



BS5837

**Arboricultural Survey, Impact Assessment and Tree
Protection**

Former Grove Court Hotel, Cleator Moor, Cleator, Cumbria

Client: Mr Colin Benn

17th July 2023

Surveyor	Author	Checked
Josh Ledbury	Josh Ledbury	Ben Knipe

Contents

	Page
1. Summary	4
2. Introduction	5
3. The Brief and Requirements	5
4. The Report	5
5. Scope and Report Limitations	5
6. Documents Provided	6
7. The Site	6
8. Legal Restrictions	6
9. Proposed Development	6
10. Survey	7
11. Arboricultural Impact Assessment	9
12. Generic Implications of Developments and Demolition on Trees.	10
13. Site Specific; Implications of the proposed development on the trees.	11
14. Site Specific; Implications of the trees on the proposed development.	11

Appendices

	Page
Appendix 1	Tree Data Table
Appendix 2	Glossary of Arboricultural Terms
Appendix 3	Surveyor Qualifications
Appendix 4	Legal Restrictions
Appendix 5	Survey Methodology
Appendix 6	Arboricultural Method Statement
Appendix 7	Cleator Moor PTC- T1
Appendix 8	Cleator Moor TPP
Appendix 9	Cleator Moor TPP- Fence
Appendix 10	Cleator Moor TPP-T1
Appendix 11	AA guidance note 12

1. Summary

- 1.1 Lowther Forestry Group Ltd has been commissioned by Day Cummins on behalf of Mr C. Benn to produce an Arboricultural Survey and Arboricultural Impact Assessment (AIA) following guidance of BS 5837: 2012 *Trees in Relation to Design, Demolition and Construction - Recommendations*. The report is to aid the planning application for residential dwellings.
- 1.2 The report aims to give a balanced judgement of the trees, their protection prior to the development phase and future management.
- 1.3 The site is a former hotel, which has been demolished in Cleator Moor, Cumbria.
- 1.4 The proposed development is to construct seven residential dwellings on the site of the former hotel.
- 1.5 The survey identified and recorded 2 trees requiring consideration prior to design or development of the site.
- 1.6 To facilitate development, 1 category C tree requires removal, and 1 Category B tree is to be retained with arboricultural works recommended prior to construction.
- 1.7 Arboricultural Method Statements are included in this report for works within the RPA of the retained tree. See Appendix 9.
- 1.8 Construction Exclusion Zone (CEZ) fencing has been recommended to restrict access to the retained tree and to protect it from physical damage. Arboricultural operations may be undertaken prior to CEZ fencing being erected.
- 1.9 All tree works should conform to BS 3998: 2010 *Recommendations for Tree Works*.
- 1.10 The plan of tree constraints can be seen in Appendix 7.
- 1.11 The tree protection plan can be seen in Appendices 8, 9 & 10.
- 1.12 Details relating to individual trees can be seen in Appendix 1, Tree Survey Data Table.

2. Introduction

- 2.1 Lowther Forestry Group Ltd has been commissioned by Day Cummins on behalf of Mr C. Benn to produce an Arboricultural Survey and Arboricultural Impact Assessment (AIA) following guidance of BS 5837: 2012 *Trees in Relation to Design, Demolition and Construction - Recommendations*. The report is to aid the planning application for residential dwellings.

3. The Brief and Requirements

- 3.1 A plan to a scale and level of accuracy appropriate to the proposal that shows the position, crown spread and Root Protection Area (RPA) of every retained tree on site.
- 3.2 A schedule of tree works for all the retained trees in 3.1 above, specifying pruning and other remedial or preventative work; whether for physiological, hazard abatement, aesthetic, or operational reasons. All works shall be carried out in accordance with BS 3998: 2010 *Recommendations for Tree Work*.
- 3.3 Identify tree removal that would be required for the proposed development to take place.
- 3.4 Highlight the location and specification of Construction Exclusion Zone (CEZ) fences to protect trees from unnecessary damage during the demolition and construction phases.

4. The Report

- 4.1 The report aims to give a balanced judgement of the trees, their protection prior to the development phase and future management.
- 4.2 The report will clearly identify the tree locations, their crown spread, and the extent of the root protection area (RPA) required at all stages of development.

5. Scope and Report Limitations

- 5.1 This is not a tree safety survey and therefore does not evaluate trees regarding their likelihood to cause death or bodily injury to any person or damage to property. Any clear and identifiable hazards are highlighted with recommendations. There may, however, be hidden defects or defects which are not identified due to weather conditions or foliage for which Lowther Forestry Group Ltd cannot be held responsible. The survey produces a picture of those trees surveyed as on the date when the survey was undertaken. It is quite possible for hazards to have developed since that time.
- 5.2 This report confines itself to the silvicultural and arboricultural aspects of the trees and does not address any ecological or engineering aspects or anything in relation to soils for which other specialists' advice may be sought.

6. Documents Provided

- 6.1 The topographical survey was provided to identify tree locations. A plan showing the proposed development was also provided (5464-07c Proposed Site Plan v2023) to aid the production of the Arboricultural Impact Assessment (AIA).

7. The Site

- 7.1 The site is the former Grove hotel, in Cleator, Cumbria. The hotel has been demolished.
- 7.2 Surrounding land use is predominantly residential.

8. Legal Restrictions

- 8.1 Trees in any location may be protected by legislation. Where development is proposed, additional legal protection may be appropriate and can be enforced by the local authority. Attention is drawn to legal controls and liabilities under common law for consideration at the earliest stages of potential site development.
- 8.2 A check on the Copeland interactive map (accessed 14.07.23) indicated that there are Tree Preservation Orders (TPO) affecting this site. T1 (sycamore) is covered by a TPO, reference number is 52, confirmed 7th October 1992.
- 8.3 Substantial penalties and or prison sentences can be incurred for contravention of legislation relating to protected species.
- 8.4 Lowther Forestry Group Ltd has not been requested to make any checks for protected species on this site.
- 8.5 Further legal considerations can be found in Appendix 4.

9. Proposed Development

- 9.1 The proposed development is to construct seven detached dwellings on the site of the former Grove hotel. These will each have driveways together with rear and front gardens.
- 9.2 The location of the proposed construction can be seen in Appendix 7.

10. Survey

- 10.1 The survey was carried out in accordance with BS 5837: 2012 *Trees in Relation to Design, Demolition and Construction - Recommendations*. A glossary of arboricultural terms used in this report can be found in Appendix 2.
- 10.2 The surveyor was Josh Ledbury. Surveyor qualifications can be found in Appendix 3.
- 10.3 The trees have been categorised in accordance with the cascade chart in Table 1 of BS 5837: 2012 *Trees in Relation to Design, Demolition and Construction - Recommendations*, page 9. The survey methodology can be seen in Appendix 5, Survey Methodology.
- 10.4 The survey identified and recorded 2 trees requiring consideration prior to design or development of the site.
- 10.5 The trees have been divided into the following four categories and are as follows:
- Category A = 0 trees
 - Category B = 1 tree
 - Category C = 1 tree
 - Category U = 0 trees
- 10.6 Table 1, Tree Quality Assessment Table shows the trees on site categorised following guidance from BS 5837: 2012 *Trees in Relation to Design, Demolition and Construction - Recommendations*.

Table 1. Tree Quality Assessment Table

Tree Quality Assessment Table			
Category	1 Mainly arboricultural values	2 Mainly landscape values	3 Mainly cultural values including conservation
A	-	-	-
B	-	T1	-
C	-	T2	-
U	-	-	-

A, B, C and U indicate the contribution in years the tree will potentially live for.

40+ years = A, 20 to 40 years = B, 10 to 20 years = C, less than 10 years = U

- 10.7 Category A trees are those of high quality and value, with an estimated remaining life expectancy of at least 40 years. No trees have been recorded in the survey area as Category A.

- 10.8 The Category B trees those are of moderate quality and value with an estimated remaining life expectancy of at least 20 years. There is one tree recorded as Category B in the survey area – T1. This is a mature tree which is in the southeast corner of the existing site. This is moderately healthy and in good structural condition.
- 10.9 The Category C trees are those trees of low quality and value with an estimated remaining life expectancy of at least 10 years, or young trees with a stem diameter below 150 mm. There is one tree recorded as Category C in the survey area – T2. This is a semi-mature cypress of limited value.
- 10.10 Category U trees are trees which are unsuitable for retention and cannot realistically be retained as living trees for longer than 10 years. There are no trees recorded as Category U in the survey area.

11. Arboricultural Impact Assessment

- 11.1 Any arboricultural recommendations for the trees aim to promote health, growth, and retention of suitable specimens within the development.
- 11.2 Recommendations may also aim to reduce the potential risk of harm to users of the site, by identifying significant defects within the trees.
- 11.3 Table 2 (below) Arboricultural Impact Assessment Table identifies trees to be removed to facilitate the development, and trees to be retained and managed within the proposed development.

Table 2. Arboricultural Impact Assessment

Arboricultural Impact Assessment Table					
		Category A	Category B	Category C	Category U
Recommendations to Facilitate Development	Fell			T2	
	Crown lift to 3 m		T1		

- 11.4 To facilitate development, T2 requires removal.
- 11.5 Arboricultural operations are recommended for T1 to benefit development, and to benefit the management of this tree in the long term. It is recommended to crown lift T1 to clear the ground by 3 m.
- 11.6 T1 will require protection from the construction works as part of the proposed development. Construction Exclusion Zone (CEZ) fences are recommended to protect these trees and can be seen on Appendices 9, 10 & 11.
- 11.7 Should the plans or methods change, then revised works will need to be approved by Copeland Council and an Arboriculturalist consulted.
- 11.8 Details of tree works can be seen in Appendix 1, Tree Survey Data Table.

