Using CU-Structural Soil™ in the Urban Environment

Cornell University

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Founded in 1980 with the explicit mission of improving the quality of urban life by enhancing the functions of plants within the urban ecosystem, the Urban Horticulture Institute program integrates plant stress physiology, horticultural science, plant ecology and soil science and applies them to three broad areas of inquiry.

They are:

• The selection, evaluation and propagation of superior plants with improved tolerance of biotic and abiotic stresses, and enhanced functional uses in the disturbed landscape.

• Developing improved technologies for assessing and ameliorating site limitations to improve plant growth and development.

• Developing improved transplant technologies to insure the successful establishment of plants in the urban environment.

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Cover Photo:
Elm trees planted in CU-Structural Soil™ in Union Square Park, NYC.

The Case for CU-Structural Soil™:

Why do we need it, what is it, and how is it used?

Urban trees experience a litany of environmental insults: soil and air pollution, heat loads, deicing salts, and impacts from utilities, vehicles, and buildings. The most significant problem that urban trees face, however, is lack of useable soil volume for root growth, since trees are often an afterthought in city planning and streescape design. (Fig. 1.1)

Fig. 1.1 Tree root ball prior to being planted in a 4' x 5' tree pit in NYC.

Fig. 1.2 Compaction is necessary to create a load-bearing surface on which to lay pavement.

Soil Compaction

Ongoing construction, including sidewalk and road repair, disturbs and compacts soil (Fig. 1.2), crushing macropores (Fig. 1.3). Loss of macropores has three negative consequences, restricted aeration, diminished water drainage, and creating a dense soil that is difficult for roots to penetrate. These effects limit useable rooting space.

Macropores

- the relatively large spaces between soil aggregates
- water drains quickly through macropores
- air diffuses through macropores

Macropores are the spaces between the soil aggregates

Fig. 1.3 Macropores are spaces between soil aggregates that allow water, air and subsequently root growth.

Fig. 1.4 Surface rooting of trees growing in compacted soils

What happens when roots encounter dense, compacted soil?

When roots encounter dense soil, they change direction, stop growing, (Fig 1.5) or adapt by remaining abnormally close to the surface (Fig. 1.4) This superficial rooting makes urban trees more vulnerable to drought and can cause pavement heaving. However, if a dense soil is waterlogged, tree roots can rot from lack of oxygen.

Fig. 1.5 Tree roots which are typically superficial can become 'containerized' by compacted soil under and around trees.

Fig.1.6 This photograph shows the effect of soil volume on tree growth. With willow oaks planted at the same time on Pennsylvania Avenue, Washington, D.C. Right, trees in tree pits, left, trees in open grassed area.

The role of soil volume on tree growth

The soil in urban tree lawns or parks can be improved by amendment or soil replacement. Where soil volume is limited by pavement, tree roots suffer (Fig 1.6). The highly compacted soils required for constructing pavements do not allow root penetration, resulting in the declining trees, all too common in cities. Yet it is precisely these paved areas such as parking lots and streets that most need the mitigating effects of shade trees.

Healthy trees need a large volume of non-compacted soil with adequate drainage and aeration and reasonable fertility. CU-Structural Soil™ meets these needs while also fulfilling engineers' load-bearing requirements for base courses for pavement.

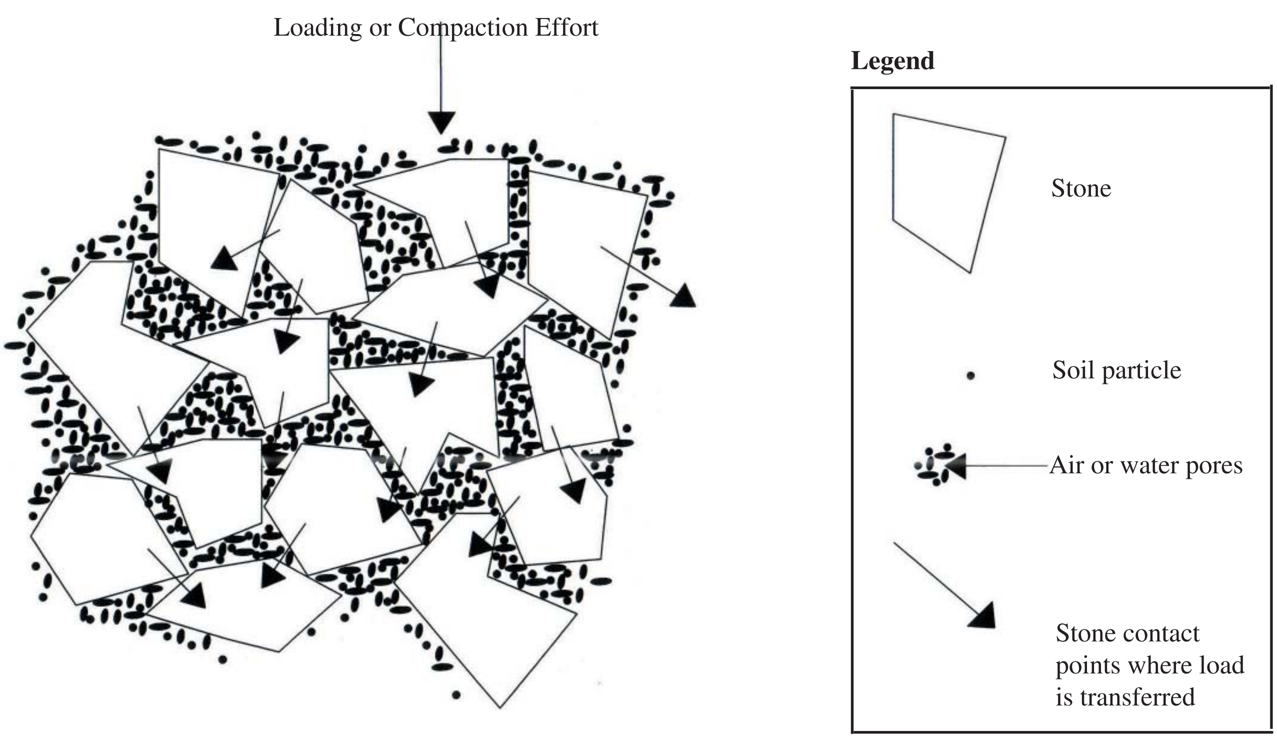


Fig.1.7 Conceptual diagram of CU-Structural Soil™ including stone-on-stone compaction and soil in interstitial spaces used as a base course for pavements.

