

Managing Stormwater for Urban Sustainability Using Trees and Structural Soils

A new space-saving infiltration BMP that mitigates runoff from paved areas

Susan Downing Day and
Sarah B. Dickinson, Editors

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Figure 1. Typical runoff from a parking lot going into a storm sewer. Notice that traces of oil are visible to the naked eye. There are many other pollutants in parking lot runoff such as various metals, sediment, salts, and litter.
Photo by Susan Day.

Urbanization disrupts natural soil profiles, increases impervious surfaces and decreases vegetative cover. These disruptions increase stormwater runoff at the expense of groundwater recharge, degrading water quality and impairing aquatic habitats. The repercussions of this non point source pollution are being felt worldwide. Creative Best Management Practices (BMPs) that harness the ability of vegetation and soils to mitigate urban runoff are needed. This material is a culmination of four years of research at Virginia Tech, Cornell University and the University of California at Davis investigating how a novel stormwater BMP that relies on shade trees and structural soils can be designed and how it will function. We do not have the answer to every question but the approach presented here works and is in place now at our demonstration sites around the country. We developed this guide to assist others in implementing this BMP. We hope it will expand your toolbox and create new approaches for harnessing the power of trees in urban settings.

Challenges for Stormwater Management in Urban Areas

Urban areas are challenged by extensive impervious surfaces, damaged soils, and little room for greenspace or for stormwater management facilities. The goals of stormwater BMP's are to reduce peak flow, reduce runoff volume and remove pollutants. The system described in this manual addresses all three of these goals by utilizing trees and structural soils to aid in water interception, storage, and infiltration while increasing evapotranspiration potential.

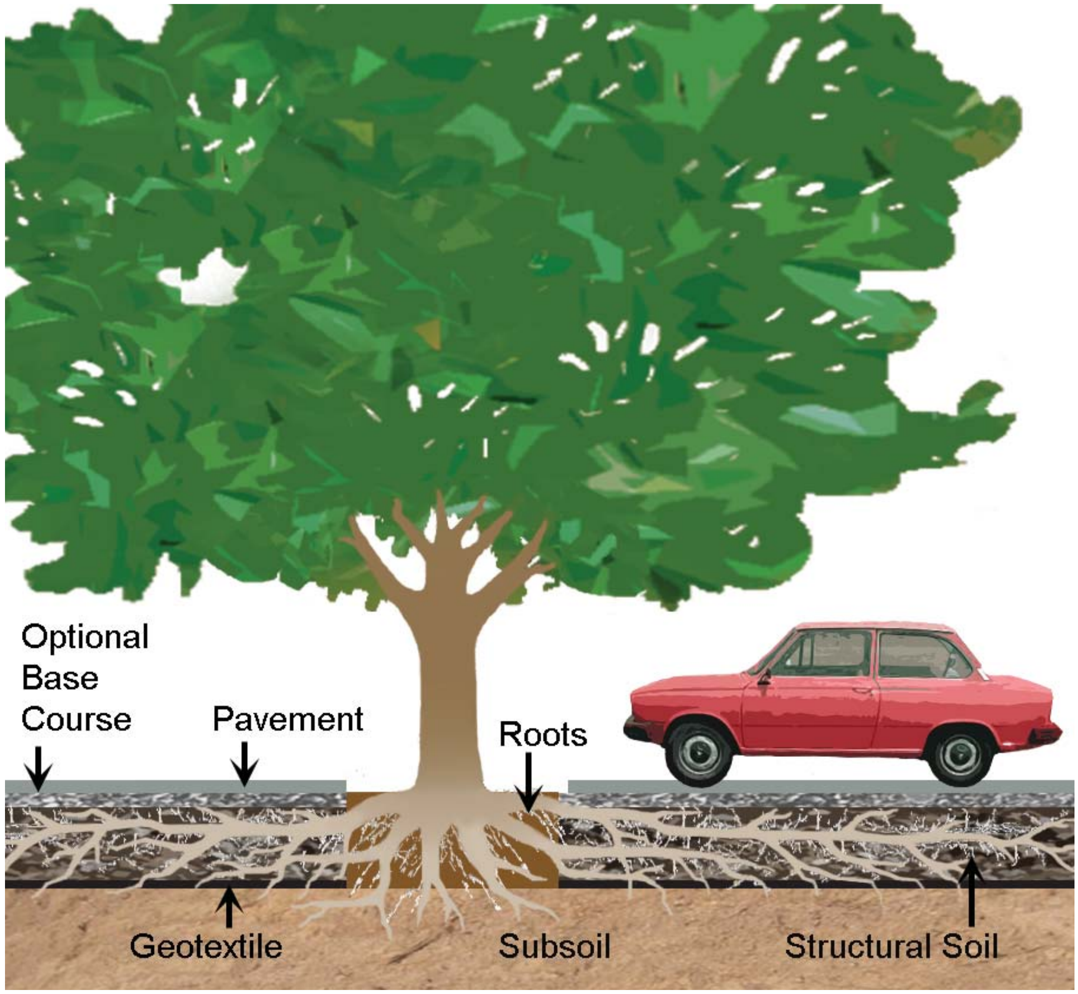

Figure 2. This system both serves as a parking lot and as a stormwater management facility. In addition to this double use of space, the structural soils also provide vastly greater soil volumes for tree root growth than traditional parking lot construction. Note: Gravel base course is optional, since the structural soil is designed to be as strong as a base.
Figure by Sarah Dickinson.

Distributed Stormwater Management in Urban Settings

Distributed stormwater management techniques, such as bioswales, are used to retain stormwater at many sites throughout the urban landscape as opposed to collecting runoff at a more centralized facility, such as a detention pond, or relying on a storm sewer system. But some sites do not have sufficient open ground to handle water collected from surrounding impervious surfaces in a dispersed fashion. In addition, sites that are largely paved usually cannot support large trees and thus may be unable to benefit from tree canopy interception and the influence of roots on soil hydrology. The system described in this manual can make it possible to use distributed stormwater management that takes advantage of the stormwater mitigation services provided by trees, even in confined, highly urban sites where space for stormwater management and vegetation are very limited. This system may prove particularly useful in areas of urban infill development. However, the system also provides an alternative to detention ponds where lack of space is not yet the primary concern.

How Does This System Work?

The system guides water to a structural soil retention area beneath the pavement where it is then temporarily stored. Water leaves the reservoir via soil infiltration, and root uptake for tree transpiration. Because the reservoir creates a large rooting volume, trees have the potential to develop full canopies, allowing increased interception of precipitation. Tree roots take up excess nutrients and water in the soil reservoir and can enhance infiltration into the subsoil. Together, trees and structural soils can create a zero runoff site. If infiltration, soil absorption, and plant uptake of water are not sufficient to handle all stormwater, then overflow drains prevent the reservoir from overfilling. Such overflow has not occurred to date in the demonstration installations of this system. This is attributed to the distributed nature of the system: because the reservoir is beneath the pavement, there is a one-to-one ratio of land area receiving rainfall and land area treating stormwater.

Before deciding on any BMP, site constraints should be evaluated. This system is designed to be installed beneath pavement and therefore stormwater management is distributed throughout the site and not confined to unpaved portions of the site. The system has not been evaluated for treating large amounts of collected runoff from adjacent areas. Infiltration BMP's are not appropriate for sites that need to handle highly polluted or contaminated water due to risk of groundwater contamination. There are also some topographical and geological features that could limit the use of an infiltration BMP (see the limitations section in Chapter 2).

Project Background and Resources

This manual is the result of a series of research studies carried out at Virginia Tech, Cornell University, and the University of California at Davis. This research evaluated multiple aspects of the novel stormwater BMP described here. Work at Virginia Tech focused on tree health and root development in the system, as well as the ability of tree roots to enhance subsurface infiltration in stormwater BMPs. Multiple projects at Cornell examined the physical characteristics of the structural soil mixes as they pertain to storing stormwater, and the feasibility of a wide variety of surface treatments—everything from porous asphalt to turf. Research at Davis in the Department of Land and Water Resources produced baseline evaluations of the ability of several structural soil mixes to remove typical urban runoff contaminants. Each university partnered with private groups or municipalities and installed one or more demonstration sites to evaluate the system as a whole. Overall, the system presented here has been successful. We have prepared this manual to help stormwater engineers, public works departments, and others to put this new approach—or elements of it—into practice.

How this Manual is Organized

The manual is designed to guide you through the features of the system, including its limitations, and how to design a system to suit the site's needs. Original research papers are referenced and are available from university libraries or by contacting the authors. Brief summaries of this research appear in the manual.

Chapter 1 introduces the stormwater management system, its attributes and limitations.

Chapter 2 provides information on designing a system with structural soils and trees based on the needs of individual sites.

Chapter 3 describes surface treatments that can be used in conjunction with this stormwater management BMP, namely turf and porous pavement. All the information in this section is based on a series of publications from Cornell University's Urban Horticulture Institute.

Chapter 4 summarizes several original research projects related to the development and evaluation of this system which were conducted by the contributors of this manual. The research in this section was made possible in part through a grant from the United States Department of Agriculture Forest Service Urban & Community Forestry Grants Program on the recommendation of the National Urban & Community Forestry Advisory Council (NUCFAC).

Figure 3. An example of a retention/detention pond adjacent to a conference center on the Virginia Tech campus in Blacksburg, Virginia. This treatment uses space that could be otherwise directed towards other uses.
Photo by Susan Day.

Stormwater management in urbanized settings faces special challenges: paved surfaces and buildings generate high amounts of runoff while at the same time leaving little space for constructed stormwater management facilities or for the soil and vegetation combination that could reduce the need for these facilities.

The system described in this manual seeks to address these limitations by using structural soils to simultaneously allow healthy tree growth, water infiltration, and pavement—all on the same land area. Tree root systems and the structural soil that supports them combine to form a shallow but extensive reservoir for capturing and storing stormwater. Structural soils are engineered soil mixes with a high porosity that allow tree roots to penetrate freely, and stormwater to infiltrate rapidly and then be stored until it percolates into the soil beneath. Tree canopies effectively intercept rainfall, reducing throughfall to the ground and lengthening the time of runoff concentration into stormwater systems. Trees also actively transpire, taking up water and nutrients present within the reservoir. As runoff infiltrates into the subsoil, pollutants and contaminants can be removed from the stormwater via filtration and/or adsorption (especially in clay soils).

This double use of land surface area (e.g. parking lot and stormwater management) increases land-use efficiency and allows water infiltration over a large area, which more closely mimics natural hydrology than stormwater management systems that concentrate storm flow. In addition, a full tree canopy increases opportunities for returning rainfall to the atmosphere via evapotranspiration and through canopy interception and storage of precipitation. The remainder of this section will introduce the specific components of this system, namely trees and structural soils.

