Design/build pyrite remediation project using geosynthetics helps open Pennsylvania freeway

A host of geosynthetic materials was used to address iron pyrite issues on Interstate-99

By Archie Filshill

Introduction

The Pennsylvania DOT's Interstate-99/S.R. 6220 project extends from the village of Bald Eagle to the Mount Nittany Expressway (U.S. 322) in Centre County, just west of State College. The project involved the construction of a four-lane, limited-access highway with four interchanges and approximately 18 miles of roadway.

Early in construction, more than 600,000 m³ of iron pyrite rock were excavated. When iron pyrite is exposed to air and precipitation, the potential for acidic runoff or acid rock drainage (ARD) exists. The acidic runoff contains elevated concentrations of contaminants, including heavy metals and sulfates. The runoff from these areas can dissolve and leach minerals from the rock that can...

Project Highlights

I-99 pyrite remediation
Timeline: December 2006–November 2008
Design/build contractor: CETCO Contracting Services, Trevose, Pa.
Engineer: Te-Yang Soong, CTI Associates
Geotextile: Geotex 1701, Propex, Chattanooga, Tenn.
Geomembrane: 40-mil HD Micro Spike, Agru/America, Georgetown, S.C.
Geocells: Geoweb, Presto Geosystems, Appleton, Wis.
Geocomposite: Texgrid, Huesker, Charlotte, N.C.
Distributor: ACF Environmental, Richmond, Va.

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potentially degrade the quality of a designated exception-quality trout stream nearby and also pollute local residential water wells.

The initial highway construction started in the spring of 2002 but all work was suspended in early 2004 in an effort to remediate and control the ARD that was occurring.

PaDOT started the process of evaluating many design concepts to encapsulate the slopes during 2004 and settled on a design/build approach. The design/build process included the ARD remediation design, detailed environmental reviews, and final permitting by the state’s Department of Environmental Protection. In addition, a series of town meetings were held among the host municipalities, PaDOT, PaDEP, and CETCO Contracting. The final permitted design included multiple layers of various types of geosynthetics used to prevent ARD from the exposed slopes.

Initially, the iron pyrite areas responsible for environmental concern were divided into two groups: movable and immovable. The moveable material was estimated at 600,000 m³. This material was excavated from large highway cuts through Skytop Mountain, and was either placed in embankment fills or stockpiled as waste material.

The immovable areas contained material that could not be transported or areas that would jeopardize the integrity of the roadway if moved. These areas included any of the remaining cut faces, embankment fills between bridges, and the bifurcation/buttress embankment fill. The bifurcation/buttress fill material had to remain in place due to slope stability concerns if it was moved. The pyritic waste areas and fills were temporarily tarped to prevent runoff from precipitation.

The remediation plan was twofold: (1) encapsulate the immovable material to prevent ARD, and (2) construct a repository for the moveable pyritic soils.
Encapsulate the immovable material
The design/build solution for the immovable material was to cover the slopes with a textured, high-density polyethylene (HDPE) geomembrane, protect the membrane between two heavy weight nonwoven geotextiles, and cover the entire system with a three-dimensional cellular confinement system filled with crushed stone.

The cellular confinement system is supported throughout the slope with high-strength stainless steel cables embedded in an anchor system above the limits of the geomembrane. The anchoring system varied throughout the project based on slope factors and access to the top of slope. There were more than 160,000m² of slopes requiring protection and the slope inclinations were varied from 3H:1V to 1H:1V.

Repository for the pyritic soils
The plan for the moveable pyritic soils was to construct an engineered rock placement area (ERPA) and encapsulate the material after blending with an alkaline waste product to balance the pH.

The ERPA was constructed along the right-of-way of the project. It consists of a geosynthetic composite-lined facility with a permanent geomembrane cap. Construction sequencing was designed to minimize stormwater runoff.

Immovable category
The immovable rock cover system was designed so that it could be applied to all of the various slopes with only minor modifications for each.

The several slope faces designated as "immovable" ranged in length from 9.0m (30ft) to 120m (400ft) and had slope inclinations from 3H:1V to 1H:1V. Due to the various lengths and slope inclinations, the general slope cover system design was adapted to meet the specific demands of each section. In particular, the slope length strongly influenced the reinforcement demand while the topography of the crest of slope limited the range of practical anchor types and dimensions.

While the use of geocells for erosion control is not itself novel, three project-specific requirements created special design challenges. These included: (1) no penetrations through the liner system were allowed on the slope face, (2) no frictional resistance to sliding on the slope face was allowed in consideration of the system stability, and (3) limited upslope area was available for anchor construction. These constraints demanded significant engineering analysis to arrive at an economical design for each section.

Geosynthetic liner system
The liner system consists of three layers: (1) 540g/m² (16oz/yd²) nonwoven geotextile bottom cushion, (2) 1.0mm (40mil) HDPE geomembrane, and (3) 540g/m² (16oz/yd²) geotextile top cushion.

The top and bottom geotextile cushions were selected to protect the geomembrane against damage by the crushed stone selected for the protective cover and irregularities in the subgrade. Because of regulatory agency demands and the slope inclinations at the project site, retention of the protective cover stone was not possible through interface friction alone. Therefore, a reinforced geocell system was required for both erosion control and general stability.
Two different reinforcement techniques were applied: (1) geogrid reinforcement of the cover materials where slopes allow its use, and (2) stainless steel wire rope reinforcement of the geocell on the longer and steeper slopes. Sizing of the reinforcement and its anchorage proceeded according to stability considerations for each section.