CU-Structural Soil™ Basics

CU-Structural Soil™ (U.S. Patent # 5,849,069) is a two-part system comprised of a rigid stone "lattice" to meet engineering requirements for a load-bearing soil, and a quantity of soil, to meet tree requirements for root growth. The lattice of load-bearing stones provides stability as well as interconnected voids for root penetration, air and water movement (Fig. 1.7). The uniformly graded 3/4"-1 1/2" angular crushed stone specified for CU-Structural Soil™ is designed to ensure the greatest porosity. Crushed or angular stone provides more compaction and structural interface of stone-to-stone than round stone. Because stone is the load-bearing component of structural soil, the aggregates used should meet regional or state department of transportation standards for pavement base courses.

Since among soil textures, clay has the most water and nutrient-holding capacity, a heavy clay loam or loam, with a minimum of 20% clay, is selected for the CU-Structural Soil™ system. CU-Structural Soil™ should also have organic matter content ranging from 2%-5% to ensure nutrient and water holding while encouraging beneficial microbial activity. A minimum of 20% clay is also essential for an adequate cation exchange capacity.

With carefully chosen uniformly-graded stone and the proper stone to soil ratio, a medium for healthy root growth is created that also can be compacted to meet engineers' load-bearing specifications (Fig. 1.8). The intention is to "suspend" the clay soil between the stones without over-filling the voids, which would compromise aeration and bearing capacity. CU-Structural Soil™ utilizes Gelscape® hydrogel as a non-toxic non-phytotoxic tackifier, in addition to stone and soil components.

Fig. 1.8 From upper left, clockwise: uniformly-graded crushed stone of 3/4" - 1 1/2" diameter, pile and close-up; CU-Structural Soil™ after mixing; clay loam.

Using CU-Structural Soil™ for Street Trees

CU-Structural Soil™ is intended for paved sites to provide adequate soil volumes for tree roots under pavements (Fig. 1.9). It can and should be used under pedestrian mall paving, sidewalks, parking lots, and low-use access roads. The Urban Horticulture Institute is currently conducting trials of its use under turf and porous asphalt to provide more porous parking areas. Research at Cornell has shown that tree roots in CU-Structural Soil™ profiles grow deep into the base course material, away from the fluctuating temperatures at the pavement surface. One benefit of this is that roots are less likely to heave and crack pavement than with conventional paving systems (Fig. 1.10).

Planting a tree into CU-Structural Soil™ is much like conventional planting. If possible, the pavement opening should be expandable (via removable pavers or using a mulched area) for the sake of the anticipated buttress roots of maturing trees (Fig. 1.11). CU-Structural Soil™ should be used at a depth of at least 24" but preferably 36" (Fig.1.12). CU-Structural Soil™ can be used right up to the surface grade where there is a pavement opening that is large enough to allow for tree installation.

Fig.1.9 Installing CU-Structural Soil™ in Ithaca, NY in 1997

Fig. 1.10 Sidewalk heaving caused by superficial tree root growth, Ithaca, NY

Fig. 1.11 Lindens in CU-Structural Soil™ in Boston, 2002

Fig. 1.12a Example of street tree planting using CU-Structural Soil™ under conventional concrete sidewalk in Brooklyn, NY