Trees— Mimicking the Hydrologic Benefits of a Forest in the City

Natural forests with their complete canopy cover, large leaf areas, and permeable soils handle rainwater effectively through interception and infiltration, returning water to groundwater and the atmosphere and protecting water quality in surface waterways. Replicating elements of this hydrologic cycle in urban settings, however, is difficult—because buildings, infrastructure, people, and other urban denizens compete for land and soil resources.

Urban forests are also widely recognized as an effective means of handling stormwater. Like their forestland counterparts, urban trees intercept rainfall, direct precipitation into the ground through trunk flow, and take up stormwater through their roots. In addition, urban tree roots penetrating through typically impermeable urban soil layers into more permeable zones have the potential to increase stormwater infiltration rates. However, urban canopy cover (and thus rain interception) is greatly limited by urban soil conditions such as compaction, reduced rooting volume, and elevated pH. Even open ground in urbanized areas is commonly disturbed or compacted, limiting normal soil hydrologic functions. This system directly addresses the limitations of urban soils to support vegetation and handle water. The system provides a highly permeable rooting environment that can support large trees, thus making these forest benefits available in the city.

"... trees intercept rainfall, direct precipitation into the ground through trunk flow, and take up stormwater through their roots."

Additional benefits of trees

- Shading, reducing ambient temperature
- Removing pollutants from the air
- Improve aesthetics

See http://www.fs.fed.us/psw/programs/cufr/ for more information

"...urban canopy cover (and thus rain interception) is greatly limited by urban soil conditions such as compaction, reduced rooting volume, and elevated pH."

Structural Soils— Supporting Tree Growth and Pavement

Why were structural soils designed?

Typically, soils beneath pavement are compacted to meet engineering requirements to support the loads from vehicles, pavement and structures. Unfortunately, most plant life cannot survive in soils compacted for these purposes. Roots cannot penetrate extremely strong soils. In addition, compacting soil destroys soil structure, collapsing the large pore spaces needed to provide the balance of air and water that roots require. The result is soil that can support pavement but cannot support trees. Structural soils were designed to meet requirements for pavement support while still allowing adequate pore space to support tree roots. Structural soils must be carefully constructed and tested according to verified specifications in order to meet these requirements.

A good structural soil will have known water-holding, drainage, structural and load-bearing characteristics. It should be able to be compacted to 95% of standard Proctor density and still support plant growth. It will also have a research-based track record of success and body of best practices. Just any mix of a stone and soil is not a structural soil. Some so-called structural soils have failed miserably when practitioners thought they were purchasing a good soil but were just purchasing an untested mix with no research verification. The two discussed here have been thoroughly tested yet each product should still be required to undergo testing after installation to ensure that the final product meets the standards of the specification. In the case of CU-Structural Soil it must be purchased from licensed producers who are required to test their materials to adhere to a research-based specification.

Figure 4. This photograph shows the effect of soil volume on tree growth. Both rows of willow oaks were planted at the same time on Pennsylvania Avenue, Washington, D.C. The trees on the left are in tree pits, and those on the right are in an open grassed area.
Photo by Nina Bassuk.

Figure 5. Compacted soil from a typical construction site. Lack of structure prohibits root penetration and growth.
Photo by John W. Layman.

How do structural soils work ?

Structural soils are engineered to meet compaction requirements for parking lots, roads and other paved surfaces and, at the same time, allow tree root penetration under the pavement. Excavated root systems from structural soils have illustrated that deep rooting of trees in these soils appears to prevent heaving of sidewalks, curbs and gutters by tree roots. Structural soil can therefore expand the soil volume available for the roots of trees in plazas and parking lots and other paved areas.

Figure 6. CU-Soil, the structural soil developed at Cornell University in the 1990s. Soil particles within the media are clearly visible and allow soil nutrients and water holding capacity for healthy root growth.
Photo by Ted Haffner.

There are many types of structural soils, but they are based on the same principal: large “structural” particles, typically an angular stone, form a matrix that distributes the load from pavement and structures through stone-to-stone contact ultimately spreading the load across the supporting subsoil. The gaps between the structural particles are then filled with a high quality mineral soil with good water-holding capacity and tilth. Hydrogel is often used in addition to the mineral soil as a tackifier—preventing segregation of the soil during mixing and installation. When structural soils are compacted, they form a rigid matrix while suspending soil as a rooting medium within the interconnected voids of the stone matrix. Roots are able to easily penetrate this uncompacted mineral soil within the compacted stone matrix. As roots expand in the structural soil, they appear to encapsulate, rather than displace the stone matrix or deform temporarily to move between the smallest pores. Because stone is the load-bearing component of the structural soil, the aggregates used should meet regional or state department of transportation standards for pavement base courses.

-Adapted from Bassuk, et al. 2005

	CU-Soil	Stalite	Soil Alone
Total Porosity	26%	32%	34%
Porosity as Macropores (as % of Total Porosity)	31%	39%	2.20%
Infiltration Rate	>60 cm/hr	>60 cm/hr	1.24 cm/hr
Plant Available Moisture	7%	9.80%	n/a

Table 1 . Comparison of physical properties of CU-Soil, Carolina Stalite and a silt-loam soil. Note: The Stalite specifications usually call for sandy loam but plant available moisture with Stalite was tested using the same interstitial silty clay loam as was used with the CU-Soil.
Table based on information from Haffner, E.C. 2008.

The history of structural soil

This manual examines stormwater management techniques that detain stormwater in under-pavement reservoirs of structural soil. The first of these soils, CU-Soil (Amereq Inc., New York, NY) was developed at Cornell University in Ithaca, New York, in the mid 1990s to address insufficient soil volumes for tree root development. This new type of soil mix resulted from research exploring a means to create a substrate that would both allow adequate tree root growth and support pavement for sidewalks, streets, and parking lots. It is this load-bearing ability that defines structural soils and differentiates them from other types of tree soils. Since then, other structural soils have been developed that use other components (e.g. Carolina Stalite, a heat expanded shale (Carolina Stalite Company, Salisbury, NC). The structural component of Carolina Stalite is porous and lightweight in comparison to the gravel used in CUSoil . Because the stone matrix has a rough surface, a tackifier is not required to prevent segregation during mixing.

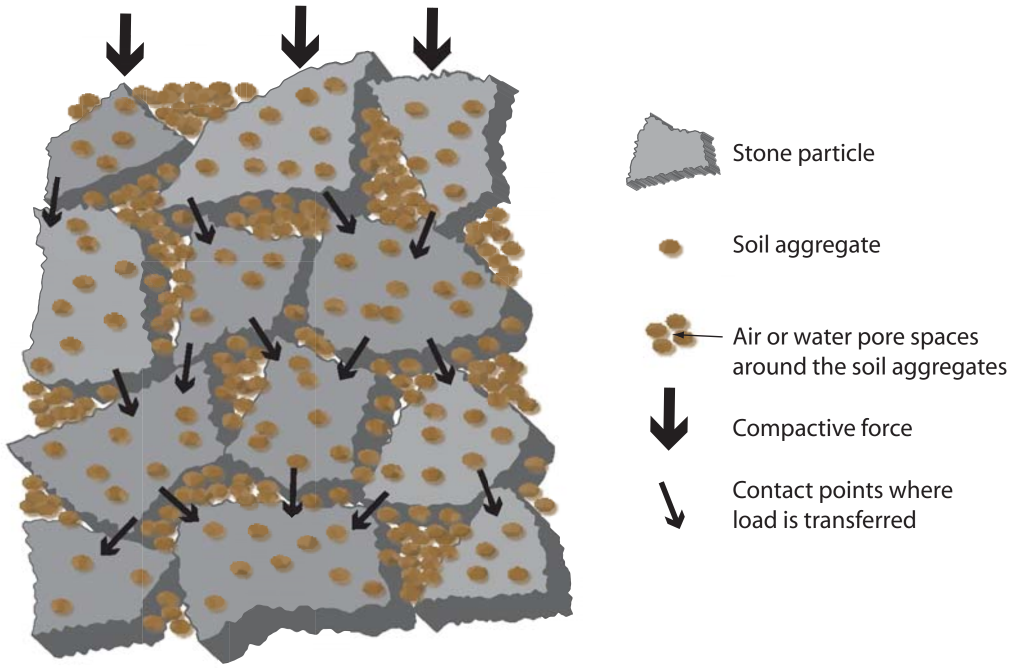

Figure 7. Conceptual diagram of structural soil including stone-on-stone compaction and soil in interstitial spaces.
Figure by Sarah Dickinson, adapted from Nina Bassuk.

Subsoils

The final component of this system is the existing subsoil upon which the structural soil reservoir will be constructed. For optimum functioning of the system, including healthy root development, the stormwater reservoir should drain within two days. If the subsoil is permeable, or has some permeable areas, infiltration is likely to be rapid because lateral water movement through structural soils is extremely rapid. If soils are impermeable but have permeable layers beneath them, root penetration into the subsoil base may ultimately improve infiltration (see Chapter 4, Tree Root Penetration into Compacted Soils Increases Infiltration), but designs should accommodate the lack of infiltration via placement of overflow pipes (see the blue box on page 15*)*. Although a separation geotextile is not normally required below structural soil sections, when the structural soil is being used as a reservoir for stormwater, subsoil may be saturated at times, resulting in lower soil strength. Therefore, a geotechnical engineer should always be consulted to determine if a separation geotextile is advisable between the subsoil and structural soil components (see Geotextiles section).

Limitations concerning subsoil infiltration

Infiltration BMP's cannot be employed everywhere. A geotechnical engineer can determine if infiltration is an appropriate BMP for the specific situation. Some conditions only require minor adjustments to the design to use infiltration but there are situations where infiltration should not be used at all. Some of these limitations include:

- When high concentrations of contaminants and/or pollutants are present in the stormwater, infiltration may not be appropriate due to the risk of groundwater contamination. Always refer to local regulations.

- Sites with very rocky soils, high bedrock, water tables less than 4 feet from the surface, limited drainage, and extreme slopes are not suitable for infiltration BMP's.

- Sites which have Karst geology could run the risk of contaminating the groundwater. This is because the effluent can go directly to the ground water without any contaminants or pollutants being removed by the soil first.

- Other factors such as cost and practicality may also apply for certain regions of the country. Carolina Stalite is produced in the eastern United States and high transportation costs make its use in western states impractical.

