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# GFR

**Engineering Solutions**

**for Roads, Soil, Water and Waste**

## *Transportation Applications*

- *Save rail lines from slope erosion*
- *Control roadway drainage and sediment migration*
- *Protect groundwater from deicing runoff*

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# Weatherizing steep slopes with geocells

## *A permeable geocellular system reinforces a deteriorating slope, preserving a railroad line.*

Unusual problems call for unusual solutions. That's why a 75-mm (3-in.) thick layer of crushed rock, confined by honeycomb-like geocells, is being used to protect the surface of nearly 1.2 ha (3 acres) of long, steep cut slopes along a 0.4 kilometer (0.25 mi) of Burlington Northern Santa Fe's (BNSF) track in the U.S. Pacific Northwest.

## Site history

The idea is to prevent the kind of landslides that occurred at this site near Castle Rock, Wash., on the railroad's busy double-track mainline between Portland, Ore., and Seattle, Wash., in February 1996. That winter, after record precipitation, the saturated soils gave way, burying the tracks under 1.5 to 3 m (5 to 10 ft.) of mud and another 1.5 to 3 m of tangled, uprooted trees. The landslides blocked heavy freight and passenger traffic for five days.

Like most areas of Washington west of the Cascade Mountains, long spells of rainy weather are the norm. In the previous few years, wet conditions had caused smaller traffic-blocking slides in the Castle Rock cut in the previous few years. The rainfall events that precipitated these slides far exceeded the norm. What's more, the massive slope failure in 1996 and subsequent failures in 1998 were far from typical. The five-day average precipitation preceding the 1996 landslides was the highest since records were first kept in 1931. The four months preceding the slides were also recorded as the wettest four-month period on record. Landslides again occurred at the site in December 1998 following heavy rains and the wettest combined November and December precipitation on record.

## Challenges

Site conditions ruled out traditional solutions. So the engineering consulting firm, Shannon & Wilson, recommended a non-traditional approach to solving the problem - improve the slope resistance to weathering by installing a fully-engineered geocellular system filled with coarse aggregate.

The idea made sense. But it also meant that the project contractor, Wilder Construction, had to devise some unconventional construction techniques for dealing with the challenging site conditions.

This BNSF Rwy. Co.-managed slope-protection project is the first of its kind in the region. The $1.1 million funding for the project itself was a result of the joint contributions under a grant program for innovative engineering practices by the Federal Railway Administration and the Rail Division of the Washington Department of Transportation.

**Photo 1**. Prior to the installation of the geocellular system, heavy storms had caused landslides that blocked rail traffic for five days.

In tackling this project, the engineers and construction crews faced a number of hurdles:

*Weak* soils. When wet, the uniform silt soils on the slopes weather and can lose their structure and apparent cohesion.

*Tricky slopes.* The 30-to-60-degree slopes, ranging 18-30 m (60-100 ft.) long (measured along the slope from top to bottom), not only added to the soil stability problem, but complicated the task of working on them.

*Tight access.* Access to the slopes was restricted at the top by a right-of-way that extended back no more than about 6 m (20 ft.) to private property lines. Meanwhile, the bottoms of the slopes edged to within about 4.5 m (15 ft.) of the railroad tracks. Access to the bottom was established by temporarily filling the ditch to construct a road between the track and slope toe. These tight spaces limited the size and operation of construction equipment.

*Rail traffic.* Slope repair work could not disrupt the movement of trains, which pass by the area every hour or so. For safety, construction work on the slope was halted when trains passed, resulting in 10 to 15 minute work disruptions.

A *short deadline. To* beat fall rains, the construction schedule called for completing slope repair work within 45 days of the project's late September 2000 start.

## Analyzing the options

Shannon & Wilson's engineering team, led by geotechnical engineer Stan Boyle, Ph.D., PE., considered a number of different approaches to stabilizing the slope. Reducing the slopes to a more stable 2H: 1V gradient would have required moving the top of the slope back 18 m (60 ft.) - not only very expensive, but well beyond the edge of the right-of-way. Covering the slopes with shotcrete was rejected as unattractive and too costly. Building catchment walls along the toe of the slopes to prevent mud and other material from flowing onto the tracks was another

*Photo 2.* Precarious installation conditions and an abbreviated work window challenged the construction team.

alternative; but that entailed the added maintenance expense of periodically cleaning out the accumulated material and train traffic disruption, not to mention difficult access for excavators and trucks.

A 6-m (20-ft.)-high vegetated retaining wall along the toe of the slope was another option. Backfilling behind a wall like this could help flatten the slope, increasing its stability. But the estimated construction costs of a wall were prohibitive. Installing a soil-filled geocell system on the face of the slope to support the growth of grass and other vegetation was also considered and would have been more economical than a vegetated retaining wall. However, this approach was discarded because of concerns that plant roots would increase fracturing and loosening of the silt soils and hasten the weathering process - the major factor contributing to the landslides in the first place.