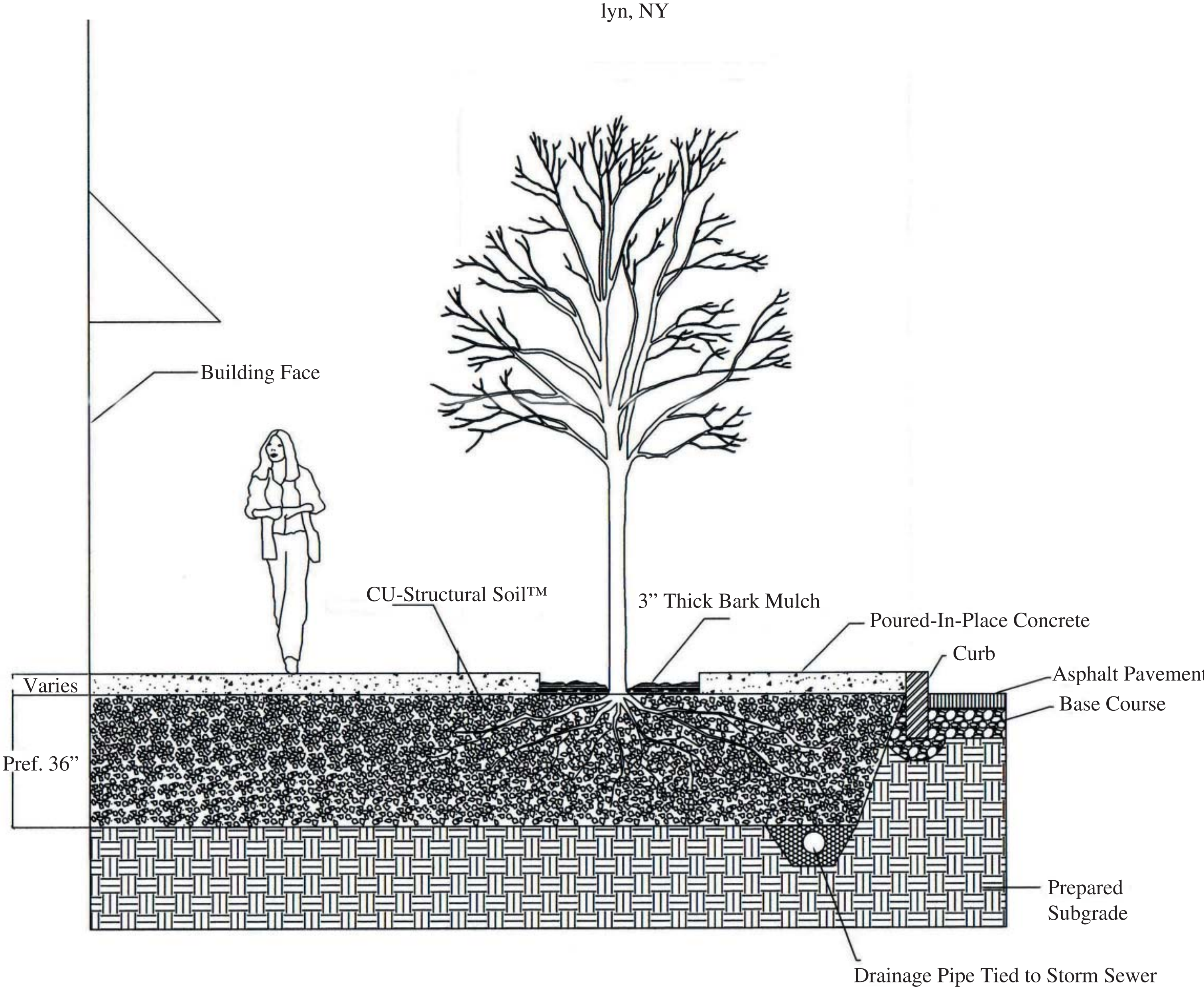


Fig. 1.12 Typical street tree planting using CU-Structural Soil™ under a sidewalk

Trees in Parking Lots and Plazas:

CU-Structural Soil™ may also be used to enlarge a 'tree island' within a parking lot. With a large tree planting area, good, well draining top soil can be used in the island and CU-Structural Soil™ added as an unseen rooting media under the asphalt (Figs. 1.13 - 1.15).

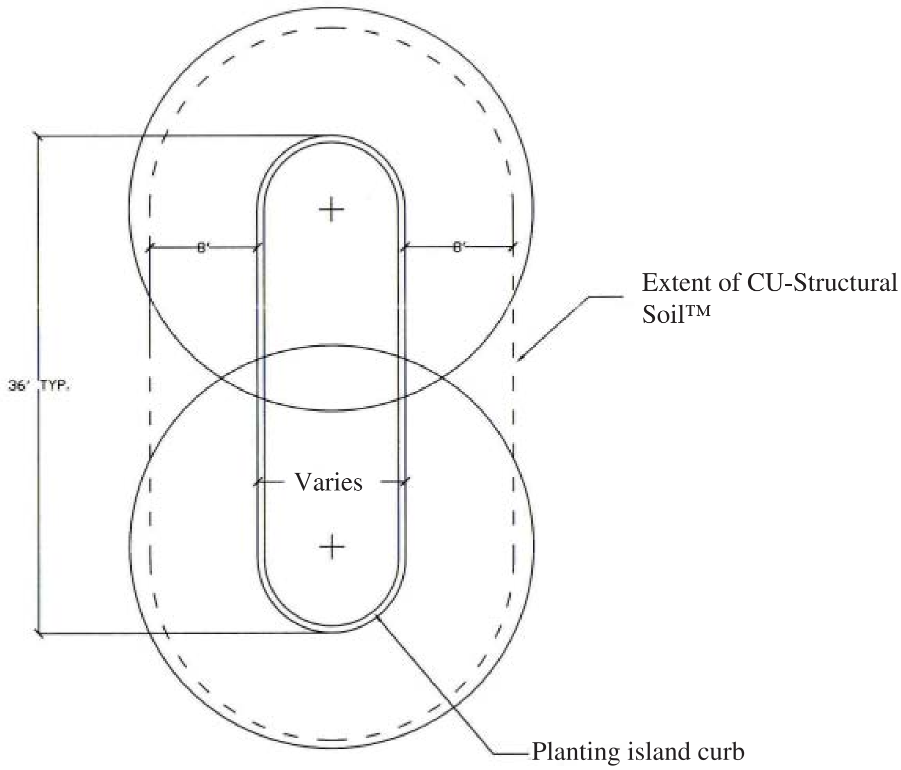


Fig. 1.13 Plan view of planting island

Fig. 1.14 Potential use of CU-Structural Soil™ to enlarge planting islands in parking lots without taking up parking space

Trees in parking lots, as well as paved plazas, benefit from the use of CU-Structural Soil™ (Fig.1.16 - 1.17). Whether there is a curb or not, good, well-drained topsoil may be used around the tree where the opening is at least 5' x 5'. If the opening is smaller, CU-Structural Soil™ may be used right up to the tree ball. Although it is not necessary to use an additional base course on top of CU-Structural Soil™, some engineers may want to do this, immediately under the pavement.

Given the large volume of CU-Structural Soil™ for tree roots to explore, irrigation may not be necessary after tree establishment—the decision depends on the region of the country and on site management. While there is less moisture in CU-Structural Soil™ on a per-volume basis than in conventional soil, the root system in structural soil has more room for expansion, allowing for increased water absorption. Supplemental water should be provided during the first growing season as would be expected for any newly planted tree. In regions where irrigation is necessary to grow trees, low-volume, under-pavement irrigation systems have been used successfully. Fertilizer can be dissolved into the irrigation water if necessary, although to date, nutrient deficiencies have not been noted, probably due to the large volume of rooting media.

Fig. 1.15 In this parking lot, there is only a 2 foot opening for tree planting. Here CU-Structural Soil™ was installed parallel to railroad tracks, 12' wide and 36" deep. With such a narrow opening, there is no reason to use a planting mix other than CU-Structural Soil™ around the tree ball.

