximately 2.5 miles northwest of the United States Naval Academy in Annapolis, Maryland (see Figure 1). The Severn River drains directly into the northern region of the Chesapeake Bay, and is known for its beautiful scenery; which has attracted the development of high-end residential properties. The banks of the river are characterized by steep bluffs that often show evidence of instability.

In May 2008, a coastal storm that yielded significant precipitation caused various slope failures in the area. This was the case in a privately-owned residence located

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above an approximately 60-foot high bluff. The slope failure destroyed a wooden staircase, which had provided access to the private dock below, and demolished a trolley used for transferring heavy items from the dock to the house at the top of the slope (see Figure 2). A wooden bulkhead at the toe of the slope was subject to displacement and severe rotation with failure of some of the timber uprights. An 18-inch diameter tree was uprooted and fell on the bulkhead and dock. Portions of the dock supported on timber piles adjacent to the slope were subject to lateral thrust and several piles rotated as consequence of the movement. The landslide undermined a wooden deck supported on spread footings but the slide scarp did not reach the main structures. However, there was considerable concern that the slide would soon encompass a larger portion of the slope including the rear wing of the house.

The use of micropiles combined with anchors provided a cost-effective solution for this slope repair with difficult access. Utilizing a flexible geomembrane face of allowed for the growth of native vegetation and was an important design aspect that helped maintain the natural look of the slope.

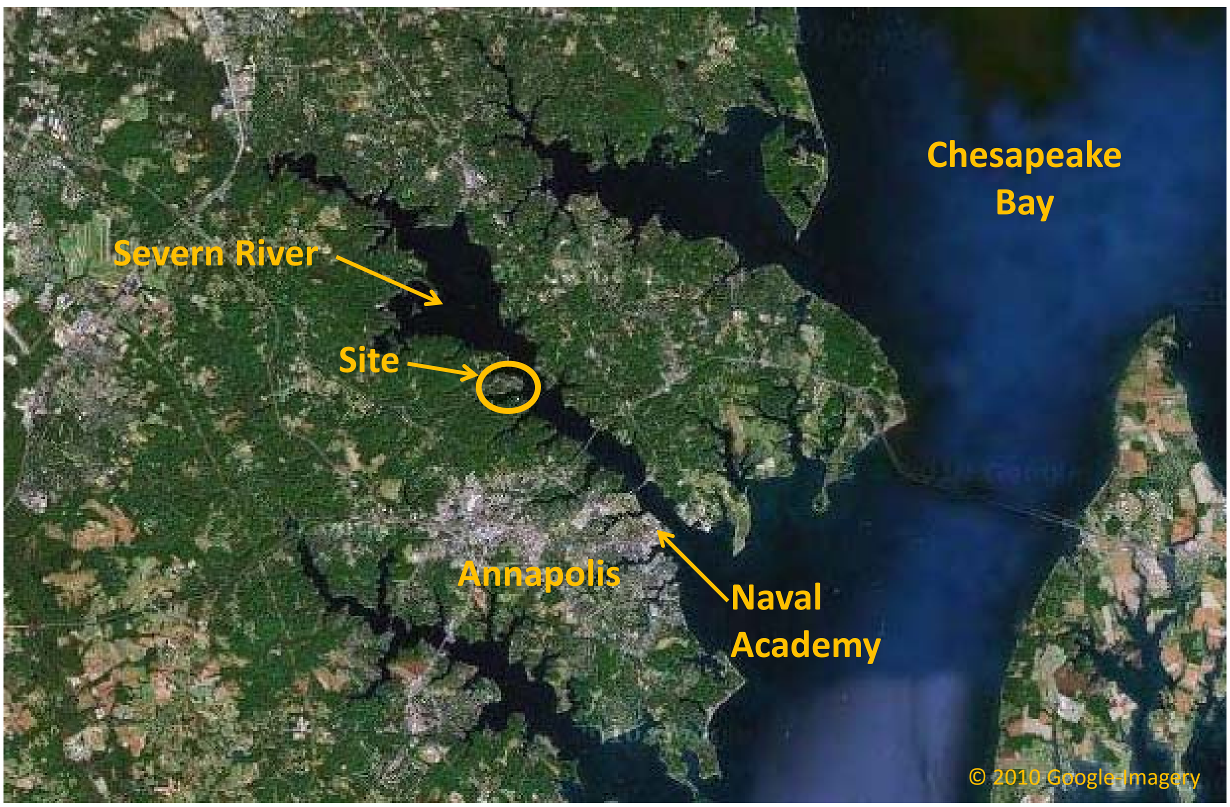

Figure 1. Project site near Annapolis, Maryland.