Citations

Bassuk, N.L., J. Grabosky, and P. Trowbridge. 2005. Using CU-Structural Soil in the Urban Environment. Urban Horticulture Institute, Cornell University, Ithaca, NY.

Haffner, E.C. 2008. Porous asphalt and turf: exploring new applications through hydrological characterization of CU Structural Soil® and Carolina Stalite Structural Soil. Master's Thesis. Department of Horticulture, Cornell University.

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Sustainable site design requires coordination and consultation with diverse professions. For instance, a geotechnical engineer can determine if this infiltration BMP can be used on your site based on underlying geology and site topography.

A stormwater engineer may determine the quantity of water that the system will need to be able to handle. In addition to water quantity, they should be familiar with the contaminants and pollutants that will be present in the stormwater and local regulation and permit requirements.

Horticulturists, foresters and other qualified plant professionals should be consulted during the design process for choosing tree species and other plantings that will perform well for a given system design and climate.

- Local rainfall data and runoff calculations will determine the minimum depth for the structural soil reservoir. The reservoir can be designed to store the desired rain event (e.g. a 25-year storm).
- For optimal growth of trees, designs must provide adequate depth and extent of structural soil (see Reservoir Sizing).
- Determine the type of soil and the seasonal water table levels underneath the reservoir. Clay soils will drain much more slowly than sandy soils and will influence how much water the reservoir can take and will also determine infiltration and groundwater recharge rates from the reservoir into the subsoil below the reservoir.
- Infiltrometer measurements may not accurately reflect drainage rates of the reservoir as a whole. This is because water moves laterally very quickly in structural soils and zones of rapid infiltration can have a disproportionately large effect.

Specifications

Surface Treatments

The intent of this BMP is to manage stormwater from the immediate vicinity— it is not meant to handle large amounts of stormwater concentrated from surrounding land areas. Regardless, the system requires that water be directed into a structural soil reservoir beneath the soil surface. There are two options for this that can be used alone or in combination:

Option 1: Pervious Pavement

Pervious pavement allows rainfall that hits the pavement to infiltrate directly through the wearing surface and into the structural soil reservoir below. Infiltration rates are typically extremely high, much higher than most rainfall rates. There are many types of pervious pavement and the choices continue to expand. For more information on alternatives to traditional impervious pavement, see Chapter 3.

Option 2: Traditional, Impervious Pavement

Water can easily be directed beneath traditional pavement as well. Structural soils allow rapid lateral water movement, so water entering at one point in a structural soil system will seek its own level, spreading out in the reservoir in accordance with the subsoil topography. Gravel swales on the edges of impervious areas allow water to enter the system. This design also can be used as a "backup" system for pervious pavement if there are concerns of clogging.

Reservoir Sizing and Overflow Pipe Design

In order to properly mitigate any storm, exact rainfall data must be obtained from local meteorological stations. To help design the proper **reservoir depth** to accommodate any rain event, the adjacent table (Table 2) can be used as a general aid. This information is based on a conservative estimation of the total porosity of any structural soil of 30%. If actual total porosity is calculated for your particular structural soil mix, the chart can be adjusted accordingly. It is important to note that while depths less than 24" will both support and mitigate a storm event up to 5.4" in 24 hours, for larger tree species, a reservoir depth of 24" to 36" is optimum.

Size of Rain Event (inches)	Required Reservoir Depth (inches)
1.8	6
3.6	12
5.4	18
7.2	24
9	30
10.8	36

Table 2. Reservoir depths and the corresponding levels of mitigated rain events based on the 30% void space within the structural soil mix (assuming an empty reservoir). Numbers in the gray box illustrates the depths necessary to accommodate optimum healthy tree root development.
Table by Ted Haffner.

Although a structural soil reservoir is a great way to collect rainwater and runoff as regulated by the National Pollution Discharge Elimination System (NPDES) guidelines and decrease demands on existing municipal storm water systems, there may be rain events that generate more runoff than the reservoir below can handle. Installing an overflow pipe above the design stormwater retention level of the reservoir can prevent system failure during extreme weather events.

Two systems combined insure against system failure.

1. The structural soil reservoirs at a predetermined depth allow water storage and infiltration to recharge groundwater, if soil conditions below the reservoir permit.

2. Traditional piping infrastructure located at a level high enough that water will not backup under the pavement if the reservoir is overfilled by multiple storm events. The combination of the two ensures the system will work during storm events that are larger than the design capacity of the system.

Placement of the **overflow pipe** should be determined based on the infiltration rate of the subsoil. Ideally this infiltration rate is calculated for the site as a whole, since rapid infiltration in one area can drain water from less permeable areas. However, if this is not possible, a series of infiltrometer tests should be made after excavation of the reservoir. If infiltration is not adequate to remove water from the rooting zone (the top 18 to 24 inches of structural soil) within 48 hours, the depth of the structural soil reservoir should be increased, or the overflow pipe should be placed such that if water rises to the level of the rooting zone it will be removed by the pipe.

Helpful Hints

- Design to capture all the runoff from the desired storm event. The system can easily be designed to capture all of the runoff from a 100— year storm in most cases. At a minimum, design the reservoir to handle the “water quality storm” for your region. This is the threshold which encompasses 90% of the yearly runoff production.
- Infiltration expectations: water should not stay in the upper 18 to 24 inches of the reservoir for more than 48 hours. Longer residencies in the tree rooting zone may interfere with tree establishment, growth, health, and stability of the rooting system.

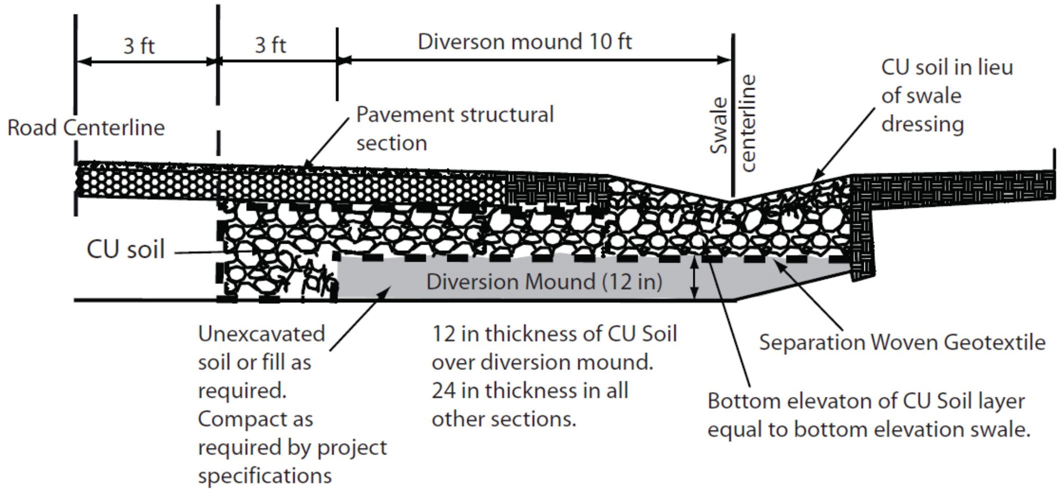

Figure 8. The top illustration shows a diversion mound system as used on a roadway. The photo to the left shows the installation of diversion mounds for an access road. The diversion mounds are circled in red. In the photo to the right you can see the mounds during the structural soil installation process.
Figure by Joe Dove. Photos by Susan Day.

Use additional drainage as necessary to decrease flooding and inundation from extreme storm events. Although structural soil is highly porous, flooding will occur if the rate of water leaving via infiltration is slower than the rate that water enters the system via rain and runoff (see Reservoir Sizing above).

CU-Soil specifications require that the mineral soil component of the mix be heavy clay loam or loam with a minimum of 20% clay, because of its greater water- and nutrient-holding capacity. Carolina Stalite structural soil mixes specify a sandy loam since the porous structural particles also hold water, but soils with a finer texture (i.e. more clay) can also be used. Structural soil should also have organic matter content ranging from 2-5% to ensure nutrient and water holding while encouraging beneficial microbial activity.

Level and Unlevel Sites

Does the reservoir need to be level? A level or nearly level reservoir will promote the maximum distribution of stormwater, allowing the infiltration capacity of the entire subsoil floor to be utilized. However, a sloped system can be designed in two ways. First the subsoil can be excavated in a series of terraces. This is appropriate for a slightly sloped parking area, for example. Alternately, diversion mounds (Figure 8) can be used to direct water under pavement on a slope. This technique was employed at an access road installation in Blacksburg, Virginia. Runoff collected in roadside swales and was then directed under the road pavement with diversion mounds that intersected the swales. In such cases, hydrostatic buildup under the pavement must be prevented by appropriate drainage. Because the reservoir will allow water movement down the slope, it will not store water and infiltration may be minimal.

Designing for Trees to Thrive is Key to System Success

A good, well drained topsoil may be used around the newly installed tree if the pavement opening allows. If this is not practical, structural soil can be used right up to the tree root ball. In drier climates, establishing some tree species directly in structural soil may require frequent irrigation because of the high porosity of the soil. Tree roots need to establish good root-soil contact before they can efficiently extract water from the soil matrix. Tree species that are sensitive to drought during establishment (e.g. swamp white oak (*Quercus bicolor*) may need close attention to irrigation during the first year or two after planting. Because structural soil gives tree roots a larger volume of soil, irrigation may not be necessary after establishment. Again, this is climate dependent and the expertise of a plant professional with local knowledge should be sought.

While structural soils may have less total moisture on a per volume basis than in conventional soil (around 16% versus a normal 25% in a agricultural soil), the plant available moisture within the structural soil matrix is actually quite comparable to a normal landscape soil (in the range of 8-11% by volume). Traditional planting designs in paved areas surround the planting hole with materials which restrict root penetration and growth. Because the use of structural soils expands total rooting volume, trees have access to greater water resources and can usually be managed very similarly to trees planted in landscape soils. Similar to trees in the landscape, supplemental water should be provided until the tree is established and then irrigation practices should follow local climatic requirements.

Geotextiles

By Joseph E. Dove

Geotextiles are part of the broad class of materials called Geosynthetics, which are synthetic polymer materials that are used in a wide range of geotechnical engineering applications such as reinforcement, erosion control, separation, filtration and drainage. General information and educational materials for geosynthetics are available from the International Geosynthetics Society (http://www.geosyntheticssociety.org/guideance.htm).