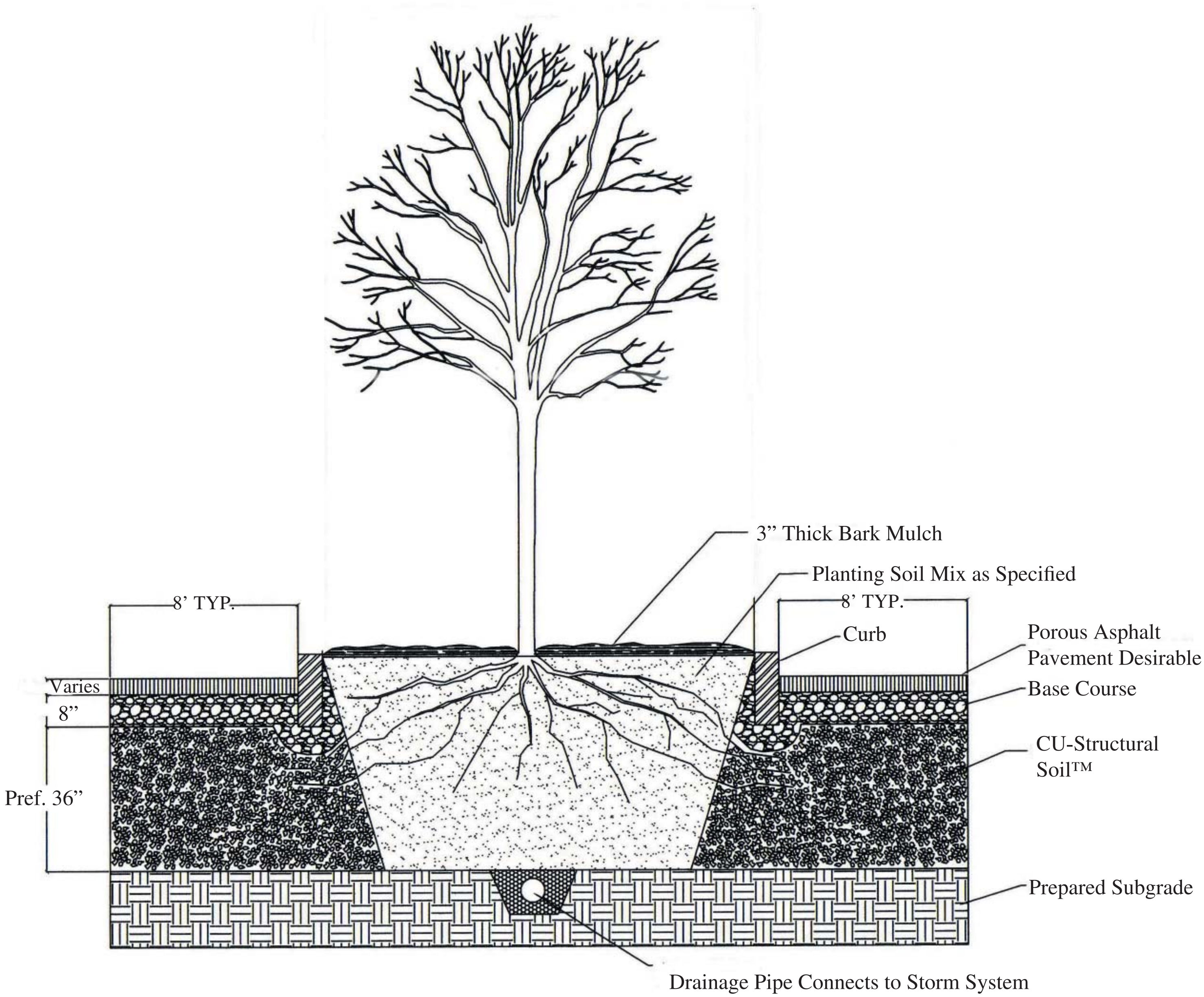


Fig. 1.16 Bare root tree in typical parking lot island or plaza

Fig. 1.17 English oaks planted in a plaza at Battery Park City, NYC

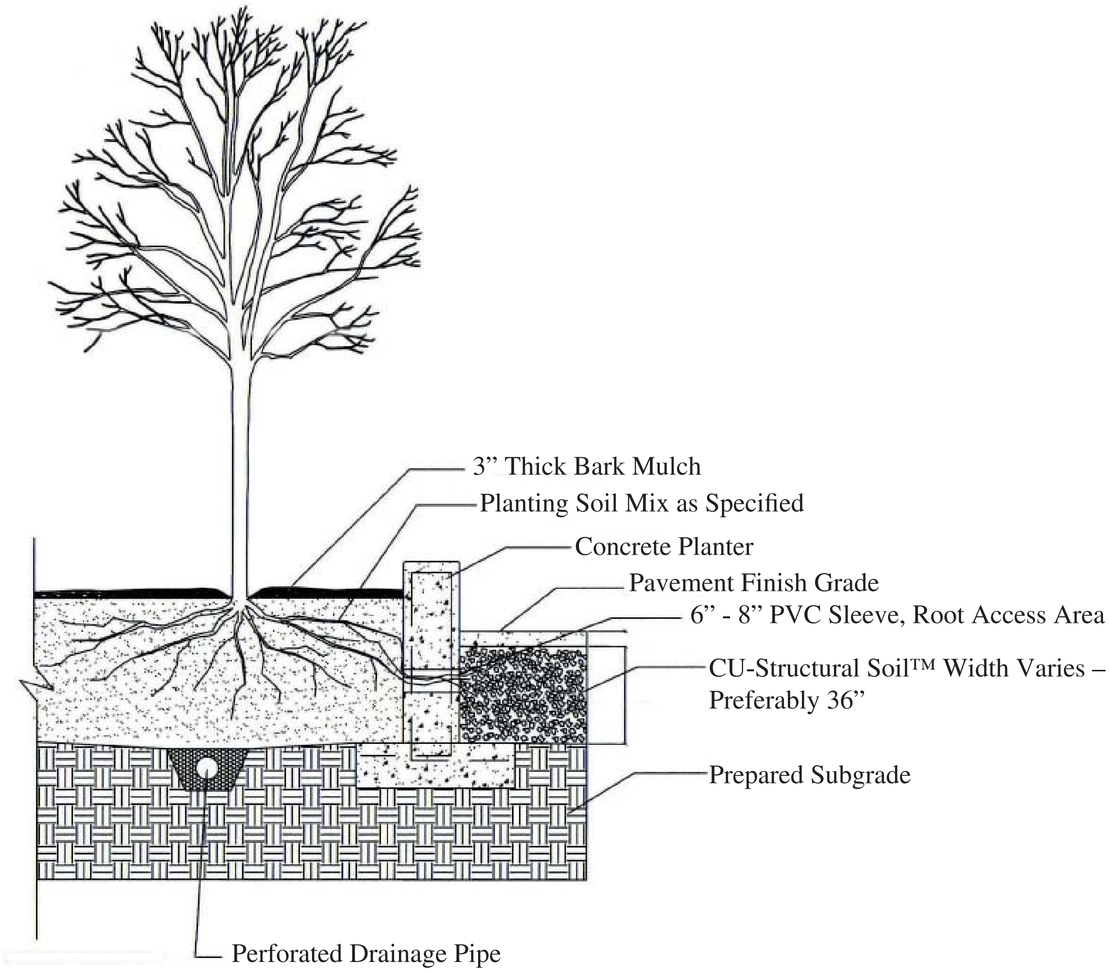


Fig. 1.18 Limited soil volume planter with root access into CU-Structural Soil™ under plaza pavement

Positive drainage below the root system is necessary in this system, since the sub-grade below the CU-Structural Soil™ may be compacted and impermeable. A perforated and wrapped drain, connected to storm drainage, should be placed between the CU-Structural Soil™ and the compacted sub-grade (Fig.1.18).