That left one other option: protecting the slopes with a perforated geocell system, filled with 35 mm (1.5-in.)-minus aggregate and underlain by a nonwoven geotextile. The solution was affordable and would discourage plant growth. It would reduce vegetation maintenance costs and root loosening of soils. Flow of rain down the slope within the geocells and aggregate would reduce the rate at which water entered the drainage system at the bottom of the slopes, thus avoiding the need to expand downstream detention systems.

## *Engineering strategy and design*

To slow the weathering process - rain and runoff - loose and weathered soil was stripped from the slopes and the underlying firm, in-place soil was covered with the geocell system. This would effectively minimize the wet-dry and freeze-thaw cycles, as the geocell would act as a protective cover, providing insulation for the soils.

By confining infill material within a network of interconnected cells, the geocell system stabilizes the aggregate on a slope steeper than its angle of repose. For this project, Presto Products' Geoweb® geocell with an engineered pattern of textured, perforated cell walls was selected to increase frictional resistance between the walls and the aggregate infill. Also, it allows lateral drainage through the system. The standard 230-mm (9-in.) diameter cells used in this project measure 75 mm (3 in.) deep. This size provided the minimum cell depth required to retain the gravel in the cell for the slope inclination at this site. Also, it reduced both the total weight of the system to be supported on the slopes and the total aggregate costs compared to a deeper cell. Often, on slope protection projects, steel stakes are used to anchor geocell sections and transfer the system's load to the ground. However, because of geological conditions and the way the soil weathers, the downslope resistance normally provided by stakes wasn't reliable. Instead, tendons, threaded through holes drilled in the geocell panels and anchored at the top of slope, provided the resistance to potential sliding. The tendons were attached to a 100-mm (4-in.) diameter deadman pipe buried in a 0.6-m (2-ft.) wide, 1.2-m (4-ft.) deep anchor trench a few feet west of the slope crest. Steel anchor stakes were used on the project to help secure the panels and hold them in place during infill placement.

The design called for 12 to 20 polyethylene-coated high-strength polyester tendons per 2.4-m (8-ft.)-wide geocell section; the number of tendons depended on the slope length and angle. These tendons had a minimum breaking strength of 600 kg (1,600 lb.). However, because of the fast-track nature of the project, the large quantity of tendon material needed, and the special manufacturer-required polyester-tendon, delivery could not meet the abbreviated construction schedule.

To maintain the schedule, galvanized steel wire rope, protected with a polyvinylchloride coating, with a minimum breaking strength of 2,600 kg (7,000 lb.) was substituted for the polyester tendons for about half the treated area. Due to its much higher strength, only four steel tendons were required for each 2.4-m (8-ft.)-wide geocell section. Load was transferred from the geocells to the tendons by tying ATRA® restraint clips to polyester tendons and attaching wire rope clips to

*Photo 3.* Following close upon the excavation crew's work, the installation team placed geotextile on the prepared slope face.

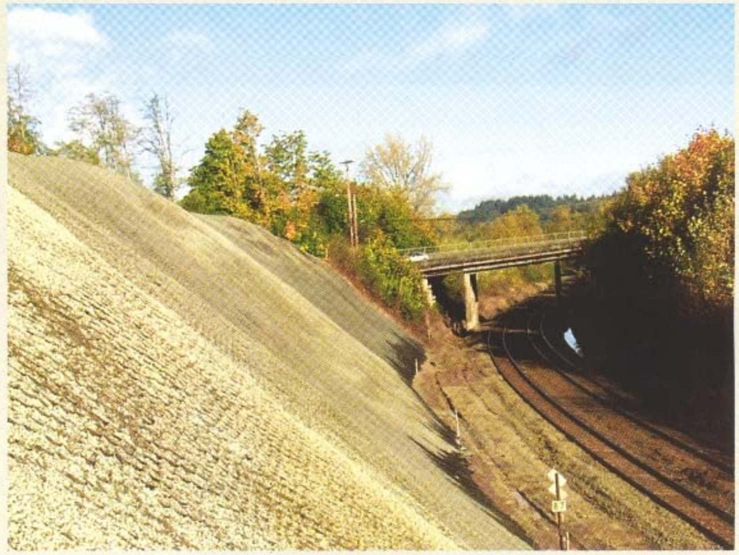

***Photo 4 (top)***. To reduce erosion and the potential for sediment runoff to nearby salmon-bearing streams, no more than 40 ft. (12 m) of slope was left exposed after each work day.
***Photo 5 (right)***. The slope after concrete fill.

wire rope. The restraint clips and wire rope clips were installed on about 1.4-m (4.5-ft.) centers along the length of each tendon and below each stapled connection of geocell panels.

