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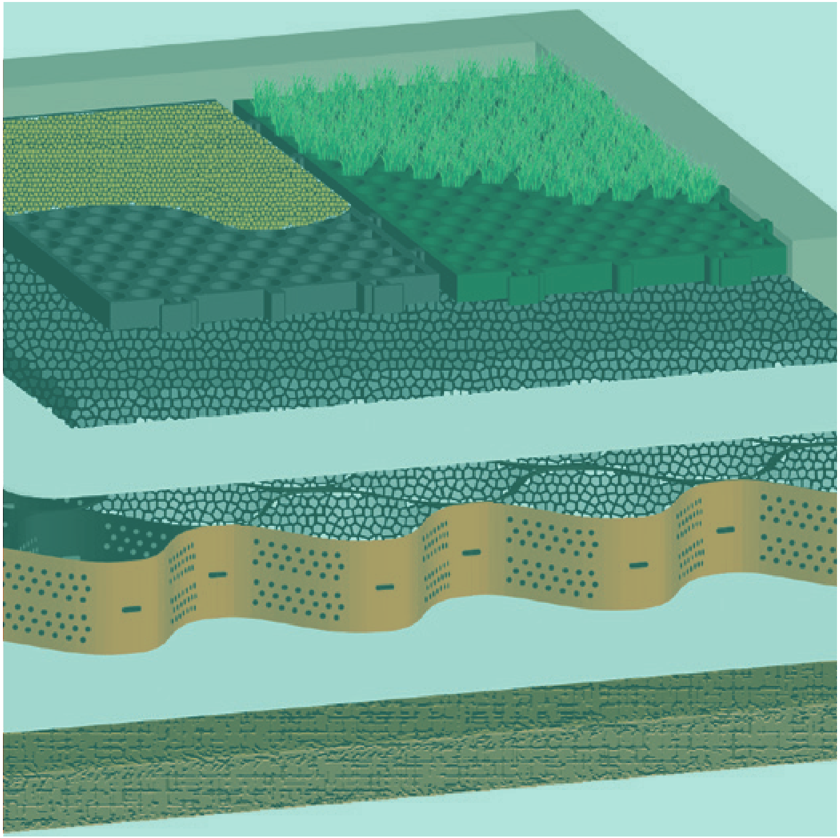
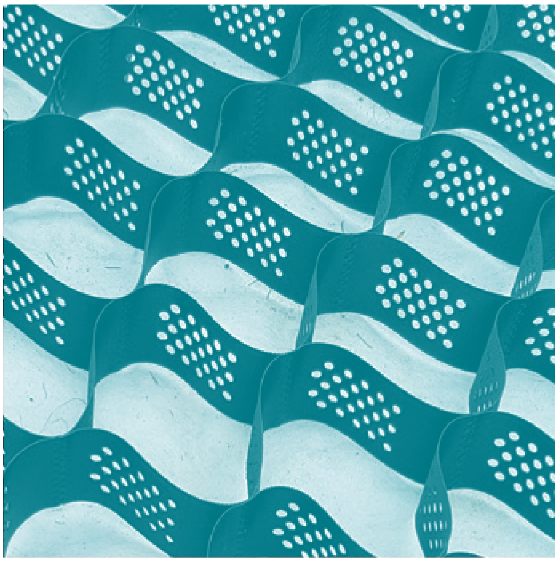
THE USE OF CELLULAR CONFINEMENT SYSTEMS NEAR TREES:
A GUIDE TO GOOD PRACTICE

GUIDANCE NOTE 12





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Background to the Arboricultural Association

Founded in 1964, the Arboricultural Association is the largest and longest-established UK body and authority for the amenity tree care profession. It has a base of circa 3,000 members in central and local government, commercial and educational employment, at craft, technical, supervisory, managerial, tutor and consultancy level.

The Arboricultural Association is regarded by central government departments, the Royal Horticultural Society and local government as the focal point for good practice in arboriculture, for certification and regulation of the industry, for information, education and research. It is unique in the profession in that its body of knowledge extends across the full spectrum of arboricultural issues and it can represent and advise a wide range of members from small operators to large corporate bodies, local and central government.

The Association publishes a range of technical leaflets, guidance notes and other publications concerning arboriculture, the quarterly *ARB Magazine* and the quarterly *Arboricultural Journal*. In its function as voluntary regulator for the arboricultural industry, the Association produces an online directory of Registered Consultants and Approved Contractors, all of whom have reached standards of excellence in arboriculture. The Association offers training through a varied programme of topical workshops, seminars, an annual trade show (The ARB Show) and an annual Amenity Conference. Various grades of membership exist for professional arboriculturists, those in related disciplines and enthusiasts.

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Foreword and acknowledgements

Foreword

This Guidance Note provides much needed technical direction for the arboricultural sector working alongside other professionals in development and construction.

The use of cellular confinement systems has increased over the last 20 years and the understanding of its effects and efficacy has also grown. To date, much practice regarding the installation of hard surfaces incorporating ground protection near to existing trees has been based upon an Arboricultural Practice Note (APN) 12: *Through the Trees to Development*, by Derek Patch and Ben Holding, which was published in 2007 by the Tree Advice Trust. APN 12 set out the principles of 'no dig' construction for hard surfaces, highlighting the impacts of excavation and compaction on tree roots and their soil environment.

Since then, research, technological advances and numerous studies of different materials and techniques have been explored, a revised edition of the British Standard BS5837 has been published and many architects and development and construction companies are recognising the benefits of using cellular confinement systems in this context. Indeed, as planning policy evolves it is becoming more and more relevant to consider these systems in order to meet the expected multiple demands of housing and commercial development density, while maintaining the maximum green infrastructure for societal benefit.

This Guidance Note sets out the background, concepts and relevance of cellular confinement systems, describes how to plan and prepare appropriate systems for a wide range of different applications and provides detailed technical advice and specification for implementing systems using a range of available surface treatments. It also includes detail on the arboricultural impact from the use of geocells and the limitations on their use.'

Acknowledgements

I am grateful to all of those that have reviewed and provided feedback on earlier versions of the text. In particular, I would like to express my gratitude to Dr Martin Dobson for providing detailed comments on several earlier drafts of the document. I would also like to thank Paul Muir for his thoughtful discussion which contributed to the final content and Manni Keates for producing the majority of the diagrams used in the document.

Section 1
Using cellular confinement systems for ground protection

1.1 Introduction

1. Cellular confinement systems can be used for ground protection in areas where tree root damage would be caused by digging into the ground to lay a conventional sub-base for new hard surfacing and where the long-term viability of trees could be harmed if soil that they may depend upon is at risk of becoming compacted. Compaction can occur for many reasons but vehicles passing over unreinforced ground are particularly damaging, although repeated foot traffic can also be detrimental to soil structure.

2. Roots penetrate soil partly by growing through existing voids and partly by moving soil particles aside, and these processes are impeded in compacted ground where soils are dense and voids are small. The combination of high soil density and elevated soil strength can directly limit root growth. Roots and soil organisms use oxygen to convert organic compounds into energy through the process of respiration, and so they require a continual supply of oxygen from the above-ground atmosphere to be distributed through the soil profile via diffusion. The large pores in a well-structured soil are important avenues for gas exchange and they are lost when soils are compacted to high bulk densities. Soil compaction also reduces the rate of water infiltration, the availability of water to roots, and the root system's ability to support a healthy crown. The compaction of soil within tree root zones[1] can ultimately lead to crown dieback and a decline in tree health (Ruark *et al.* 1982). Once a soil has become compacted it is difficult to reverse the effects and restore a soil structure suitable for tree root growth; even with positive intervention, soil rehabilitation may take years to achieve.

3. Roads and pavements cannot be placed on an excessively yielding subgrade because if the ground moves the surface will deform or crack after a few load repetitions. To create a lasting load-supporting surface the standard engineering practice is to remove the upper layer of soil and lay a compacted sub-base that is capped by a durable wearing course. The final surface is usually engineered so that the top dressing is level with the surrounding ground. However, surfaces constructed in this way can cause severance of tree roots at shallow depth and future root growth can be inhibited by the soil compaction caused during the installation of the surface. One way to prevent damage to roots is to keep roads and paths away from trees, but with modern-day pressures to develop land it is sometimes deemed necessary to install new hard surfacing near to established trees. In such cases, where the adjacent trees are to be retained, the soil needs to be protected in some way.

4. The use of above-ground cellular confinement systems, or 'geocells', to install surfacing near trees has been employed in the UK for over 20 years. The accepted approach involves laying a geocell mat on a non-woven geotextile laid on the surface of the ground, filling it with clean stone aggregate, and topping this sub-base with a wearing course (see Figure 1). In recent years this approach has been regularly used in construction projects because it is considered to be an acceptable way of creating a new hard surface above tree root zones. But the use of geocells is not always a simple matter and the limitations of the approach are often misunderstood. Also, very few research studies have been conducted regarding the long-term effects of installing such surfaces on soil structure and on the health of adjacent trees.