Where the curb footer goes to greater depth for a planter, a 6”- 8” PVC sleeve filled with uncompacted soil should be used to give tree roots access to the CU-Structural Soil™ beyond the planter wall (Figs 1.18-1.19).

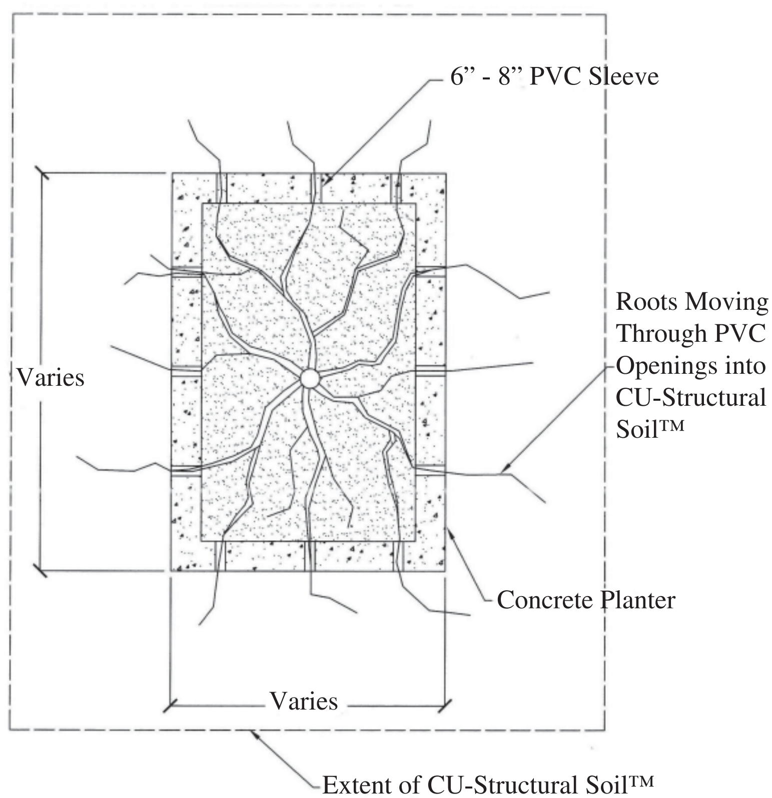


Fig. 1.19 Plan view of limited soil volume planter

Creating break-out zones for trees in narrow tree lawns

Where there is an adjacent green space, whether a park or front lawn, CU-Structural Soil™ may be used as a channel for roots to safely grow under pavement into this green space (Figs. 1.20 - 1.23). Generally two 5' concrete flags are removed, then the area is excavated to 24"- 36" and CU-Structural Soil™ is backfilled into them. Paving slabs are then replaced in a conventional manner.

Fig. 1.20 Break-out zone with CU-Structural Soil™ under a sidewalk between a narrow tree lawn and adjacent landscape area