12. Generic Implications of Developments and Demolition on Trees.

- 12.1 All tree works should conform to BS 3998: 2010 *Recommendations for Tree Works*. Damage can be caused when untrained persons attempt to carry out pruning to clear a tree canopy away from access structures for example. All pruning to facilitate access should be undertaken prior to the construction phase.
- 12.2 Collisions with trees are possible when machinery is moving around a site. Likely scenarios include loading and storing materials next to the trunk, colliding with the trunk and the use of long reach booms i.e., excavators, needing space to rotate or lift the buckets to gain the correct angle. The use of tree protection fences and a well-designed site should avoid this form of damage. Any wounds caused to the trees by poor pruning or impact damage can be potential entry points for pathogens. These can have detrimental effects on the physiological health and structural integrity of retained trees.
- 12.3 Activities such as materials storage on top of the root structure, vehicle and plant traversing or regular foot traffic above the root structure will cause the soil around the roots to become compacted. This will change the structure of the soil and therefore the roots' ability to uptake nutrients and water and access oxygen. It is worth noting that for this to happen the objects above the soil do not need to be heavy i.e., a person, or continual i.e., one heavy vehicle passing over for this to have an effect.
- 12.4 Activities which may cause root damage or severance, such as digging around roots and especially linear trenches used for foundations, will have a substantial effect on the trees' physiological condition and structural integrity. The roots provide the anchor and security to hold the tree in position. Trees will not be able to adapt to a quick and sudden loss to any substantial roots which may be providing essential security for its stability.
- 12.5 Spillage of chemicals of any sort are likely to have a negative effect on the tree either through being taken up directly into the tree and causing its decline, or by affecting the soil around it. Chemicals which leach into the soil have the potential to change the pH of the soil. Trees typically grow in certain soil types and the requirements of each species are different. It is not desirable to change the soil conditions for established trees.
- 12.6 Changes in soil levels can have a significant effect, e.g., small changes of up to 150 mm will be substantial to surface roots. It is therefore essential that any change of soil level within the RPA is to be avoided, either by removal of soil or storing excavated soil on top of the current RPA. A change in soil levels will have similar consequences as compaction with a negative impact on soil structure, available nutrients, and gas exchange.
- 12.7 Any fire within close proximity to any part of the above or below ground parts of a tree is to be avoided. Heat from fire can kill and damage the entire tree or parts of the tree, which may lead to irreversible decline and death. Fire above ground has substantial effects on the temperature below the surface where many roots will be located. Heat from fire within the top 300 mm of soil can cause irreversible damage to roots and the overall health of a tree.

13. Site Specific; Implications of the proposed development on the trees.

- 13.1 For T1, the current layout of the parking area impedes into its root protection area (RPA). Excavation within the RPA can have potentially detrimental effects on the tree's health, shortening its lifespan and in some cases decreasing its stability. See Appendix 7 & 8 for RPA.
- 13.2 There are numerous small shrubs beneath T1 which will require removal to facilitate the proposed plans.
- 13.3 Care needs to be given to the future relationship of a tree to its surroundings in the proposed development. In particular, the ability to perform any work on the tree due to access issues, and shading from the tree as it continues to grow, may have implications and cause reason for future works if this is not considered at the design stage.
- 13.4 T2 will require removing to facilitate the proposed plans. There is plenty of scope within the landscaping phase to accommodate the planting of suitable garden trees to mitigate the loss of T2.

14. Site Specific; Implications of the trees on the proposed development.

- 14.1 T1 is a large mature tree which is proposed to be in the front garden of plot 5. This will create for the most part an entirely shaded garden with little or no views to be seen from the upper windows of the dwelling. The proximity of T1 to the plot, depending on the potential buyers, may be seen as either positive or negative. Some may like a large tree in their garden, while others may be discouraged from purchasing the plot. See Appendix 7 & 8 for the shading arc and canopy spread of T1, and its relationship to the proposed development.

Appendix 1 Tree Data Table

Tree Number	Species	Height (m)	Diameter (mm)	Crown Spread (m)	Crown Clearance (m)	Category	Physiological condition	Structural Condition	Recommendations Prior to Development
T1	Sycamore (<i>Acer Pseudoplatanus</i>)	15	652	N-8, E-6, S-7, W-5	2	B 2	Fair	Good	None
T2	Cypress (<i>Cupressus</i> sp.)	6	Average	N-2, E-2, S-2, W-2	0	C 2	Fair	Fair	None

Appendix 2 Glossary of Arboricultural Terms

Term	Description
Bat Potential	The potential for the tree to be used by bats.
Botanical Name	Scientific name
CEZ	Construction Exclusion Zone
Common Name	Common name
Crown Clearance	Height in metres of crown clearance above adjacent ground level (to inform on ground clearance, crown stem ratio and shading).
Crown Spread	Distance from stem to crown edge. Usually specified as a single average distance or as four separate measurements for north, south, east, and west.
Hazards	Defects present on a tree which pose a risk to persons or property
Height	Height in metres
Physiological Condition	e.g., good, fair, poor, dead
Recommendations	Preliminary management recommendations, including further investigation of suspected defects that require more detailed assessment and potential for wildlife habitat.
RPA	Root Protection Area
Stem Diameter (DBH)	(Diameter at breast height) Stem diameter in cm taken at 1.3 m above adjacent ground level (on sloping ground to be taken on the upslope side of the tree base) or immediately above the root flare for multi-stemmed trees.
Structural Condition	e.g., good, fair, poor. Based on the presence of any decay and physical defect.
SULE	Safe Useful Life Expectancy - estimated by the surveyor in years
Target	For risk assessment - the location or object which a tree or part may fall onto or damage.
TPO	Tree Preservation Order
Tree ID	Reference number, or tag number

Appendix 3 Surveyor Qualifications

PROFESSIONAL CURRICULUM VITAE

Name	Josh Ledbury
Position in Company	Surveyor
Professional Qualifications	Technicians Certificate in Arboriculture Professional Tree Safety Inspection qualification QTRA, Quantified Tree Risk Assessment

Appendix 4 Legal Restrictions

Trees in any location may be protected by legislation. Where development is proposed, additional legal protection may be appropriate and can be enforced by the local authority. Attention is drawn to legal controls and liabilities under common law for consideration at the earliest stages of potential site development.

The Town and Country Planning Act 1990 requires that, except in certain circumstances, “no work shall be carried out which will affect trees over a certain size which are situated in Conservation Areas”. Six weeks’ notice of intent must be given to the local authority before the work is carried out. This provides an opportunity for the local authority to make a Tree Preservation Order (TPO) under this Act to protect the trees.

Tree Preservation Orders allow for trees to be protected either as individuals, groups, areas, or woodlands. The orders have the effect of preventing the cutting down, topping, lopping, uprooting, wilful damage, or wilful destruction of trees, except in certain circumstances, other than with consent of the local authority.

Even when no specific legal protection exists, it may be necessary to obtain a felling licence. These apply if the volume of timber exceeds specified amounts; site clearance, even of small areas, before detailed planning permission has been granted could exceed the felling licence quota. The Forestry Commission, under the Forestry Act 1967, administers felling licences.

Before carrying out any arboricultural or forestry operations, consideration should be given to the following legislation for protected species of flora and fauna: The Wildlife and Countryside Act 1981 (as amended), the Conservation (Natural Habitats & c.) Regulations 1994 (as amended), and the Countryside Rights of Way Act 2000 protected species of flora and fauna. This will prevent any harm or damage to protected species.

Substantial penalties and or prison sentences can be incurred for contravention of legislation relating to protected species.

Lowther Forestry Group Ltd has not been requested to make any checks for protected species on this site.

Appendix 5 Survey Methodology

The survey was carried out in accordance with BS 5837: 2012 *Trees in Relation to Design, Demolition and Construction - Recommendations*. A glossary of arboricultural terms used in this report can be found in Appendix 2.

All recommendations of tree works should be carried out to BS 3998: 2010 *Recommendations for Tree Work*.

Tree categorisation is the method by which a value is placed on an individual tree using the method described in BS5837: 2012. The method considers the Safe Useful Life Expectancy (SULE). This is measured in numbers of years. Trees of greater than 40 years = A, The Category A trees are of high quality with an estimated remaining life expectancy of 40 years. A minimum of 20 years = B, The category B trees are of moderate quality and value with an estimated remaining life expectancy of at least 20 years. A minimum of 10 years = C, The category C trees are trees of low quality with an estimated remaining life expectancy of at least 10 years, or young trees with a stem diameter below 150 mm.

Once this is established a trees contextual attributes are determined and come under the following three headings.

- Mainly Arboricultural values.
- Mainly Landscape values.
- Mainly cultural values, including conservation.

Category U trees are those in such a condition that any existing value would be lost within 10 years, and which should, in the current context, be removed for reasons of sound arboricultural management.

A single tree can come under one or more of these headings and can therefore be found twice in the quality assessment table. This does not give the tree a higher value than one with a single value in the same table.

The trees have been categorised in accordance with the cascade chart in Table 1 of BS 5837: 2012 *Trees in Relation to Design, Demolition and Construction - Recommendations*, page 9.

All trees were tagged except for trees on neighbouring properties which were inaccessible. The tree tags correspond with the tree numbering in the Tree Survey Data Table in Appendix 1.

Where access to the tree trunk is restricted, the diameter is approximate. This is highlighted in by a hash mark (#) in the tree data table.

All measuring equipment is regularly checked and calibrated to ensure accuracy.

Appendix 6 Arboricultural Method Statement

Arboricultural Method Statement and Tree Protection Plan (Appendices 9, 10 & 11) to identify:

- Sequence of Work
- Construction Exclusion Zone
- Site Layout
- Trees work schedule.
- Trees to be retained- Shown on TPP.
- Protective fencing locations and specification- Shown on the TPP and detailed below.
- Ground protection locations and specification- Shown on the TPP and detailed below.
- Mitigation strategies for minimising shade impacts of T1- detailed below.
- Driveway Construction specification- detailed below.