[1] For the purposes of this document, tree root zones, or root protection areas, are considered to be the minimum area around a tree deemed to contain sufficient roots and rooting volume to maintain the tree's viability. The recommended methodology for calculating root protection areas is described in *BS5837:2012 Trees in relation to design, demolition and construction – Recommendations* and is generally a radial distance equivalent to 12 times the trunk diameter measured at a height of 1.5m. Greater separation distances are required for veteran trees. It is advised that a buffer zone around a veteran tree should be at least 15 times larger than the diameter of the tree or 5m from the edge of the tree's canopy if that area is larger than 15 times the tree's diameter. For ancient woodlands, the buffer zone should be at least 15m wide.

1 Section
Using cellular confinement systems for ground protection

5. Guidance on installing new surfacing near trees was previously provided by Arboricultural Practice Note 12: *Through the Trees to Development* (Patch & Holding 2007). The aim of this guide is to draw on the subsequent industry experience in order to provide updated guidance that will be helpful to arboriculturists, landscape architects, engineers and building contractors.

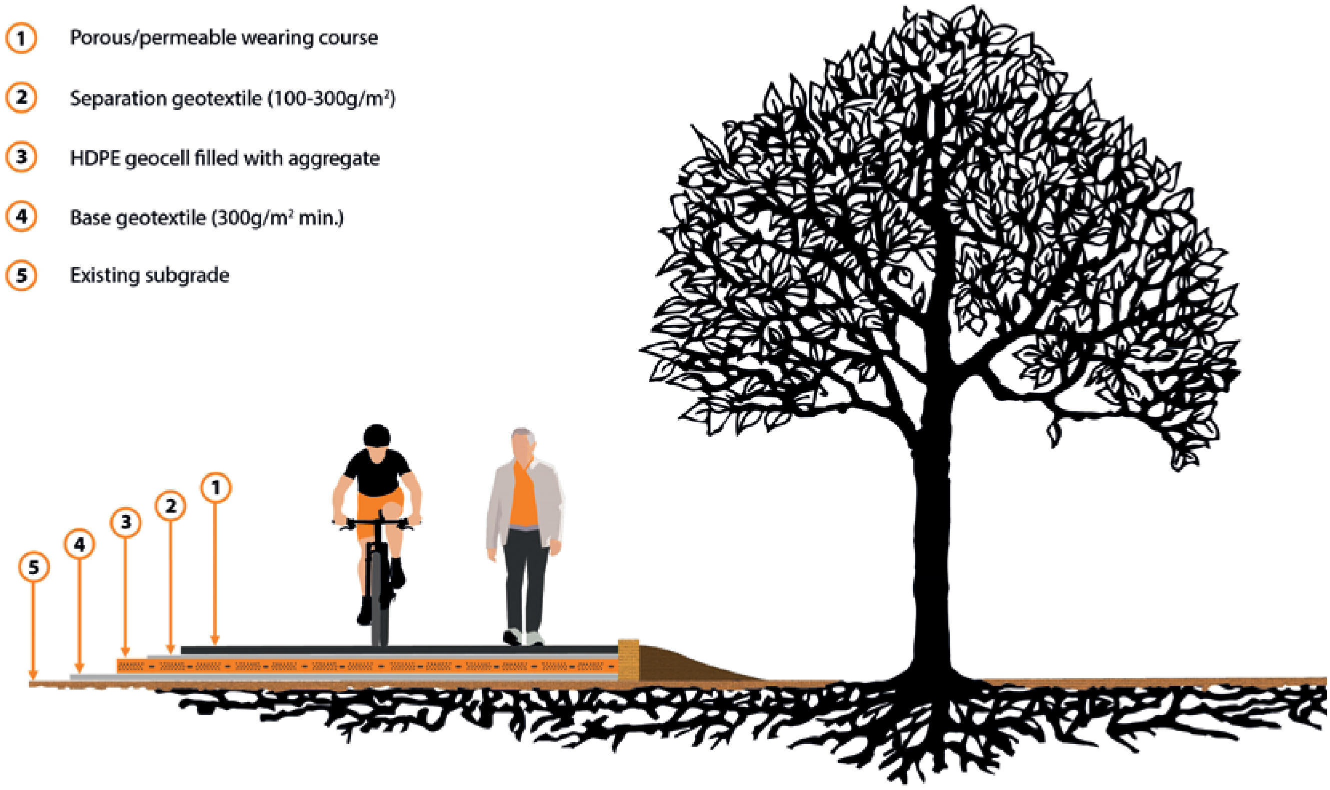

Figure 1: The basic approach to using cellular confinement systems for ground protection near trees [*image courtesy of Core LP*].

1.2 The concept of cellular confinement systems

6. A cellular confinement system is a series of geocells arranged in a honeycomb-like formation that is combined with an underlying geotextile and angular stone to spread loads in such a way as to minimise compaction of underlying soil. Due to its 3-dimensional structure, a geocell mat offers all-round confinement to the encapsulated material, which provides a long-term improvement in the performance of the sub-base. When a surface is reinforced in this way the load is distributed over a larger area of the subgrade-base interface, leading to lower vertical stress and reduced deformation of the subgrade (Bathurst & Jarrett 1988; Saride *et al.* 2011). Cellular confinement systems are considered to be cost effective, durable and easy to use. They also function effectively in all weather conditions (Hegde 2017). There are a variety of uses for cellular confinement systems in the construction industry, but this guidance focuses on their use when new hard surfacing is installed near trees.

7. It is relatively common for engineers to specify planar reinforcement[2] to improve the service life of a surface and/or to obtain equivalent performance with less depth of material. This is

typically a 2-dimensional geogrid[3] installed beneath a minimum depth of 150mm compacted stone aggregate (GMA 2000). The geogrid and the aggregate interlock and together they form a composite material that has better load-bearing properties than the aggregate alone. But this approach is not suited for use near trees because when the stone is compacted there is a high risk of compacting the soil beneath. Also, geogrids transfer loads via the 'tensioned membrane effect', and the stretching of a geogrid under tensile loading allows a degree of deformation which results in wheel rutting and the compaction of the subgrade beneath. Therefore, the use of geogrids alone is not recommended for installing new footpaths or roads near trees. They can, however, be installed beneath a geocell mat as a separation layer and to add extra strength.

8. In order to create a stable base for hard surfacing near trees it is recommended that a cellular confinement system made of high-density polyethylene (HDPE) should be used. The plastic strips are ultrasonically bonded together to form a 3-dimensional matrix that can be filled with soil, sand, aggregate, or concrete (as shown in Figure 2), but when new hard surfacing is constructed over tree roots it is necessary to infill the geocells with angular stone because this type of fill increases friction between stones and enhances load spreading. In this context stone infill has the added benefit of being permeable, which allows water ingress and gaseous diffusion into and out of the soil.

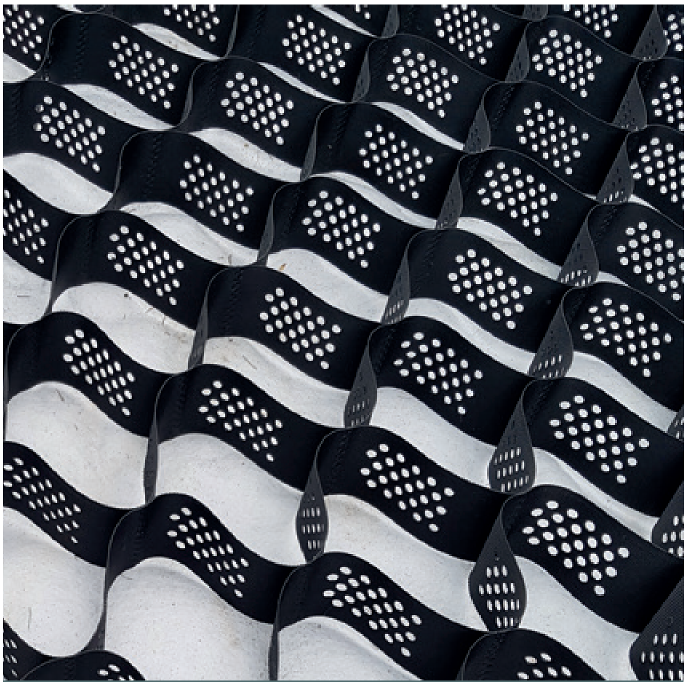

Figure 2: An expanded geocell sheet before it has been filled with stone [*image courtesy of Bosky Trees*].

9. The seam strength of the cells is critical to the durability of the system because these are often the weakest part of the system, and so products used should conform to ISO 13426-1:2003 Geotextiles and geotextile-related products – strength of internal structural junctions – Part 1: Geocells.

10. The walls of each cell should be textured to provide additional friction with the infill material. When geocells are infilled with stone aggregate a new composite entity is created that possesses enhanced mechanical and geotechnical properties.

[2] Reinforcement is a way to improve the performance or to reduce the thickness of a flexible hard surface. Hard surfaces can be reinforced using 2-dimensional or planar reinforcement, or 3-dimensional (geocell) reinforcement, or a combination of both, to improve the performance or to reduce the base layer thickness without compromising the required level of service. For this reason, these methods are commonly used to reinforce sub-bases below roads or other structures.

