Biotechnical Soil Stabilization of Decomposed Granite Soils on Buckhorn Mountain

by John McCullah

Background

OVER the last 20 years there have been many efforts at discovering techniques for erosion control and slope stability in the severely decomposing granitic soils of Buckhorn Mountain. Buckhorn Mountain is an exposed decomposed granite (DG) batholith, at a 2000-3000 foot elevation, that separates Shasta and Trinity Counties in Northwestern California. Westbound State Route 299, which serves as the main arterial between the Northern Sacramento Valley and the Northern California Coast, traverses Buckhorn Mountain for almost 15 miles over steep mountainous terrain. Safety and maintenance (sediment and snow) have been constant concerns for California Department of Transportation (Caltrans). Long range plans to improve and re-align the highway include addressing sensitive environmental issues, one being the potential for erosion and sedimentation from an estimated 5 million cubic yards of cut and fill. The region can experience 50 inches of rain in the winter punctuated by numerous freeze-thaw cycles then followed by six months of no precipitation at all. Summer temperatures can often exceed 100 degrees for weeks on end.

In 1990 a Caltrans research project on a cutslope, known as Kelsey's Site, revealed that nearly as much sediment was produced by freeze-thaw and gravity as was produced by rainfall erosion.

Early experiments in 1990 tested benched slopes and surface treatments. Note the rolls of ECBs, precursors to straw wattles, at the toe of the treatments.

In the early 1980s slopes were treated with jute netting, hydroseeding, and willow wattles and stakes. Notice how the willow bushes have persisted, though not vigorous, for 25 years.

These conditions make stabilization and revegetation extremely difficult. The soil texture and composition is another impediment to easy stabilization.

Weathering of Decomposed Granite Cutslopes

The decomposed granite parent material weathers rapidly to a sandy-silt textured soil which is considered by many to some of the most erosive soils in the nation (André and Anderson, 1961). The badly decomposing nature of this granitic batholith is due to its mineral makeup, having a high percentage of biotite and mica-type minerals. When these minerals weather, they expand and the rock weakens and becomes more porous. In addition, the batholith is deeply fractured, thus allowing the extensive intrusion of water.

On exposed cut slopes the competent-appearing bedrock quickly decomposes and ravels due to freezing and wet-dry cycles. The course granular ravel that collects on the toe of exposed slopes soon weathers into fine silt (frost flour). This fine, powdery material forms a seal that reduces infiltration and increases overland flow. Because of the lack of cohesion, these weathered soils are easily eroded and transported by gravity, wind and water. In 1990 a Caltrans research project on a cutslope, known as Kelsey's Site, revealed that nearly as much sediment was produced by freeze-thaw and gravity as was produced by rainfall erosion.

The experiment also indicated that the best remedy for both of the sediment-producing mechanisms, freeze-thaw and raindrop erosion, was the same – maintaining or establishing a good vegetative

Top: The slope with Brushlayering required minor repair. Inset: The "standard" construction failed and required complete reconstruction.

Soil-filled gabions used as gravity toe wall.

cover. The plant roots apparently compensate for the lack of cohesion and provide stability and soil strength, while the above-ground vegetative cover dissipates raindrop impact and provides a protective cover of mulch and duff. The accumulation of pine needles on bare soils, observed on many relatively stable slopes, was believed to be "nature's way" of providing temporary erosion control.

Bioengineering and Biotechnical Slope Stabilization

Bioengineering is a term generally used to describe the use of live plant materials to reinforce soils with roots, and the incorporation of branches and stems into the construction. *Biotechnical stabilization*, however, refers to the combination of live plant materials with structural/engineering elements in a "mutually reinforcing manner" (Gray and Sotir, 1996). The most widely-used plant material used in bioengineering is the ubiquitous willow (*Salix* spp.) because of its ability to root and grow from cuttings.

Archival research revealed that early highway construction on Buckhorn Mountain utilized bioengineering techniques, such as *Brushlayering*, to reinforce long, steep fill slopes. Bioengineering became less widely used with the advent of modern materials and construction techniques but there has been a recent resurgence and interest in biotechnical erosion control techniques. The choice of plant materials is important. Willow and native grasses, because of their ability to send out extensive fibrous roots, are extremely beneficial in stabilizing the DG soils. The choice of technique is also important to the success of the project – branch cuttings used as brushlayers are more likely to grow and less likely to desiccate because they are incorporated deeply into the soil. Willow stakes however are inserted relatively shallow and may not develop sufficient roots before the onset of hot, dry summers. There are many manuals and guidance documents available that provide construction techniques, specifications, and detailed typical drawings. BioDraw 3.0 and ESenSS are examples of guidance manuals on CD which are becoming widely-used by DOTs throughout the US and Canada.