Geotextiles are continuous sheets of flexible, permeable material which have the general appearance of a cloth fabric. They are typically manufactured from polypropylene or polyester and are categorized as either woven or nonwoven. Woven geotextiles are produced by interweaving two orthogonal sets of yarns. They typically have high tensile strength and resistance to elongation. Non-woven geotextiles are manufactured by extruding individual filaments randomly onto a horizontal surface to form a mat. The filaments are then interlocked through needle punching or heat bonding processes. Needlepunched geotextiles typically have high permeability; whereas heat bonded non-woven geotextiles have higher tensile strength characteristics.

In the structural soil system, possible locations for a geotextile include (Figure 8): 1) between the top of the natural (subgrade) soil and the base of the structural soil, and/or 2) below the aggregate base soil supporting the pavement or other surface treatment and the top of the structural soil. In the first case, the geotextile potentially could provide both reinforcing and separation functions. However in the second case, the geotextile provides a separation function only. The reinforcing function arises when the subgrade soil is weak and loads applied by traffic cause deformation of the subgrade, resulting in rutting at the ground surface. This function typically requires geotextiles with high tensile strength. A civil engineer can determine if a reinforcing geotextile is required and recommend tensile strengths for selecting candidate materials, if needed. The separation function in the second case arises to prevent the aggregate base from commingling with the structural soil below. This downward migration can result in decreased pavement performance and a separation geotextile may be warranted as a mitigation measure. A check can be made to assess if the aggregate base soil has a particle size gradation sufficiently fine to permit portions of the base soil to fall into the voids between the underlying structural soil particles. Fortunately, migration of aggregate base soil has not proved to be a problem in other installations. Geotextiles are not be required if the above consequences are not significant to the owner.

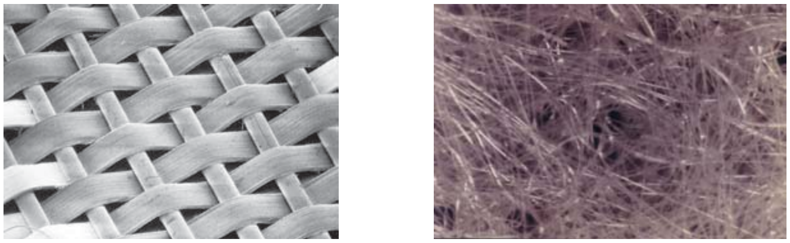

Figure 9. Enlarged view of woven and nonwoven geotextiles.
Photos from "IGS Geosynthetics in Drainage and Filtration by J.P. Gourc and E.M. Palmeira."

Selection of a geotextile is made after the required material properties are estimated from design computations performed by a civil engineer (for examples, see Koerner 2005). An important consideration in selecting a geotextile for this application is the reduction in mechanical performance due to damage during installation in the field (survivability). The American Association of State Highway and Transportation Officials (AASHTO) standard materials specification M288-00 "Geotextile Specifications for Highway Applications" provides guidance geotextile selection. This standard is intended for geotextiles used in subsurface drainage, separation, stabilization and permanent erosion control functions. M288-00 defines three different classes of geotextiles and specifies minimum mechanical properties for each function. Selection of the minimum geotextile material properties for survivability is made from tables included in the specification. Finally, selection of locally available candidate geotextile products with the required engineering properties is made from information published by manufacturers. Most manufacturers of geotextiles provide the M288-00 survivability class for each of their products.

It has been found that the woven geotextiles tested in the structural soil system do not prevent tree root penetration, a summary of this research is in Chapter 4 (Tree Root Penetration into Compacted Soils Increases Infiltration).

Citation

Koerner, R.M., 2005. Designing with geosynthetics, 5th Ed. Prentice Hall, Upper Saddle River, NJ.

Trees and Other Plants

Trees are an integral component of this stormwater system and must grow well in order to realize maximum stormwater mitigation. By enlarging the rooting volume typically available to trees in paved areas, canopy size has the potential to increase faster and trees may ultimately reach a greater size. Rainfall interception, storage, and ultimately evapotranspiration from leaf surfaces, are directly related to canopy size. In addition, rainfall captured by tree canopies is often directed down limbs and trunks into the soil at the base of the tree—effectively bypassing the pavement.

Trees are living organisms and have certain requirements in order to grow well and provide long-term environmental benefits. Here we will outline issues with specific tree selection and site design of special relevance to this stormwater system. However, tree selection should never be undertaken without qualified professional assistance (an urban forester, horticulturist, arborist, or related professional). Pest resistance, urban forest diversity, regional climate factors, growth form, invasive potential and numerous other factors need to be weighed in the final selection.

Soil Chemistry

Structural soils can have very different pHs than local mineral soils. Structural soils with a limestone base will typically have high pH. A structural soil with a granite base may have lower pH. The soil pH determines nutrient availability among other things. A pH of 7 is neutral, with lower pH being acid and a higher pH, basic or alkaline. The ideal pH for most trees is about 5 to 6.5, but urban soils are typically very basic (pH 7.5 to 8.5) because of disturbance, including concrete and limestone debris mixed into the soil. A typical symptom of nutrient deficiency caused by high pH is interveinal chlorosis, or yellowing, of the leaves (Figure 10). If the structural soil used in the system has a high pH, then a "pH tolerant" tree species should be used. These include many elms and ashes and certain maples and oaks as well as a variety of other species (see the tree guide sources at the end of this chapter). **The key is to test the structural soil pH and select trees that tolerate it.**

Figure 10. Visual comparison of a healthy pin oak leaf (left) and a chlorotic leaf (right). This chlorosis ultimately interferes with carbohydrate production in the plant and is a result of nutrient deficiencies stemming from elevated soil pH.
Photo by Susan Day.

Innovative Solution: High Shipping Costs of Structural Soils for Western States

High shipping costs can make using Carolina Stalite, produced in North Carolina, prohibitively expensive in Western states. The University of California at Davis designed an engineered soil from local, inexpensive volcanic rock and gave it the name of Davis Soil. This soil has been successfully used to increase drainage in open areas adjacent to parking lots and in certain turf applications. **Davis Soil is not considered a structural soil** because it cannot support the weight of pavement, cars and other structures. It can maintain perviousness under foot traffic and supports healthy tree growth. It is very porous (40 % porosity), and so it is able to store stormwater which can be then be used by trees. In addition, its large surface area with many nooks and crannies act to trap common stormwater pollutants. Contact Qingfu Xiao at qxiao@ucdavis.edu for more information on obtaining Davis Soil.

Figure 11. Davis Soil, a non-loadbearing soil (i.e. not a structural soil) with high infiltration rate and high potential for water storage.
Photo by Qingfu Xiao.

Soil Volume

Trees need enough room to grow—for their roots as well as their canopy. Tree pits (a.k.a. cutouts, planters) should be as large as possible—but how large is that? The key to designing sites that support large trees is to have essentially unlimited rooting space. A typical 4 × 4 ft. cutout with no access to surrounding soil limits tree growth almost immediately. A 25× 25 ft. cutout limits growth very little until the tree is quite large. The usable rooting space provided by any cutout can be expanded by a continuous structural soil bed under pavement. Some species are more adept at exploiting weakness in pavement, penetrating compacted soils, or reaching nearby open spaces. However, the system should be designed to support the tree fully without infrastructure damage. Structural soils have been shown to support deeper root systems than conventional pavement profiles and therefore should supply rooting space without compromising structural integrity. Again, species selection and site conditions must be compatible so a plant professional should be consulted. Always consider local regulations and permitting requirements.

Drainage and Reservoir Capacity Influence Tree Growth

This stormwater system collects water, and how it is designed will influence tree root development. In experiments conducted with flood tolerant species (see Chapter 4, Tree Development in Structural Soils at Different Drainage Rates), root systems developed best when water was retained in the rooting zone no more than 48 hours. Many flood tolerant species, such as swamp white oak (*Quercus bicolor*) or American elm (*Ulmus americana*) can survive many months with inundated root systems, but survival alone is not sufficient in urban settings. If infiltration into the soil below the reservoir is rapid, less flood-tolerant species may be selected. If infiltration into the soil below is slow and overflow pipes must be relied upon, then flood-tolerant species should be selected. Depending upon the final use of the space, other plants such as turf or groundcovers can be used if climate permits. See Chapter 3 for more information on surface treatments.

Although high water tables may limit tree rooting depth, when species selection and site design allow trees to root into lower soil regions and penetrate through impervious zones, they may be an effective tool to increase infiltration (see Chapter 4, Tree Root Penetration into Compacted Soils Increases Infiltration). This increase can be expected to be most dramatic in highly restrictive soils. To ease establishment, trees should ideally be established in mineral topsoil, with the structural soil components being reserved for under the pavement. However, establishing trees directly in structural soil can simplify installation. If trees will be irrigated regularly during establishment and climatic conditions are appropriate, this approach can be used.

Tree root systems are wide spreading. For maximum tree growth, provide rooting area about twice the diameter of the ultimate canopy for which you are designing.

General tree guide sources:

Dirr, Michael. Woody Landscape Plants.

PLANTS Database, http://www.plants.usda.gov/

Northern Trees, http://orb.at.ufl.edu/TREES/index.html

Tree guide sources for the Eastern United States:

Appleton, B. 2001. New York / Mid Atlantic Gardener's Book of Lists. Taylor Publishing Company, Dallas.

Bassukm N.L. Cornell Department of Horticulture Woody Plant Database, http://hosts.cce.cornell.edu/woody_plants/

Bassuk, N.L., J. Grabosky, and P. Trowbridge, 2005. Using CU-Structural Soil in the Urban Environment, http://www.hort.cornell.edu/uhi/outreach/csc/index.html

Day, S.D. Virginia Urban Tree Selector, http://www.cnr.vt.edu/dendro/treeselector/

Trowbridge, P.J. and N.L. Bassuk. 2004. Trees in the Urban Landscape: Site Assessment, Design, and Installation. Wiley and Sons, New York.

Tree guide sources for the Western United States:

McPherson, E.G., J.R. Simpson, P.J. Peper, Q. Xiao, D.R. Pittenger and D.R. Hodel. 2001. Tree Guidelines for Inland Empire Communities. Sacramento, CA: Local Government Commission

McPherson, E.G., J.R. Simpson, P.J. Peper, K.I. Scott and Q. Xiao. 2000. Tree Guidelines for Coastal Southern California Communities. Sacramento, CA: Local Government Commission

McPherson, E.G., J.R. Simpson, P.J. Peper and Q. Xiao. 1999. Tree Guidelines for San Joaquin Valley Communities. Sacramento, CA: Local Government Commission

Special Concerns

Soil Migration

The excavation of a seven-year-old traditional installation of a London plane (*Platanus* x *acerifolia*) tree in CU-Soil with a pervious surface did not show any aggregate migration. The pores between stones in the structural soils are mostly filled with soil so there are few empty spaces for soil to migrate to.