[3] A geogrid is 2-dimensional geosynthetic material made of polypropylene or high-tenacity polyester used to reinforce soils and similar materials. Soils pull apart under tension and, compared to soil, geogrids are strong in tension. This property allows them to transfer loads to a larger area of soil than would otherwise be the case.

11. As with other geosynthetics used as surface or planar reinforcement, the development of resistance in a cellular confinement system is the result of different mechanisms working together to develop improved bearing capacity over soil. However, unlike 2-dimensional planar reinforcements which trigger the confinement and membrane effects, cellular confinement systems employ a third mechanism – the stress dispersion effect, which distributes the applied load over a wider area (Avesani Neto *et al.* 2013). The walls of the cells confine the infill material and hoop stresses prevent it from expanding laterally under load. Additional support is provided by the passive resistance of adjacent cells (as illustrated in Figure 3). A further benefit is that the downward pressure of the geocell mattress prevents the soil beneath from moving upward outside of the area directly beneath the load. All these properties work together to prevent ground deformation under load (i.e. wheel rutting). Experience has shown that harmful compaction of the soil around a tree can be avoided if an appropriate thickness of geocell is used for the loading and frequency of traverse experienced during its lifetime.

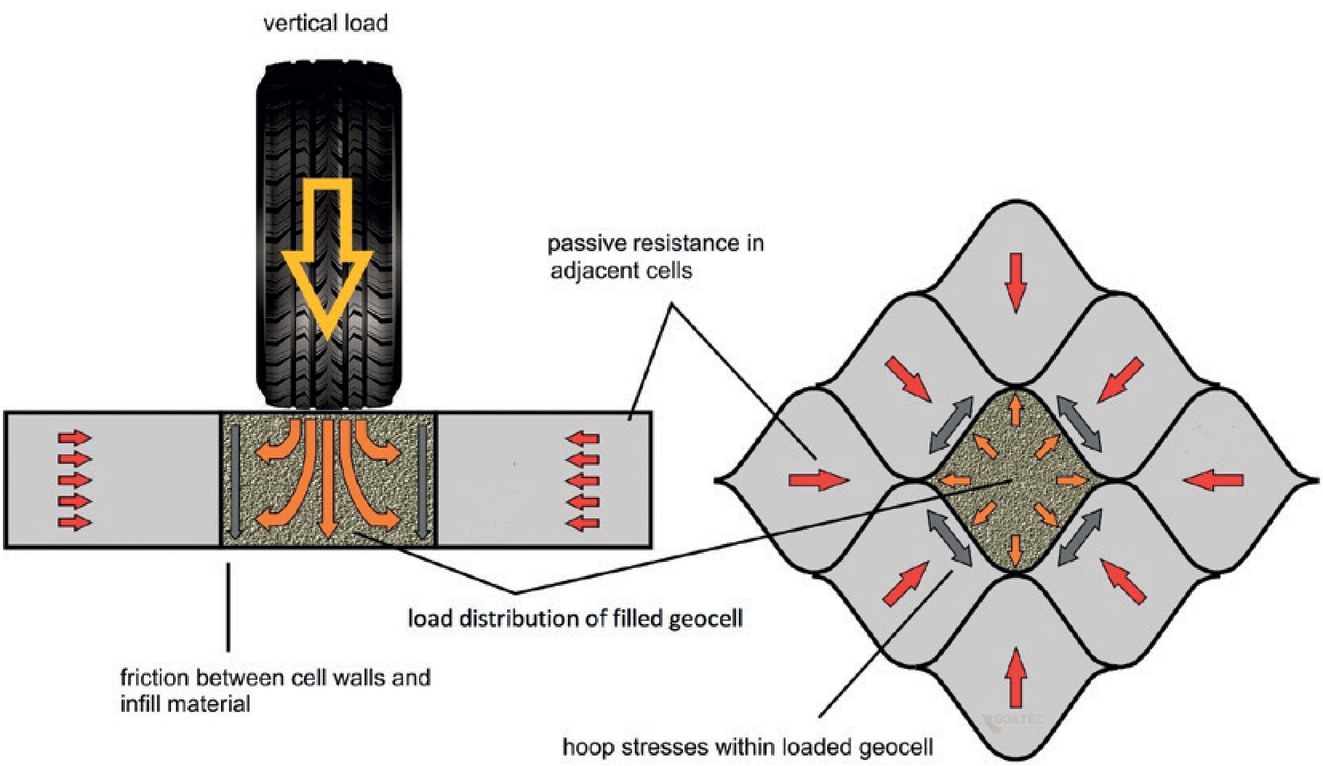

Figure 3: This diagram illustrates how forces are dispersed when a vertical load is applied to a cellular confinement system [*image courtesy of Presto Geosystems/Greenfix*].

12. For a cellular confinement system to function effectively it is crucial that all of the cells are fully expanded and filled to capacity. Geocells made out of flexible geotextiles are generally unsuitable for use near trees because they have a tendency to deform as they are filled with stone which impairs their dimensional stability and consequently their ability to spread the load.

13. Studies have shown that geocell foundations can provide adequate support at approximately 50% of the thickness required by non-reinforced base courses (Bathurst & Jarrett 1988). Therefore, the use of cellular confinement systems can significantly reduce the amount of material required to stabilise a soil. Sometimes this will mean that the use of a geocell sub-base is cheaper than using conventional surfacing techniques because less extensive groundworks are required and a smaller volume of new material needs to be transported to the site.

1.3 The relevance of different types of ground conditions

14. The basic approach of using a cellular confinement system over tree root zones can be prescribed by an arboriculturist, but in order to guarantee that the surface will be suitably durable the final specification should be produced or approved by a civil engineer. This may be the project engineer or an engineer from a geocell provider (such advice is a standard service provided by most UK geocell suppliers and adds little or nothing to the cost of the installation).

15. The soil conditions need to be considered when designing a cellular confinement system because the strength of the particular soil plays an important role in the effectiveness of the geocell-reinforced base. Standard recommendations for suitable geocell depths are based on a minimum subgrade California Bearing Ratio (CBR) of 3.[4] If the ground is soft (CBR <3) an engineer should be consulted to determine if an additional sub-base is needed beneath the cellular confinement system. It is important that the project engineer has soil information prior to the surface being specified; if a site-specific soil survey is to be carried out the key information that the engineer requires is the **saturated CBR value** of the soil.

16. In most situations the majority of a tree's fine root system is located within the upper 30cm of soil (Perry 1989; Gilman 1990), and so topsoil stripping within a tree's root zone is likely to cause harmful root damage. However, the depth and nature of the soil influence where tree roots are able to grow. In deep and well aerated soils the greatest density of roots, and almost all woody roots, will be contained in the upper 60cm of soil, although some may extend to depths of 2–3m (Dobson 1995). But in shallow or waterlogged soils roots will be located just beneath ground level, and if these roots are damaged there would be greater consequences for the tree.

17. Geocell mats need to be laid on level surfaces, so sloping or uneven ground can be challenging. The recommended approach in such situations is to first install an edge restraint (as detailed in Section 2.7), followed by the base geotextile, and then add infill to the lower areas to raise the level up to the highest point (see Figure 4). Sharp sand can be used to ramp over protruding roots but deep layers of sand beneath geocells should be avoided because there is a risk that they could be eroded by water movement which may lead to surface failures. For this reason, the use of angular stone aggregate is advised (ideally this would be the same as the infill material).

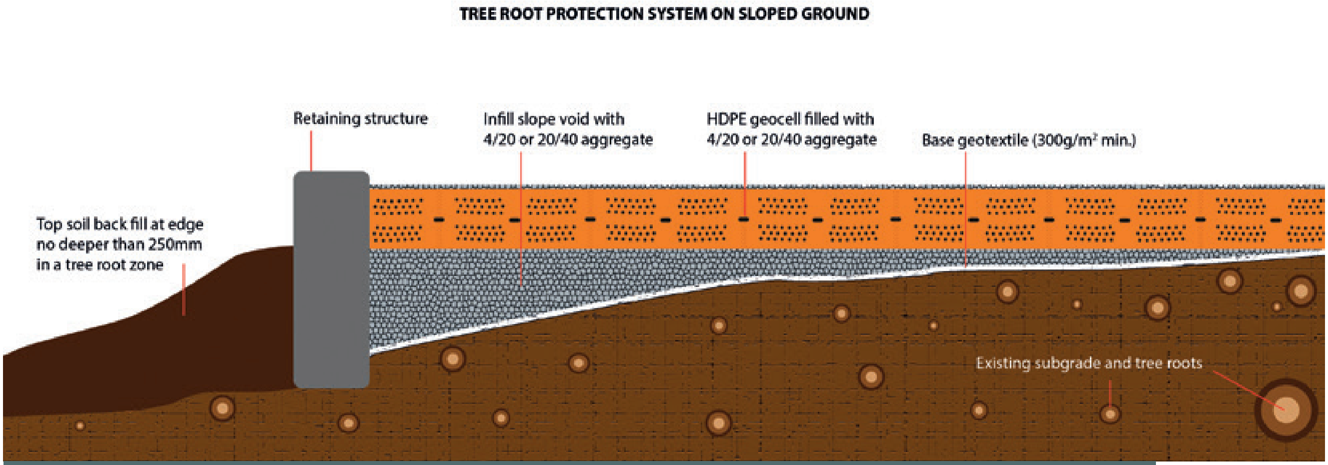

Figure 4: An example of how cellular confinement systems should be installed when the ground is sloping or uneven [*image courtesy of Core LP*].