Early in the 1980s the SCS (now the NRCS) and Humboldt State University conducted several early hydroseeding applications, installations of jute netting and bioengineering techniques (willow staking) on the cut slopes in Trinity County. Twenty-five years later some

Fall 2003 begin construction of 'fill-cut' and 'soil flaps' while UC Davis researchers monitor compost trials.

willow stakes have persisted and survived without irrigation in this environment of 2000 foot elevation and 100 degree summers, although the slopes are still raveling. A selection of alternative techniques and native grasses would most likely have better results.

One of the primary failure mechanisms of decomposed granite fill slopes is described by Donald Gray as a relatively shallow, translational-type failure caused by saturated soil.

Highway Fill Slopes

Highway fill slopes also present special challenges. Highway engineers have severe constraints such as limited right-of-way and steep, mountainous terrain. These constraints often necessitate steep cuts and fills. Decomposed granite materials have a natural angle of repose of approximately 2:1 (run:rise), however this slope angle is quite unfeasible in steeper terrain because of the high cuts required and the huge quantities of earth moved. Unfortunately, any fill slope steeper than 2:1 is very unstable and any cut steeper than 2:1 is nearly impossible to revegetate as it continues to slough, rill, gully and ravel.

In several instances we have tried, unsuccessfully, to build un-reinforced fill slopes steeper than 2:1 that were then treated with standard erosion control practices. The worst case scenario was a fill slope that was by necessity 1.5:1 and longer than 100 ft. In 1991 Caltrans constructed two - 300 foot long "sliver fills", as part of a safety and curve correction project. The first fill slope was designed with drainage benches and standard erosion control (punched in straw mulch and hydro seeding) while the adjacent slope had one of the earliest brush layering trials. Early winter storms exposed the newly constructed slopes to a severe "rain on snow" event – nearly 1 ft of snow followed by almost 7 in. of rain. The first slope failed that winter and ultimately had to be reconstructed while the slope reinforced with brushlayering required only hand labor to repair the gullies and rills. The primary failure mechanism appeared to be saturated soil failure followed by gully erosion. The brushlayered slope apparently remained stable because the willow branches, though not rooted yet, provided internal drainage, reduced pore pressure, and soil reinforcement while the branches emanating from the face increased slope roughness. A brushlayer every 6 ft. vertical instead of the 12 ft. interval chosen would have been more effective.

One of the primary failure mechanisms of decomposed granite fill slopes is described by Donald Gray as a relatively shallow, translational-type failure caused by saturated soil. The soil tests conducted by UC Davis indicate that the undisturbed soils and native granite parent materials have relatively high infiltration rates and permeability (>100 mm/hr). In contrast, the constructed fills have relatively low infiltration and permeability (<30 mm/hr), especially when the granular soils are disintegrated and compacted by heavy equipment. As pore pressure builds at the contact between the face of the more porous parent material and the compacted fill, small pockets of less compacted soil served as a collection and conveyance feature for subsurface flow. Following complete saturation, downslope seepage forces acting parallel to the slope greatly increase destabilizing shear forces and mass failure occurs when downslope shear forces exceed the shear resistance of the soil.

Under saturating conditions it is possible for a slope composed of granular materials to fail at an angle considerably less than the angle of repose of this same material when in a dry or damp condition. The problem is exacerbated further if seepage daylights or exits from the face of the slope. This failure mechanism has been verified by observations that the rills and gullies tend to originate in the mid- to lower slope regions even when no signs of runoff are apparent.

Fill-cut and soil flaps nearly completed at day three.

Relatively steep and long slopes can be designed for slope stability and erosion control. Internal drainage should be provided, concentrated runoff must be completely eliminated, and surface stabilization for raindrop and sheet erosion is necessary. Accordingly, the designs will require the incorporation of additional techniques that: 1. Reinforce the slopes with horizontal inclusions (such as brushlayering and geotextiles), 2. Reduce the pore pressure at the soil surface (compost incorporation and brushlayers favorably modify the subsurface flow regime and allow water to drain horizontally), 3. Counter the forces that result in saturated soil surface failure and raindrop erosion by "wrapping" the soil face or establishing plants with deep fibrous roots, and 4. Shorten the effective slope length by reducing the effective slope length with benches or alternatively with layers of protruding brush (brushlayers break up a slope, increase surface roughness, and slow runoff velocity) or by covering with heavy coir fabric.