Sequence of Work

It is essential that to prevent damage during the construction phase of the development, that work is carried out in a logical order, and this must be adhered to as far as possible. Without doing so there will inevitably be conflict between the construction site/workers and trees.

Stage 1; Any tree work that has been agreed as part of this document must be the first actions carried out on the development site, prior to any other contractors entering or starting in any way, that may reduce the effectiveness of the mitigation strategies set out in the following sections.

Stage 2; The erection of fences and signs to secure the Root protection areas (RPA) and any temporary ground protection for vehicles and pedestrians to move through or within the RPA if this has been agreed in this document This area will become the **Construction Exclusion Zone (CEZ)**.

Stage 3; All contractors may now enter the site. Any office cabins, toilets or other temporary structures may be placed on the site in any areas not fenced off as CEZ unless otherwise stated. Construction work may now start.

Stage 4; Construction completed, and all temporary structures removed. The temporary surfaces and CEZ fencing may now carefully be removed causing as little disturbance to the ground within them as possible.

Stage 5; Any soft landscaping and replanting works planned to take place within the CEZ may now be carried out.

Construction Exclusion Zone

No works will be undertaken within any Construction Exclusion Zone. The CEZ are to be afforded protection at all times and will be protected by fencing. A protective fence shall be erected prior to the commencement of any site works e.g., before any materials or machinery are brought on site, development or the stripping of soil commences. The fence shall have signs attached to it stating that this is a Construction Exclusion Zone and that no works are permitted within the fence. The protective fence may only be removed following completion of all construction works.

The Tree Protection Plan (Appendices 9, 10 & 11) details the locations for the fences to be erected.

Site Layout and Services

The site access is via the existing entrance driveway.

Site huts/offices and amenities must be located outside of Construction exclusion zones (CEZ).

Schedule of Tree Work

-Remove T2. Stump to be removed with an excavator.

-S1 (stump) to be removed to a depth of 200 mm with a stump grinder, arisings removed and backfilled with topsoil.

-S2 (Stump) to be removed with an excavator.

-T1 Raise the canopy to clear the ground by a height of 3 m on all sides. (This work will require a separate application for works to a protected tree)

-Remove all shrubs beneath T1, stumps to be removed with a stump grinder to a depth of 200 mm, arisings removed and backfilled with topsoil.

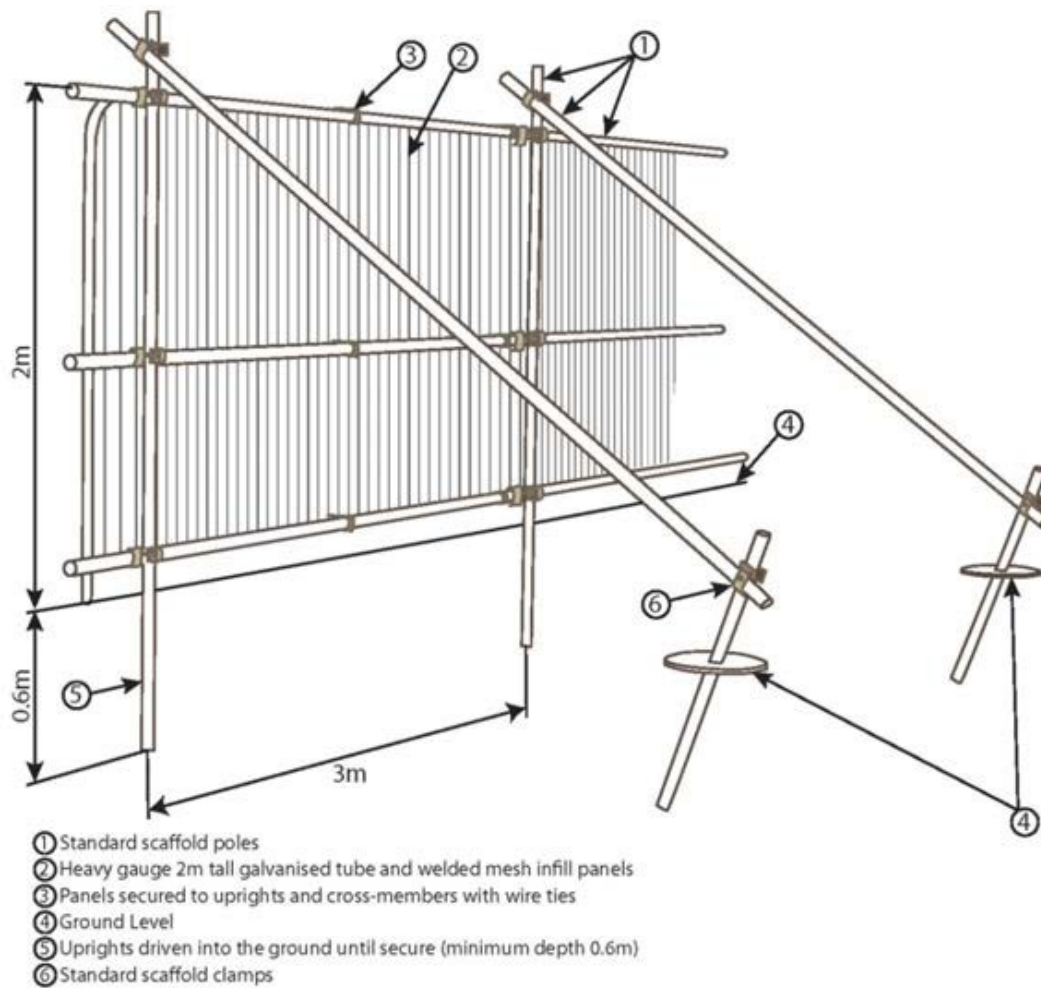
Fencing

The protective fencing for T1 should follow the diagram below. If any other type of fencing is used it must be fit for purpose and securely anchored to the ground so it cannot be moved.

Refer to Appendix 10 for the exact locations of the fencing.

The primary fencing (red on the TPP) and the secondary fencing (blue on the TPP) are to be erected simultaneously.

The Primary fencing where the driveway is to be situated may be removed to allow the construction of the driveway. It must not be removed until immediately before the driveway is to be constructed.



Ground Protection

Ground protection is to be installed immediately after the section of primary fencing is removed to construct the driveway.

The ground protection should be made up of the following. 50 mm of wood chip as an absorbent layer, with 18 mm plywood boards laid over. The plywood should be pinned securely to the ground.

This ground protection is suitable for pedestrian use only.

The location of the ground protection is pictured in Appendix 9 & 11.

Shading Mitigation

The canopy of T1 is to be raised to clear the ground by 3 m to allow light under the tree.

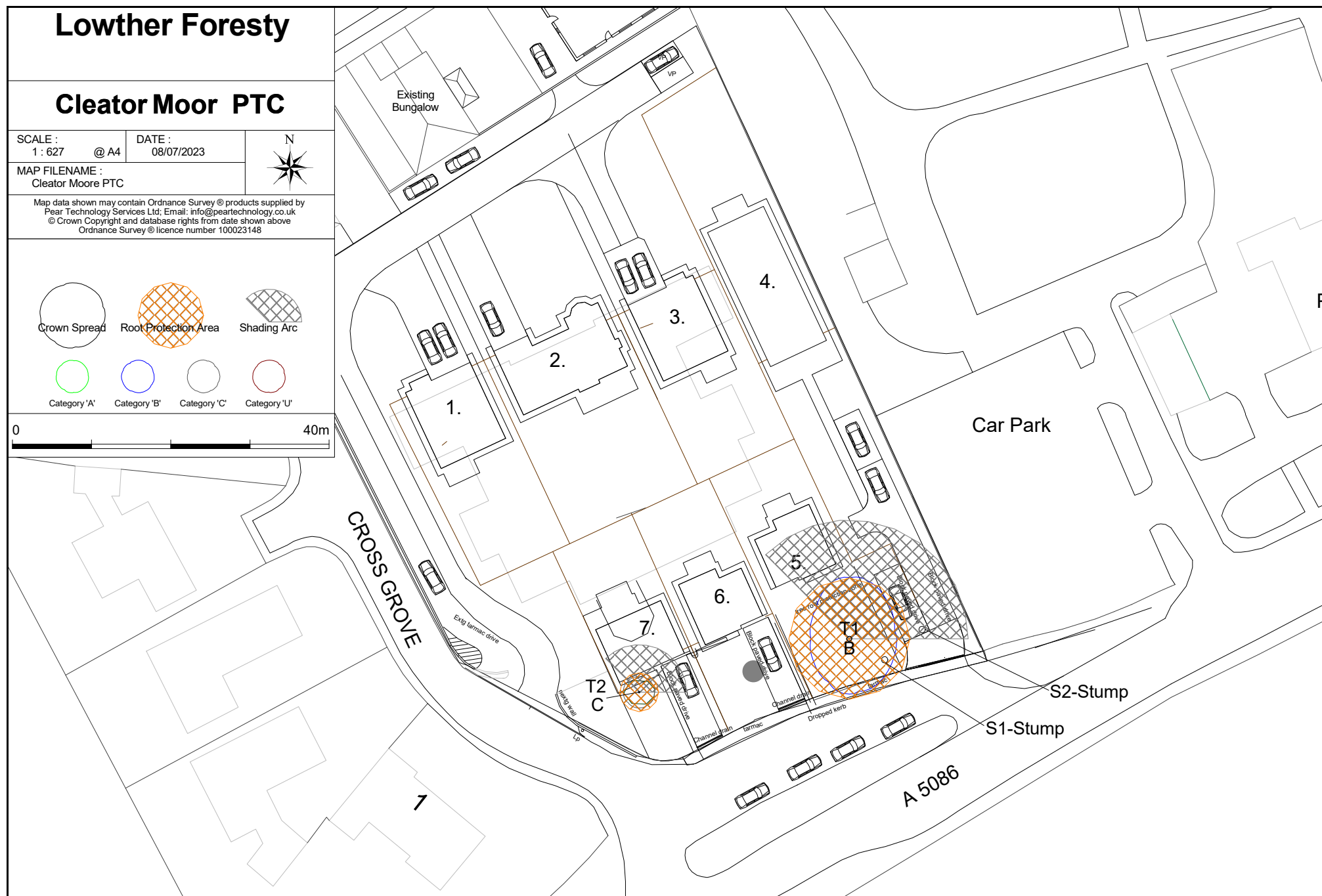
Plot 5 should have the bathrooms located on the SW corner, the most shaded area, of the property.

