THE LANDSCAPE BELOW GROUND II

Proceedings of a Second International Workshop on Tree Root Development in Urban Soils

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Held March 5 and 6, 1998
San Francisco, California

Published by
International Society of Arboriculture
P.O. Box 3129
Champaign, IL 61826-3129 USA

Structural Soil Investigations at Cornell University

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Over the past several years, Cornell's Urban Horticulture Institute, among others, has been developing alternative layered pavement systems to integrate pavement stability and horticultural requirements for street trees surrounded by pavement. The most recent approach has focused on gap-graded skeletal soil materials (SSMs). Initial testing formulations of SSMs were successful in establishing seedlings and demonstrating the efficacy of a hydrogel in preventing aggregate separation. A second study demonstrated the potential for English oak to quickly establish in fully compacted materials with bearing strengths exceeding minimum criteria for pedestrian and parking sub-base materials. Several observations were made from these studies. Adding fine-grained material quickly impacts the formation of the stone skeleton and its strength. Excessive soil can result in structural and horticultural failure. A zone of overlap exists between horticultural and structural requirements. The maximum amount of soil is likely to be dictated be engineering demands and the minimum soil by horticultural demands. Larger paved installations were deemed necessary for observing plant response over time.

Street trees surrounded by pavement have historically displayed a short average lifespan. We believe one of the most ubiquitous limitations faced by the typical street tree—and hence the greatest challenge to tree establishment—is the volume of root-penetrable soil available to support sustainable healthy tree growth. The current standardized tree pit designs (16 to 24 ft^2 [1.5 to 2.2 m^2] openings of 36 in. [91.4 cm] maximum depth) do not provide enough soil volume for even the most conservative of estimates for sustainable tree growth and health. While the situation may be improving with new construction design methods, trees that do survive in conventional pavement designs often become problematic by heaving curbs and sidewalks. It is the older established trees that often cause pavement failure when roots grow directly below the pavement in the interface between the wearing surface and the base material. Displacement of pavement becomes a tripping hazard; as a result, legal liability compounds expenses associated with structural repairs. Pavement repairs often have detrimental impacts on the trees with significant damage and removal of major roots, resulting in tree decline and death.

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The problem does not necessarily lie with the plant installation but with the design f the system in which the tree and the pavement—two elements with conflicting equirements—are expected to coexist. The tree needs a porous soil that can be freely xplored by its roots, while the pavement requires a dense, load-bearing base that will ot allow the pavement to subside or fail. Moreover, the green industry has largely eglected to communicate to design and engineering professionals a reasonable un-erstanding of what is required for healthy tree growth in safe pavement design. A oncerted effort to work with designers and engineers to develop innovative details nd site-specific creative solutions to pavement and tree installation is essential. One otential tool for urban tree establishment and management is a new design for the ntire pavement profile to meet traffic loading on pavement while encouraging deep oot growth away from the pavement wearing surface.

In 1993, Cornell's Urban Horticulture Institute (UHI) initiated its current approach o resolving the opposing needs of trees and pavement. The approach was influenced y Spomer's critical sand component work in amended landscape soils (7), Patterson's vork with expanded shales in highly trafficked turf applications (6), the PGA golf-reen specifications for rooting zones (8), and UHI's prior experience with similar naterial from earlier trails. The system we have developed is essentially a gap-graded tone-soil mixture that depends on the stone fraction establishing a load-bearing lat-ice or skeleton. In the desired mixture the soil is "suspended" within the stone lattice oids during mixing, placement, and compaction.

Stone-Soil Mixes

In identifying an appropriate stone-to-soil mixing ratio, we attempt to maximize he soil fraction without unduly compromising the formation of the load-bearing stone keleton. The soil is meant only to partially fill the voids in the stone skeleton to allow apid aeration potentials, retain some moisture reserve for transpirational demand, nd allow some expansion room for roots to grow (Figure 1). The new approach ocused on two immediate goals. The first was to address the problem of aggregate eparation, seen as a major problem in early mixing attempts in field trials. The sec-ond goal was to identify a family of stone-soil mixtures and establish the existence of "zone of overlap" in acceptable mix design for plant establishment and engineering ehavior prior to field testing.

