DS.602
Structural design of pavement foundation layers

Rev.	Status	Created by	Date	Approved by	Date
A	Final	D.Farnham/J.Howe	07.02.12	D.Waters	27.03.12
B	Final	D.Farnham	04.04.12	D.Waters	10.04.12
C	Final	D.Farnham	01.11.12	M.Hill	07.11.12
D	Final	D.Farnham	07.02.13	D.Waters	08.02.13
E	Final	D.Farnham	02.05.13	D.Waters	08.05.13
F	Final	D.Farnham	11.12.13	M.Hill	31.01.14
G	Draft	G Lake	11.07.17	D Foden	18.07.19

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1 Introduction

a. This standard explains design requirements for the foundation layers of pavements, comprising the subbase and (where necessary) capping layer (sometimes known as the subgrade improvement layer). It also addresses how to treat underlying subgrades and related sub-drainage measures. It applies to all types of pavements (e.g. carriageway, footway, footpath and Cycle Track). Its purpose is to explain general requirements for the design of all pavement foundations, to provide information on particular design systems and materials, and to explain when given design systems and materials may or must be used.

b. See standard DS.501 about the design and construction of tree pits under streets.

c. See standard DS.601 about the design and construction of pavement upper layers including bases, laying courses, binder courses surface courses and associated inter-layers.

d. See the Southwark Highways Specification for further details about materials noted in parenthesis, e.g. [H-CBGMB-B/R-C20]. This provides a quick reference look-up list for relevant Southwark Highway Specification Clauses.

e. Site investigations must be undertaken as the basis for design to determine the design subgrade stiffness modulus and to discount the otherwise standard requirement for sub- drainage. If constructions include geo-cellular unit assembles or works over basements then Design Reports must be produced in keeping with Eurocode requirements and referenced in Pavement Design Statements accompanying design approval submission.

f. In new streets and spaces, a drainage blanket and/or filter drains should always be provided at formation level unless it can be demonstrated that the subgrade is more permeable than the subbase and ground water levels are suitably low. The drainage blanket may be left out if capping is required and is of a suitable class. When carrying out major improvement or refurbishment to existing pavements then the adequacy of existing sub-drainage measures must be checked. If they are likely to have become blocked or blinded then existing sub- drainage lines, layers and any associated geotextiles must be replaced else (if missing in the first place) introduced. Any existing bound foundation layers should normally be perforated if they are retained. In new streets and spaces, subsoil drainage must be introduced if there is a possibility of ground water levels rising to within 600mm of pavement formation levels.

2 General requirements

2.1 Basic design method for foundations

a. Except where ‘b’ applies, foundations should be designed in accordance with the following design methods.

i. <u>For pavements with unbound precast concrete flag and natural stone slab surfaced pavements</u>

- Foundation layer thicknesses for unbound precast concrete flag and natural stone slab surfaced pavements should be determined using the design method in BS 7533-8:2003 by selecting the greater thickness obtained by comparing Figure 1 of that standard and the relevant other figure as Table 1.

Upper face area of flag/slab unit (mm) (see note 1)	Example of typical nominal dimensions (mm)		Relevant BS 7533-8:2003 figure to use for comparison with Figure 1 of the same standard
	Length	Width	
≤90000	300	300	Figure 3
>90000 but ≤270000	400	400	Figure 2
	450	450	
	450	600	
>270000 but ≤ 450000	600	600	Figure 2 (values may be reduced by 20%, see note 2)
	600	750	
>450000	600	900	Figure 2 (values may be reduced by 35%, see note 2)

<u>NOTE</u>
1) If random length/gauge units are used then this value should be based upon the smallest expected unit size.
2) Minimum layer thickness ≥ 100mm.

Table 1. BS 7533-8:2003 figure to be used for subgrade over-stressing analysis

- Except if a geo-cellular system assembly as section 7 of the main design standard is used to the subbase (in which case analytical design is required, see section 2.4 of the main design standard).