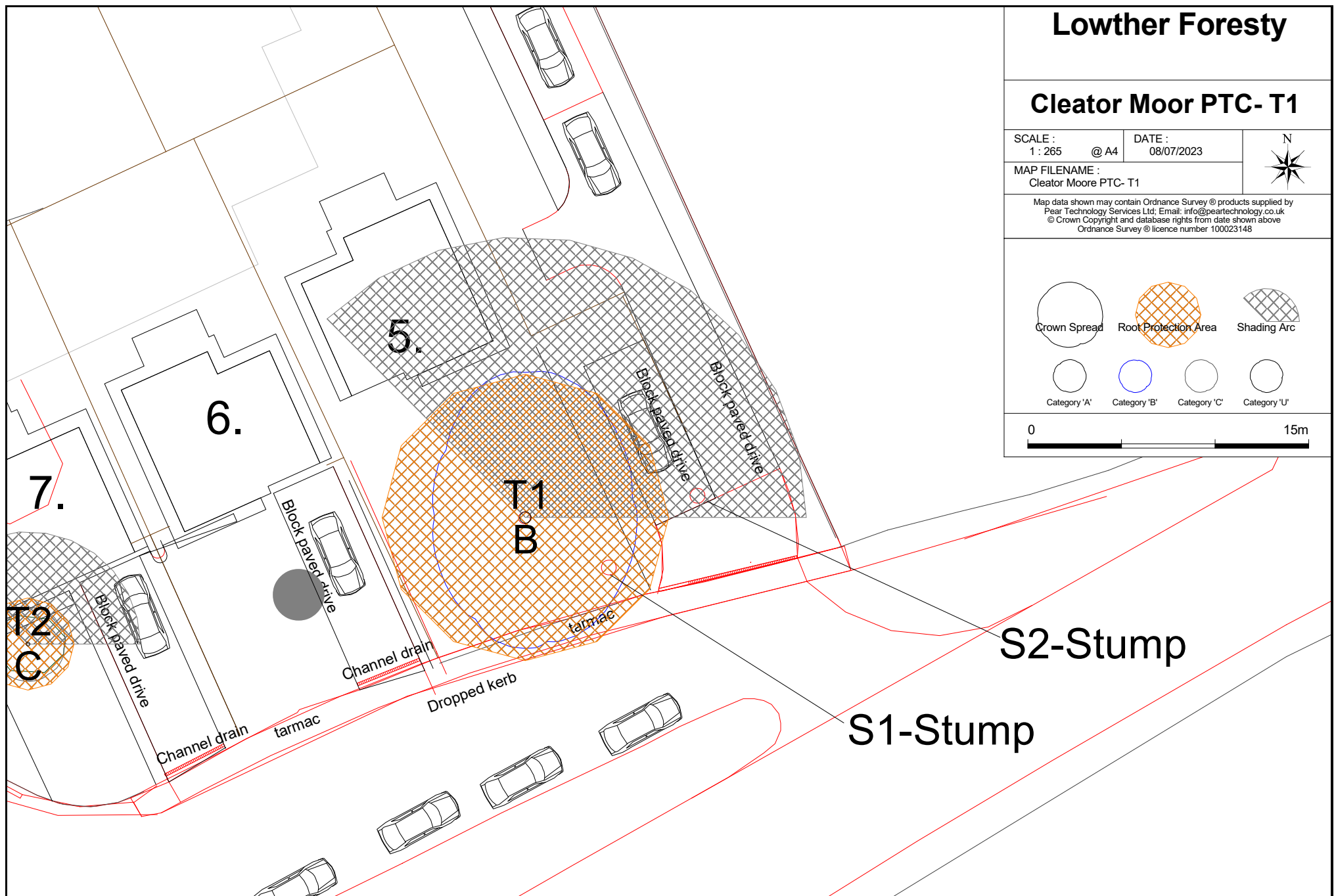
Driveway Construction

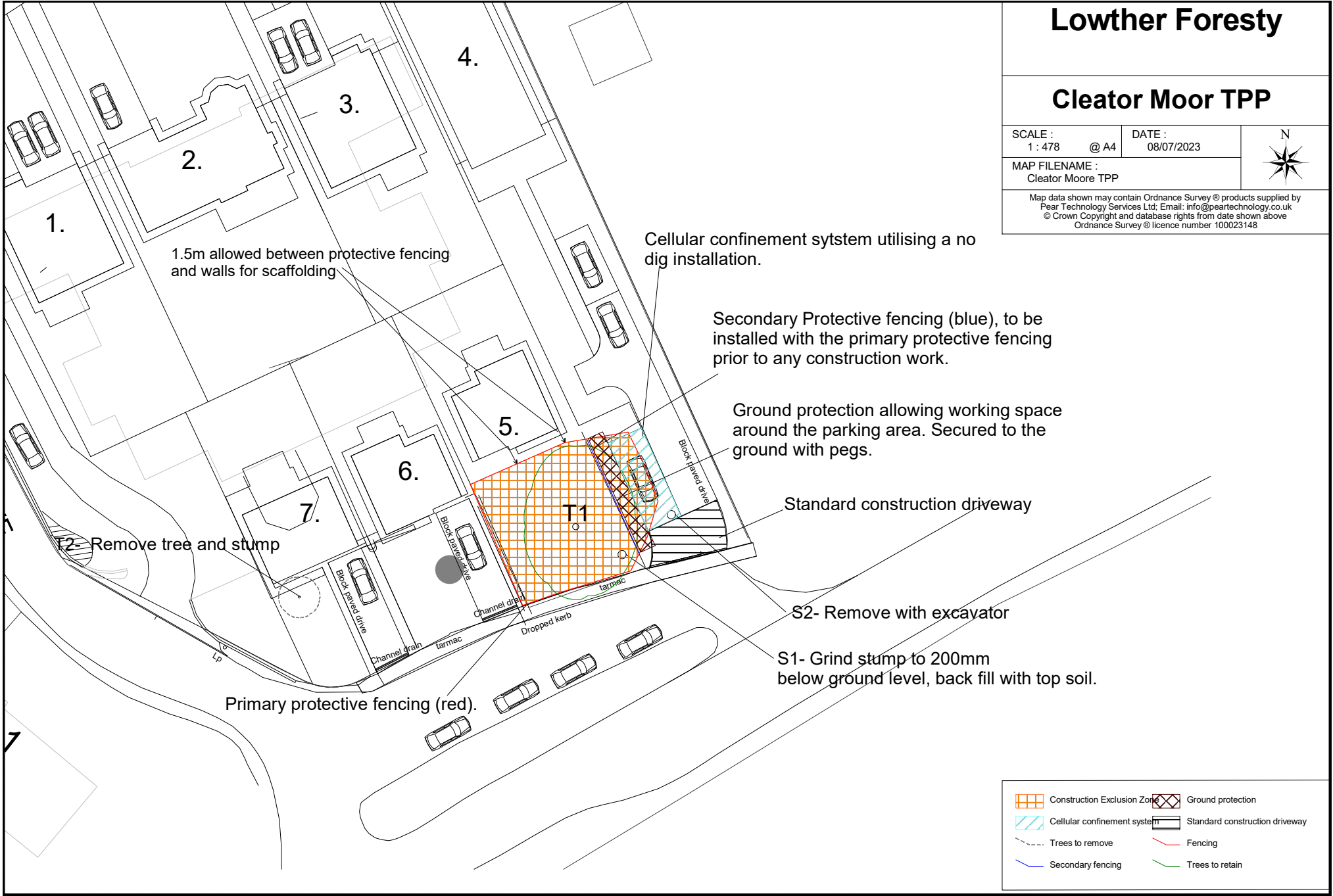
Part of the driveway for plot 5 must be constructed with a no-dig cellular confinement system. This system must be in accordance with the Arboricultural Association Practice Note 12, Appendix 12.