Figure 2. View of the site immediately after the 2008 landslide. Note collapsed staircase and overturned tree (center), collapsed trolley (right), and undermined wooden deck (upper left).

PROJECT CHALLENGES

The banks of the Severn River are protected by the Critical Area Act of the Chesapeake Bay. By order of this act, construction along the river banks must maintain the natural look of the habitat around the Chesapeake Bay. That meant that the bluff needed to be protected in such a way that inherent vegetation would grow on the slope. It also meant that the structures used for the stabilization project should “blend” with the vegetation to maintain the natural look of the bluff. Various initial proposals submitted by contractors were rejected as they included construction of reinforced concrete walls or concrete facing.

Access to the slope from the street above was very limited. There was no space available on the southern side of the house where the undermined deck was located, and access on the northern end consisted of a narrow walkway. It was then necessary to access the slope from the river. Therefore, the stabilization solution had to be implemented using light weight equipment that could either be placed on the unstable slope or suspended from a barge crane. Materials and equipment had to be brought to the site on a barge that would also act as work platform. Tide fluctuation was critical to the project schedule as low tides prevented movement of the barge. Accessing the slope from the river also reduced disturbance to neighbors, which was an important consideration for the owner. Control of sediments into the river was also a challenge during construction and the stabilization solution had to limit the amount of debris and sediment and incorporate the necessary elements to control runoff.

The stabilization solution also considered restoring the functionality of recreational areas of the residence, which included a garden atop the bluff, the wooden deck, and the lifting trolley from the upper slope to the wooden dock. Access to the dock would be provided through a walking path incorporated into the stabilization scheme. Finally, the selected stabilization scheme minimized the volume of excavation from the slope.

SOIL CONDITIONS

The subsurface profile generally consisted of medium dense silty sands with low fine content. The sands increased in density with depth and contained varying amounts of silt and clay. Geologically speaking, the site falls into the Western Shore Uplands Region of the Coastal Plain Province which is characterized by sand, gravel, and small deposits of iron ore. The lightly cemented sand on the bluff is susceptible to movement and vibration. The high water table led to saturated conditions on the slope which may have contributed to the failure.

SELECTED STABILIZATION APPROACH AND DESIGN

Figure 3 is a cross section through the bluff depicting the stabilization scheme selected for this project. Global stability concerns were addressed by including various rows of post-tensioned tiebacks distributed on the slope face. Two rows of tiebacks were installed across the central and southern thirds of the slope. The bottom row of tiebacks was installed immediately behind the existing bulkhead. The upper row was installed about mid height on the slope. The northern portion presented more severe stability problems and was also a natural path for water runoff. In this area, three rows of tiebacks were installed.

Local bearing capacity failure of the shallow loose soils under the tieback loads could compromise the efficiency of the tieback system. Therefore, reinforced concrete tie beams were included in the design to transfer the horizontal component of the tieback loads to the ground. The concrete tie beams were designed as simple beams over an elastic foundation and included vertical expansion joints at regular intervals because of their significant length. Smaller sections of beam also allowed it to follow the horizontal contours of the slope and provide a snug fit against the sinuous slope surface.