Frost Heave

By design, structural soils are gap-graded to provide rapid drainage, and limits the silt fraction to be consistent with very low frost heave susceptibility as defined by the US Corp of Engineers Cold Weather Research Laboratories. However, two important issues are related to this question. First, if the design system is installed as a trench under the pavement, there needs to be an awareness of the depths of layers in each pavement layer profile, and their different frost heave potentials. The designer needs to be sure there is not a major difference in frost heave potential at the interface of the two systems or else the pavement surface will move and crack as the total layered systems will behave differently. Secondarily, frost concerns also suggest snow removal concerns, so the placement of trees in the system and the needs of snow removal and storage on site need to be addressed with the maintenance authority to prevent the loss of the trees or damage to the system.

Observation of structural soil throughout the US and Canada shows that the depth of the reservoir negates any heaving due to consequent freezing and thawing. Additionally, there have been no observed instances of freeze/thaw damage in any structural soil installations in the fifteen plus years since its inception.

This section describes two surface treatments that can be used with this system: turf and porous pavement. The sections in this chapter are summaries from manuals published by the Urban Horticulture Institute (Cornell University). A citation to the complete manual is provided at the end of each section.

Chapter 3— Surface Treatments

Structural Soils and Turf

By Nina Bassuk, Ted Haffner, Jason Grabosky, and Peter Trowbridge

Introduction

Turf is primarily used as a ground cover in residential lawns, parks, playgrounds and athletic fields. It is used both for providing a sense of open space and as a protective surface for recreation. If turf is properly installed, it can have additional uses such as limited access fire lanes, and parking lots. In these instances, turf can contribute to a sense of open green space and reduce temperatures in urban settings that may otherwise be paved.

Figure 12. Area of park used for a weekly farmers market in Chicago. Compaction from foot and vehicle traffic has denuded the grass in this section of the park.
Photo by Ted Haffner.

When turf is used for these applications, however, it is susceptible to traffic which will compact the soil. These situations also limit drainage, healthy root growth, and the ability of turf to grow at all.

Figure 13. Photo simulation of turf-covered perimeter parking at a big box lot in Ithaca, NY. For best results, turf should be only placed in parking stalls and not in driving lanes of the parking lot.
Photosimulation by Ted Haffner.

Cornell Developments in Turf Use

Cornell University has combined turf with structural soil to create a healthy growing medium for the grass that withstands traffic, is designed to be virtually maintenance free, and can be used in areas that receive high levels of both pedestrian and vehicular traffic. These areas include open field public gathering spaces, fire lanes, and parking lots.

Structural soils have two benefits. The first is that structural soil is designed to be compacted, and will therefore withstand heavy amounts of traffic, allowing both people, cars and temporary structures to safely use a turf covered surface installed on structural soil. In addition, the system can allow water to infiltrate the turf surface and hold it in a reservoir underneath the grass. Increased water and air within the structural soil media not only allows for healthier root and shoot growth for the grass, but also allows rainwater and runoff to be collected and held within the reservoir in large amounts until it can slowly infiltrate into the ground below. This reduces the need for drainage and sewer system infrastructure and also recharges the groundwater levels over time. This combination, then, not only serves the environment from a water quality standpoint, but also adds a "sustainably green" component to highly urbanized areas.

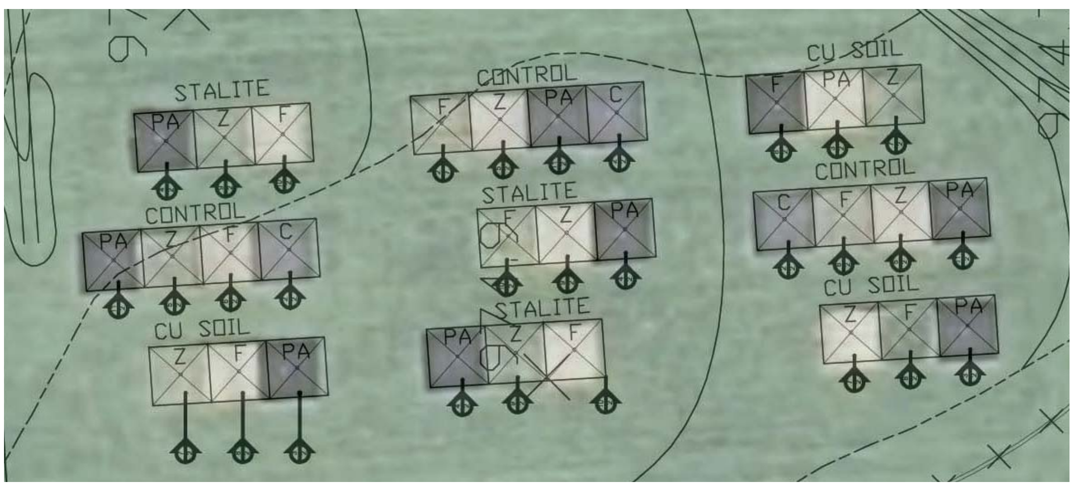

Figure 14. Aerial view of structural soil and turf experimental plots at Cornell University in Ithaca, NY. Surface Treatments: PA= Porous Asphalt, Z= Zoysia Grass, F= Tall Fescus, C= Traditional Asphalt.
Graphics by Ted Haffner. Underlying photo by Google Earth.

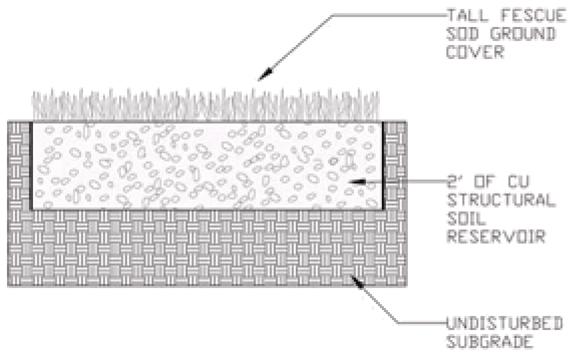

Figure 15. Construction detail for turfgrass and structural soil profile. Note that the 24" reservoir depth was based on local rainfall data and will vary by region according to the local rainfall data and/or anticipated runoff amounts. *Figure by Ted Haffner.*

- Minimize vehicular wear on the turf as much as possible. To do this, place turf only in parking stalls and not the driving lanes of the lot.
- Angle parking stalls to minimize turning from automobile wheels. Excessive turning causes the turf grass leaf blades to tear and can create bare patches in the turf. Research indicates that turf can recover from this damage but it takes extra time.
- Use turf only in overflow parking areas on the outskirts of large parking lots.
- Use inset stonework between stalls, or posts to demark parking stalls. This design maneuver may cost more upfront to install, but will save time and money during post-installation maintenance.
- Specify proper post-installation maintenance regimes. Mowing every 10 days is necessary, as is the application of annual fall fertilization with proper application rates.
- Never snow plow the turf portion of the parking lot. The blades from the plow will damage the turf surface, removing the turf and necessitating costly replacement.

Designing and Working with Turf and Structural Soil

Contrary to popular belief, growing healthy turfgrass is very difficult to achieve. With many different factors involved in the process, it is not as simple as spreading seed or unfurling a roll of sod. Proper decision making at every step of the planning, design, installation, and post-installation process are absolutely necessary.

Working with turf and structural soil requires a change in the way that designers and contractors go about their work. Rather than just installing sod or seeding grass directly onto existing soil, entire areas will need to be excavated to a depth of at least 18" to 24" (to accomodate stormwater- see Table 2), depending on the desired reservoir depth, and filled with structural soil. Once the structural soil mix is in place it must be compacted with a vibratory or rolling compactor. Once compacted, the sod should be installed directly onto the structural soil and then irrigated for a number of weeks until established. Once established, research indicates that maintenance requirements are minimal, other than regular mowing and periodic fertilization.

With the previous guidelines, a few simple construction details will provide the bulk of information needed for bidding and installation of a construction project. While a few simple drawings are helpful, keep in mind that every design is different and will necessitate the level of detail appropriate for each different design scenario. Additional details will be needed for, ADA compliance curbing, tree planting and staking, hydrant water supply, signage

FAQs

What type of maintenance is needed for a turfgrass and structural soil system?

Our research was performed with the idea of the most basic maintenance regime in mind. Test plots on the Cornell campus received no maintenance other than routine mowing once every 7 to 10 days during the growing season. Additional annual fertilization in the fall is recommended with the proper application rates.

What happens when neighboring tree roots expand in structural soil?

There will come a time when the roots will likely displace the stone because there are no pavement layers above the structural soil, but if the roots are, as we have observed, deep down in the profile, the pressure they generate during expansion would be spread over a larger surface area. We have seen roots move around the stone and actually surround some stones in older installations, rather than displace the stones.

Case Study

Turf on CU-Soil has been successfully used at a Mercedes dealership (Crown Automobile) in Alabama. At this installation, the soil in an entire median was excavated and replaced with CU-Soil and then sod was placed on top. The median can now properly withstand the compaction from the weight of the cars and serves as a flexible open space for the dealership, providing impromptu space to display inventory, or as overflow parking for the dealership. After three years, this installation is maintenance free and as healthy as the day it was installed.

Figure 16. In winter when the sod is dormant, the median serves as additional storage and display space for the dealership inventory. This flexibility is invaluable to the dealership.
Photo by Bill Isaacs.

Citation:

Haffner, E.C. 2008. Porous asphalt and turf: exploring new applications through hydrological characterization of CU Structural Soil and Carolina Stalite Structural Soil. Master's Thesis. Department of Horticulture, Cornell University.

Using Porous Pavement on Structural Soils

By Ted Haffner, Nina Bassuk, Jason Grabosky, and Peter Trowbridge

A porous asphalt system allows water to flow through the pavement and into a reservoir of structural soil beneath the surface. There water can slowly filter into the subgrade below, naturally recharging groundwater levels.

Porous asphalt is similar to traditional asphalt in every way but the mix specification. Unlike traditional asphalt, porous asphalt leaves out fine particles in the mix. Leaving out these finer particles leaves gaps within the profile of the asphalt that allow water to flow through the pavement, rather than over the pavement. In order for the water to properly infiltrate, slopes on porous pavements should be limited to 1-6%.