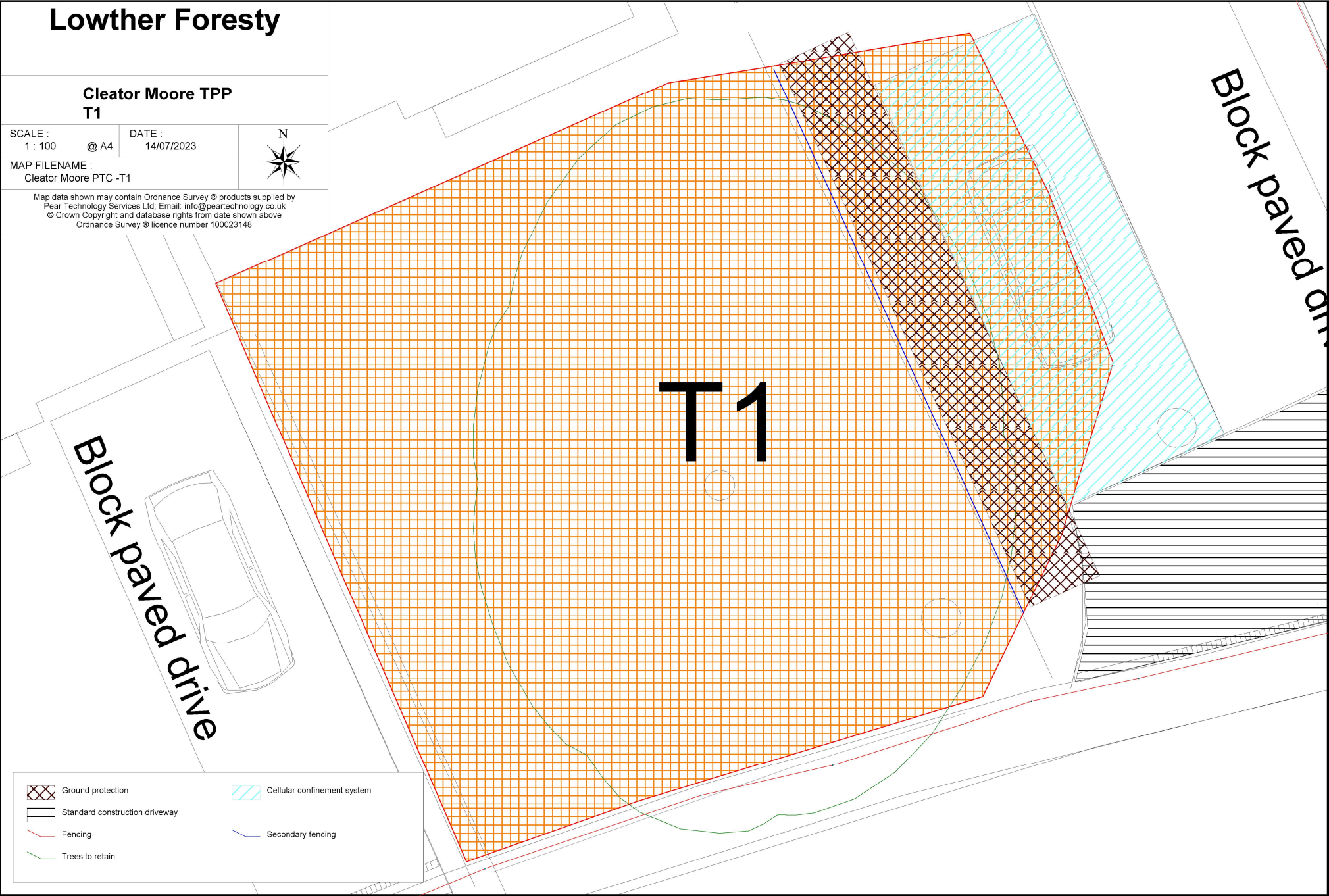
The locations where this type of driveway and a standard type of construction are displayed in Appendix 9 & 11.

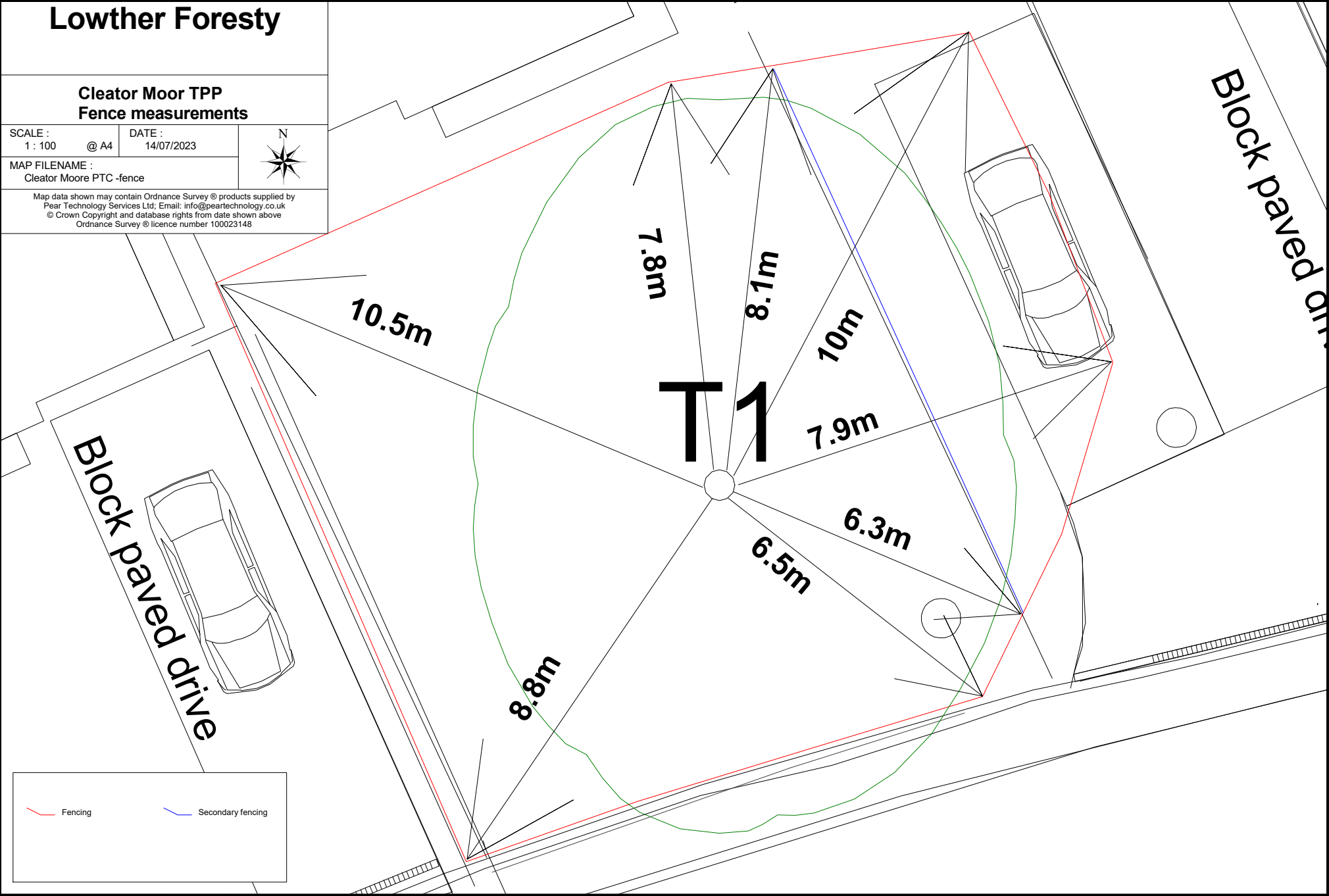
End of Arboricultural Method Statement





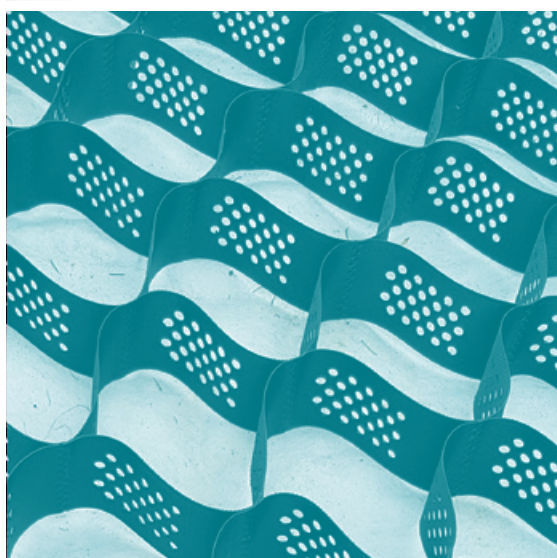
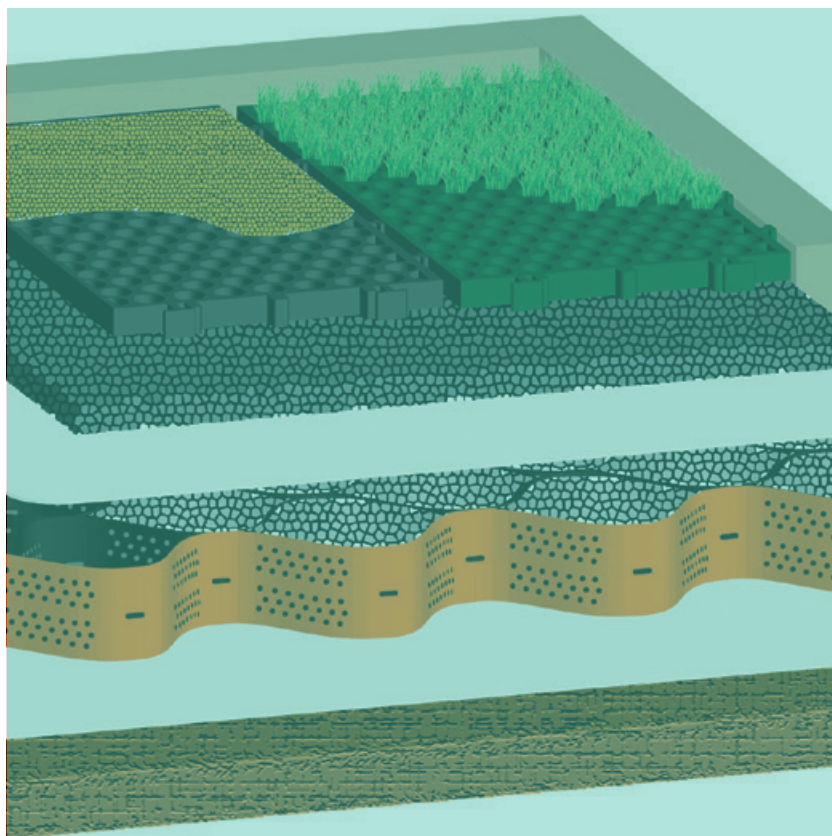






THE USE OF CELLULAR CONFINEMENT SYSTEMS NEAR TREES: A GUIDE TO GOOD PRACTICE

GUIDANCE NOTE 12



Author:
Ben Rose

Published in the UK by

Arboricultural Association,

The Malthouse, Stroud Green, Standish, Stonehouse, Gloucestershire GL10 3DL

Tel: **+44 (0)1242 522152**

Email: admin@trees.org.uk

Web: www.trees.org.uk

First published in September 2020

with the support of



Arboricultural Consultancy

ISBN 978-0-900978-65-4

© Arboricultural Association 2020

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.