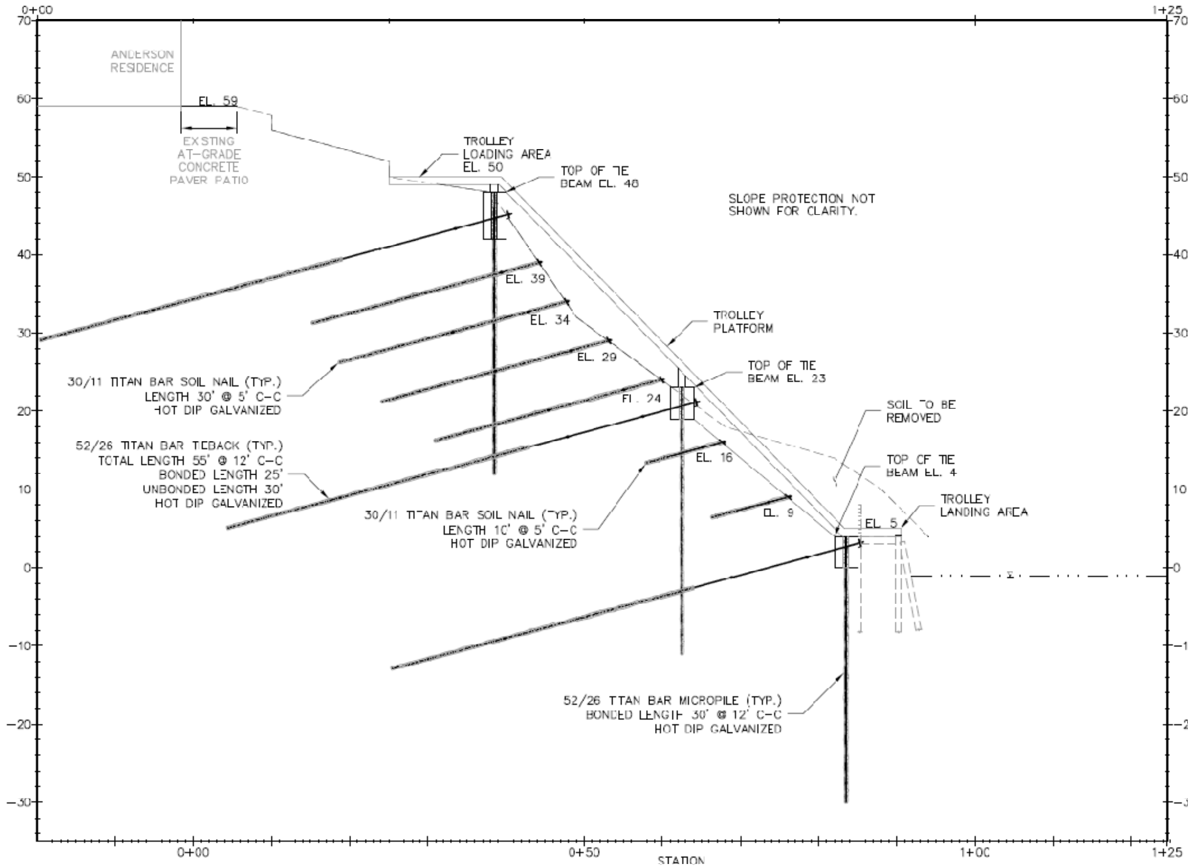

Figure 3. Typical cross section in northern portion of slope.

Micropiles were installed to provide vertical support for the tie beams under the vertical component of the tieback loads. They also provide additional safety in case scour at the base of the beams or local instability of the slope between the beams takes place over the life of the structure. In addition, the micropiles were conceived as soil reinforcing limiting the potential for localized soil "flow" under the tie beams and increasing the efficiency of the stabilization. The system of hollow core bar tiebacks and hollow core bar micropiles is therefore a post-tensioned A-Wall.

Micropiles were also used for underpinning of the undermined deck, and as foundation for the replacement trolley.

There was also concern about potential, local instability of the slope between the tie beams, which might lead to bearing or sliding failure of the grade-beams and loss of tieback support. To mitigate the potential for this mode of failure, a 5-foot pattern of relatively short soil nails were installed across the entire slope. The function of the nails was to prevent local instability of the slope and to affix the flexible membrane and vegetative substrate to the slope.

The use of micropiles in combination with tiebacks connected to concrete beams provided a stabilization solution that could be installed using light-weight equipment. The concrete beams could be partially buried or covered to blend with the vegetation on the slope. The designers used the computer software SlopeW by GeoSlope to perform local and global slope stability analyses of the slope. A back analysis was performed to estimate the properties of the soil strata at the site. These were compared to soil properties estimated based on correlations with Standard Penetration Test (SPT) blow count and grain size distribution. The minimum tieback forces required for a minimum factor of safety of 1.5 against global failure were determined considering the soil properties established from the back analysis. The analyses also considered the presence of the ground water table as depicted in Figure 4.