Field application examples: Post Mile 0.1 and the "Soil-Flapping Technique"

A very innovative and cost-effective technique was successfully completed in the fall of 2003. This trial was a research project funded by the Caltrans Stormwater Program and administered by the Caltrans Landscape Architecture Program and Caltrans District 2. UC Davis, Department of Land, Air, and Water Resources, and Salix Applied Earthcare, Redding, CA conducted the research. The project was part of a larger, 3-year study intended to look at reducing erosion and restoring slopes with adverse soil conditions.

The site was located at SHA Post Mile 0.1. Hwy 299W, just 0.1 mile below Buckhorn Summit (elevation 3000 feet). Caltrans Maintenance workers declared the badly eroded cut slope to be one of the most persistent cleanup problems (estimated at 200 - 300 cu yd/yr, M. Apple, Caltrans, personal communication) as the sediment generated washed out onto the highway.

This novel biotechnical repair called for a "fill-cut" – the construction of a fill slope out of a cut slope. It was widely known that compost amendment will increase infiltration rates, rooting depth, fertility and water holding capacity, all determined to be limiting revegetation on these adverse slopes. Additions of 12 % compost by volume were observed to increase infiltration, but 24 % additions were required to bring infiltration to levels comparable to a stable, revegetated reference site. Other results of these compost admixture trials are described in "Effective Compost and Bioengineering Techniques for Adverse Soil Conditions", McCullah, J. et al., 2005 and Curtis et al., 2006.

Slope stability on this site was achieved by constructing a soil-filled gabion basket toe wall, reinforced with willow poles inserted through the baskets into the slope toe. The cutslope was then converted to a 1.5:1 fill slope, approximately 90 feet high, by building successive soil lifts from the highway toe to the top of the slope.

The standard construction of Vegetated Mechanically Stabilized Earth (VMSE or "Soil Wrap") requires that the geotextile is laid horizontally on the terrace, the soil lift is then placed and compacted and then the geotextile is pulled around and over the soil lift. The "wrap" is then complete and the process can then be continued on the next higher lift. It was believed that this construction technique would be impractical for large-scale projects. Caltrans District 2 engineers came up with an innovative construction technique termed "soil flaps". Each soil lift was approximately 5 feet high, graded at an inslope angle of 10º, and then reinforced with brush layering. The face was covered with an uncompacted, 8 - 12 inch layer of the DG:compost admixture . The slope surface was covered by coir netting (900 grams per meter), which has high tensile strength and an expected durability of 5-7 years.

A 4 meter-wide (13 ft.) roll of the coir geotextile was laid out on the bench with 2.7 meters (9 ft.) flapping over the face. The next lift was built and a soil flap is installed and this technique was continued up the slope. For cost-effectiveness and constructability, brush layering was not installed continuously across each terrace, but instead they were installed in a staggered, crosshatched pattern.

The geotextile-faced slope was expected to reduce surface erosion, but we were cognizant that an identified failure mechanism for fill slopes is soil "sapping" at the face.

The geotextile-faced slope was expected to reduce surface erosion, but we were cognizant that an identified failure mechanism for fill slopes is soil

Ion
new

Haybuster
new

"sapping" at the face. To resist the forces coming out of the slope face the soil flap needs to be anchored in a way to counter those forces. The resisting and anchoring forces were achieved by using 28 inch-long steel anchors with a 1 inch washer on the end. The anchors were inserted through pre-drilled, 13/8" x 13/8" wooden lathing strips and used to secure the bottom of the flap. Addition anchor pins were used on the coir mat every three feet on center in a diamond pattern.

The "soil flap" approach closely mimics a slope stabilization procedure known as an "anchored geosynthetic system" (Gray and Sotir, 1986; Ghiassian et al., 1998). In this approach a geogrid or net is placed on a slope and then pulled down tightly against the surface by means of driven line anchors. This anchoring procedure develops some curvature and tension in the overlying geogrid which in turn imparts a normal or confining stress on the ground surface. Granular or non-cohesive materials are very weak (i.e., lack shear strength) near the surface, where there is normally little if any confining stress. Granular material requires some level of normal or confining stress to develop resistance to shear stresses and hydraulic piping forces. Anchoring as described above provides this shear strength and resistance near the surface.