Front cover image credits:

*Images courtesy of Core LP,
Advanced Arboriculture Ltd and Bosky Trees*

Image credits:

*Illustrations courtesy of Core LP and
Presto Geosystems/Greenfix.*

Photo images courtesy of

*Advanced Arboriculture Ltd, Bosky Trees
and Hauraton Ltd*

Contents

1	Using cellular confinement systems for ground protection	5
1.1	Introduction	5
1.2	The concept of cellular confinement systems	6
1.3	The relevance of different types of ground conditions	9
2	Practical application	10
2.1	Project planning	10
2.2	Suitable machinery to use for installation	12
2.3	Ground preparation	13
2.4	The use of geotextile membranes in cellular confinement systems	14
2.5	Suitable stone infill	14
2.6	Installing geocell ground protection	15
2.7	Edge supports	16
3	Suitable surface finishes	18
3.1	The need for permeable surfacing	18
3.2	Surfacing options	19
3.2.1	Porous asphalt	19
3.2.2	Loose gravel	20
3.2.3	Resin-bound gravel	20
3.2.4	Permeable block paving	21
3.3	Surface maintenance	22
4	Arboricultural implications	23
4.1	Potential impacts on tree health	23
4.2	Limitations of geocells	24
5	Key recommendations	25
	References	26

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 Using cellular confinement systems for ground protection

1

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 zones¹ 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.

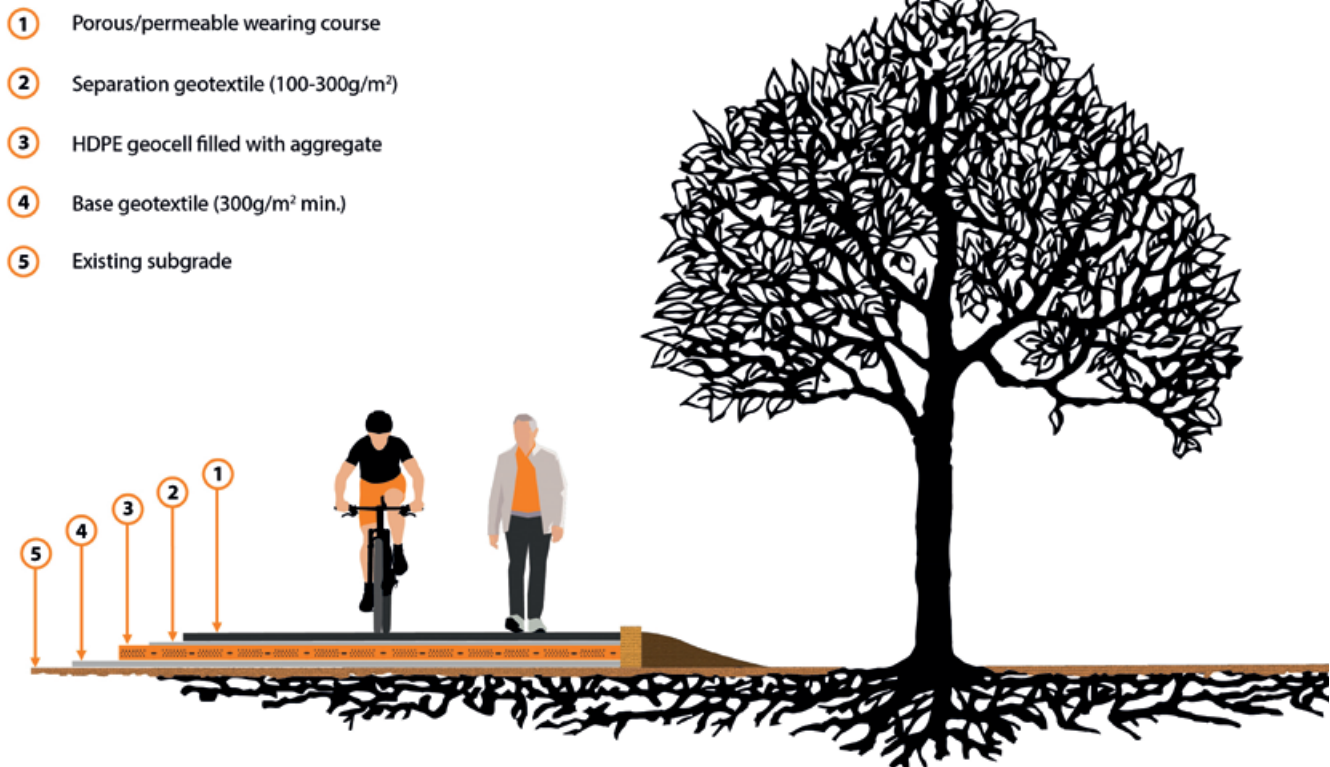


Figure 1: The basic approach to using cellular confinement systems for ground protection near trees [image courtesy of Core LP].

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 reinforcement² to improve the service life of a surface and/or to obtain equivalent performance with less depth of material. This is

Section Using cellular confinement systems for ground protection

1

typically a 2-dimensional geogrid³ 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.

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.

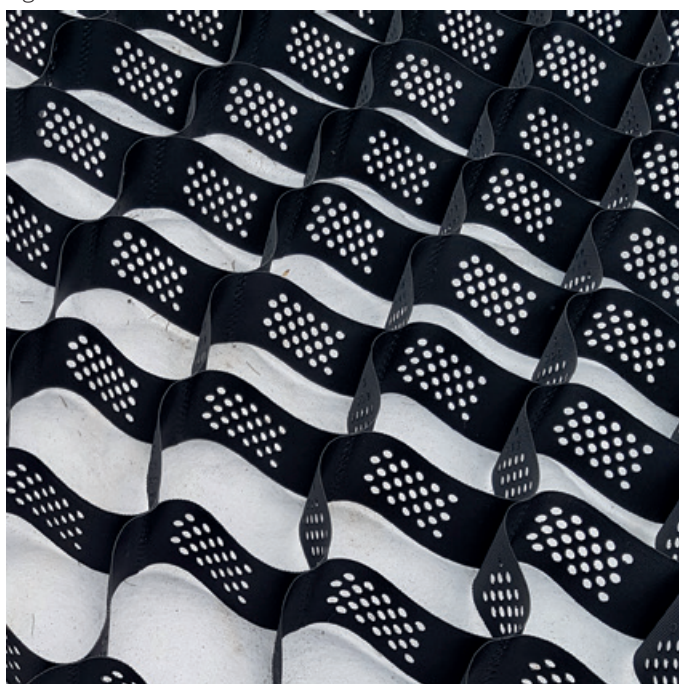


Figure 2: An expanded geocell sheet before it has been filled with stone
[Image courtesy of Bosky Trees].

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.

1

Section Using cellular confinement systems for ground protection

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.

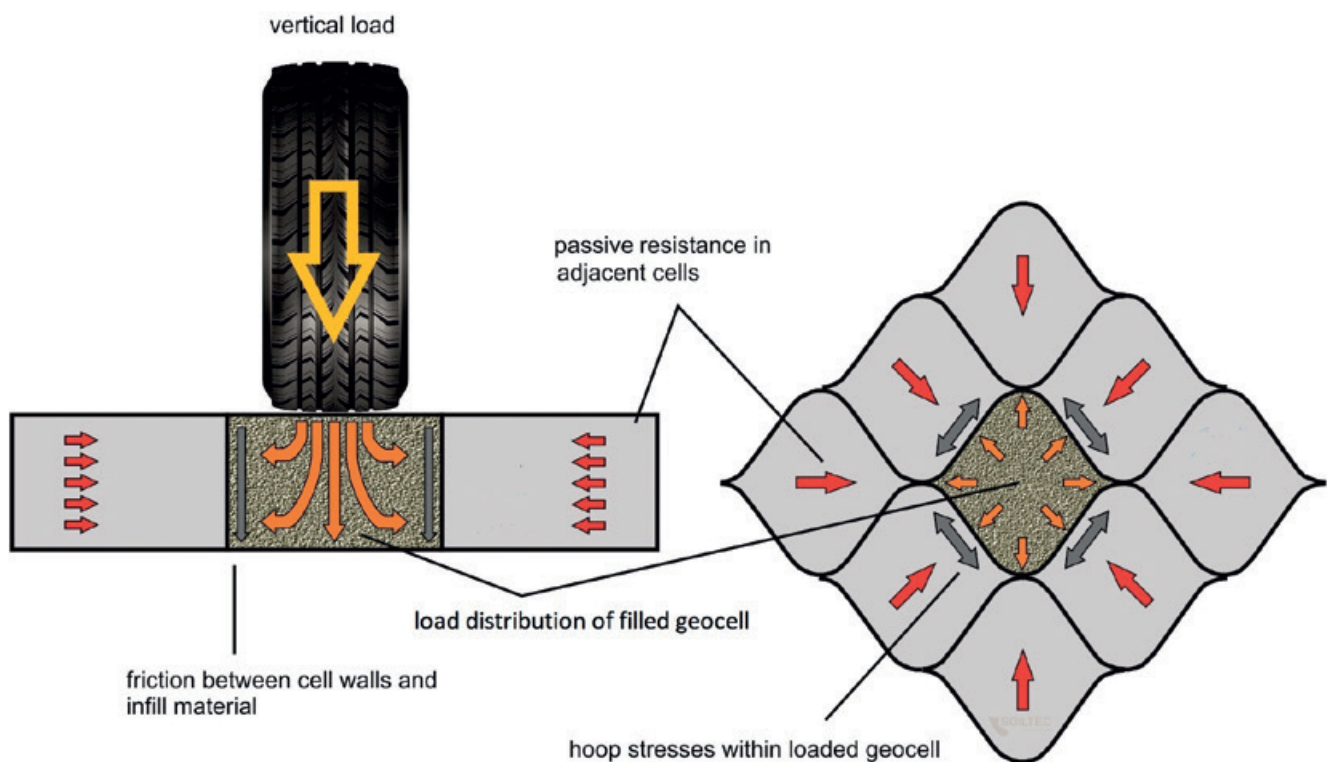


Figure 3: This diagram illustrates how forces are dispersed when a vertical load is applied to a cellular confinement system [image courtesy of Presto Geosystems/Greenfix].