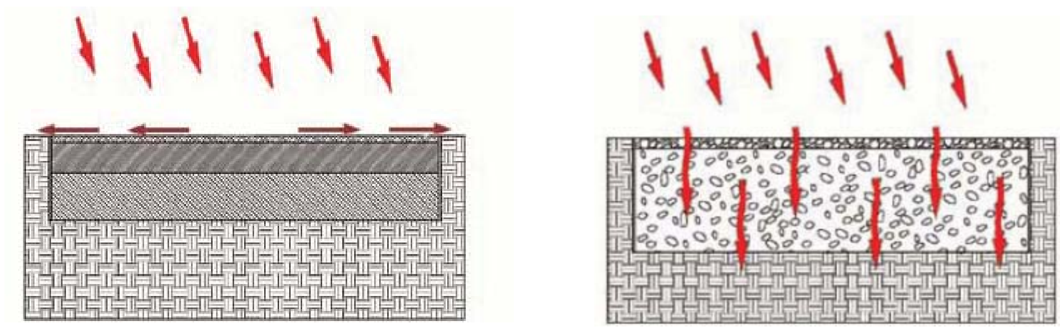

Figure 17. The left figure shows rain on a traditional asphalt parking lot- after it hits the surface it typically runs off into a storm sewer system. The right figure shows rain on a porous asphalt parking lot- after it its the surface it infiltrates through the pavement into the structural soil reservoir below. Water then infiltrates into the ground, recharging the groundwater over time.
Both figures by Ted Haffner.

Structural soil and porous asphalt are a new combination of 15- and 30-year-old technologies. As such, the first installation of this combination exists in Ithaca, NY and was installed in 2005. Porous asphalt parking lots are numerous and the oldest include the Walden Pond Reservation in Concord, MA, the Morris Arboretum in Philadelphia, PA, as well as an ever expanding list of corporations and universities across the United States. Structural soil has been used extensively without porous asphalt pavement and the two oldest installations date to 1994; the first is a honeylocust *(Gleditsia triacanthos)* planting at the Staten Island Esplanade Project in New York City, the second is a London planetree *(Platanus acerifolia)* planting on Ho Plaza on the Cornell campus, Ithaca, NY. There are now hundreds of installations of various sizes across the United States and Canada.

Figure 18. A comparison of traditional asphalt (left) and porous asphalt (right) when wet. The gaps created by leaving out the finer particles in porous asphalt allow water to infiltrate pavement and into the structural soil reservoir below. As a result, porous asphalt appears dull when wet, because water runs through and does not pond, which creates a high friction surface.
Photo by Ted Haffner.

Concerns of Clogging

The best maintenance for any type of porous pavement is a vacuum treatment every two to five years to remove sediment from the pores within the pavement, although the oldest installations have never been vacuumed and show little effects of clogging. Porous asphalt systems should not be pressure washed since this treatment further embeds sediment within the surface. Additionally, porous asphalt systems should never be sealed. Once a sealant is applied, the system will not work ever again.

Porous Bituminous Asphalt Specification

Ithaca, NY Porous Asphalt Medium Duty Parking Lot

1. Bituminous surface course for porous paving shall be two and one-half (2.5) inches thick with a bituminous mix of 5.5% to 6% by weight dry aggregate. In accordance with ASTM D6390, draindown of the binder shall be no greater than 0.3%. If more absorptive aggregates, such as limestone, are used in the mix then the amount of bitumen is to be based on the testing procedures outlined in the National Asphalt Pavement Association's Information Series 131 – "Porous Asphalt Pavements" (2003) or NYSDOT equivalent.

2. Use neat asphalt binder modified with an elastomeric polymer to produce a binder meeting the requirements of PG 76-22. The elastomeric polymer shall be styrene-butadiene-styrene (SBS), or approved equal, applied at a rate of 3% by total weight of the binder. The composite materials shall be thoroughly blended at the asphalt refinery or terminal prior to being loaded into the transport vehicle. The polymer modified asphalt binder shall be heat and storage stable.

3. Aggregate in the asphalt mix shall be minimum 90% crushed material and have a gradation of:

U.S. Standard

Sieve Size Percent Passing

½” (12.5mm) 100

3/8” (9.5mm) 92-98

4 (4.75mm) 32-38

8 (2.36mm) 12-18

16 (1.18mm) 7-13

30 (600 mm) 0-5

200 (75 mm) 0-3

4. Add hydrated lime at a dosage rate of 1.0% by weight of the total dry aggregate to mixes containing granite. Hydrated lime shall meet the requirements of ASTM C 977. The additive must be able to prevent the separation of the asphalt binder from the aggregate and achieve a required tensile strength ratio (TSR) of at least 80% of the asphalt mix.

The asphaltic mix shall be tested for its resistance to stripping by water in accordance with ASTM D-3625. If the estimated coating area is not above 95 percent, anti-stripping agents shall be added to the asphalt.

Citation:

Haffner, T., Bassuk, N.L., Grabosky, J., and P. Trowbridge. 2007. Using Porous Asphalt and CU-Structural Soil. http://www.hort.cornell.edu/uhi/outreach/csc/index.html Urban Horticulture Institute, Cornell University, Ithaca, NY.

Tree Root Penetration into Compacted Soils Increases Infiltration

Based on Research by Julia Bartens, Susan Day, Joseph E. Dove, J. Roger Harris, and Theresa Wynn, Virginia Tech

Research Summary

A container experiment with recently transplanted black oak *(Quercus velutina)* and red maple *(Acer rubrum)* tested whether roots can penetrate into compacted soil and once they penetrate, if they can increase water infiltration. Both tree species were grown in pine bark and surrounded on all sides and the bottom with compacted soils. Within 12 weeks, both tree species were able to penetrate into compacted soil and increase infiltration. Roots penetrating into subsoil increased infiltration by 153%. There was no difference in performance between black oak (coarse roots) and red maple (fine roots).

Figure 19. Ash roots penetrating geotextile after compacted subsoil has been washed away. Roots increased infiltration by a factor of 27. *Photo by Susan Day.*

In a second container experiment, green ash *(Fraxinus pennsylvanica)* were grown in CU-Soil and were separated from the compacted subsoil by geotextile. Roots were able to penetrate into compacted subsoil and increase the infiltration rate by a factor of 27.

Next Steps/Research Needs

This research was done in containers and research confirming that this also applies to larger scale trees in the ground needs to be done. Tree species with different requirements should also be observed.

Citation

Bartens, J., S. D. Day, J. R. Harris, J. E. Dove, and T. M. Wynn. 2008. Can urban tree roots improve infiltration through compacted subsoils for stormwater management? Journal of Environmental Quality, 37 (6):2048-2057.

Chapter 3— Surface Treatment

Tree Development in Structural Soils at Different Drainage Rates

Based on Research by Julia Bartens, Susan Day, J. Roger Harris, Joseph E. Dove, and Theresa Wynn, Virginia Tech

Research Summary

A container experiment involving 2 tree species (swamp white oak *(Quercus bicolor)*, and green ash *(Fraxinus pennsylvanica)*, 3 drainage rates (slow, medium, rapid), and 2 structural soils (CU-Soil and Carolina Stalite) evaluated the optimal reservoir detention times for tree root development and water uptake from the reservoir. Structural soils had an impact on root distribution— tree roots grew wider in Carolina Stalite than with CU-Soil. Drainage rate also had an impact on tree growth; Root:shoot ratios for swamp white oak were much higher for the slow drainage treatment and trees were smaller with shallow root systems. Green ash trees were more flood tolerant and no difference in Root:shoot ratios for the different drainage rates was observed but roots did grow deepest in the rapidly draining treatment.

Recommendations based on this research

In general, water should drain from the parking lot within 2 days so adequate root systems can develop. For water uptake from the reservoir it is clearly beneficial to have root systems explore the full reservoir depth. Prolonged inundation can prevent this deeper root exploration, depending upon species. Transpiration rates were varied but similar to trees grown in traditional landscapes. Of course, size of tree canopy is important in determining amount of water that can be removed. In general, the largest trees with the best developed root systems removed the greatest amount of water from the stormwater reservoirs.

Next Steps/Research Needs

Temperatures of the structural soils could be compared in future experiments because this could also be affecting the root growth and maybe of interest if water does exit the system through an overflow pipe (because of the potential for thermal pollution of waterways). In addition, a field study would give more information about lateral root growth (which was limited in this experiment because of containers). Although tree species with similar flood/drought tolerances can be expected to respond similarly, more species trials would be useful.

Citation

Bartens, J., J. R. Harris, S. D. Day, J. E. Dove, and T. M. Wynn. 2008 Ecologically integrated stormwater distribution using urban trees and structural soils. (in review)

Drainage Rate at the Mini Parking Lot Demonstration Site in Blacksburg, VA

Based on Research by Mona Dollins, Virginia Tech

Research Summary

A Mini Parking Lot demonstration site which had a Carolina Stalite structural soil reservoir (18' x 18' x 23") was completely filled with water and then allowed to naturally drain into the clay textured subsoil beneath. The water levels were checked from 15 observation wells every 5 minutes (during the first 40 minutes) to 15 minutes (during the remainder of the experiment) to determine the speed of drainage and lateral water movement through the system.

Within 2.5 hours, the water had completely drained from the reservoir. Lateral water movement within the reservoir was very rapid through the structural soil media traveling over 18 feet in a matter of minutes.

Next Steps/Research Needs

Drainage data from larger systems, at varying depths, and different types of subsoils should be tested to gain better understanding of the systems behavior in different conditions.

Note: some fine textured soils will not drain as quickly as they did in this trial. An initial soil drainage test and incorporating an overflow pipe is always recommended (see the blue box on page 15).

System Effects on Water Quality

Based on Research by Qingfu Xiao, University of California at Davis

Research Summary

Research shows that 97.9-99% of the hydrocarbons found in pollutants such as oil are suspended within the first few inches of the surface. During suspension, microorganisms biodegrade the hydrocarbons into their constituent parts of simple chemical components which cease to exist as pollutants and render them harmless to the environment.

Surface runoff from four types of parking lots was collected (commercial, older institutional (>10 years), newer institutional (<3 years), and residential). Pollutant removal (nutrients, heavy metals, soil column tests) by 3 types of substrates (CU-Soil, Davis Soil, and Carolina Stalite) were compared. Tests: single event test, multiple events test and synthetic runoff test.

All three engineered soils were effective at removing nutrients and materials in polluted surface runoff. Pollutant removal rates were strongly related to the type and size of the rainfall event.

Next Steps/Research Needs

Research that determines the pollutant saturation point for these soils should be done. Also, the figures reported are baseline data for structural soils alone. Once tree roots explore the reservoir it is expected that they would enhance pollutant removal— but research is needed to accurately evaluate these effects.

How effective the system is at removing/degrading nutrients and pollutants with trees in the system.

How can pollutant fluxes be balanced in the system? In heavily polluted areas other BMPs need to be used for pre-treating the surface runoff.