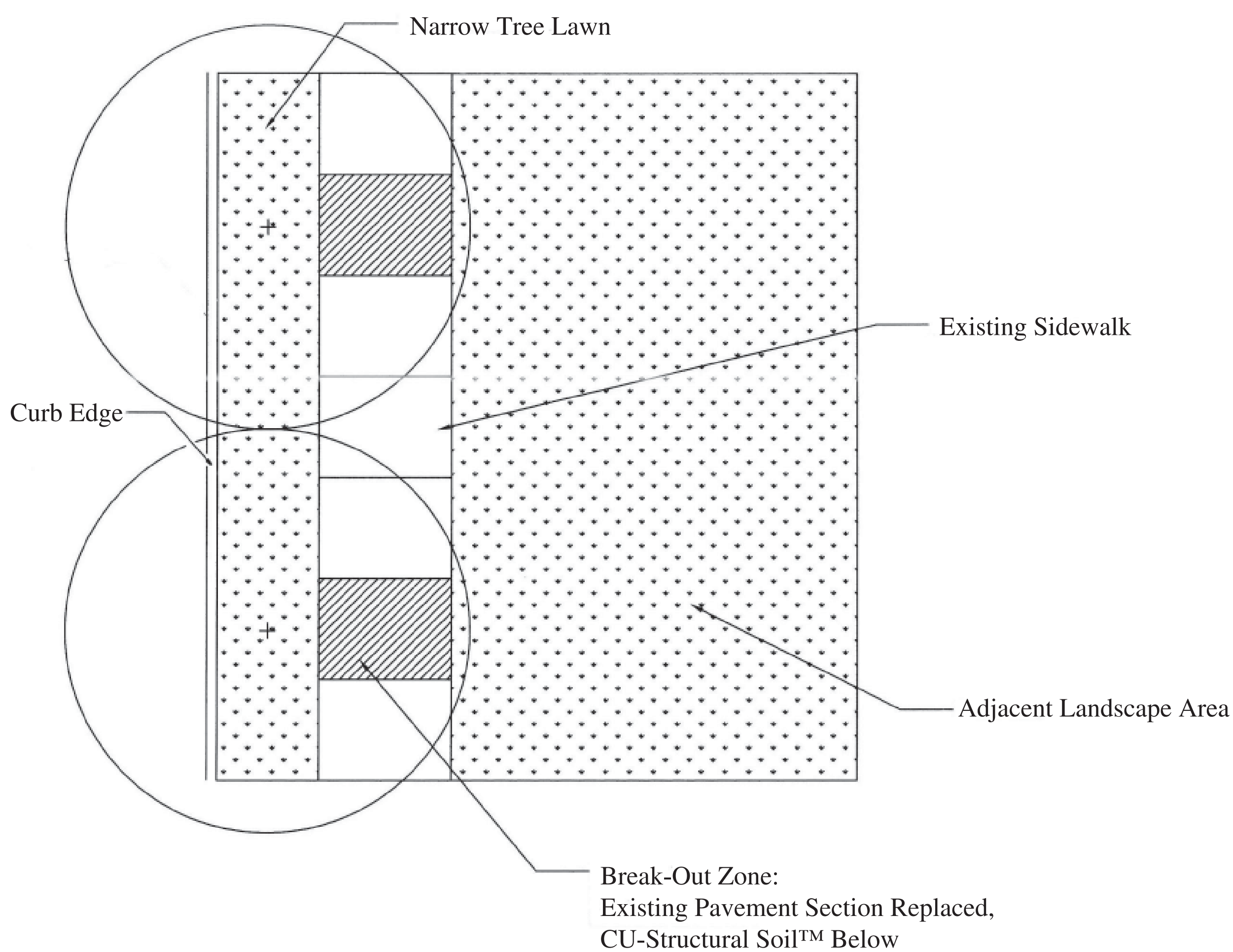


Fig. 1.21 Plan view of retrofitted CU-Structural Soil™ break-out zone

Fig. 1.22 Trees planted in Brooklyn, NY in 1997 where CU-Structural Soil™ was installed in a continuous trench 7' wide adjacent to the park fence.

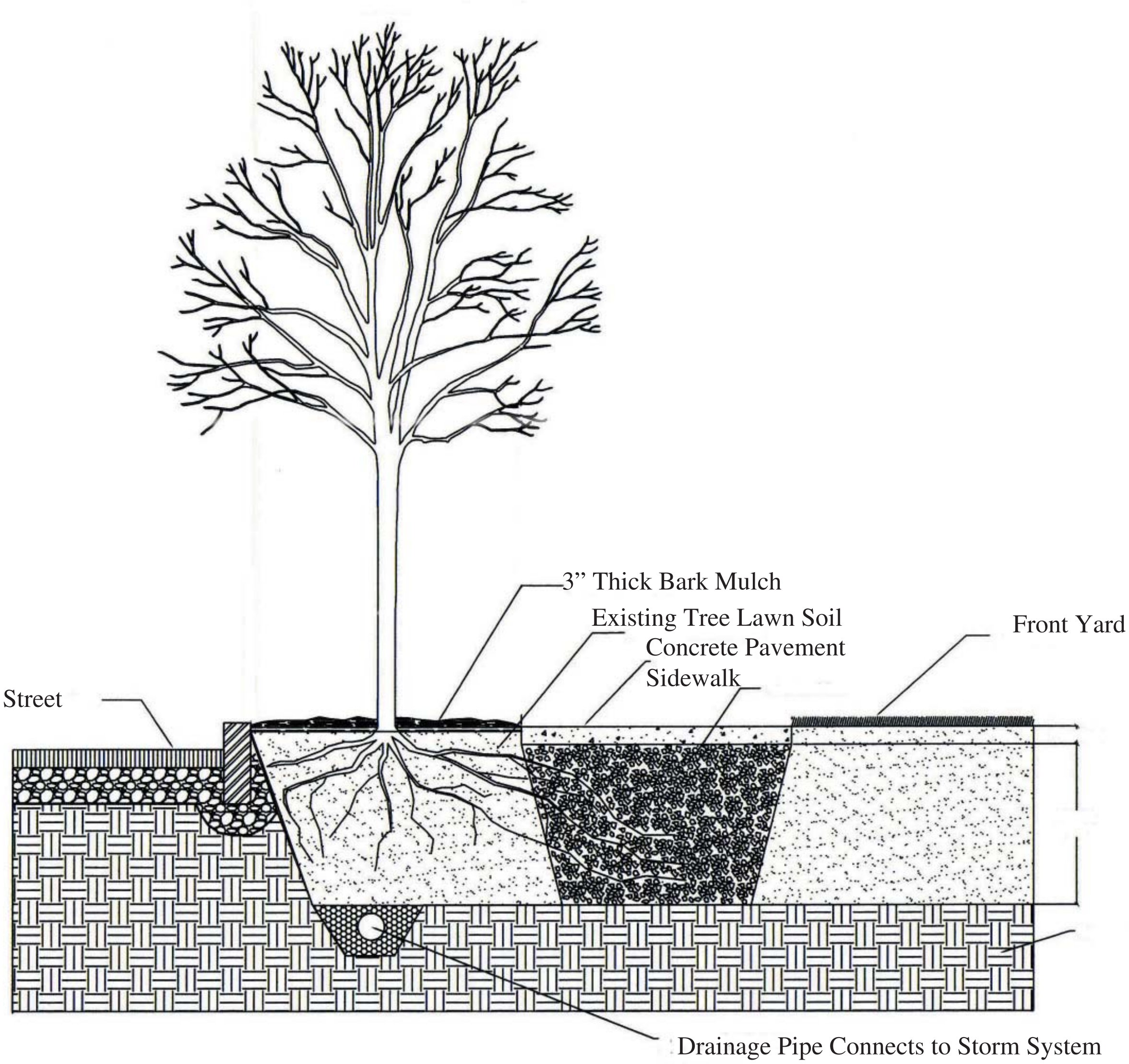


Fig. 1.23 CU-Structural Soil™ break-out zone from narrow tree lawn to adjacent landscape area

CU-Structural Soil ™ use with permeable pavers

If non-mortared pavers are used, a setting bed of uniformly-graded coarse sand should be used, to a depth specified by paver manufacturer specifications. To discourage rooting in this layer, a geo-textile—one that does not restrict water movement—can be used between this material and the CU-Structural Soil™ (Figs. 1.24 - 1.25).