The first goal was to prevent separation of the fine soils from the stone that oc-curred during the mixing, and prevent the migration of soil through the stone matrix luring placement, compaction, and watering. This was easily met with the addition of small amount of tackifier in the system to stabilize the mixture. We used a cross-inked, potassium salt, polyacrylamide hydrogel as the tacking agent. The addition of ydrogel was observed to simplify mixing, prevent the separation of soil and stone, nd prevent washing of soil without influencing plant response in the first planted tudy (4, 5). The specific hydrogel used in the study (Gelscape®, Amereq Corp., New City, New York) provided the additional benefit of increasing the plant-available water n the bulk system. The use of a tackifier allowed us to introduce very small amounts f soil into the stone matrix in a uniform manner.

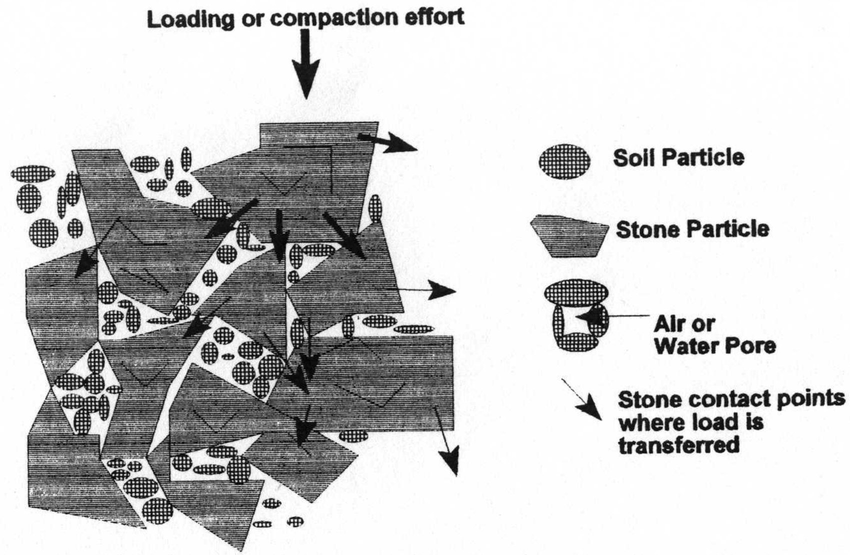

Figure 1. The stone matrix bears loading while the soil partially fill the matrix voids.

The second objective was more complex. Use of readily available materials and technology, low cost, and ease of manufacture governed the project approach. The material is designed to work as a high-strength, well drained sub-base within the existing layered design familiar to pavement engineers. In a standard design, there is a surface pavement material, such as concrete, and a highly compacted base material over-arching the rooting zone (Figure 2). Below that would be the compacted sub-base rooting material that is placed over the compacted preexisting subgrade mate-rial. Full compaction of the rooting zone is required to meet the need for strength to support overlying materials. Working within this layered design allows for the use of the base material as a root exclusion zone to act as a buffer, distributing the potential root expansion pressures over a larger area on the bottom side of the wearing surface. If the structural soil mixture is strong enough, it could be used as a base material with a minimal buffer if it could be demonstrated that the roots were not predisposed to running near the surface (pavement heaving).

Defining measurable parameters to evaluate the structural soils under consideration has been driven by engineering behavior. We have chosen a compaction effort level of 592.7 kJ/m^3 (12,375 ft · lbf/ft^3), which translates to a standard Proctor compaction test (1). From this standardized test, the best moisture content for compaction and an ex-pected density to specify in field installation can be identified. From this information, materials can be tested for bearing capacity relative to a material of empirically known strength in penetration/deflection resistance, known as a California Bearing Ratio (CBR) (2). A CBR of 50 at peak density is now the minimum criterion we suggest for potential mixtures.