Pollutant reduction (percent)

	Max			Min			Mean			STD			[1]No		
	CS	CU	DS	CS	CU	DS	CS	CU	DS	CS	CU	DS	CS	CU	DS
TKN	67	39	85	8	20	12	42	29	46	21	8	19	17	4	23
NH4-N	100	99	100	36	7	42	84	54	83	18	31	16	15	13	17
NO3-N	95	88	95	58	58	58	77	73	77	26	21	26	2	2	2
[2]P_S	96		95	13		11	62		59	26		25	16	0	19
P	82		78	0		0	58		52	23		25	16	0	19
[2]K_S	78		73	25		34	59		56	16		13	9	0	9
K			64			37			50			19	0	0	2
Zn	100	100	100	50	50	50	80	75	80	21	21	21	15	15	14
Cr	100	100	100	0	0	50	78	88	92	36	35	20	9	8	6

[1]: Number of samples.

[2]: S stands for soluble.

Table 3. Pollutant removal of single storm event. CU= CU Soil, CS= Carolina Stalite, and DS= Davis Soil.
Table by Qingfu Xiao.

Pollutant reduction (percent)

	Max			Min			Mean			STD			[1]No		
	CS	CU	DS	CS	CU	DS	CS	CU	DS	CS	CU	DS	CS	CU	DS
TKN	70	60	71	11	6	4	48	30	50	23	22	23	15	8	13
NH4-N	100	99	100	29	27	23	76	64	77	23	20	22	15	12	15
NO3-N	95	92	92	58	48	58	85	71	76	18	22	15	4	4	5
[2]P_S	94	48	95	15	48	23	65	48	65	24		25	14	1	13
P	89	0	86	0	0	0	55		55	29		25	15	0	13
[2]K_S	77	0	79	1	0	4	53		54	24		23	9	0	9
K	77	0	77	45	0	45	61		61	22		22	2	0	2
Zn	100	100	100	50	33	50	74	86	80	20	21	20	15	15	14

[1]: Number of samples.

[2]: S stands for soluble.

Table 4. Pollutant removal of multiple storm events. CU= CU Soil, CS= Carolina Stalite, and DS= Davis Soil.
Table by Qingfu Xiao.

Balages, J.D., L. Legret, and H. Madiec, 1995. Permeable pavements: pollution management tools. Water Science and Technology, 32 (1): 49-56.

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Note: These structural soil specifications are provided as a convenience to the reader and are presented “as is” from resources provided by the manufacturers or licenses. Inclusion of the specifications in no way represents an endorsement of or warranty of these products by Virginia Tech, Cornell University or University of California at Davis or any of their employees.

CU-Soil is a patented material and must be purchased from a licensed supplier. Amereq (http://www.amereq.com/) licenses the manufacturing of CU-Soil to ensure quality control of installations.

Carolina Stalite is composed primarily of a manufactured component available from Carolina Stalite Company (Salisbury, NC). It is available through the horticultural division of Carolina Stalite (www.permatill.com).

CU-Soil Specification and Mixing Procedure

CU-Soil is a patented material and must be purchased from a licensed supplier. Amereq (http://www.amereq.com/) licenses the manufacturing of CU-Soil to ensure quality control of installations.

1.01 SAMPLES AND SUBMITTALS

A. At least 30 days prior to ordering materials, the Contractor shall submit to the Engineers representative samples, certificates, manufacturers literature and certified tests for materials specified below. No materials shall be ordered until the required samples, certificates, manufacturers literature and test results have been reviewed and approved by the Engineer. Delivered materials shall closely match the approved samples. Approval shall not constitute final acceptance. The Engineer reserves the right to reject, on or after delivery, any material that does not meet these specifications.

B. Submit two - one half cubic foot representative samples of Clay Loam and two - two cubic foot representative samples Structural Soil mixes in this section for testing, analysis and approval. Submit one set of samples for every 500 CY of material to be delivered. In the event of multiple source fields for Clay Loam, submit a minimum of one set of samples per source field or stockpile. Samples shall be taken randomly throughout the field or stockpile at locations as directed by the Engineer and packaged in the presence of the Engineer. Contractor shall deliver all samples to testing laboratories and shall have the test results sent directly to the Engineer. Samples shall be labeled to include the location of the source of the material, the date of the sample and the Contractors name. One of the two samples is to be used by the testing laboratory for testing purposes. The second sample of all Clay Loam and Structural Soil shall be submitted to the Engineer at the same time as test analysis as a record of the soil color and texture.

1. Submit the locations of all source fields for Clay Loam.
2. Submit a list of all chemicals and herbicides applied to the Clay Loam for the last five years and a list of all crops grown in the Clay Loam source fields for the last three years.

C. Submit soil test analysis reports for each sample of Clay Loam and Structural Soil from an approved soil-testing laboratory. The test results shall report the following:

1. The soil testing laboratory shall be approved by the Engineer. The testing laboratory for particle size and chemical analysis may be a public agricultural extension service agency or agricultural experiment station.

2. Submit a particle size analysis including the following gradient of mineral content:

USDA Designation Size in mm.

Gravel	+2mm
Sand	0.05 -2 mm
Silt	0.002-0.05 mm
Clay	minus 0.002 mm

Sieve analysis shall be performed and compared to USDA Soil Classification System.

D. Submit a chemical analysis, performed in accordance with current AOAC Standards, including the following:

a. pH and Buffer pH.

b. Percent organic matter as determined by the loss of ignition of oven dried samples.

c Analysis for nutrient levels by parts per million including nitrate nitrogen, ammonium nitrogen, phosphorus, potassium, magnesium, manganese, iron, zinc, calcium and extractable aluminum. Nutrient test shall include the testing laboratory recommendations for supplemental additions to the soil as calculated by the amount of material to be added per volume of soil for the type of plants to be grown in the soil.

d. Analysis for levels of toxic elements and compounds including arsenic, boron, cadmium, chromium, copper, lead mercury, molybdenum, nickel, zinc and PCB. Test results shall be cited in milligrams per kilogram.

e. Soluble salt by electrical conductivity of a 1:2 soil/water sample measured in Millimho per cm.

f. Cation Exchange Capacity (CEC).

1 Submit 5-point minimum moisture density curve AASHTO T 99 test results for each Structural Soil sample without removing oversized aggregate.

2. Submit California Bearing Ratio test results for each Structural Soil sample compacted to peak standard density. The soaked CBR shall equal or exceed a value of 50.

3. Submit measured dry-weight percentage of stone in the mixture.

4. The approved Structural Soil samples shall be the standard for each lot of 500 cubic yards of material.

5. All testing and analysis shall be at the expense of the Contractor.

1.02 DELIVERY, STORAGE, AND HANDLING

A. Do not deliver or place soils in frozen, wet, or muddy conditions. Material shall be delivered at or near optimum compaction moisture content as determined by AASHTO T 99 (ASTM D 698). Do not deliver or place materials in an excessively moist condition (beyond 2 percent above optimum compaction moisture content as determined by AASHTO T 99 (ASTM D 698).

B. Protect soils and mixes from absorbing excess water and from erosion at all times. Do not store materials unprotected from large rainfall events. Do not allow excess water to enter site prior to compaction. If water is introduced into the material after grading, allow material to drain or aerate to optimum compaction moisture content.

MATERIALS

2.01 CLAY LOAM

A. Clay Loam / Loam shall be a " loam to clay loam" based on the "USDA classification system" as determined by mechanical analysis (ASTM D-422) and it shall be of uniform composition, without admixture of subsoil. It shall be free of stones greater than one-half inch, lumps, plants and their roots, debris and other extraneous matter over one inch in diameter or excess of smaller pieces of the same materials as determined by the Engineer. It shall not contain toxic substances harmful to plant growth. It shall be obtained from areas which have never been stripped of top soil before and have a history of satisfactory vegetative growth. Clay Loam shall contain not less than 2% nor more than 5% organic matter as determined by the loss on ignition of oven-dried samples.

B. Mechanical analysis for a Loam / Clay Loam shall be as follows:

Textural Class	% of total weight
Gravel	less than 5%
Sand	20 - 45%
Silt	20 - 50%
Clay	20- 40%

C. Chemical analysis: Meet or be amended to meet the following criteria.

1. pH between 6.0 to 7.6
2. Percent organic matter 2 -5% by dry weight.
3. Nutrient levels as required by the testing laboratory recommendations for the type of plants to be grown in the soil.
4. Toxic elements and compounds below the United States Environmental Protection Agency Standards for Exceptional

Quality sludge or local standard; whichever is more stringent.

5. Soluble salt less than 1.0 Millimho per cm.
6. Cation Exchange Capacity (CEC) greater than 10
7. Carbon/Nitrogen Ratio less than 33:1.

2.02 CRUSHED STONE

A. Crushed Stone shall be a DOT certified crushed stone. Granite and limestone have been successfully used in this application. Ninety-100 percent of the stone should pass the 1.5 inch sieve, 20-55 percent should pass the 1.0 inch sieve and 10 percent should pass the 0.75 inch sieve. A ratio of nominal maximum to nominal minimum particle size of 2 is required

B. Acceptable aggregate dimensions will not exceed 2.5:1.0 for any two dimensions chosen.

C. Minimum 90 percent with one fractured face, minimum 75 percent with two or more fractured faces.

D. Results of Aggregate Soundness Loss test shall not exceed 18 percent. Losses from LA Abrasion tests shall not exceed 40%.

2.03 HYDROGEL

A Hydrogel shall be a potassium propenoate-propenamide copolymer Hydrogel such as that which is manufactured under the name Gelscape by Amereq Corporation. (800) 832-8788

2.04 WATER

A. The Contractor shall be responsible to furnish his own supply of water to the site at no extra cost. All work injured or damaged due to the lack of water, or the use of too much water, shall be the Contractor's responsibility to correct. Water shall be free from impurities injurious to vegetation.

2.05 STRUCTURAL SOIL

A. A uniformly blended mixture of Crushed Stone, Clay Loam and Hydrogel, mixed to the following proportion:

MATERIAL	UNIT OF WEIGHT
Crushed Stone	80 units dry weight
Loam (screened)	as determined by the test of the mix. (Approx. 20 units dry weight)
Hydrogel	0.03 units dry weight/100units stone
Total moisture	(AASHTO T-99 optimum moisture)

B. The initial mix design for testing shall be determined by adjusting the ratio between the Crushed Stone and the Clay loam. Adjust final mix

dry weight mixing proportion to decrease soil in mixture if CBR test results fail to meet acceptance (CBR > 50).