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.

Section Using cellular confinement systems for ground protection

1

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).

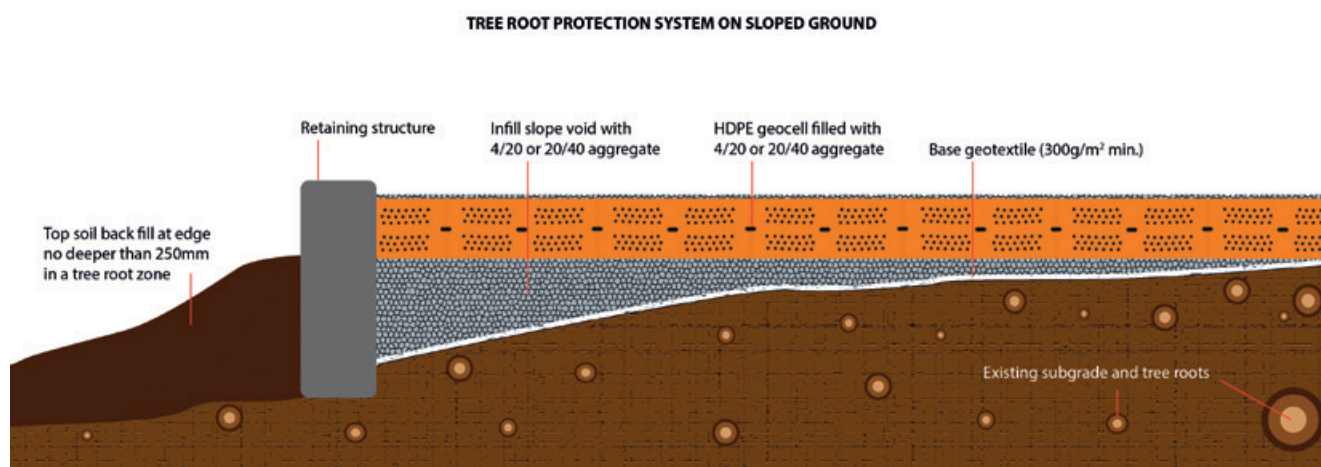


Figure 4: An example of how cellular confinement systems should be installed when the ground is sloping or uneven [image courtesy of Core LP].

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 reasons⁵ 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).

Section 2

Practical application

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.

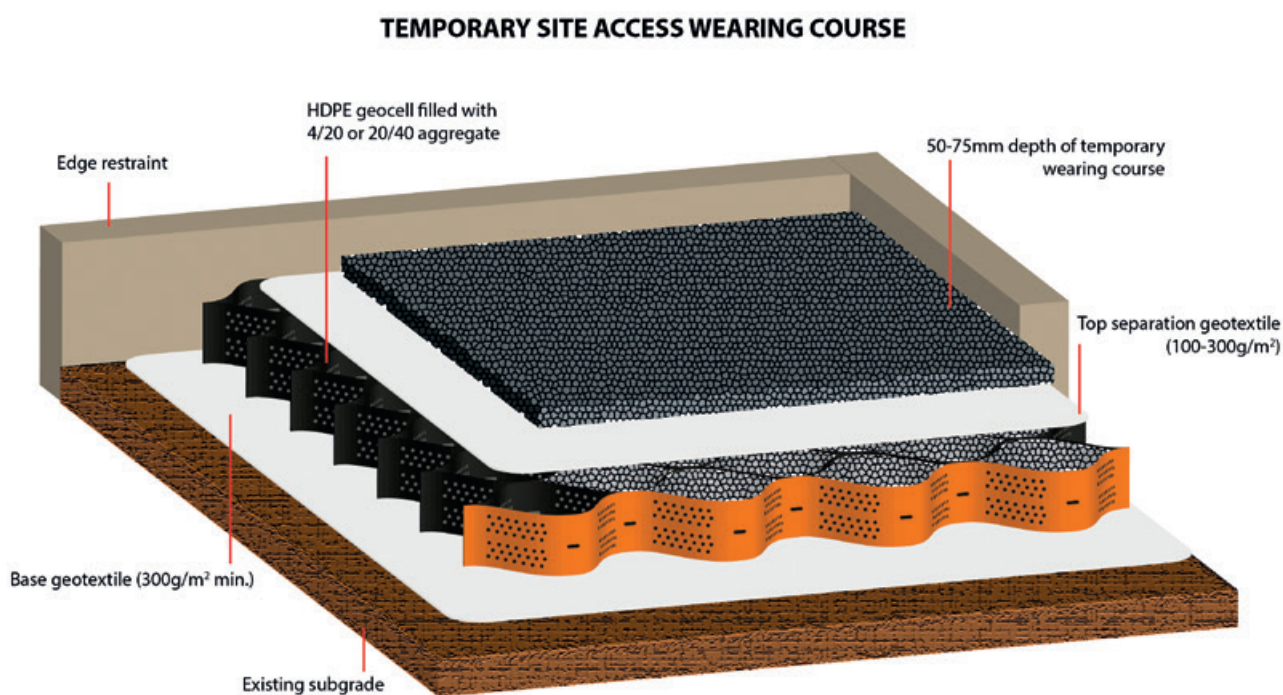


Figure 5: A geocell surface used during construction needs to be protected by a temporary wearing course and an upper geotextile is required to prevent mud from migrating down into the infill [image courtesy of Core LP].

2 Section

Practical application

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 Section

Practical application

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/m²) 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/m²). 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 Section

Practical application

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 kerblines 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.

	<p>Peg-and-board edging</p> <p>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.</p> <p>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.</p>
	<p>King-posts</p> <p>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].</p>

Section 2

Practical application



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.

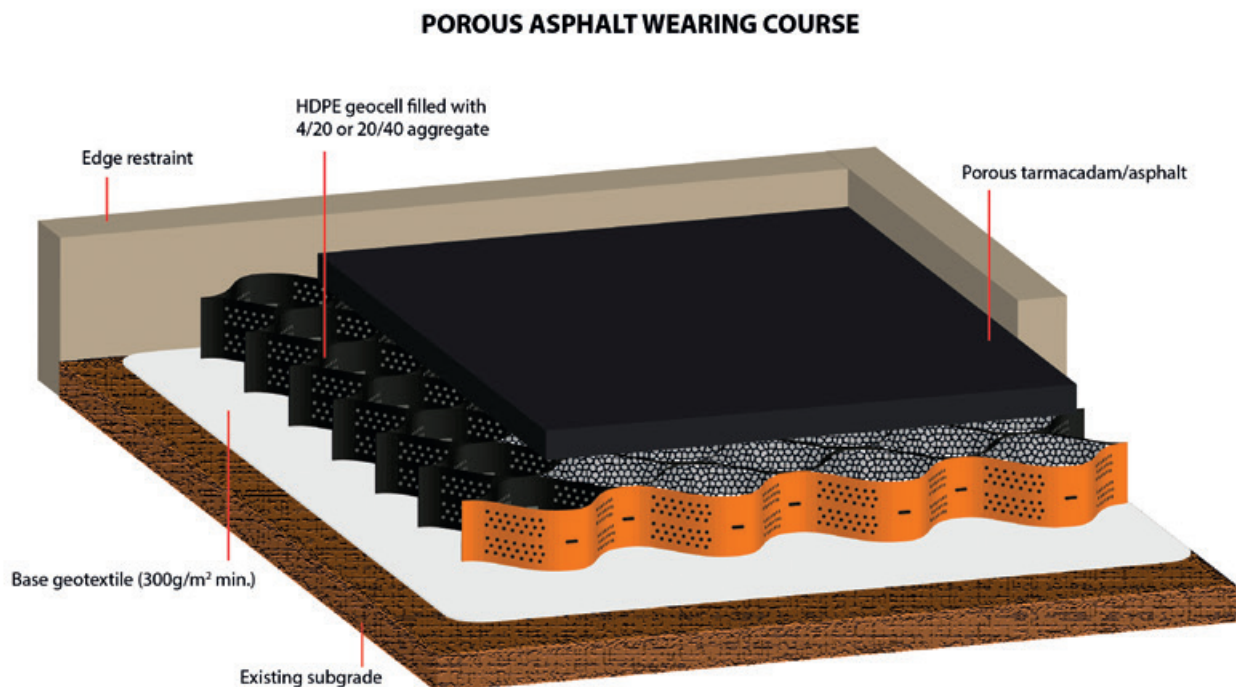


Figure 6: The typical composition of a porous asphalt surface with a geocell sub-base [image courtesy of Core LP].

