Geotechnical Engineering Meets Ecology

Bioengineering GROUP

Building Sustainable Communities on an Ecological Foundation

Stabilization of natural landforms such as riverbanks and constructed features such as levees presents many technical challenges. Flooding, erosion, landslides, and related public safety risks and hazards must be suitably addressed. Steep slopes, weak soils, high flows and waves, seepage issues, and other factors can introduce multiple engineering impediments. Additionally, the land/water interface frequently plays crucial roles enhancing fish and wildlife habitat, and also public recreation and community character. Engineers' approaches to providing rigorous and dependable stability and security can be met with vigorous disagreement and concern by community advocates and habitat stewards who object to the loss of trees and shrubs from key riverside and shoreline settings. At times, this conflict can become hotly debated, pitting community members against each other and slowing decisions about planning, design, funding, and maintenance, often when great demand exists to proceed with critical repair or improvement. However, solutions do exist for balancing engineering requirements with habitat function, aesthetic value, and maintenance practicality. By tapping some of the latest research and following in the footsteps of pioneering innovative projects, sustainable solutions can be tailored to project demands.

COURTESY OF US ARMY CORPS OF ENGINEERS

Standard uniform turf levee

Standard practice for vegetating levees, dams, and landfill caps has traditionally shunned use of woody plants, especially large shrubs and trees. Instead, grassy vegetative cover is specified, regular maintenance in the form of mowing prevents other types of plants from becoming established over time, and shallow rooted turf grasses with regular short mowing is the standard. At times, structural armor is used as a stronger substitute for turf grass cover, but planting of trees and shrubs on levees has long been avoided. The reason for this is logical, and supported by examples of tragic failures triggered in part by the role tree roots can play in causing damage to earthen structures. One problem is that storm force winds can cause a tree to topple, leveraging out a large root ball of soil, essentially excavating a major hole into the earth. Another is that woody roots can grow to be quite thick in diameter, and when eventually the root dies and decomposes, a significant flow channel can form in its place, allowing water to seep preferentially through an embankment, potentially creating major soil piping flow and even failure. One final problem is that larger sized rough textured vegetation can interfere with routine inspection to ensure that burrowing animals, landslips, or other factors have not begun to compromise the integrity of the structure. It is clear that cautious engineering dictates a need to avoid problems like these.

Restored saltmarsh and groves of trees are features of a capped landfill converted to an urban park

However in practice, many levees (and other earthen structures) have existed for decades without adequately implemented maintenance plans, and large trees do in fact exist on or near critical infrastructure earthworks. While in some situations trees may present a true hazard, in others the case may not be so simple. Plans to remove cherished trees can be met with vocal resistance, and though safety must certainly be addressed, removal is not generally the only option available. Similarly, on newly constructed or repaired landfill caps, levees, and dams, there often are viable methods for incorporating trees, shrubs, and tall native grasses into the design, and the benefits can far outweigh the risks and costs. Increasingly, native plants including tall meadow grasses and shrubs or trees are purposefully incorporated into earthwork design using thoughtful ecological planning, careful engineering analysis, special construction methods, and prescribed maintenance routines. Special measures can allow plants to coexist with sensitive structures while managing the risk of failure. In many cases, vegetation can complement earthwork and construction materials to provide added strength and risk reduction. The applied science of integrating vegetation into

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engineered soil structures, known as bioengineering, has been practiced for centuries and has been increasingly investigated and applied by federal agencies during the past 20 years.

Current research by the United States Army Corps of Engineers (USACE), academics, and practitioners has examined the positive and negative consequences of using vegetation to stabilize soil embankments. One key finding is that properly designed, plant roots can contribute significantly to soil strength. The mechanical contribution of root reinforcement is important in predicting soil behavior and some grasses and trees have been demonstrated to produce up to a five-fold increase in soil shear resistance. Modern multi-dimensional computer software for slope stability analysis can serve as a powerful tool in the hands of a coordinated team of geotechnical engineers, landscape architects, and ecologists working to prepare site-specific and context-sensitive recommendations to meld vegetation management for biodiversity and beauty with engineering soundness and life cycle value. In typical scenarios, various standard design approaches and construction specifications are used to address deep-seated failure, and upper layers of soil ranging from 2 to 5 feet in depth or more are treated using specialized methods to effectively incorporate plants to add complementary structural value.

Modified ASTM method direct shear test of saturated vegetated soil allows qualtification of root reinforcement

Fortunately, decades of investigation and documentation exists for selecting appropriate tree, shrub, and grass species which are adapted to site conditions, and an increasing level of quantitative research has been conducted into the structural properties or strengthening influences of suitable plants. While many woody plants are known to have long, strong roots, many non-woody species have highly fibrous roots that often form dense mats within the upper 1 to 3 feet of soil, or deeper. In many settings, grasses are better adapted than trees and shrubs to zones where soil saturation and inundation are common. In other settings, woody and herbaceous plants can coexist and provide complementary functions.

Due to the significant differences in rooting characteristics between woody and herbaceous plants, it is important to understand how roots and soils interact from an engineering standpoint. Additional targeted information about the qualitative and quantitative effects of roots on soil strength can guide the design and management of vegetative stabilization systems. In practice, few engineers have been aware of existing data and systematic analytical approaches to applying vegetation for soil reinforcing purposes. Not surprisingly most engineers have consistently tended to favor familiar structural measures which unfortunately have low ecological values, unlike their vegetative counterparts which offer numerous habitat and water quality benefits. Increasingly, creative project examples representing effective collaboration between engineers, scientists, regulators, and key stakeholders establish both the merits and some practical approaches to incorporating vegetation for its physical functions in land stabilization, including for situations where it has been long routinely disregarded.