[4] It should be noted that CBR is often referred to as a number rather than a percentage, e.g. 3 rather than 3%.

2 Section

Practical application

2.1 Project planning

18. If they are to be effective, cellular confinement systems must be installed properly with due regard to the particular circumstances of the site. Practitioners must approach projects of this nature with the same degree of knowledge, care and ingenuity that they would bring to any other aspect of a construction project.

19. There are alternative construction techniques which may sometimes provide a better solution than cellular confinement systems for surfacing above tree root systems. Suitable alternatives may include piled raft solutions using conventional or screw piles, or the use of stone-filled wire gabions. All options for bridging over tree root zones should only be considered acceptable where there are discernible reasons why encroachment into the root protection areas of retained trees cannot be avoided.

20. BS5837 states that *'where permanent hard surfacing within the RPA is considered unavoidable, site-specific and specialist arboricultural and construction design advice should be sought to determine whether it is achievable without significant adverse impact on trees to be retained'*. On that basis, sufficient justification should be provided where cellular confinement systems are proposed over the root zone of trees that have been assessed to be particularly vulnerable, or those that are considered at risk of being less resilient to even a minor degree of negative impact. Also, it may be inappropriate for a cellular confinement system to be used in a root protection area when it would be one of several impacts on a tree to be retained, such that the cumulative effect might be considered to be detrimental.

21. Veteran trees are valuable and may be less resilient than trees at earlier life stages, which is why in 2012 the concept of *buffer zones* was introduced for the protection of veteran trees and ancient woodland in England (Forestry Commission & Natural England 2018). To minimise the potential for harm to veteran trees or ancient woodland it is recommended that the installation of cellular confinement systems should not be permitted within the buffer zone of an ancient woodland or a veteran tree unless it can be determined that any direct impacts to soil and roots are likely to be tolerated by the affected tree(s). A cellular confinement system could be appropriate for ground protection when temporary access is required past a veteran tree if there are no other viable options available, or as a mitigation measure if a local planning authority has decided that there are wholly exceptional reasons[5] for surfacing to be required in a buffer zone. It should be recognised during the design process that incorporating features which encourage activity close to a veteran tree or an ancient woodland is likely to create additional pressures on the long-term management of those trees. Though not directly related to the impact of the cellular confinement system on roots and soil, a precautionary approach is recommended to ensure that the tree(s) and the species that they support would not be put at risk by any indirect impacts that may be caused by introducing the new feature.

22. When geocells are used to protect tree root zones the central concept is that they are installed *above ground* and this normally results in a surface that is around 150mm above the existing ground level for footpaths, and in excess of 300mm above for roads and driveways. In many cases the necessary level differences required for the installation of cellular confinement systems over tree root systems make the approach infeasible. Designers and their clients need to be aware of this and make sure that the necessary level differences can be accommodated within a project layout.

23. Clean angular stone is an essential component required for filling the cells, and the haulage costs of this stone can be a large proportion of the overall cost (often the proximity of quarries to the site will dictate the types of infill materials that are available). For large installations this stone is typically transported in 30-tonne heavy goods vehicles (HGVs) and so a site must

[5] For example, infrastructure projects where the public benefit would clearly outweigh the loss or deterioration of habitat (MHCLG 2019).

be accessible to an HGV and must include a suitable location where the load can be tipped and stored. This is particularly important when long roads or footpaths are being installed because the delivery lorries will need to deposit the stone in a suitable location away from root protection areas. The storage area needs to have enough space for the stone and for loading-vehicles to fill the dumpers that will transport the stone to the installation site.

24. In order to protect soils near trees the geocell surface often needs to be installed at the start of the project to protect ground in advance of demolition and construction activities. Alternatively, the area where the geocells are to be installed will need to be fenced off and treated as a construction exclusion zone until the time of installation.

25. If the geocell surface needs to be used as an access road during construction, its installation should be one of the first tasks the contractor carries out. In order to do this the contractor should be informed of the root protection areas required by the trees that are to be retained (determined in accordance with the guidance provided in Section 4 of BS5837:2012). Another factor that needs to be considered is the type of traffic that the surface will be subjected to during construction because very often this is heavier than the traffic that it will experience during its intended use; vehicles of particular concern include loaded dumpers and HGVs. Geocells are suitable for temporary access routes or roadways because it is a relatively simple operation to use an excavator to carefully remove a cellular confinement system when it is no longer required.

26. In some circumstances it may be necessary to install additional protection above the geocell during the demolition/construction phase. This may be required to prevent soil compaction by heavy vehicles during the development process, or as a temporary alternative to the final wearing course which might otherwise be damaged during the work. If a temporary wearing course is not used there is also a risk that mud could sink into the stone aggregate which would reduce its long-term permeability and effectiveness in maintaining gaseous exchange with the soil.

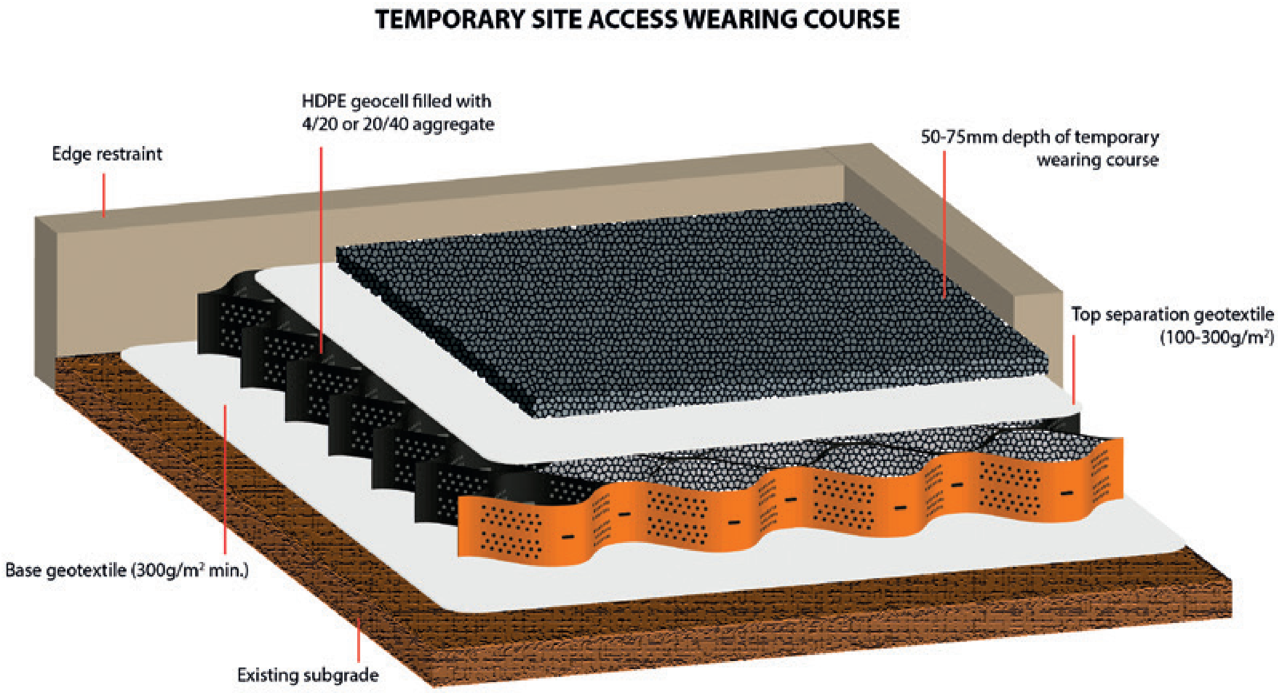

Figure 5: A geocell surface used during construction needs to be protected by a temporary wearing course and an upper geotextile is required to prevent mud from migrating down into the infill [*image courtesy of Core LP*].

In most situations overfilling the geocells with 50–75mm of material could be a suitable solution for temporary protection (as illustrated in Figure 5) but for long-term construction projects additional temporary protection would be required. Options for temporary surfacing include ply boards (for light use), heavy-duty plastic sheets, metal road plates, or a temporary sacrificial geocell layer over the surface. The latter approach is preferred as it is more likely to maintain porosity and permeability – a central concept to maintaining a healthy soil environment beneath.

27. A suitably qualified engineer should specify the appropriate depth of geocell to use for a specific location and this will depend on the bearing capacity and the strength of the soil. However, the general consensus from geocell manufacturers is that for soils with a CBR of 3 or above a loaded 6-tonne dumper can be supported by a 100mm geocell that has been overfilled by a minimum of 50mm of the same infill stone without damaging the soil structure beneath. A 150mm geocell depth is appropriate if the access road is to be used extensively by light construction traffic. However, loaded HGVs delivering construction materials, cranes, or piling rigs will require a geocell sub-base of at least 200mm.