Since part of this research involved the benefits of adding compost to the soil face and encouraging deep rooting of native grasses and willows, the design did not require compaction of the soil lifts to the standard 95+%. We did however monitor the compaction achieved (87% to 93%) with the dozer while maintaining optimal moisture (approximately 15%). The vegetative treatment included, in addition to the willow branches and compost admixture, broadcasting slow-release organic fertilizer (Biosol), mycorrhizae inoculant (AMB 100), and proven native seed mixture including *Elymus glaucus*, *Festuca idahoensis*, and *Bromus carinatus*.

Soil compaction can influence plant growth in a variety of ways. Agronomists generally recommend minimal soil compaction so as not to impede growth and development of crops and native plants. Soil must retain enough interconnected void space to allow storage and passage of air and water in the soil (McCullah and Gray, 2005). Gray (2002) discusses different strategies for optimizing soil compaction in order to balance engineering requirements and plant growth needs in slope protection and erosion control work. Several studies appear to support the concept of a growth-limiting bulk density (GLBD) that exists for a given soil texture or type. Compaction rates corresponding to growth-limiting bulk densities vary (Goldsmith et. al., 2001) from 82 to 91 percent of Standard Proctor densities, with an average of 84 percent. This limit can vary, however, depending on particular soil and site conditions.

Top: October 2003, Day 4, soil flap near completion. Inset: April 2005, after two winters the slope remains stable.

Conclusions

The slope has withstood several significant winter storms including snowfall events over the last three years. During the first winter season, severe storms hit within weeks after construction, and several months later storms produced 5 inches of precipitation in three (3) days but the slope remained stable. No slumping or failures occurred, suggesting that the flaps succeeded in neutralizing the forces caused by subsurface flow or seepage within the slope. The total cost of the coir flap installation was less than $60,000. The construction costs included 5 workers and the use of a backhoe, excavator, small bulldozer, and a water truck for four (4) days, and $5,000 in materials. Effectiveness and constructability make benching and anchored coir flaps an important consideration for use in non-cohesive soils subject to failures that occur as a result of saturation and mass soil movement.

Vegetation of native grasses and willows establishment was greatly improved with the addition of compost. Compost incorporation improves infiltration and percolation and nutrient availability, and was critical in this project to restore vegetation and proper soil function to a degraded, droughty soil. **L&W**

Fore more information, contact John McCullah, CPESC, Watershed Geologist Salix Applied Earthcare, 225 Locust Street, Suite 203, Redding, CA 96001 (530)247-1600 Fax 539 247-1601 www.salixaec.com info@salixaec.com or M.J. Curtis and V.P. Claassen, Department of Land, Air and Water Resources, University of California, Davis 95616.

Acknowledgements: The authors thank Chris Cross for help with field plot construction and John Haynes and Doug Brown, Caltrans, for review of the manuscript.

André, J. E. and Anderson, H.W. 1961. “Variation of soil erodibility with geology, geographic zone, elevation, and vegetation type in northern California wildlands,” Journal of Geophysical Research, 66, 3351-3358.

Curtis, M. J., Grismer, M. E. and Claassen, V. P. 2006. Compost incorporation increases infiltration and reduces erosion from a decomposed granite road-cut. (submitted)

Goldsmith, W., Silva, M., and Fischenich, C. (2001). “Determining Optimum Degree of Soil Compaction for Balancing Mechanical Stability and Plant Growth Capacity.” ERDC-TN-EMRRP-SR-26, U.S. Army Engineer Research and Development Center, Vicksburg, MS. http://www.wes.army.mil/el/emrrp

Gray, D. H. and Sotir, R., (1996). Biotechnical and Soil Bioengineering Slope Stabilization. John Wiley and Sons, New York, N. Y.

Ghiassian, H., Gray, D.H., and Hryciw, R. (1998). “Stabilization of Coastal Slopes by Anchored Geosynthetic Systems.” J. of Geotechnical Engineering (ASCE), Vol. 123, No. GT8, pp. 736-743.

Gray, D.H. (2002). “Optimizing Soil Compaction and Other Strategies,” Erosion Control 9(6):27-34 (Sept/Oct 2002)

McCullah, J. A. (2004). BioDraw 3.0., A Compendium of Biotechnical Soil Stabilization Techniques on CD. Salix Applied Earthcare, Redding, CA

McCullah, J. et.al., (2005), Effective Compost and Bioengineering Techniques for Adverse Soil Conditions, Proceedings, International Erosion Control Association Conference, Dallas 2005.

McCullah, J. and Gray, D., (2005). “Environmentally Sensitive Channel- and Bank-Protection Measures”, NCHRP Report 544, Transportation Research Board, Washington, D.C.