- Materials for the foundation should be as permitted in the main design standard. As per section 2.3, if materials different to those permitted as BS 7533-8:2003 are required then they should be used to a thickness that provides equivalent performance.

ii. For all other types of modular unit surfaced pavement

- The relevant part of BS 7533 (see standard DS.601). However, see section 2.7 about the potential need for capping layers.

iii. For bituminous mixture surfaced footway and cycleway pavements (excluding at commercial Vehicle Crossings

- Foundation layer thicknesses for bituminous mixture surfaced footway pavements (other than at commercial Vehicle Crossings) should provide equivalent structural performance to the values stated in Table 2 for the chosen materials.

Design CBR of subgrade (see notes 1)	Pavement area (as Table 2 in DS.601)	
	Heavy Overrun (see note 2)	Light Overrun
	Required thickness of [U-Type 1A] subbase (millimetres) (see note 3)	
≥ 5	150	150
> 2.5 but < 5	200	
≤ 2.5 (see note 4)	250	200

NOTE
1) See also '2.7d' of the main design standard for further requirements for subgrades with low CBRs, including the potential need for geotextile filter inter-layers.
2) The values in this Table are not suitable for use where planned commercial vehicle overrun of footways will occur. If this is the case then the entire footway (including its foundations layers) should be designed to carriageway standards.
3) If other materials than [U-Type 1A] normal graded unbound granular mixtures are used for subbase then this must be to a thickness that provides equivalent structural performance. See section 2.3 of the main design standard for further discussion.
4) The Highway Authority reserves the right to require capping to be used if footways have equilibrium CBR values ≤ 2.5. Depending upon the exact proposed capping materials and thickness, it may then permit a reduced subbase thickness of 150mm. See section 2.7. for further information about capping

Table 2 Required subbase thicknesses for bituminous mixture surfaced footway and cycleway pavements.

- Requirements about which materials may be used in different circumstances can be found in the main design standard.

iv. For bituminous mixture surfaced carriageway and commercial Vehicle Crossing pavements

- Highways Agency 'Design Manual for Roads and Bridges', HD 25/94. Thicknesses should be determined from Standard Design graphs.
- Highways Agency "Design Manual for Roads and Bridges', HD 25/06. Restricted Designs using:
  - Class 3 foundations should be used if [B-Ba2E] or [B-Ba1E] EME2 base courses are used.
  - Class 2 foundations should be used in all instances other than the above unless level 1 departure is agreed. See also however 'b'.

v. For self-binding gravel surfaces to existing paved areas that have been disturbed by tree roots

- If the equilibrium CBR at formation level is:
  - ≥ 3.5% then a [X-G2] geo-grid should be installed over the formation as an interlayer (see note 1). Table 5 confirms the subbase thickness that should be installed over this assuming that standard materials that are permitted as per the main design standard are used. A filter compatibility check should always be carried out to confirm that the grading of the surface course aggregate is compatible with the subbase aggregate and that it will not migrate through. If the aggregates are not compatible then a further 30mm layer of a mutually compatibly blinding material may need to be used between them. [L-QZ2/6] open graded quartz bedding grit is likely to be effective in the majority of circumstances though this should nevertheless be confirmed by checking. Geotextile separators should not be used to prevent migration as they will create a slip plane.
  - < 3.5% then the design of the subbase will be determined on a case specific basis with approving

officers. Capping is likely to be required.

- Special care must be taken to lay both the subbase (both at top and bottom) to falls towards a drainage outlet as the structural integrity of the self-binding gravel surface will be undermined if it becomes saturated Introducing un-filled weep joints between kerb units at the edge of carriageway may be appropriate if other solutions cannot be identified, though sub-drains may need to be retrofitted in some circumstances.