28. The surface may also need to be protected from excessively heavy loading after construction and so vehicle use may need to be restricted; for example, bollards or barriers could be installed to prevent cars from accessing a surface that has been designed to be a cycle path only.

29. A crucial and often overlooked aspect of installing geocells is the interface between the surface laid on geocell sub-base and adjacent surfaces that have been laid on a conventional sub-base. Often the tree root zone is circular, and the intended hard surface is to cover a larger area than the sensitive root zone, and so it is tempting to only specify a geocell sub-base for the sensitive area. However, it is much easier to install surfacing in larger discrete blocks, and the final surface is likely to be much more durable if any interfaces between different surfaces are considered in the design. Therefore, it is advised that geocell is used beneath the full width of the surface rather than just part of it. The interface between different sub-bases can be incorporated within the design so that differential movement will not cause a crack to appear between the two different surface types. In order to achieve this an interface can be hidden at a point where the surfacing naturally changes (e.g. between a car-parking space and an access drive).

2.2 Suitable machinery to use for installation

30. Is not essential to use powered machinery to install geocell surfaces, and for small areas it may be easier to install them using only a shovel and a wheelbarrow.

31. Standard installations require a tracked excavator and a dumper truck. The dumper can tip stone directly into the cells and the bucket of the excavator can be used to spread the stone. The excavator should be fitted with an un-toothed spreading bucket, and on sloping ground an excavator with a tilting bucket may be more practical.

32. The ground pressure exerted by tracked excavators and loaded tracked dumpers (≤6-tonne) of all sizes is generally low enough to avoid soil compaction (provided the soil is not saturated), and so they are often the most suitable machines to use when installing cellular confinement systems in root protection areas. However, tracked vehicles are not always appropriate because although they exert lower ground pressures, their skid steering can cause surface smearing which reduces gas permeability and water infiltration rates and thus causes harm to the living soil. Therefore, if a tracked vehicle needs to turn it is advised that thick plywood boards or plastic ground guards/metal sheeting are put down so that the vehicle can turn on top of them. Ground protection is more difficult to achieve when larger vehicles are employed and so they should track outside the tree's root protection area before turning.

33. Clay soils and silty clay loams are particularly prone to compaction and smearing and so vehicle use on these types of soils needs to be managed with close attention. Wet soils are also particularly susceptible to compaction and smearing because they are more pliable than drier soils. Accordingly, arboriculturists must specify that no vehicle use is permitted in root protection areas when the ground is saturated. Contractors and clients must accept that this may involve time delays but that it is necessary to minimise the impacts of installing new surfacing near established trees.

2.3 Ground preparation

34. Cellular confinement systems can be laid directly on top of lawns or other flat soil surfaces but in most cases a degree of ground preparation is required. This is often the part of the process where trees are at the greatest risk of being damaged, and so in order to minimise the risk of harming them it is advised that any ground preparation works required are carried out under the supervision of a professional arboriculturist.

35. For most projects, the removal of up to 50mm of leaf litter and surface vegetation is appropriate but if there are obvious surface roots, or if the soil layer is shallow, it may not be appropriate to remove any surface material at all. Any protruding rocks should be removed, and it is recommended that tree stumps are ground out because this causes less disturbance than digging them out. Ramps made of sharp sand should be used as a protective layer to cover up any surface roots so that they are not damaged when the infill is introduced.

36. The concept of no-dig construction was first described in Arboricultural Practice Note 1: *Driveways Close to Trees* (Patch & Dobson 1996), and the three principles set out in that guidance remain valid today:

- Roots must not be severed.
- Soil must not be compacted.
- Oxygen must be able to diffuse into the soil (and carbon dioxide out of the soil) beneath the engineered surface.

37. The design should not require excavation into the soil but if there are no obvious surface roots the turf layer or any other surface vegetation may be removed. A tracked excavator with a grading bucket is normally the best machine to use to remove the turf layer because this creates an even surface. For this application excavators should be of an appropriate size for delicate works (i.e. ≤5tonne). **Ground preparation works using excavators in root protection areas must be supervised by an arboriculturist** to make sure that significant roots (single roots >25mm diameter or clusters of roots 10–25mm in diameter) are preserved and to ensure that vehicles are being used appropriately. Where there are deep soils it may be possible to remove more than 50mm from the surface, but care is essential because a large proportion of the root system is likely to be near the soil surface. Surface skimming must be stopped immediately by the supervising arboriculturist if the upper side of any significant tree roots is exposed. Even though the ground is broken by such works this approach may still be described as 'no-dig' in the context of installing hard surfacing near trees – the crucial distinction is that the standard practice of installing sub-surface foundations by replacing soil with compacted stone aggregate is avoided when a cellular confinement system is used.

38. With careful application a glyphosate-based systemic herbicide could be used to kill off turf in advance of laying a cellular confinement system. But in general, the application of herbicides near trees is undesirable because there is a risk that they could affect adjacent trees. However, no herbicide application is necessary prior to laying down geocells because the base geotextile and surface layers are likely to be enough to prevent vegetation growth beneath the surface.

2.4 The use of geotextile membranes in cellular confinement systems

39. Geotextiles are manufactured from synthetic polymers in a process that produces either a non-woven or a woven fabric. When cellular confinement systems are installed the fabric is unrolled directly on to the subgrade before the placement of the geocell mat. Its primary function is to separate the soft ground from the stone aggregate infill because when stone aggregate is placed on fine-grained soils the soil can enter the voids of the stone aggregate and impair its drainage capacity. Also, the stone aggregate can intrude into the fine soil, resulting in a reduction in the strength of the aggregate layer. For installations above tree root zones it is important that the geotextile is permeable to air and water.

40. Woven geotextiles tend to have a few openings of a relatively large size, whereas non-woven geotextiles tend to have numerous small openings and are therefore more suitable for filtration applications (CIRIA 2015). The holes in the fabric function as particle filters and in some circumstances this can prevent pollutants from reaching the soil beneath. A needle-punched non-woven geotextile is best for installing geocells near trees because it provides adequate tensile resistance and allows water to reach the subgrade (Fannin 2000).

41. Very often a second geotextile is required above the geocells to stop the bedding layer (often sand) above from mixing with the infill. The only type of surfacing that does not require a second geotextile is asphalt.

42. It is recommended that the base geotextile is made of polypropylene or polyester (min. 300g/m^2) with a CBR puncture resistance of 4000N. These properties are required because the angular stone infill can puncture thinner geotextiles. The upper geotextile is required for protecting the infill matrix; this can be of the same thickness or slightly thinner (100–300g/m^2). Geotextiles made from recycled products are becoming increasingly available and they can be used in cellular confinement systems if they have sufficient tensile strength and puncture resistance.

43. Sometimes a 'cake' can form on the upper side of a filtration geotextile and because of this there will always be a concern that the geotextile will clog and become less permeable. It must be accepted that any geotextile will partially clog because some soil particles will embed themselves on or in the geotextile fabric. However, there is a lot of data suggesting that permeable surfaces are very robust and in most cases do not completely seal (DCLG 2009). The aim should be to avoid situations where the geotextile will clog to the degree where the system will be insufficiently permeable to gas and water. This is the primary reason that the infill used should not contain fine-grained material. It is worth considering the risk of sediment migration when designing the cellular confinement system, to ensure that stormwater does not carry too much material downhill onto the permeable surface. It follows that a cellular confinement system with a permeable surface course should not be installed at the low point of a site's surface drainage.

2.5 Suitable stone infill

44. Angular stone binds through interlocking, and in cellular confinement systems this cohesion is aided by the texture of the geocell walls. If the stone is not angular it does not lock within the geocells and the surface will deform in use. Marine-dredged shingle and river gravel are therefore unsuitable infill materials because they have rounded edges.

45. For cellular confinement systems above tree root zones, given the size of the geocells and the interlock required, the infill should ideally be crushed 20/40 stone (this means stones that are between 20mm and 40mm in diameter). However, where this is not available 4/20 stone can be used. In all situations the infill material should be washed or graded so that it contains no fine particles (fines).

46. The aggregate must have enough internal strength to perform both during installation and in the long-term. Preferably the infill will be a crushed hard rock. However, due to haulage costs, the availability of infill will be dictated by the site location and the material produced at local quarries. Some parts of the UK do not naturally contain suitable stone for infilling cellular confinement systems and so it would need to be imported from elsewhere. Crushed granite, basalt or limestone are ideal. Flint is less suitable because some rounded edges remain after it has been crushed and the shiny faces of the fractured stone are slippery. When geocells are used for tree protection, MOT Type 1, Type 2 and Type 3 are not suitable for use as infill because they contain fines.

