Flexible Rockfall Mitigation Design for Varying Site Conditions

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ABSTRACT

Perry County, Pennsylvania is the location of the longest stone masonry arch railroad viaduct in the world. To provide sandstone blocks needed for bridge construction, quarries were developed near the bridge. A road was later constructed at the base of the quarry high-walls in the 1930s which later became U.S. Route 11, a heavily-traveled commuter highway.

Soon after highway construction, rockfall hazards to the highway developed. At the time of construction, rockfall mitigation from the highly fractured, sandstone highwall was not considered. In 2015, the Pennsylvania Department of Transportation (PENNDOT) retained a local geotechnical engineering company to perform the initial site investigation, analyses, and preliminary mitigation design.

Following the project bid award, the contractor was required to retain a consultant engineer specializing in rockfall mitigation. The engineer’s responsibility was to finalize the mitigation design following clearing of the vegetation and scaling. The engineer then provided daily construction oversight which allowed design modifications to be made quickly and efficiently. The engineer and contractor could implement in-field changes as construction proceeded. Due to the highway closure, a strict deadline of forty days to complete the construction was put in place. Open and rapid communication between all parties allowed the project to be completed within time constraints. In addition, the formation of a team of the most qualified contractors and geohazard specialists available created the optimal environment for a successful project.
INTRODUCTION

Rockfall mitigation in the United States has become essential when constructing and improving roads and highways adjacent to rocky slopes or blasted high-walls. Due to the necessity of rockfall mitigation, the technology and infrastructure for rockfall protection has grown greatly in recent years. Improved options to mitigate different rockfall situations have allowed engineers and geologists to design and implement the most appropriate mitigation for each unique hazard present in a rockfall prone area. A combination of systems often provides the best mitigation for complicated rockfall hazards. By conducting a detailed site investigation and rockfall analyses, rockfall energies can be accurately modeled for specific sections of the site. The findings and results can pinpoint locations of higher rockfall energies for specific mitigation, thereby optimizing the overall mitigation with a combination of systems. In this way, the overall design maybe reduced in size and price, Figure 1.

1. Combined drapery mesh and rockfall barrier for rockfall mitigation

Mitigation options used in rockfall protection today include passive rockfall protection and active rockfall protection. Passive rockfall protection includes systems that allow rockfall to occur, but in a controlled manner. Examples of these systems include rockfall barriers, attenuators, draperies, ditches, and embankments. Active rockfall protection systems prevent rockfall from occurring. Active systems include pinned or tensioned mesh, rock bolts, and cable lashing. There are advantages and disadvantages with each system, but the distinct characteristics of the site conditions and the surrounding area determine the best option(s) for mitigating the hazards present.
BACKGROUND

The project site is in Perry County, Pennsylvania along U.S. Route 11. Geographically, Perry County is located in the State of Pennsylvania north of Harrisburg, along the Susquehanna River, Figure 2. Perry County is the location of the largest stone masonry arch railroad viaduct in the world. It is in still in use today. To construct the bridge, sandstone blocks were quarried from the adjacent river bluffs. Highwalls ranging in height from 300-ft to 1,100-ft high resulted from the blasting exposing interbedded layers of fractured sandstone and soft shale. Due to the differences in resistance to erosion, differential weathering occurs resulting in large overhangs of highly fractured sandstone throughout the area. Over time, these highwalls became highly vegetated with shrubs and trees varying in size reducing the visibility of the site’s geologic exposures.

In the 1930’s the interbedded sandstone-shale highwalls became the boundaries of U.S. State Route 11. During the initial construction of the road, rockfall was not considered resulting in numerous rockfall events impacting the road. These rockfall events were not only dangerous, they also created a great deal of maintenance work for the Pennsylvania Department of Transportation, (PENNDOT). Small catchment ditches were constructed along the toe of the highwalls to help limit the number of rocks entering the road, but have not been effective in providing protection to drivers, Figure 3. In 2015, PENNDOT decided to move forward with designing rockfall mitigation along U.S. State Route 11 in Perry County.