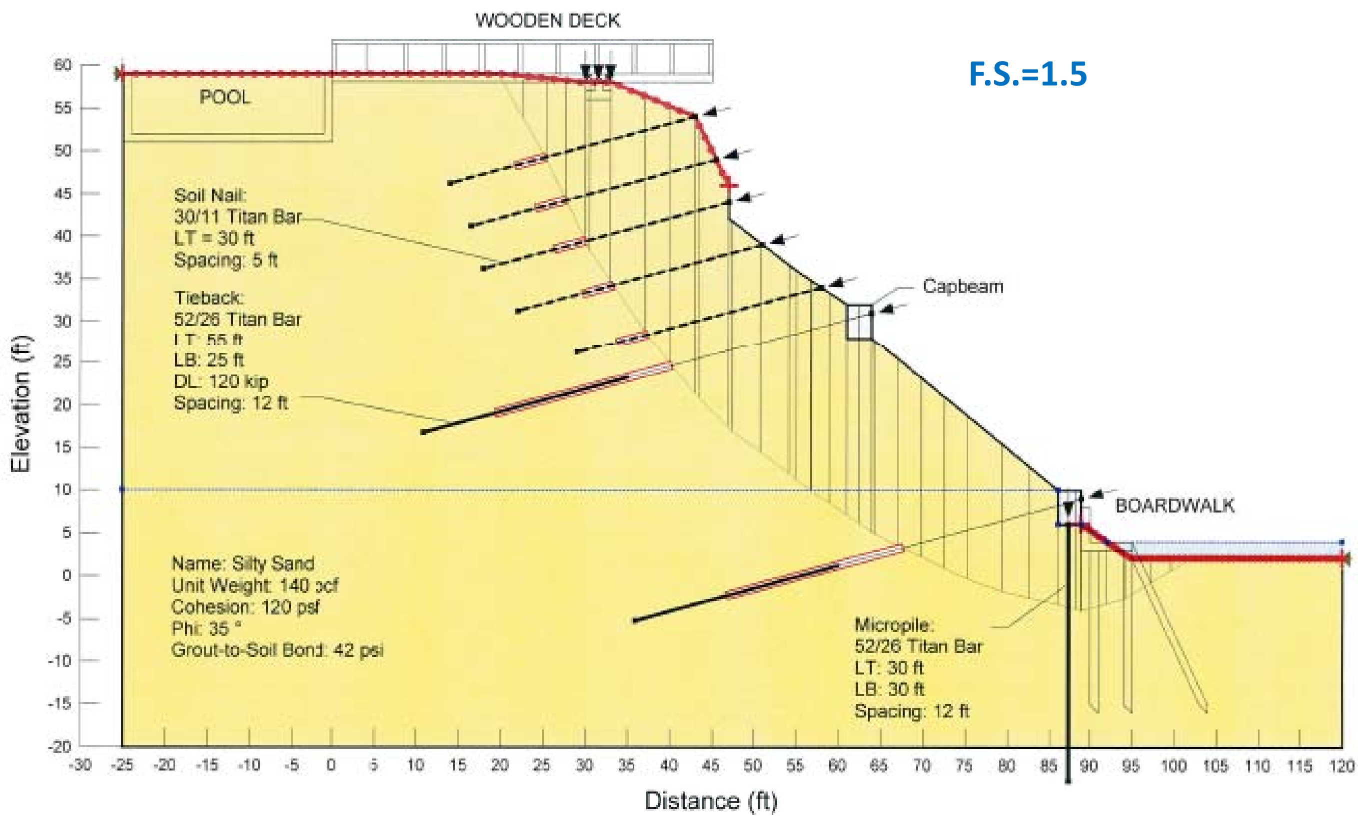

Figure 4. Slope Stability Analysis with Limiting Factor of Safety

MICROPILE INSTALLATION

The contractor Clark, Arvig, and Traylor (CAT) installed the micropiles using a drilling mast suspended from a crane. The crane was situated on a barge, which permitted limited lateral mobility on both sides of the dock. Toward the northern end of the site, it was necessary to position the crane on the shore as the barge could not approach the slope sufficiently. The reach of the crane boom allowed the drill mast to reach the upper portions of the slope to install vertical or sub-vertical micropiles (see Figures 5-8).

Figure 5. Barge arriving on site with crane and supplies.

Figure 6. Crane-suspended mast for micropile installation

Figure 7. Installation of hollow core bar micropiles for tie beam.

Figure 8. Completed tie beams on the northern end of the slope.

Hollow core bars were specified in the design of the micropiles for several reasons. In the experience of the authors, hollow core bars are ideally suited for granular soil formations, where they can develop substantial geotechnical capacity. Hollow core bars allowed the use of a light drill mast, which was critical in order to reach the upper portions of the slope with a reasonably sized crane. Finally, installation of the hollow core bar system is faster, allowing a reduction in the construction schedule, which is important when working on an unstable slope.

The design considered the use of hot dip galvanized 52/26 CTS/IBO Titan Bars, installed using neat cement grout with compressive strength f'c = 4,000 psi at 28 days. Load testing of the micropiles was not required because hollow core bars were also used for the tiebacks and soil nails, which were subject to verification and proof testing. The test data shows that the soil nails and tiebacks were suitable for a design bond stress of 21 psi with a factor of safety of 2.0. Soil nails proved suitable for a load transfer ratio of 3.9 kips per foot considering a nominal grout body diameter of 5 inches (3⅝" nominal bit diameter) and a factor of safety of 2.0. Tiebacks showed a load transfer ratio of 4.8 kips per foot considering a nominal grout body diameter of 7 inches (5¼" nominal bit diameter) and a minimum factor of safety of 2.0.