Fig. 1.24 Concrete unit pavers on a coarse sand setting bed on top of a continuous trench of CU-Structural Soil™ in Ithaca, NY

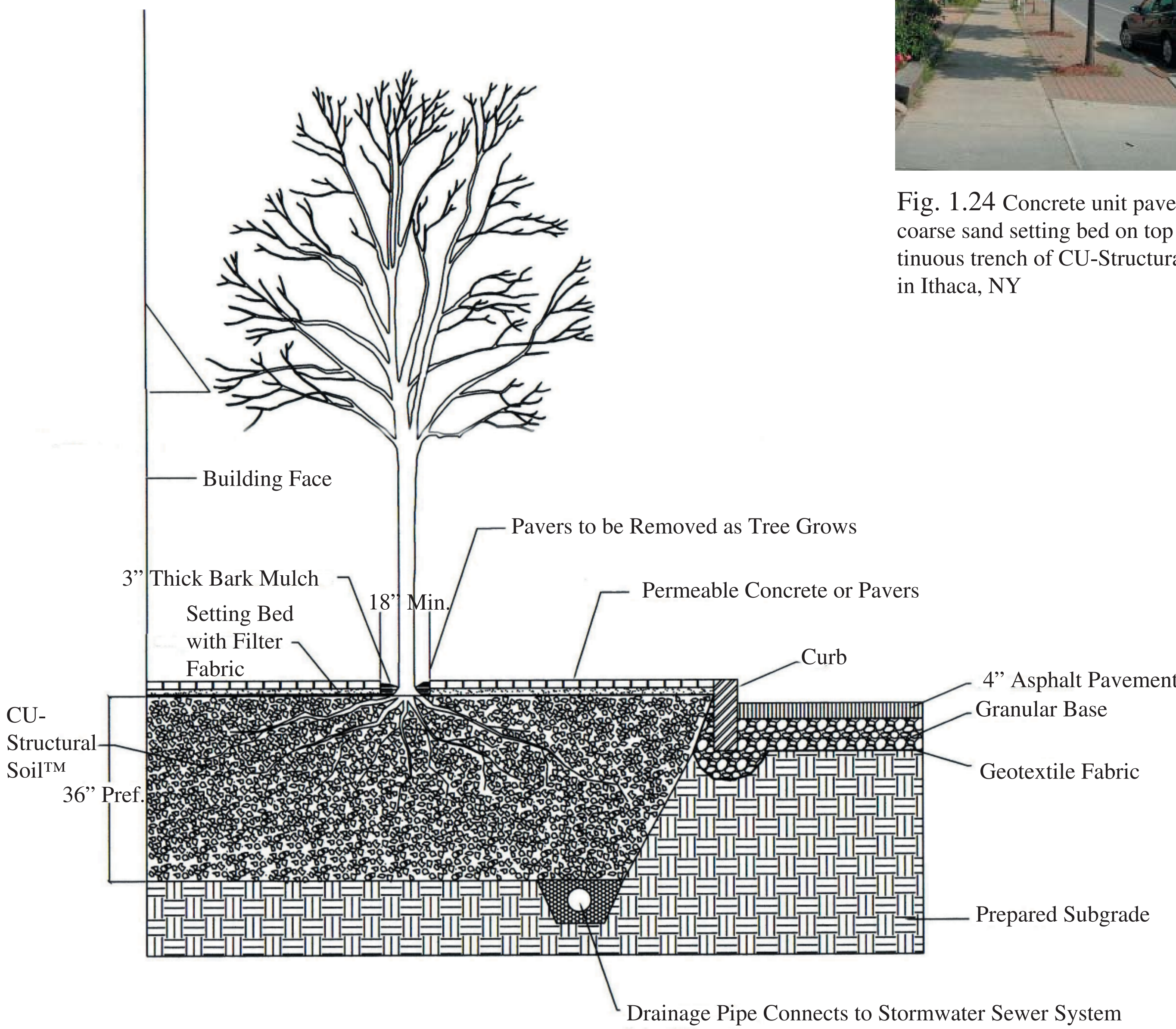


Fig. 1.25 Street tree detail with permeable pavers

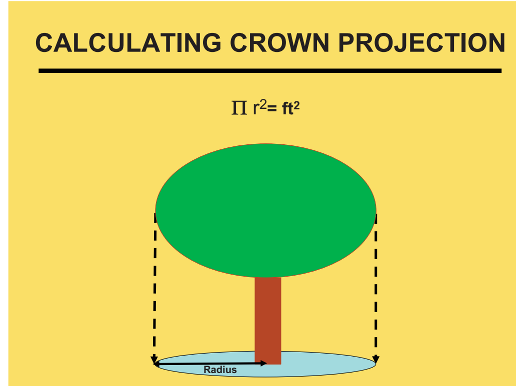
Street Trees Appropriate for use in CU-Structural Soil™

(Guiding selection criteria: moderate to highly drought tolerant and alkaline soil tolerant trees)

Botanic Name	**Common Name**
Acer campestre	Hedge Maple
Acer miyabei	Miyabei Maple
Acer nigrum	Black Maple
Acer platanoides	Norway Maple
Acer pseudoplatanus	Sycamore Maple
Acer truncatum	Painted Maple
Carpinus betulus	European Hornbeam
Catalpa speciosa	Northern Catalpa
Celtis occidentalis	Hackberry
Cercis canadensis	Redbud
Cornus mas	Cornelian Cherry
Cornus foemina (Cornus racemosa)	Gray Dogwood
Corylus colurna	Turkish Hazelnut
Crataegus crus-galli	Cockspur Hawthorn
Crataegus phaenopyrum	Washington Hawthorn
Crataegus punctata	Thicket Hawthorn
Crateagus viridis	Green Hawthorn
Eucommia ulmoides	Hardy Rubber Tree
Fraxinus americana	White Ash
Fraxinus excelsior	European Ash
Fraxinus pennsylvanica	Green Ash
Ginkgo biloba	Ginkgo
Gleditsia triancanthos	Honey Locust
Gymnocladus dioicus	Kentucky Coffee Tree
Koelreuteria paniculata	Goldenrain Tree
Maclura pomifera	Osage Orange
Malus spp.	Crabapple
Parrotia persica	Ironwood
Phellodendron amurense	Amur Cork Tree
Platanus x *acerifolia*	London Plane
Populus alba	White Poplar
Populus deltoides	Northern Cottonwood
Populus tremuloides	Quaking Aspen
Pyrus calleryana	Callery Pear
Pyrus ussuriensis	Ussurian Pear
Quercus macrocarpa	Mossy-Cup Oak
Quercus muehlenbergii	Chinkapin Oak
Quercus robur	English Oak
Robinia pseudoacacia	Black Locust
Styphnolobium japonicum (Sophora japonica)	Japanese Pagoda Tree
Sorbus alnifolia	Korean Mountain Ash
Sorbus thuringiaca	Oak-Leafed Mountain Ash
Syringa reticulata	Japanese Tree Lilac
Tilia americana	Basswood
Tilia cordata	Littleleaf Linden
Tilia tomentosa	Silver Linden
Tilia x *euchlora*	Crimean Linden
Ulmus americana	American Elm
Ulmus carpinifolia	Smooth-Leaf Elm
Ulmus parvifolia	Lace Bark Elm
Ulmus spp.	Elm Hybrids
Zelkova serrata	Japanese Zelkova