47. Generally, the amount of infill required can be calculated using the following equations:

Quantity of 4/20 stone infill required = **m² of coverage** × **depth of geocells (m)** × **2 tonnes**

Quantity of 20/40 stone infill required = **m² of coverage** × **depth of geocells (m)** × **1.8 tonnes**

48. An aggregate cover on top of the geocells does not contribute towards the increase of the bearing capacity of the surface but it protects the geocells, and so it is advised that geocells are overfilled by a minimum of 25mm additional aggregate before the surface layers are installed above.

2.6 Installing geocell ground protection

49. A base geotextile is always required beneath a cellular confinement system to separate the fill material and the subgrade; this geotextile must cover the entire area to be surfaced. If several sheets are required they should overlap by at least 30cm. On top of that the geocell mat is stretched out and staked in place. J-hooks (steel reinforcing bars bent into a 'candy cane' shape) are the easiest type of stake to use, but construction pins or wooden stakes can also be used. Ideally the length of the stake should be at least three times the cell height.

50. If conditions require that adjacent sections of the geocell be joined together rather than butted against each other, zip ties or staples can be used. Staples through each set of adjoining cells are attached using a heavy-duty stapler (usually available from the geocell supplier) and surplus cells can be cut off using a Stanley knife with a hooked blade. The infill material is then poured into the open pockets of the geocell.

51. Where possible, vehicle use should be restricted to areas outside the tree root zones. When introducing the stone the excavator should be positioned outside of the root protection area or on top of a stone-filled geocell mat. In some situations it may be possible to fill the geocells from the side of the track furthest away from the trees without any vehicles entering the root protection areas. When tracked vehicles are used in root protection areas, installers should start at one end of the area to be surfaced and work progressively past the tree(s) so that the need for manoeuvring is reduced, but if this is not possible additional ground protection may be required (as described in Section 2.2).

52. Engineers and contractors who are unfamiliar with cellular confinement systems will instinctively want to compact the infill but this is inappropriate when installing cellular confinement systems near trees because it would result in the compaction of the soil beneath the geocells and defeat the purpose of using the system. It is recommended that settlement of the infill material is achieved by a minimum of four passes of a smooth roller (max. weight of 1000kg/m width without vibration), or alternatively by several passes with a tracked excavator. After several passes the infill reorients and becomes stable, causing local fill stiffening. The aim is to reach the point where the infill is consolidated. Checks should be made to ensure that the infill is fully consolidated before laying the wearing course.

2.7 Edge supports

53. Edging is not required for the stability of the cellular confinement system but it is necessary to retain the wearing course and the filling of incomplete cells at the edge of a surface. Block paving that does not have a fixed edge can shift and the joints can spread, leading to movement and potential migration of the bedding material beneath. Asphalt can also crack at the edge if it is not properly retained. In all cases the appearance of the surface is adversely affected, and the longevity of the surfacing is greatly reduced. For these reasons all projects that include the use of cellular confinement systems should include a detailed specification for surface edging.

54. Kerb stones set in concrete haunchings dug into the ground are typical edging for standard surfaces but often this method of installation is not suitable where the kerbline passes through a tree root zone because the necessary excavations are likely to result in damaged roots. There are a variety of suitable alternative solutions including fixed sleepers, peg-and-board edging, concrete kerbs set above ground and pinned metal or plastic edging. Suitable systems are described in Table 1.

Table 1: The types of edging available for retaining wearing courses.

	**Peg-and-board edging** The use of treated timber peg-and-board edging is often the simplest option. However, loading can be high when the surface course is laid and so pegs are required at 1m spacing to prevent the side boards from bowing. A drawback of this approach is that the wood can splinter if tracked vehicles drive over it. Also, the wood deteriorates over time and so it is not a suitable solution for projects that are intended to have long life spans. Thicker tanalised boards can be used for longer-term installations. The wide boards typically provide a more attractive finish and they last a lot longer than thinner boards.
	**King-posts** Where deeper above-ground support is needed steel I-bars can be used to support large wooden sleepers. A drawback of this approach is that the I-bars need to be set in concrete, and that part of the process could damage roots if it is not carried out with due care [*image courtesy of Advanced Arboriculture Ltd*].

Standard kerbs set on top of concrete-filled geocells

If the levels suit, standard kerbstones can be set on top of the geocells. The edge cells can be filled with concrete and the haunchings are above the cellular confinement system. The finish can look very good when this has been carried out properly.

Small concrete kerbs pegged and set in concrete

Where only small load resistance is required narrow concrete kerbstones can be set in concrete at the edge of the geocells, and these can be further stabilised by wooden pegs. This creates an attractive finish that is comparable to standard surface installations.

Railway sleepers fixed in place

An advantage of using railway sleepers is that they are easy to source and quick to install. They are particularly good for temporary access roads because they can be easily removed at the end of the project and re-used.

Metal or plastic edging strips

There is a range of edging products that are designed to retain block paving or to provide a clean edge to landscape areas. These are typically L-shaped edging strips that are secured by being pinned into the ground below [*image courtesy of Hauraton Ltd*].

3 Section

Suitable surface finishes

3.1 The need for permeable surfacing

55. Permeable paving needs to be suitable for pedestrian or vehicular traffic and contain pathways that allow air and water to pass through. Although some permeable paving materials are nearly indistinguishable from non-permeable materials in construction and appearance, their environmental effects are qualitatively different because they allow gases, water and heat to be exchanged between the soil and the atmosphere.

56. In the UK, sustainable drainage systems (SuDS) are actively encouraged in new development schemes. Cellular confinement systems topped with a permeable surface can be part of a SuDS design because they allow water to infiltrate directly into the soil and contribute to managing stormwater by detaining runoff, increasing infiltration, and treating water quality (Ferguson 2005).

57. If a permeable surface is acting as a road surface it may need to be adopted by the local highway/roads authority or drainage approval body. This is a complex subject, and guidance on relevant approval or adoption protocols may need to be sought from local stakeholders before a detailed design is drawn up.

58. In most cases standard tarmac surfacing is inappropriate above tree root zones because it seals the surface of the soil, preventing the ingress of water and gaseous exchange between the soil and the atmosphere. If this is a concern, alternative pathways for air and water to reach the soil beneath can be designed. Still, there may be exceptional circumstances where an above-ground geocell sub-base with a sealed surface is the only way of avoiding a standard foundation that would cause direct damage to tree roots. In order to decide if an impermeable surface is a suitable solution the arboriculturist will need to assess the overall impact of such works by considering the health of the affected trees, the proportion of the root zone affected, and whether the soil structure and water supply will be sufficient to fulfil the physiological needs of the tree in the long-term.

3.2 Surfacing options

3.2.1 Porous asphalt

59. Porous asphalt is an open-graded aggregate bound with asphalt cement to produce a permeable surface that allows water and air to pass through. It is probably the best surface to use over cellular confinement systems because it tends not to have cracking or pothole formation problems. Also, it provides a neat finish that looks very similar to standard tarmac. The asphalt binder never really hardens and so it interacts with the geocell base to form a single flexible structure. The installation of porous asphalt is marginally more expensive than standard tarmac but it has benefits for adjacent trees, pollution control, site drainage and stormwater management.

60. An advantage of porous asphalt is that it does not require proprietary ingredients to be manufactured. Most asphalt providers can easily prepare the mix, and since installing it does not require unusual equipment or specialised paving skills, general paving contractors can install it as they would standard surfaces. The asphalt must be thoroughly mixed immediately before being laid or there can be an uneven distribution of binder as the surface is laid, and this leads to some parts of the surface being impervious because they have too much binder in the pores and other areas breaking up because there is too little binder around the aggregate. Standard porous asphalt may be used for cyclepaths and footpaths but stronger binding agents are required for car parking areas and driveways because the power steering of modern vehicles can cause the surface aggregate to break up.