3

Section

Suitable surface finishes

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

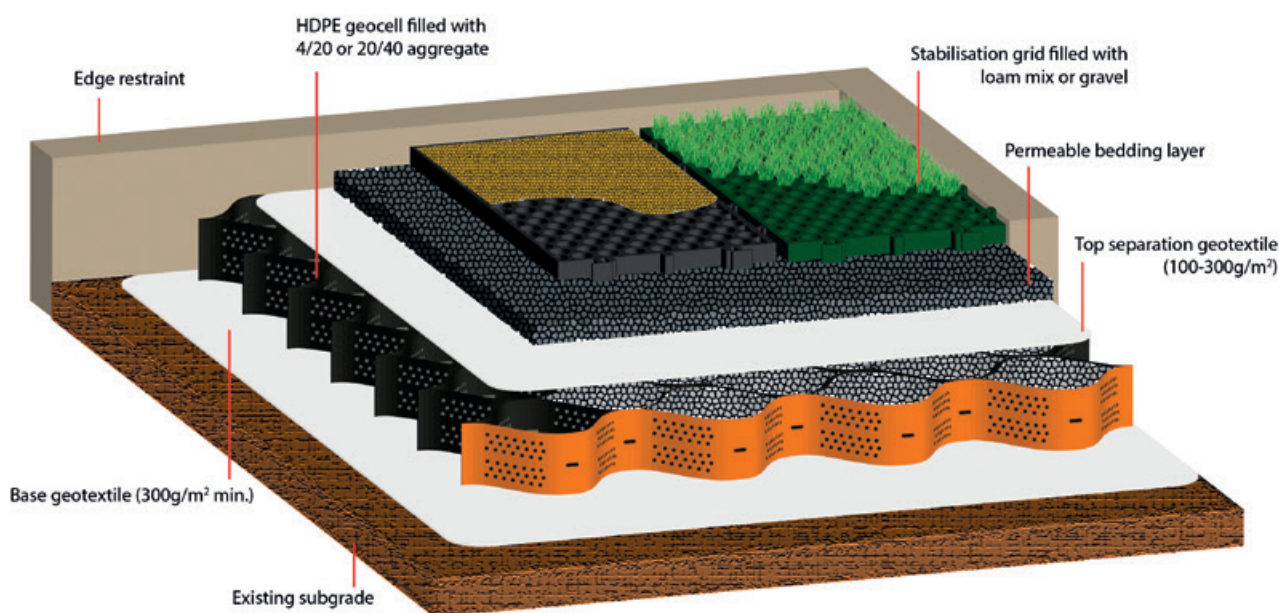


Figure 7: The sub-base configuration required for gravel or grass surfacing [image courtesy of Core LP].

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.

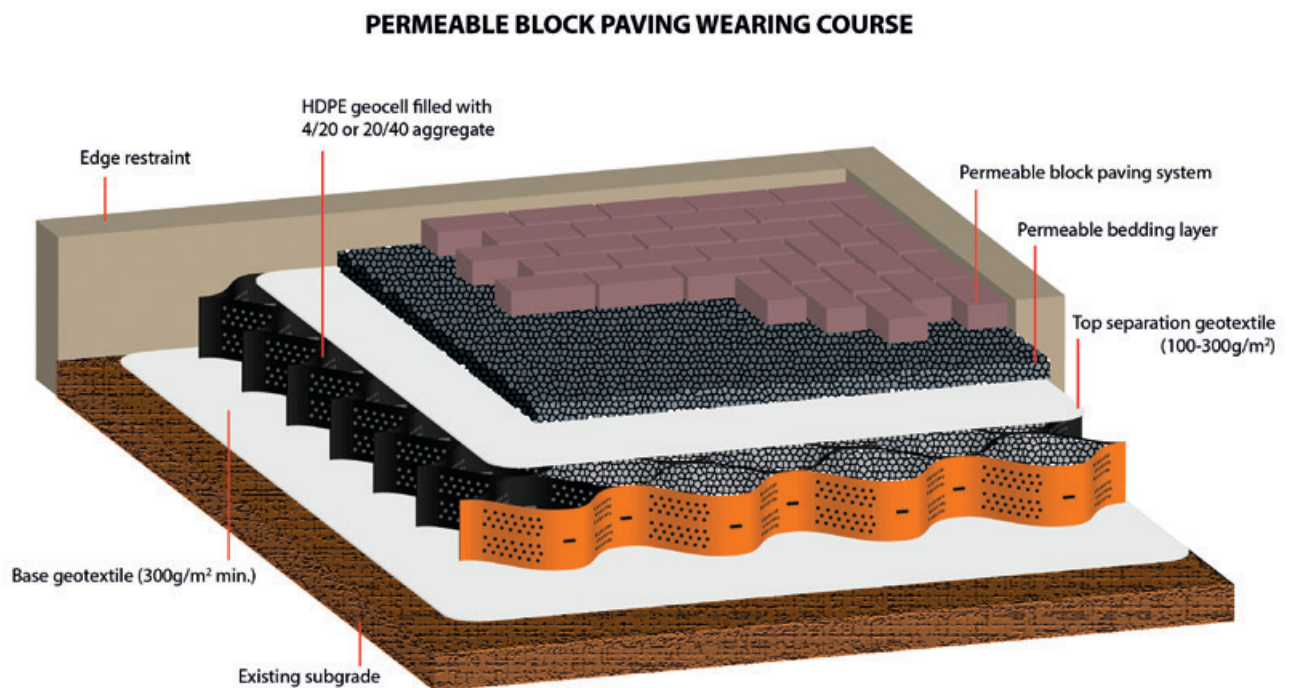


Figure 8: The recommended specification when installing permeable block paving above a cellular confinement system
[image courtesy of Core LP].

3

Section

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.

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 tortuosity⁶ 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

Section

Arboricultural implications

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 caused 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.

References

- Avesani Neto, J.O., Bueno, B.S. and Futai, M.M. (2013). A bearing capacity calculation method for soil reinforced with a geocell. *Geosynthetics International*, Vol. 20(3):129–142.
- Bathurst, R. and Jarrett, P.M. (1988). *Large-Scale Model Tests of Geocomposite Mattresses over Peat Subgrades*. Transportation Research Record Journal of the Transportation Research Board.
- BSI (2012). BS5837:2012 *Trees in relation to design, demolition and construction – Recommendations*. British Standards Institution, London.
- CIRIA (2015). *CIRIA 753: The SuDS Manual*. CIRIA. London.
- Craul, P.J. (1992). *Urban Soil in Landscape Design*. John Wiley & Sons Inc.
- DCLG (2009). *Understanding Permeable and Impermeable Surfaces – Technical Report on Surfacing Options and Cost Benefit Analysis*. Department of Communities and Local Government. London.
- Dobson, M.C. (1995). Tree Root Systems. *Arboriculture Research and Information Note 130/95/ARB*. Arboricultural Advisory and Information Service. Farnham, Surrey.
- Fannin, J. (2000). *Basic Geosynthetics: A Guide to Best Practices in Forest Engineering*. Ph.D., P. Eng., Forest Resources Management and Civil Engineering, University of British Columbia, Canada.
- Ferguson, K. (2005). *Porous Pavements*. CRC Press, Florida.
- Forestry Commission and Natural England (2018). *Ancient Woodland, Ancient Trees and Veteran Trees: Protecting them from Development*. Available at: www.gov.uk/guidance/ancient-woodland-and-veteran-trees-protection-surveys-licences
- Gilman, E.F. (1990). Tree root growth and development. 1. Form, spread, depth and periodicity. *Journal of Environmental Horticulture*, Vol.8: 215–220.
- GMA (2000). *Geosynthetic Reinforcement of the Aggregate Base/Subbase Courses of Pavement Structures – GMA White Paper II*; by Berg, R. B., Christopher, B. R. and Perkins, S.; prepared for American Association of Highway and Transportation Officials Committee 4E, Geosynthetics Materials Association, Roseville.
- Hegde, A. (2017). Geocell reinforced foundation beds – past findings, present trends and future prospects: A state-of-the-art review. *Construction and Building Materials*, Vol. 154: 658–674.
- Jackson, R.B., Canadell, J., Ehleringer, J.R., Mooney, H.A., Sala, O.E. and Schulze, E.D. (1996). A global analysis of root distributions for terrestrial biomes. *Oecologia*, Vol. 108: 389–411.
- MHCLG (2019). *National Planning Policy Framework: Conserving and enhancing the natural environment*. Available at: www.gov.uk/government/publications/national-planning-policy-framework--2
- Patch, D. and Dobson, M. (1996). *Driveways Close to Trees*. Arboricultural Practice Note 1. Arboricultural Advisory and Information Service. Alice Holt Lodge, Surrey.
- Patch, D. and Holding, B. (2007). *Through the Trees to Development*. Arboricultural Practice Note 12. Arboricultural Advisory and Information Service. Alice Holt Lodge, Surrey.
- Perry, T.O. (1989). Tree roots: facts and fallacies. *Arnoldia*, Vol. 49, 1–21.
- Roberts, J., Jackson, N. and Smith, M. (2006). *Tree Roots in the Built Environment*. DCLG, TSO, London.
- Ruark, G.A., Madler, D.L. and Tattar, T.A. (1982). The influence of soil compaction and aeration on the root growth and vigour of trees – a literature review. Part 1. *Arboricultural Journal*, Vol. 6(4), 251–265.
- Saride, S., Sitharam, T.G. and Puppala, A.J. (2011). The function of basal geogrids in minimizing rutting of geocell reinforced subgrades. *ASCE Geofrontiers*, 4645–4652.
- Weltecke, K. and Gaertig, T. (2012). Influence of soil aeration on rooting and growth of the Beuys-trees in Kassel, Germany. *Urban Forestry & Urban Greening*. Vol. 11, 329–338.

Arboricultural Association

The Malthouse, Stroud Green, Standish, Stonehouse, Gloucestershire GL10 3DL

☎ **01242 522152** ✉ admin@trees.org.uk www.trees.org.uk

ISBN 978-0-900978-65-4

Printed September 2020

© Arboricultural Association 2020