Most reinforcement design concerns involved the stainless steel wire rope tendons proposed for the longer slopes. The initial design recommended the use of a lightweight fill to reduce the load demand placed on the reinforcing tendons. This design was prohibitively expensive and an alternate design using conventional stone materials for the protective cover was implemented.

As a result, higher strength reinforcement and anchorage were required. Given the site constraints, an understanding of the function of the selected stainless steel tendon reinforcement and unconventional anchorage systems were key to resolving these issues.

**System redundancy and anchors**

System redundancy was provided as follows:

1. The load stresses on the tendons were calculated assuming no contribution of friction by the cover system to resist sliding. Interface friction test results on the actual liner materials installed indicated that significant frictional resistance was available.

2. More than 50% additional tendons were included in the design than required to support 100% of the downslope load from the cover system without breaking. Thus, significant redundancy is built into the reinforcement system.

Anchors designed for the 1-99 slope cover system are of several types. For the geogrid-reinforced sections, the geogrid was anchored through burial in a trench. Tendon anchors required for the geocells included 3 types: (1) concrete deadmen, (2) laterally-loaded piles, and (3) ground anchors. The type of anchor selected for each section depended on the load demand and the available space.

The concrete deadman anchor was employed along the large buttress (below-left), which had relatively abundant space and short slopes. Laterally-loaded piles were used on the small cut face, which had longer slopes and limited space. The vertical installation of the piles allowed sufficient construction vehicle access behind the anchor.

Steel beams were placed behind these piles to anchor the tendons. The large cut face had the longest slope, 107m (350ft), and hence the greatest load demand. Space was also limited here. Unlike the small cut face, the pile size required would be prohibitive, but sufficient back-
slope was present to permit the installation of ground anchors.

**Reinforcement**

Where geogrid was used to reinforce the cover system, the geocell only provides lateral confinement and erosion control, with all loading transferred directly from the cover material to the geogrid.

When using the stainless steel tendons, the geocell also functions to transfer the load from the cover material to the reinforcement. A key consideration in the reinforcement application of geocell was the amount of load that could be effectively transferred from the tendon to the geocell. Load is transmitted from the geocell to the tendon through a bearing-washer/stop-sleeve assembly.

The stresses developed within the stop-sleeve/tendon connection are well-understood. However, the bearing resistance of the washer against the geocell was less understood. Due to the attention given this issue by PaDOT and PaDEP, a laboratory study of this pullout resistance was completed.

In this study, a prototype washer assembly was pulled through a two-ply geocell wall to simulate the loading in the field. The ultimate load obtained from this test was 2.89kN (650 lbf) for a 100-mm (4-in.)-deep, 1.3-mm (50-mil)-thick geocell. This value was exactly twice the value predicted with the single-ply strength of the perforated geocell wall ($T_w$) as input. Thus, the pullout strength at these connections was limited by the tensile strength of the adjacent perforated geocell wall sections. This conclusion was supported by the failure mode observed in the laboratory.

In summary, the greatest challenges involved selecting safe, economical reinforcement and providing adequate an-
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chorage to that reinforcement within a limited space. The unique scope of the project provided an examination of specific aspects of the geocell reinforcement that may contribute to future designs of similar systems.

**Moveable category**
The movable material was estimated at 600,000 m³ of pyritic rock, which was stockpiled on-site and temporarily tarped to prevent runoff from precipitation.

The plan was to construct an engineered rock placement area (ERPA) and encapsulate the material after blending with a waste lime product to balance pH. The ERPA was constructed along the right-of-way of the project. It consisted of a geomembrane/geosynthetic clay liner (GCL) cell floor and single geomembrane liner cap. Construction sequencing was designed to minimize stormwater runoff from the site.

A large containment berm surrounded the footprint and anchored the bottom barrier liner system. The bottom liner system consists of: (1) compacted soil subbase, (2) double-sided drainage geocomposite serving as a detection zone, (3) composite liner system consisting of a GCL and 60-mil high-density polyethylene (HDPE) geomembrane, (4) collection piping network within an 18-in.-thick layer of aggregate, and (5) geotextile cushion also serving as protective cover for the geomembrane.

Beneath the liner system, a network of underdrain trenches was installed to intercept shallow groundwater and divert it away from the liner system. The pyritic rock was then placed over the lining system, mixed with waste lime, and compacted in lifts to form a dense fill. Once placed, the pyritic rock/waste lime fill was covered with a capping system.

The capping system includes: (1) soil cover base, (2) 40-mil linear low-density polyethylene (LLDP) geomembrane, (3) double-sided drainage geocomposite, and (4) 122 cm (48 in.) of final soil cover to support a varied planting of approved grasses, shrubs, and trees.

At the perimeter of the fill area, the cap geomembrane liner was anchored with the bottom liner, thereby fully encapsulating the pyritic fill.

The geosynthetic materials portion of this project started in December of 2006 and was completed in November 2008.

**Conclusions**
Geosynthetics played the key role in a design/build proposal to remediate pyritic soils for this major highway project in central Pennsylvania.

The design/build option offered significant savings to the DOT but also offered an engineered solution that was constructed within the tight timeline required by PaDOT. The design had to pass the scrutiny of PaDOT, PaDEP, and local municipalities and residents.