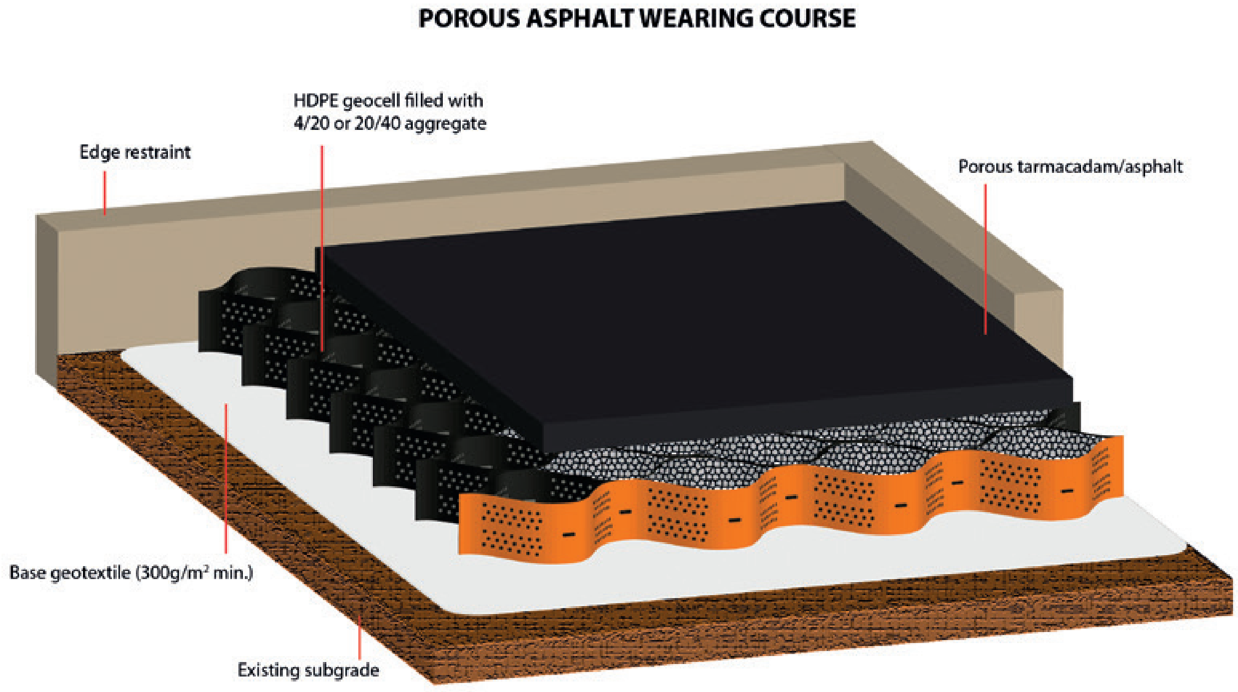

Figure 6: The typical composition of a porous asphalt surface with a geocell sub-base [*image courtesy of Core LP*].

3.2.2 Loose gravel

61. Residential driveways typically bear light and slow-moving vehicular traffic and unbound gravel is suitable for this type of use. It can also be used as a temporary surface, but the gravel is often disturbed by vehicles turning, and there is a risk of the upper separation geotextile tearing and the gravel contaminating the infill. Also, as with all gravel installations, the surface camber must be suitable or the gravel will migrate downhill.

62. Small plastic stabilisation grids are the best solution for car parking areas. They are not a solution in themselves beneath trees because they do not spread loads sufficiently to prevent soil compaction and they also need to be laid on a sub-base. However, they can be used to retain gravel or soil above a geocell sub-base (see Figure 7). One particular benefit of these small panels is that they are lightweight and easy to put into position. Another advantage is that they can easily be removed and replaced if necessary.

63. Stabilisation grids with grass are possible over tree root systems but their appearance suffers under heavy traffic. For this reason, permeable grass-covered surfacing is best for overflow parking areas or other areas that have only occasional use.

STABILISATION GRID WEARING COURSE FILLED WITH SOIL OR GRAVEL

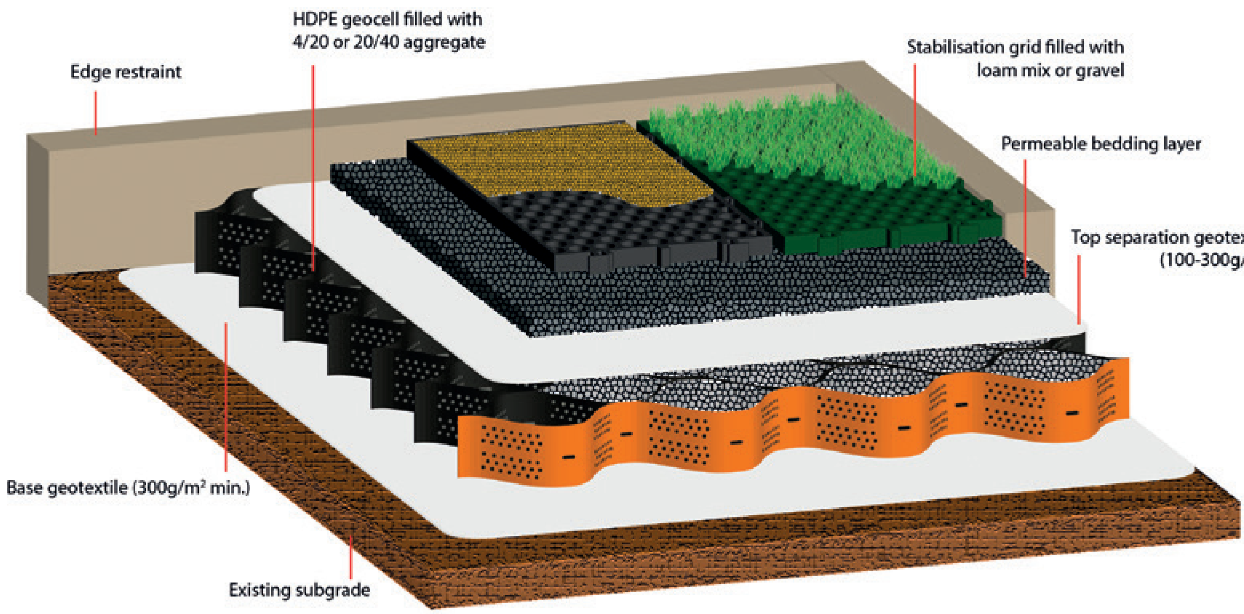

Figure 7: The sub-base configuration required for gravel or grass surfacing *[image courtesy of Core LP]*.

3.2.3 Resin-bound gravel

64. Resin-bound gravel provides a permeable and durable wearing course. It is better than loose gravel when a surface has heavy traffic because it remains stable. The resin is typically UV-stable polyurethane, mixed with aggregate with a typical grading of 6–10mm. A variety of resin-bound products are available, and they come in a range of colours. Specifiers should be aware that resin-bonded surfaces are typically thin layers (18–25mm) and they have to be laid on a porous asphalt base (80–150mm deep).

3.2.4 Permeable block paving

65. Block paving (concrete block permeable paving, porous block paving, and clay block permeable paving) can be used as a wearing course. It is commonly used because the final surface is attractive. It is highly permeable and can bear heavy traffic. Another benefit is that this is a surface that most contractors know how to install.

66. Joint fill material is spread into the joints and the surface is vibrated to settle the blocks, bedding and joint-fill into a firm position. Block paving is a sensible solution on corners or on sloping ground because the surface is given stability by the interlocking blocks. The adjacent blocks wedge together and so creep is resisted when they are put under horizontal loads such as vehicle braking or turning.

67. Paving blocks need to be laid on a bed of sand or fine stone chippings and so a second geotextile is required above the infill to prevent the sand from migrating down the profile. There are numerous different types of block paving available and paving experts should be consulted to find the best type for specific applications.

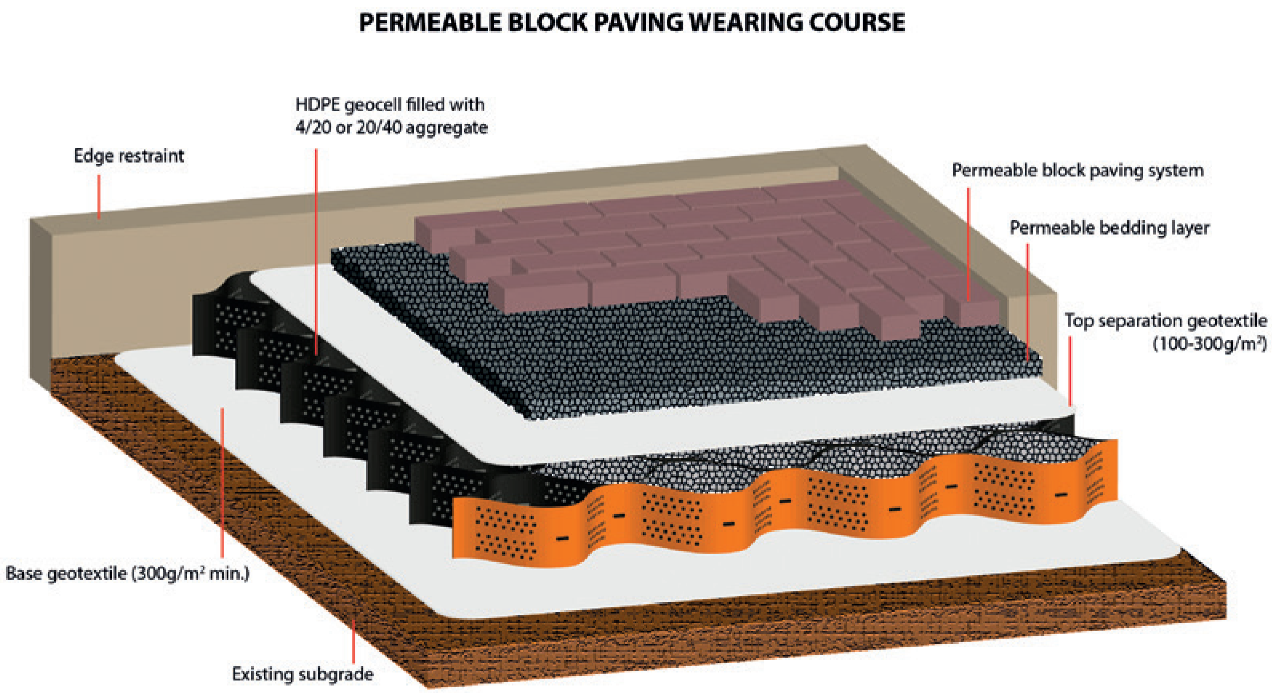

Figure 8: **The recommended specification when installing permeable block paving above a cellular confinement system** [*image courtesy of Core LP*].