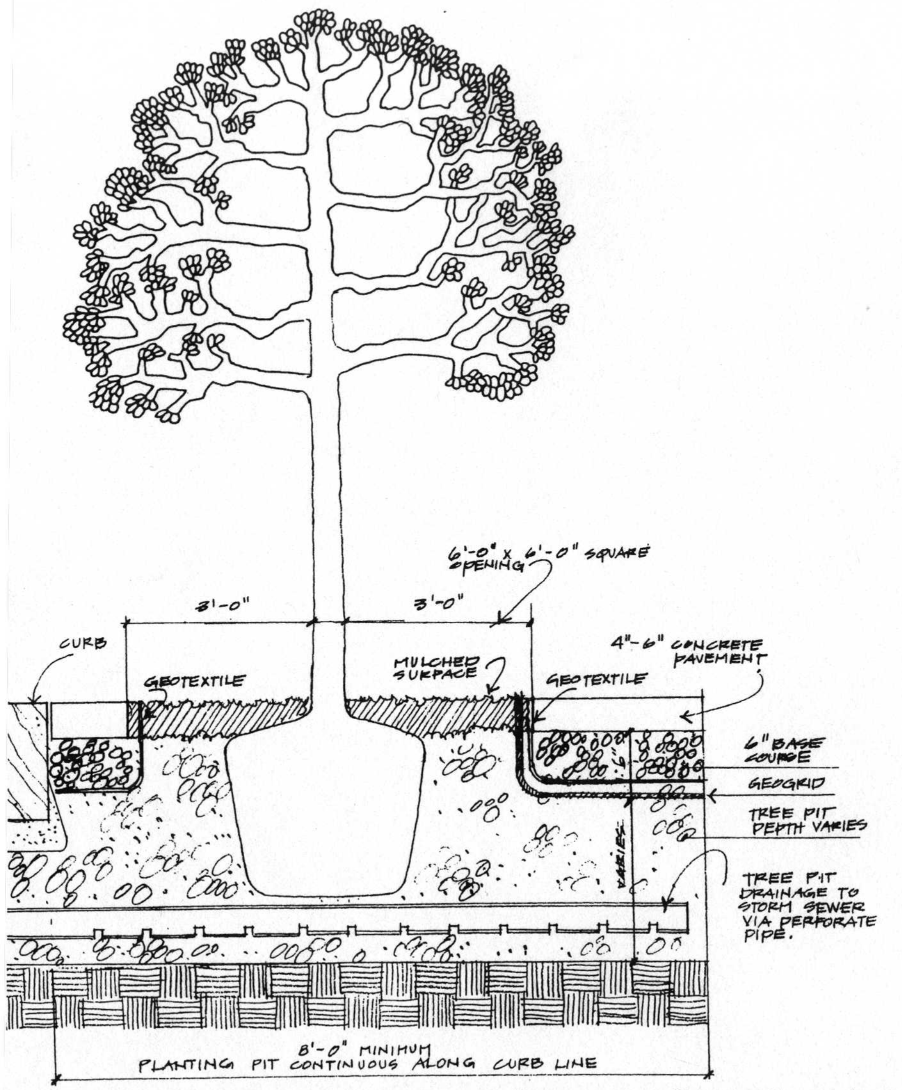

Figure 2. Elevation plan of a proposed structural soil pavement profile using the sub-base as the rooting zone.

Optimizing Soil Content

We have confirmed that the formation of the stone skeleton is changed with the addition of any fine material (soil). This is caused by the physical presence of additional soil particles between the stones as they come together and the presence of moisture and clays impacting the frictional "lock-in" of the stones into a load-bearing matrix. Figure 3 demonstrates this effect by tracking the decrease in fractional density of the stone (at peak AASHTO T-99 density) as increasing amounts of soil are added to the mixture. As the density of the stone matrix is decreased, the porosity of

the lattice is increased and mixture strength is decreased. This effect is shown in Figure 4 as the strength (California Bearing Ratio) increases with the stone fractional density in compacted structural soil test specimens. Because the stone lattice is changed as soil is added, a straightforward calculation of the optimal soil content for any given stone source is not yet available.

Optimizing the soil content definitely cannot be calculated from a presumed stone density and porosity from its unit weight in a stockpile. We can, however, suggest very conservative estimates of soil that could be added, test the resulting mixtures, and amend the mixture accordingly. These estimates can range from 13% to 22% soil by weight. Variables influencing the first estimation for mixing ratios include the size distribution and angularity of the stone and the soil properties. Overestimation of the desired soil content can lead to the soil dominating the behavior of the mix rendering the system useless for trees *and* pavement.

The second planted study tested a family of structural soil materials matched with materials known to be structurally sound and expanded the soil component to a point of engineering failure (especially in light of the increased minimum acceptable strength). We found the plant response to encompass a wider range of mixtures than the engineering strength requirements allowed (3). The roots were also observed to deform and wrap around the stones in the profile rather than displace them upward.