CONSTRUCTION METHODS

3.01 SOIL MIXING AND QUALITY CONTROL TESTING

A. All Structural Soil mixing shall be performed at the Contractor's yard using appropriate soil measuring, mixing and shredding equipment of sufficient capacity and capability to assure proper quality control and consistent mix ratios. No mixing of Structural Soil at the project site shall be permitted. **Portable pugging may be used**

1. Maintain adequate moisture content during the mixing process. Soils and mix components shall easily shred and break down without clumping. Soil clods shall easily break down into a fine crumbly texture. Soils shall not be overly wet or dry. The contractor shall measure and monitor the amount of soil moisture at the mixing site periodically during the mixing process.

2. A Mixing procedure for front-end loader shall be as follows:

    a. On a flat asphalt or concrete paved surface, spread an 8 inch to 12 inch layer of crushed stone.
    b. Spread evenly over the stone the specified amount of dry hydrogel. Water the hydrogel on the stone before adding the soil.
    c. Spread over the hydrogel and crushed stone a proportional amount of clay loam according to the mix design.
    d. Blend the entire amount by turning, using a front-end loader or other suitable equipment until a consistent blend is produced.
    e. Add moisture gradually and evenly during the blending and turning operation as required to achieve the required moisture content. Delay applications of moisture for 10 minutes prior to successive applications. Once established, mixing should produce a material within 1% of the optimum moisture level for compaction.

3. A pugging operation mixing procedure may be as follows:

a. Feed a known weight of crushed stone into the mixing trough.
b. Add hydrogel as a slurry into trough and mix slurry and stone into a uniform blend.
    c. Meter in soil in proper proportion of Clay loam soil

While stone-slurry mixture is in motion.

d. Add water to bring mixture to target moisture content after factoring in water from the slurry and the Clay-loam moisture.

e. Auger out to stock pile or transport vehicle (or into pit if using a portable pugging operation).

B. The Contractor shall mix sufficient material in advance of the time needed at the job site to allow adequate time for final quality control testing as required by the progress of the work. Structural Soil shall be stored in piles of approximately 500 cubic yards and each pile shall be numbered for identification and quality control purposes. Storage piles shall be protected from rain and erosion by covering with plastic sheeting.

C. During the mixing process, the Contractor shall take two - one cubic foot quality control samples per 500 cubic yards of production from the final Structural Soil. The samples shall be taken from random locations in the numbered stockpiles as required by paragraph 1.03.B of this specification. Each sample shall be tested for particle size analysis and chemical analysis as described in Paragraph 1.03. C.2 and 3 above. Submit the results directly to the Engineer for review and approval.

D. The quality control sample Clay Loam-Crushed Stone ratio's shall be no greater or less than 2% of the approved test sample as determined by splitting a known weight of oven dried material on a #4 sieve. In the event that the quality control samples vary significantly from the approved Structural Soil sample, as determined by the Engineer, remix and retest any lot of soil that fails to meet the correct analysis making adjustments to the mixing ratios and procedures to achieve the approved consistency.

3.02 INSTALLATION OF STRUCTURAL SOIL MATERIAL

A. Install Structural Soil in 8 inch lifts and compact each lift. (Minimum of 24" total structural soil depth, preferably 36" recommended).

B. Compact all materials to peak dry density from a standard AASHTO compaction curve (AASHTO T 99). No compaction shall occur when moisture content exceeds maximum as listed herein. Delay compaction 24 hours if moisture content exceeds maximum allowable and protect Structural Soil during delays in compaction with plastic or plywood as directed by the Engineer.

C. Bring Structural Soils to finished grades as shown on the Drawings. Immediately protect the Structural Soil material from contamination by toxic materials, trash, debris, water containing cement, clay, silt or materials that will alter the particle size distribution of the mix with plastic or plywood as directed by the Engineer.

D. The Engineer may periodically check the material being delivered and installed at the site for color and texture consistency with the approved sample provided by the Contractor as part of the submittal for Structural Soil. In the event that the installed material varies significantly from the approved sample, the Engineer may request that the Contractor test the installed Structural Soil. Any soil which varies significantly from the approved testing results, as determined by the Engineer, shall be removed and new Structural Soil installed that meets these specifications.

Carolina Stalite Structural Soil Specification

Section 02911 INSTALLATION GUIDELINES – STALITE STRUCTURAL SOIL MIX FOR TREES

PART 1 – GENERAL

PART 2 - PRODUCTS

2.1 MATERIALS

A. STRUCTURAL SOIL MIX

1. The Structural Soil Mix shall be Stalite Structural Soil Mix (a special pre-mixed blend of 80% 3/4" graded **"STALITE"** Expanded Slate Aggregate and 20% approved sandy clay loam).

B. TREE PIT BACKFILL PLANTING MIX

1. The tree pit backfill planting mix shall be high quality topsoil PermaTill mix.

PART 3 - EXECUTION

3.1 PREPARATION

A. GENERAL

1. The paving contractor shall obtain necessary approvals before placing each SSM layer.

2. The paving contractor shall use adequate numbers of skilled workmen who are thoroughly trained in the necessary crafts and are completely familiar with the specified requirements and methods needed for proper performance of the work in this section.

3. The contractor must provide access for and cooperate with the testing laboratory.

4. Adequacy of the final compaction of all elements requiring compaction shall be determined in the field by the engineer to achieve the minimum specified compaction level.

B. PREPARING SUBGRADE

1. The subgrade shall be prepared according to the following procedure:
   a. Remove all organic matter, debris, loose material and large rocks.
   b. Dig out soft and mucky spots and replace with suitable material.
   c. Loosen hard spots and uniformly compact the subgrade to 95% of its maximum dry density.

C. PERFORATED UNDERDRAIN SYSTEM

1. The underdrain system shall be Installed, including sock or soil separator fabric, according to drawing and specifications, and connected to the storm drain.

3.2 PLACING STRUCTURAL SOIL MIX BY PAVING CONTRACTOR

A. GENERAL

1. Adequacy of the final compaction shall be determined in the field by the engineer by proof roll.

2. The soil vents and drains shall be installed as specified and structural soil compacted under and around each pipe.

3. **Optional – If wooden tree pit forms are used, they shall be installed as directed by the Landscape Architect.**

4 The SSM shall be placed in approximately uniform lifts over the entire area of project and each lift compacted, including the open tree pit areas. Construction equipment, other than for compaction, shall not operate on the exposed structural soil mix. Over-compaction should be avoided. No foot or equipment traffic should be allowed on the compacted material until the paving is placed.

5. The drip irrigation system is to be installed and tested during the installation to avoid disturbing the compaction of the mix.

B. COMPACTING

1. Use of portable vibratory plate compacting machine (Recommended)

a. Place structural soil mix in horizontal lifts not exceeding 12 inches of compacted depth. Use a minimum of two passes, of not less than 10 seconds per pass, before moving the vibratory plate to the next adjacent location. Additional passes may be required and should be determined in the field by the engineer to insure stability of the layer. Continue placing and compacting 12" lifts until the specified depth is reached.

2. Use of vibratory steel roller (Recommended)

a. For large spaces, a vibratory steel roller weighing no more than 12 tons static weight can be used. Horizontal lifts should not exceed 12" compacted. The minimum number of passes is two and maximum number is four. Additional passes may be required and should be determined in the field by the engineer to insure stability of the layer.

3.3 PLACING PLANTING MIX

A. GENERAL

1. All necessary approvals shall be obtained from the contractor before placing the Surface planting mix.
2. Place panting mix directly on the structural soil.
3. Do not place planting mix against the trunks of existing trees

3.4 MULCH PLACEMENT

A. Mulch can be placed as specified directly on the compacted structural soil.

PART 4 - TREE PLANTING

4.1 PLANTING PIT PREPARATION BY LANDSCAPE CONTRACTOR

A. PLANTING PIT EXCAVATION

1. The Landscape Contractor shall excavate the tree pit using these procedures:

   a. Excavate the structural soil mix to a depth equal to the height of the root ball of the tree to be planted. Remove the SSM to within two feet of the edge of the paved area.

   b. Place the tree in the pit and backfill as soon as possible, as recommended in section "B". No tree pit shall remain excavated for more than 2 hours unless forms are used.

B. TREE PIT BACKFILL PLANTING MIX

1. The landscape contractor shall backfill the tree pit by using these procedures:

   a. Remove any optional wooden forms. Immediately place the tree in the pit as detailed and mix the excavated structural soil 50:50 with the specified topsoil backfill planting mix in one foot lifts and tamp until firm.

   b. Tamp the planting mix in one foot lifts until the pit is filled to the specified grade above the planting.

   c. Dispose of the excavated structural soil mix (do not re-use as structural soil).

   d. Attach drip irrigation as specified.

Carolina Stalite Mixing Specification

PART 2 - PRODUCTS

2.1 STRUCTURAL SOIL

A. Provide a Structural Soil mix using the two components listed below that will meet the ASTM standards as follows:

¾" Stalite Expanded Slate	80%
Sandy Clay Loam *	20%

*Percentages of sand and clay may vary to meet testing requirements

1. Air Filled Porosity: 10% - 15% by volume

2. Water Retention (ASTM D2325) at 0.1 bar: minimum of 10% - 12% by volume, up to 30%

3. Permeability (Hydraulic Conductivity) (ASTMD2434 or D5084): Minimum 1/4" - 1/2" per hour

2.2 Structural Soil Components

A. 3/4" Stalite Rotary Kiln Expanded Slate

1. ASTM C29 Unit Dry Weight loose (48 lbs/cf to 55 lbs/cf) Saturated Surface Loose (55 lbs/cf to 60 lbs/cf)

2. ASTM C127 Specific Gravity to meet 1.45 to 1.60 Dry Bulk

3. ASTM C330 to meet the ASTM Gradation 3/4" - #4 size

3/4" to #4

Sieve Size	% Passing
1"	100
3/4"	90 - 100
3/8"	10-50
#4	0 - 10

4. Test for degradation loss using Los Angeles Abrasion testing in accordance with **ASTM C-131 modified method FM 1-T096.** No more than 28% of the weight of the aggregate must be lost to degradation.

1. Texture

40%-65% sand

15%-25% silt

20%-35% clay

2%-5% 0rganic matter

2.2 MIXING OFFSITE

A. Structural Soil

1. Mechanically mix the sand and loam thoroughly if mixing is necessary to meet the specifications.

2. Saturate the 3/4" Expanded Slate with water and mechanically mix the sandy clay loam until the slate particles are completely coated.

4. When stockpiling the finished mix, cover the pile with a plastic tarp to prevent drying out or soil separation from rain.

5. Install the mix within 48 hours of mixing.