The micropiles were installed before completion of the tie beams. The connection of the micropile to the tie beams was achieved by direct bond of the hollow core bar to the beam concrete.

INSTALLATION OF MICROPILES FOR THE WOODEN DECK

The undermined wooden deck required stabilization, which was achieved by installing micropiles through the deck. Connection of the micropiles to the deck was developed using needle steel beams spanning the floor joists (see Figures 9 and 10). The micropiles were installed using the suspended drill mast and using hollow core bars identical to those used for the grade beams. The micropiles were adjacent to the top of portion of the slope, which sloped very steeply toward the middle tie beam below. Consequently, there was concern about the lateral stability of these micropiles. To address this issue, the density of soil nails was increased near the top of the slope to limit the potential for lateral movement of the micropiles.

The sequence of installation consisted of first removing the floor boards, then installing the micropiles using the suspended drill mast without placing any load on the deck. Then the needle beams were installed under the floor joists and bolted to the bearing plates of the micropiles to the floor boards. Finally, the needle beams were encased in concrete and the floor boards replaced. The owner indicated that this operation was closer to a surgical procedure than to typical construction. Once this operation was completed, there was no evidence of the significant foundation work that had just taken place.

Figure 9. Installation of micropiles through existing deck. The drill mast is suspended from the crane located on a barge below.

Figure 10. Needle beams for connection of micropiles to deck

As part of the micropile operation at the deck, an inclinometer was installed by the contractor through the existing deck. Periodic readings of the inclinometer have shown no movement since essential completion of the stabilization portion of the project in April 2009.

QUALITY CONTROL

The designer of the slope stability solution provided full-time observation during installation of the micropiles, tiebacks and soil nails. Field personnel logged the drilling rates, grout return, cutting types, etc. They also measured the specific gravity of the grout, and prepared grout specimens for compressive testing.

Drilling Rates

Drilling rates were measured during installation of each reinforcing element micropile. The authors found that measurement of the drilling rates was an invaluable tool to confirm the materials encountered and to have firm data for technical discussions with the project team.

Specific Gravity Measurement

Specific gravity was the primary quality control of the grout. It was measured using a calibrated mud balance according to API RP 13B-1, “Recommended Practice Standard Procedure for Field Testing Water-Based Drilling Fluids”. The specific gravity of the drilling grout varied from 1.5 to 1.7 The specific gravity of the final grout generally varied from 1.9 to 2.1. The minimum specific gravity value was specified at 1.4 for the drilling grout and 1.8 for final grout. Drilling grout was collected at the top of micropiles, tiebacks and soil nails to be recirculated. Once the final embedment of each reinforcing element was reached, a batch of final grout was mixed and pressure injected until all drilling grout was flushed. Recirculation of drilling grout allowed for better control of grout disposal and prevents grout from reaching the river. It is important to note that, for specimens of grout with specific gravity ranging between 1.8 and 1.9, the compressive strength after only three days was greater than 4500 psi. After 28 days, the compressive strength was greater than 6000 psi. In the experience of the authors, these results are typical of neat cement grout mixes.

CONCLUSIONS

Utilization of hollow core bar micropiles in this project provided an effective slope stability solution for a project with difficult access. This afforded significant schedule savings by allowing simultaneous micropile drilling, grouting and placement of reinforcing. Recirculation of the drilling grout allowed savings in cement and limitation of the environmental impact to the site.

During the repair of the slope, inclinometer casing was installed in two areas so that lateral movement of the slope could be monitored in the months following the repair. Inclinometer 1 casing is located at the top of the slope and has not shown any movement since the slope repair (approximately 18 months). Inclinometer 2 is located in the upper middle of the slope and has seen some shallow localized movements. These movements are likely due to a pathway being cut in the slope nearby and some shallow erosion occurring as a result.

Figure 11 shows the completed stabilization. The partially developed vegetative cover now entirely conceals the lower half of the stabilization system. It is projected that the upper half of the slope will also be entirely covered, although specific vegetation species will be required in the steeper portions.

Figure 11. View of the completed stabilization a few months after end of construction. Note slope partially covered in vegetation (Photo courtesy of owner)

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