(names in parentheses are older botanic names)

Frequently Asked Questions



What volume of CU-Structural Soil™ is needed for a given tree?
The Urban Horticulture Institute at Cornell has found that, with the exception of the desert southwest, two cubic feet of soil is needed for every square foot of crown projection (the anticipated area under the drip line of the tree at expected maturity). Trees growing in CU-Structural Soil™ in areas that normally use irrigation to grow trees should also provide low volume drip irrigation in CU-Structural Soil™ installations.

What is the recommended depth for CU-Structural Soil™?
We suggest a minimum of 24" but 36" is preferred. A base course of gravel is not needed on top of CU-Structural Soil™ because it was designed to be as strong as a base course. Properly compacted to 95-100% Proctor Density or Modified Proctor Density, it has a CBR of 50 or greater.

What is the recommended length and width for CU-Structural Soil™ installation?
There is no established minimum. However, CU-Structural Soil™ was designed to go under the entire pavement area. This homogeneity would ensure uniform engineering characteristics below the pavement, particularly in regard to frost heaving and drainage. Ideally, the installation should focus on a whole sidewalk section from building face to curb, potentially for a whole block. If it is impossible to use the entire sidewalk area, using CU-Structural Soil™, it can be placed in a 5'- 8' wide trench parallel to the curb.

Won't the soil migrate down through a CU-Structural Soil™ profile after installation?
The excavation of a seven-year-old installation did not show any aggregate migration. The pores between stones in CU-Structural Soil™ are mostly filled with soil so there are few empty spaces for soil to migrate to.

Does hydrogel break down over time?
Over a long period of time, the soluble salts from which the hydrogel was produced, i.e. potassium (from potassium hydroxide) and ammoniacal nitrogen (from acrylamide) is released. The inert hydrogel becomes a minimum part of the soil system. Beyond that, we believe that colonizing roots and other organisms will, over time, replace the spatial and tackifying roles of the hydrogel. Research on this subject is on-going.

What happens when roots expand in CU-Structural Soil™?
There will come a time when the roots will likely displace the stone, 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.

Is CU-Structural Soil™ susceptible to frost heave?
This topic has not been rigorously tested, but we have not observed frost heave damage in the Ithaca, NY installations. Based on drainage testing and swell data on this extremely porous system, CU-Structural Soil™ appears quite stable.

Can you add normal soil in the tree pit and CU-Structural Soil™ under the pavement?
It would be desirable to use CU-Structural Soil™ under the tree ball to prevent the root ball from sinking. Planting trees directly in CU-Structural Soil™ provides a firmer base for unit pavers close to the root ball than does conventional soil. If the tree pit is sufficiently large, greater than 5' x 5', a conventional soil could be used in the open tree pit surrounding the root ball with CU-Structural Soil™ extending under the pavement.

Can you use balled-and-burlapped, bare root, or containerized trees in CU-Structural Soil™?
Trees from any production system can and have been used. It is important to water the newly planted tree as would be expected in any soil.

Should CU-Structural Soil™ be used in urban areas without pavement over the root zone?
CU-Structural Soil™ was designed to be used where soil compaction is required, such as under sidewalks, parking lots, medians, plazas, and low-access roads. Where soils are not required to be compacted, a good, well-draining soil should be used.

Can you store large quantities of CU-Structural Soil™?
CU-Structural Soil™ is produced by licensed producers and is preferably not stockpiled. It is mixed as necessary and should be delivered and installed in a timely manner. If any stockpiling is required, protection from rain and contamination should be provided.

Can CU-Structural Soil™ be utilized under existing trees?
There are several instances where CU-Structural Soil™ was utilized under and adjacent to existing trees. It appears that if few tree roots are damaged during the installation, the trees continue to grow well. Research is currently under way to investigate this issue.

What are the oldest installations of CU-Structural Soil™, and where are they?
The two oldest installations date to 1994; the first is a honeylocust planting at the Staten Island Esplanade Project in NYC, the second is a London plane tree planting on Ho Plaza on the Cornell campus, Ithaca, NY. There are now numerous installations of various sizes across the United States and Canada. For more information about installations, visit www.structuralsoil.com or contact Brian Kalter at Amereq, Inc. (see below).

Obtaining CU-Structural Soil™

CU-Structural Soil™ has been patented and licensed to qualified producers to ensure quality control; its trademarked names are CU-Structural Soil™ or CU-Soil™. By specifying this material, the contractor is guaranteed to have the material mixed and tested to meet research-based specifications. There are licensed producers throughout the US and in Canada. To find the one in your region or to become a licensee, contact Brian Kalter (bkalter@amereq.com) or Fernando Erazo (FE@amereq.com) at Amereq Inc., 19 Squadron Blvd. New City, New York 10956. (800) 832-8788

Further Information

See the Urban Horticulture Institute website:
www.hort.cornell.edu/uhi and go to Outreach > Structural Soil

A DVD showing videos of the mixing, installation and tree growth in CU-Structural Soil™ is available at:
www.hort.cornell.edu/uhi/outreach/csc/index.html

Or contact Dr. Nina Bassuk (nlb2@cornell.edu), (607) 255-4586

Research papers supporting this work:

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Fig 1.26 In this three-year field study a normal soil profile under sidewalk pavement as well as one with CU-Structural Soil™ were compared. Species used were hedge maple, little leaf linden, and crabapple.