Benefits of Native Vegetation for Soil Stabilization

- More durable, reliable vegetative cover on embankments than turf grass
- Deeper rooted species provide better drought tolerance and higher strength
- Small patches or rows in select spots can add high habitat value amidst mown areas
- Many native shrubs and grasses can be mown annually to allow for easy inspection
- Reduced mowing frequency can minimize costs and habitat disturbance
- Mown biomass can serve as biofuel or co-burning stock, offsetting mowing cost
- Vegetated slopes can capture and store Carbon faster than fuel is burned for mowing
- Many species are well adapted to allowing additional soil fill to be placed over time
- Plants have capacity for regeneration and self repair after impacts cause minor damage
- Trees provide shade to maintain cool temperatures and good oxygen levels in rivers
- Trees provide resting and nesting spots for birds and wildlife dependent on bank habitat

We Can Help

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Bioengineering Group's skilled team of science and engineering professionals perform a range of services related to geotechnical engineering featuring solutions that incorporate functional vegetation. Our experienced interdisciplinary team works together closely to fulfill client objectives sustainably, achieving ecological, social, and economic value. We pride ourselves on being able to develop creative solutions that balance ecological productivity and structural integrity. We can assist with:

- **Levee inspection in compliance with Levee Safety Program requirements**
- **Levee design and certification in compliance with 44CFR65.10**
- **Variance applications** →
- **Related services**
  - **Subsurface investigations** to characterize surficial soil conditions and deeper geologic conditions critical to proper design for slope stability
  - **Slope stability analysis** incorporating traditional engineering approaches with additional consideration of vegetation
  - **Scour and erosion potential** due to high runoff, wave action, or river flows, including design of countermeasures
  - **Seepage analyses** to determine where critical areas exist and how construction materials and plants affect seepage on a site-specific level
  - **Settlement analyses** to determine anticipated consolidation settlement overburden placement for levees and other structures including maintenance recommendations affecting performance of engineered elements
  - **Operations and maintenance programs development** including vegetation management, routine inspections, periodic repairs, and other requirements
  - **Economic assessments comparing** bioengineering techniques versus typical engineering design
  - **Resource beautification and enhancement** such as park design over existing landfill caps

Recent research and administrative action by USACE has reversed long-standing assumptions that there is universally negative effects due to woody vegetation on levees. Though modifications to the existing vegetation policy, which was implemented in 2007, are still forthcoming, USACE recently approved a variance in the Sacramento area that allowed trees to stay on 42 miles of levees. This newly issued vegetation variance process permits trees to remain based upon demonstration that levees will still meet acceptable standards of safety.

Analysis and design advances allow rigorous treatment of vegetation in the engineering design process

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Success Stories

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Pond features earthen dam incorporating shrubs and trees

Federal Bureau of Prisons Water Management System, Devens, MA

Bioengineering Group designed a stormwater management system for a new secure medical facility located on a former Army base. Creative measures served to provide combined flood discharge control and water quality improvement with ecological enhancement of the site. The stormwater system releases water to a National Wildlife Refuge and a downstream lake. The interdisciplinary design team created a series of three ponds along the relocated stream course, relied on vegetation as the basis of channel erosion control in order to maximize the habitat value. An earthen dam stabilized with carefully placed shrubs and trees and a notched weir allow the channel and pond complex to function as a detention basin, while blending into the landscape visually. For its combination of many innovative and rigorously designed features in a multipurpose channel and basin complex this project was recognized with the 1997 Environmental Achievement Award from the International Erosion Control Association.

Dormant native vegetation installed between lifts of carefully compacted soil

Shelby Bottoms Park Bank Stabilization, Nashville, TN

When trails and overlook structures at the Shelby Bottoms Greenway and Nature Park were jeopardized by severe erosion of the banks of the Cumberland River, Bioengineering Group was tasked by USACE Nashville District to design measures for the rehabilitation of a 3,000-foot reach of the riverbank affected by heavy navigation and flood impacts. The design included three different bioengineering treatments, employing techniques such as live poles through a rock toe, live stakes, brush layers, and brush fascines combined with soil benching, to provide improved habitat, water quality, and natural views. The final design was compatible with the existing hydrologic, hydraulic and geotechnical conditions, effectively stabilized the eroding bank, utilized native plant materials, was extremely durable, and resulted in a cost-effective and low maintenance solution appreciated by the recreating public and also public and fish/wildlife stakeholders.

Earthen levees and spillway structures interface with trails, boardwalks, overlooks, an amphitheater, and native plants (trees, shrubs, and wetlands)

Alewife Stormwater Wetlands, Cambridge, MA

Located within the 100-year floodplain in Alewife Brook Reservation, an urban wild, the site served as habitat for diverse wildlife and offered recreational on informal hiking and bike trails. The challenge was to design a constructed wetland basin that met the technical requirements for stormwater detention and treatment while simultaneously meeting the habitat and recreational functions envisioned for the area in the Massachusetts Department of Conservation and Recreation Master Plan for the Alewife Brook Reservation. Bioengineering Group designed this multifunctional stormwater management facility to serve the objectives of combined sewer overflow compliance, wildlife habitat enhancement, and recreation/education. The system creatively incorporates both conventional and bioengineered structures designed with natural form and function that won praise from stakeholder groups and saved public agencies millions of dollars compared to alternatives.

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