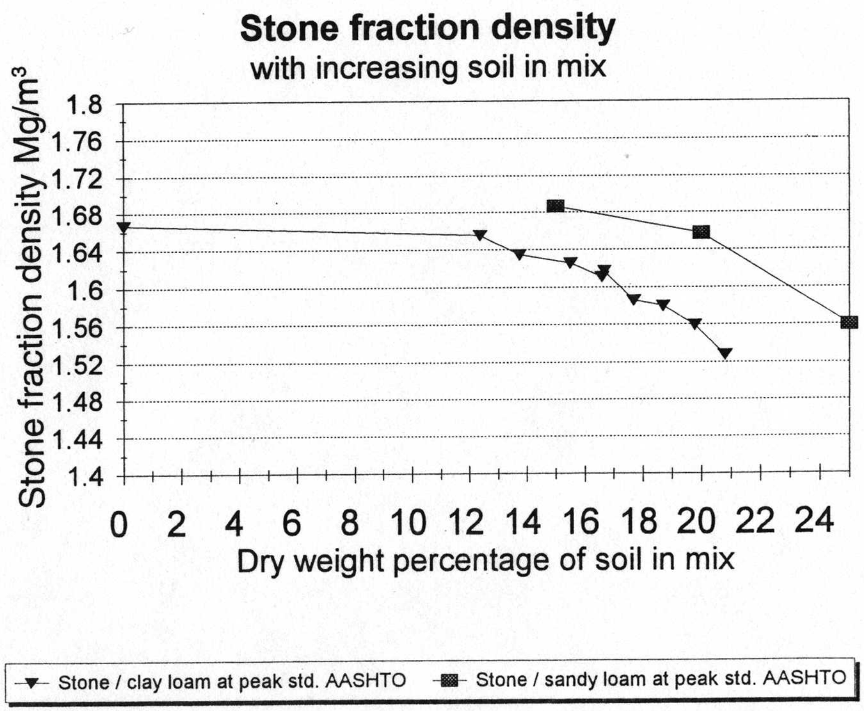

Figure 3. Addition of soil into the system changes the formation of the stone matrix.

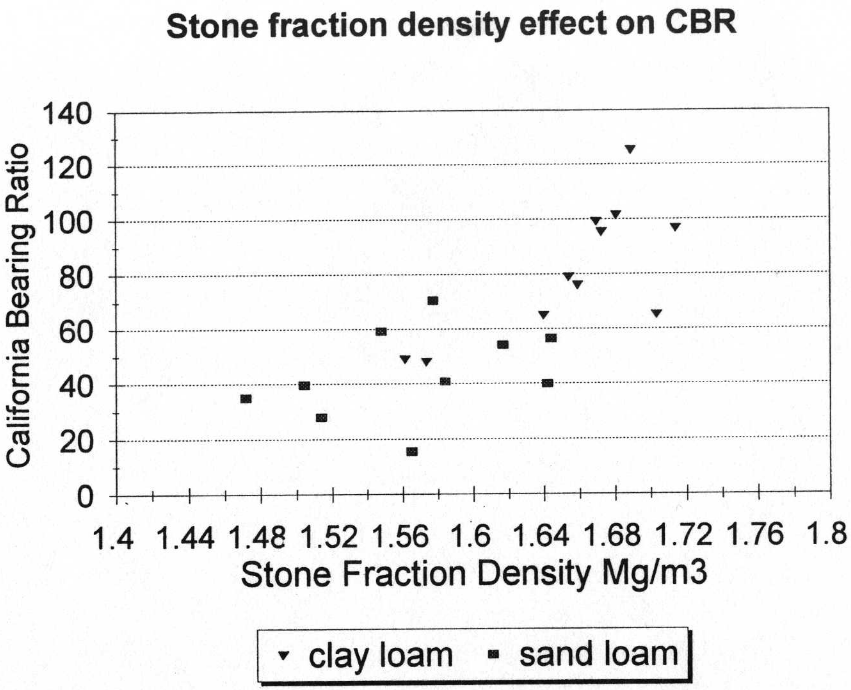

Figure 4. The formation of the stone matrix influences the bearing strength of the mixture.

Based on these encouraging results on short-term tests, larger installations for long-term monitoring were considered.

For more controlled testing, a field study monitoring the rooting zone environment, evaluating above-ground plant responses, and observing root distribution was initiated. The preliminary results from this study are presented in the following article, Pilot Field Study of Structural Soil Materials in Pavement Profiles. Completion of the root excavation work and final analysis will continue during 1998. Current testing of these systems includes plant-available moisture measurement, preliminary testing of organic component limits in design, pore size distribution, and hydraulic conductivity measurement. Several other avenues for testing have presented themselves for future investigations.

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