The mitigation construction project was a design-build contract where preliminary plans, designed and engineered by a local firm, were utilized as a basis for design. The awarded contractor was responsible for obtaining an engineer experienced in rockfall mitigation to design and finalize the preliminary rockfall...
The retained rockfall engineer was to be present onsite daily during the construction to address any concerns and to work closely with PENNDOT and their contracted engineer if any in-field changes were necessary.

The site required full traffic control which included a total road closure for most the construction. This created major traffic delays and detours in the area. Because U.S. Route 11 is a heavily traveled road, the project had a strict deadline of 45-days for construction completion.

**SITE GEOLOGY**

The project site is part of the Valley and Ridge Physiographic Province of Pennsylvania. This area is located within the Appalachian Mountain Section and the Susquehanna Lowland Section of the Province. Compressional forces formed a series of synclines and anticlines throughout the area creating long, narrow ridges and valleys. The project area is located on the south limb of a regional fold known as the Cove Syncline.

The rock types found throughout the Perry County Project area are of the Bloomsburg Formation, (Boyer, 1984) and are mostly interbedded, fissile shale and fractured sandstone with a thick conglomerate bed at the southern-most section of the road cut. Due to the differential erosion, and fractured nature of the sandstone, over hangs dominate the slopes causing continual rockfall, Figure 4.

**PENNDOT PRELIMINARY SITE INVESTIGATION AND MITIGATION DESIGN**

Prior to the Project’s bid, a local engineering company was retained to conduct a site investigation, rockfall analyses, and provide a preliminary mitigation design based on their findings.
The preliminary investigation was conducted before clearing and grubbing of the slope’s thick vegetation. Conducting a rockfall investigation on a highly-vegetated slope is not ideal for design. Areas that may prove important may be overlooked if their location is covered with vegetation. Using visible outcrops, available reports detailing geology, and a surveyed topographic overview of the area, the retained engineering company could obtain general rockfall bounce heights and energies. These results were utilized in the design of the preliminary rockfall mitigation plan for the two highwalls within the project area.

The bid plans outlined a general concept of installing a drapery mesh in areas producing lower energy rockfall. It was requested the drape be pinned along the base of the slope to help with limiting maintenance along the roadside. A large, low-deflection rockfall barrier was also specified for areas with higher energy rockfall. To mitigate smaller, overhanging areas of the slope, it was recommended to support the overhangs using re-enforced shotcrete. An additional area of concern was a thick, acid-bearing shale bed. This shale layer is extremely susceptible to erosion and underlies a more resistant sandstone layer creating large overhangs at the contact, Figure 5. The preliminary design called for this area to be further investigated and a recommendation for stabilization be provided to PENNDOT for approval.

These preliminary plans provided a general plan for mitigation, and was put out to bid to contractors for construction. The contractors were responsible for sub-contracting the finalization of the mitigation plan to an engineering consultant of their choice.

**DESIGN FINALIZATION**

Following the project’s award to HI-TECH Rockfall Construction, KANE GeoTech was retained by HI-TECH to finalize the drapery and tensioned high-strength steel mesh designs, and submit construction drawings to be reviewed by PENNDOT and their consulting engineer. KANE GeoTech visited the site to verify the locations of the preliminary design for mitigation. However, heavy snowfall and vegetation made it difficult to verify the locations specified in the preliminary plans, Figure 6. KANE GeoTech used the available resources provided by PENNDOT to complete the final engineered design of the preliminary plans.
The final design consisted of anchor depths and locations for the previously recommended rockfall drapery. KANE GeoTech recommended that Geobrugg TECCO high-strength steel wire mesh be used for the drapery and that most of the localized reinforced shotcrete support systems be replaced with tensioned Geobrugg Spider mesh systems to allow for a larger stabilization coverage area. Tensioned Spider mesh was also used in stabilizing large, sandstone blocks that were overhanging at the contact with the acid bearing shale seam.

Due to the highly-fractured nature of the slope, and the fractures’ orientation, KANE GeoTech specified long rock dowels, approximately 20-ft, along the base of the slope. These bolts acted to create a buttress for the base of the slope and were also utilized as the maintenance pins for the bottom drapery rope requested by PENNDOT.