Suitable surface finishes

3.3 Surface maintenance

68. Over time all permeable surfaces are likely to require a degree of maintenance to prevent them from becoming clogged because this would impair their function and could therefore adversely impact adjacent trees. Smaller particles trap larger particles. Therefore, the rate of clogging increases as more fines are trapped. It is a good idea to install permanent signs to alert maintenance personnel to keep silt and debris away from a porous surface; and also to warn them not to seal the pavement or use de-icing salts if there are adjacent trees.

69. Surface clogging can be managed by regular maintenance. Brush and suction road sweepers should be used for regular cleaning of roads and car parks. Leaf and litter vacuums are a quick and effective way to clean porous surfaces; these are small machines that are pushed by the operator. Hand-held pressure washers can also be used to unblock surface pores that have become blocked with moss, tree leaves and needles. All types of cleaning are most effective when they are done before clogging is complete.

70. As a general rule, permeable surfaces should be cleaned once every year to remove silt and dirt particles. Surfaces beneath trees that drop lots of blossom or fruit may need to be cleaned more regularly (refer to Section 20.14 of the CIRIA SuDS Manual for more detailed maintenance guidance).

71. The HDPE that makes up the cells can degrade if exposed to sunlight and the cells can also be damaged by traffic if they protrude. Consequently, the functionality of the system is impaired and the surface develops a tatty appearance. Therefore, uncapped cellular confinement systems need to be checked annually and topped up with suitable stone if any cells are visibly exposed.

Section 4

Arboricultural implications

4.1 Potential impacts on tree health

72. A major concern about surfacing above a tree root zone is the impact that this will have on the availability of water and oxygen to the soil immediately beneath the surface. Soil aeration deficiencies result in reduced levels of tree root growth (Weltecke & Gaertig 2012) and so it is important that new surfacing above a tree root system maintains gas permeability at the soil–atmosphere interface.

73. Laying a new load-bearing surface over an area of ground is likely to increase the bulk density of the soil beneath to some degree. As a result, the soil will contain less macropore space and the pores will have fewer connections between them. With these effects on the soil profile, wide or extensive surfacing above a root zone will have the effect of decreasing the saturated hydraulic conductivity and increasing the tortuosity[6] of flow paths through the soil. With reduced levels of oxygen and water there will also be reduced biological activity in the soil, which will consequently decrease the opportunities for soil-pore creation and the turnover of soil organic matter. An inadequate supply of oxygen impairs root growth and function because respiration becomes anaerobic, which is inefficient and does not release enough energy to maintain essential physiological processes in root tissue (Roberts *et al.* 2006). Consequently, the uptake of water and nutrients by the root system decreases, causing reduced photosynthesis above ground. It has been found that low soil oxygen concentrations increase the susceptibility of plants to diseases, the virulence of pathogens, or both (Craul 1992). These adverse effects would be more extreme beneath an impermeable surface because air and rainwater would be prevented from infiltrating directly from the above-ground atmosphere.

74. There is a risk that the preparatory works required to level the ground could cause direct root damage which would leave affected trees vulnerable to soil-borne pathogens and, ultimately, this could lead to the accelerated decline of the tree.

75. Taking into consideration the effects that surfacing has on soil structure and permeability, it cannot be said that any form of hard surfacing will have no impact on the environment of tree roots growing beneath. When the full implications of installing cellular confinement systems are considered, one has to conclude that the impact of installing such a surface will inevitably have a small adverse impact on the health of affected trees. But experience has shown that healthy trees usually remain in good health when a permeable hard surface is laid on top of a geocell sub-base within their root zones. Overall, it seems that in a great majority of cases the impact of installing cellular confinement systems in tree root zones is small enough for it not to result in an obvious deterioration in the condition of affected trees, and the benefits of using this approach far outweigh the problems of laying a conventional surface.

76. BS5837:2012 recommends that new permanent hard surfacing should not exceed 20% of any existing unsurfaced ground within the root protection area of a tree (BSI 2012). This is a cautious recommendation and it should not necessarily be considered an absolute limit because in some circumstances covering a higher proportion of the root zone with a permeable surface may be acceptable, provided that it has been sufficiently justified.

[6] Tortuosity is one of the properties of a porous material, usually defined as the ratio of actual flow path length to the straight distance between the ends of the flow path. In terms of void connectivity, a highly tortuous soil is the opposite of an uncompacted and biologically active loam soil. If the soil's pore passages are tortuous (as in a compacted soil), gaseous diffusion and soil water movement are inhibited.

4.2 Limitations of geocells

77. Underground services should not be routed beneath cellular confinement systems because they may need to be accessed in the future, either for repair or for making new connections, which could severely compromise the installation. On many development sites this can be a significant limitation. Therefore, when cellular confinement systems are specified the requirement for new underground services, and where they need to be installed, must be detailed at the planning stage.

78. Ramping up from an existing road to a new geocell surface can be difficult to achieve if there are tree roots at the edge of the road. It may be necessary to create a build-out in the road so that the ramp can be installed before the geocell begins. The preference would always be to have ramping formed outside tree root zones but the level change cause by building a new surface above ground often means that it is not practically feasible to ramp up from existing roads. In such situations some dig (and possibly ground consolidation) within the root protection zone of adjacent trees would be required in order to smoothly connect the two different types of surface construction. Alternatively, a metal ramp can be installed on mini-piles. Adjacent trees could be compromised if there are significant roots where the excavation for a ramp is required, and all parties involved should be aware that in this context the use of a cellular confinement system may not be an appropriate solution. The level differences caused by installing above-ground surfacing can have a variety of consequences; for example in some cases they will dictate the floor level of buildings in the vicinity.

79. HDPE geocells are made of virgin plastic and, provided they are not exposed to sunlight, they have a design life of 120 years. They can also be reused. The design life of permeable paving is approximately 20 years (DCLG 2009; CIRIA 2015). Therefore, in most cases the wearing course or edging would need to be replaced before the cellular confinement system.

80. The static load of the infill is low (approx. 15–20kPa per metre height depending what infill is used), and geocell mats disperse active loads. Therefore, unless the ground is particularly soft (CBR < 3), the stone-filled geocell sub-base can be up to 2m deep and used by refuse trucks or fire engines without causing compaction of the soil beneath.

81. There are few long-term studies that demonstrate the effectiveness of cellular confinement systems near trees. At present it is difficult to say with confidence what the long-term impacts of such surfacing may be on the soil beneath. Independent studies that measure the bulk density, moisture and oxygen levels of soils beneath geocells would help develop understanding of how effectively they function. Also, key features of cellular confinement systems, such as the effects of infill materials, stress distribution patterns, joint strength and wall deformation characteristics, have still not been fully explored. Refined guidance should be developed as the use of cellular confinement systems increases and if data from long-term tree health monitoring studies become publicly available.

5 Key recommendations

1) The use of cellular confinement systems can be effective in protecting soils and tree root systems when new hard surfacing is required near trees. However, in this context the installation of geocell sub-bases inevitably involves working on top of tree root systems and as such there will be an elevated risk of damaging tree roots and the structure of the soil. Therefore, careful working procedures are required to ensure that trees are suitably protected when the installation works are carried out.

2) The installation of cellular confinement systems should be directed by a project-specific arboricultural method statement. The arboricultural method statement should list any aspect of the proposed construction project that has the potential to adversely impact adjacent trees and detail appropriate methodologies for how the works will be undertaken in ways that would minimise those impacts.

3) Tree roots can be directly damaged as the ground is levelled in advance of laying down a cellular confinement system and so it is recommended that this part of the process is carried out under arboricultural supervision. The use of a tracked excavator within a tree's root protection area should only be permitted if it is supervised by a suitably qualified arboriculturist. Local authorities should condition such supervision and stipulate that records of the supervision visits be provided to demonstrate that the works have been carried out appropriately.

4) The cellular confinement system must be filled with clean angular stone that contains no fine material. To protect the geocell membrane it is advised that geocells are overfilled by a minimum of 25mm. In order to function effectively it is crucial that all of the cells are fully expanded and filled to capacity. Therefore, if there is insufficient space for a cell to be expanded it should be cut away and discarded.

5) When cellular confinement systems are installed within tree root zones it is important that the wearing course is permeable so that air and water can reach the soil beneath. Systems should be put in place to ensure that the surface is regularly cleaned so that it maintains its porosity.

6) The means to successfully prevent ground compaction during construction need to be planned from the conceptual stages of a building project. It may be that the no-dig surface needs to be installed and used during construction, and in other situations the ground may need to be protected until it is time to install the cellular confinement system. Therefore, the project arboriculturist needs to work with the architect, the project engineer, and the building contractor during the planning stages as well as during the construction of the surface.

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