The geotechnical engineer chose to place the geocell system on top of a 7-oz./yd.² non-woven geotextile to reduce erosion and rilling of soils below the geocell by water flowing through or beneath the geocell and infill material, permit infiltration during typical rainfall, and encourage runoff during intense storm events. While a geomembrane would have prevented any water from soaking into the ground and adding to the weathering problem, it would have required more expensive methods to anchor the geocell system and was less cost-effective than the geotextile. Plus, benefits offered by a geomembrane would be offset by the ability of the geotextile-geocell system to permit water to infiltrate the slope and avoid groundwater pressure buildup.

## *Installation techniques*

Wilder Construction displayed creative thinking and impressive equipment-operating skills in preparing the slopes and installing the geocellular system.

The first step was to smooth the slopes for the geotextile by removing vegetation and loose soil. Depressions left by uprooted trees were shaped - no easy task considering the height and steepness of the slopes. Access restrictions at the top and bottom of the slopes, train traffic considerations, and soft, wet soils prevented the use of heavy excavators to do the work. Instead, a spider excavator operating on the slope was used to prepare the slope. The excavator was cabled to a bulldozer at the top of the cut slope and a hydraulic winch was used to lower and raise the excavator as it progressed across the slope. Skillfully working the boom, bucket and legs of the excavator, the operator kept one step ahead of another crew, which covered the prepared slope face with the geotextile. At the end of each day, only a swath of prepared slope, no more than about 12 m (40 ft.) wide, was left exposed, the rest having been covered with the geotextile. That was done to reduce erosion and potential for sediment to be transported to nearby salmon-bearing streams.

Next, the geocells and tendons were installed. The number of individual panels required to cover each length of slope (top to bottom) were stapled together and placed at the top of the slope. After threading the tendons through holes drilled into the walls of the compressed panels, the tendons were attached to the deadman pipe. Next, laborers, tethered on safety harnesses, brought the geocell structure down the slope, expanding the panels like a venetian blind as they went and securing the tendons at the bottom.

The ability to adjust the width and length of each panel proved helpful in keeping the edges straight while accommodating dips, mounds and other curves on the slope faces. The installation crew spray-painted a plumb line to indicate where to place the edge of each succeeding geocell section, and the panels were stretched or compressed to fit.

The crew worked from personnel hoists, stationed at the base of the slope, to drive the stake anchors, secure the geocell to the slope, and install clips and wire rope clips on the tendons. In addition to speeding the work, the use of personnel hoists improved safety and reduced potential damage to the geocell from personnel working on the slope.

Filling the expanded geocells with AREMA No.4/No.5 aggregate also required some innovative techniques. That was accomplished using a concrete conveyor truck equipped with a 30-m (100-ft.) conveyor boom. A flexible elephant trunk on the end of the conveyor allowed the crew to fill the cells while dropping the rock from a height of no more than 1 m (3 ft.) so as not to damage the geocell or displace geocell sections. Accurate control of the elephant trunk and conveyor feed rate effectively eliminated the need for hand rakes to distribute the infill evenly across the slope face.

Construction crews were able to place a tremendous amount of rock in a short period of time. The conveyor truck was brought in only three different times to do the entire slope, resulting in significant labor savings.

## *Encouraging results*

Because of the project's experimental nature, the geocell system was installed only on the west side of the cut. As part of the project, BNSF and the engineering lead are monitoring the effectiveness of the geocell system in reducing weathering of the soils. In addition to covering 490 m (1600 ft.) of slope (parallel to the railroad) with geocell, a 23-m (75-ft.)-long test section was created on the southern end of the project. The slope for the test section was stripped of vegetation and loose soil, as was done for the geocell-covered slope, but was hydroseeded with grass instead. An erosion mat was placed over the hydroseeded area to help reduce erosion until the grass was established.

One-and-one-half years after the project was completed, soil in the hydroseeded area had weathered to as deep as 0.6 m (24 in.). However, the soils protected with the geocell system are moist, but not wet, loose to a depth of about 2.5 cm (1 in.) and medium stiff for another 5 to 8 cm (2 to 3 in.). Below that, the soils remain firm and unweathered.

The untreated east slope of the cut continues to experience some slumping. Although the results of the test plots met the design engineer's expectations, it was noted that the soils with the hydroseeding treatment showed significant weathering for such a short time. But the mode of weathering occurring is what has been previously observed at the site. With similar weathering and site conditions, the geocell solution to slope stability problems should be appropriate elsewhere. **GFR**

## *Project Information*

**Location:** Castle Rock, Washington

**Project Manager:** Mark Hillyard, Wilder Construction

**Engineers:** Stan Boyle, Ph.D., PE., Shannon & Wilson, Inc., Seattle, Wash.; Trent Hudak, Engineering Manager, and Bob Boileau, AVP System VP, Burlington Northern Santa Fe Railway

**Installer:** Wilder Construction

**Material Supplier:** Joseph Whiston, Transportation Resources, Inc.

**Geocelluar system:** GEOWEB® system from Presto Products Co., Appleton, Wisconsin