KANE GeoTech utilized the provided Geotechnical Report and the Post Tensioning Institute (PTI) Guidelines to calculate the anticipated loads and dowel depths for the TECCO drapery anchor design. The Geobrugg software, RUVOLUM, was used in the Spider sections’ anchor design and layout.

The finalized design was reviewed by PENNDOT and their consultant engineer and the notice to proceed with construction was given to the contractor, HI-TECH Rockfall Construction, (HI-TECH).

**IN-FIELD DESIGN CHANGES DURING CONSTRUCTION**

Prior to the start of construction, the slope’s heavy vegetation was cleared exposing a number of additional potentially hazardous areas. KANE GeoTech worked closely with HI-TECH, PENNDOT, and their contracted engineer to design and engineer additional protection in areas that were not concerning prior to vegetation clearing. The tensioned Spider mesh was easily utilized in several areas making field condition changes quick and efficient when needed. Revised final plans and drawings were submitted to PENNDOT for review and approved for construction, Figures 7 and 8.
7. Final plan for Southern highwall using tensioned Spider mesh overlaid with TECCO drapery

8. Final plan for Northern highwall using tensioned Spider mesh overlaid with TECCO drapery
CONSTRUCTION SEQUENCE

Due to the different components of the systems used to the rockfall mitigation systems, and the strict timeline for construction, a detailed plan for construction was created to maximize efficiency. Construction on the face of the slope was prohibited to prevent uncontrolled rockfall before road closure went into effect, however, drapery anchors were authorized to be drilled at the slope’s crest prior to the road closure. This maximized the time for site preparation and reduced the amount of drilling during the allotted 45-days. The TECCO mesh was also cut and seemed into panels during this preparation time for quick and efficient installation.

Following the road closure, the slopes were completely cleared, grubbed, and scaled. As a part of the PENNDOT specifications, a temporary, moveable rockfall drape was designed and used during scaling to protect the road, workers, and the railroad located below U.S. Route 11, Figure 9.

Verification anchors were installed and tested to verify rock strengths in actual, worst-case field conditions, Figure 10. By conducting these tests, an in-field rock/grout bond strength was obtained so anchor depths could be drilled to their most appropriate depth.

Following clearing, grubbing, and scaling the tensioned Spider section anchor holes were laid out and drilled using two air rotary drills hung from cranes. An additional air rotary drill mounted to a Spider excavator subsequently drilled the bottom Spider section holes and 20-ft holes for the buttress anchors. Anchors were then installed and grouted.
The Spider mesh was hung and tensioned down at each location to conform to the slope using the manufacturer’s anchor plates, Figure 11.

After the tensioned Spider mesh installation was complete, the TECCO drapery mesh was installed by a helicopter raising and laying the prepared panels on the crest of the slope, Figure 12. These panels were shackled to the installed anchors and wire support rope at the crest of the slope. The TECCO panels were then laced together vertically and along the bottom of the mesh with wire rope. Finally, the bottom of the mesh was pinned along the toe where the buttress anchors were installed.

A final inspection of all connections and system components was conducted by KANE GeoTech following the construction completion. A letter of conformance was submitted to PENNDOT for review and was approved bringing the rockfall mitigation construction on U.S. State Route 11 to a close.

CONCLUSION

As a result of heavy rockfall, a need for mitigation along U.S. Route 11 in Perry County was inarguable. Because the hazards in this area are so complex, utilizing different rockfall mitigation approaches allowed for the best possible protection to be installed, Figure 13. By permanently stabilizing the large fractured areas with tensioned Spider mesh, the need for large barriers throughout the sectioned was eliminated. Also, by substituting the tensioned Spider mesh for the originally planned shot-crete, a larger area of the slope was able to be stabilized, thus increasing the rockfall protection.

The design-build approach taken by PENNDOT was successful. However, the number of in-field changes may have been avoided if the preliminary design was less specific. Once the
slope was cleared prior to the final design, a more appropriate design for the site conditions was possible. Nevertheless, having an engineer’s representative onsite daily allowed these in-field changes to be made quickly and efficiently.

REFERENCES