Subbase material	Use requirements	Equilibrium CBR value at formation level	Will the subbase material be installed within a cellar confinement system as section (see note 1)				
			No	Yes			
				Type of cellular confinement system (see note 1)			
				[XCF-200]	[XCF-150]	[XCF-100]	[XCF-75]
			Required thickness of subbase (mm) (see notes 2-3)				
[U-Type 1A/F] normal graded unbound granular mixture as section 3 of the main design standard	To be used in all circumstances other than the below	<2.5%	Requirements to be agreed on a case specific basis with approving officers				
		≥2.5% but < 3.0% (see note 4)	290	N/A	180	220	240
		≥3.0% but < 4.0%	230	N/A	N/A	160	175
		≥4.0% but < 5.0%	200	N/A	N/A	125	150
		≥5.0% but < 10.0%	190	N/A	N/A	110	130
		≥10.0%	150	N/A	N/A	N/A	130
[U-Type 3/20] open graded unbound granular mixture as section 4 of the main design standard	To be used if existing soft landscaped areas are being paved over. May be used in other circumstances by level 1 departure. Drainage issues must be carefully considered and addressed	<2.5%	Requirements to be agreed on a case specific basis with approving officers				
		>2.5% but < 3.0% (see note 4)	N/A	420	453	485	500
		≥3.0% but < 4.0%		370	400	440	450
		≥4.0% but < 5.0%		345	380	410	426
[U-SMS] structural soil as section 5 of the main design standard (see note 5)		≥5.0%		250	280	310	330

NOTES

1. See section 8 of the main design standard for further information about cellular confinement systems. Generally the suffix in the type designation code indicates the thickness of the system (for instance 200mm for [XCF-200]. A cellular confinement system must always be used if [U-Type 3/20] open graded unbound granular mixtures are used for the subbase (though see note 2 below). If the thickness of the system is less than the required depth of the subgrade then the top of it should always be flush with that of the subbase.
2. Even if the surface level of the pavement around a tree is raised (which may be permitted as per standard DS.501 in some circumstances) it will not be possible to maintain the subbase construction all the way up to the existing trunk flare. As this is approached the thickness of the subbase will need to be gradually reduced and the cellular confinement system ultimately discontinued. When to do so is a matter of judgement for the designer and supervising Council officers. This will largely be informed by the surface bulge that will likely occur owing to laying over the existing and future structural root plate (though the cellular construction can be cut back in future if necessary). However, when the thickness of [U-Type 1A/F] that can be laid is< 75mm or of [U-Type 3/20] < 50mm then the subbase should generally be discontinued and an increased thickness of self-binding-gravel surface used.
3. If a blinding a 30mm blinding layer is provided between the subbase and the surface course then the required thickness of subbase may be reduced by 25mm (but not 30mm).
4. For equilibrium CBR values < 3.0% then, as per section 2.7 of the main design standard, a geotextile filter interlayer must also be provided at formation level.
5. If [U-SMS] structural soil is used then, as discussed in section 5 of the main design standard, it must always be covered with 110mm of [U-Type 3/20]. This can be subtracted from the overall thickness of subbase required.

Table 3 - Subbase design requirements for retro-fitted self-binding-gravel surfaces over existing footway areas that have been disturbed by tree roots

NOTE 1: This geo-grid interlayer will help reduce the impact of future root disturbance beneath it by ensuring that the pavement lifts smoothly such that the surface 'rolls' with the heave. A cellular confinement system alone will not achieve this.

NOTE 2: Generally, whilst pruning fine absorbing roots and narrow lateral roots is likely to be permitted, cutting of larger woody lateral roots having a diameter greater than 25mm and, particularly, anything within the structural root plate will not. Shaving of lateral roots close to the surface is generally to be avoided since trees will grow thick reaction wood in response to this to seal the wound/weak point. This may cause pavement heave, so doing more harm than good.

NOTE 3: In addition to other requirements, the layer thickness for a given material should not be less than the minimum required as per any British or European Standard. See in particular BS 594987:2007 for bituminous mixtures, BS EN 13877-2 for pavement quality concrete, BS EN 8500 for lean concretes, and BS EN 14227 for hydraulically bound mixtures. Note that in all instances the primary determinant of minimum thickness is typically the normal maximum particle size for any component aggregate. For unbound granular mixtures, the minimum layer thickness for a given material should not be less than 2.4 times the normal maximum particle size for the mixture grading and should not be less than 100mm unless a level 1 departure is agreed. This applies equally to materials that are used to pavement upper layers as standard DS.601.

b. If an alternative foundation material to be used to those recommended in 'a' above, then the thickness of that alternative material should be adjusted to provide equivalent structural performance. This should be determined as standard DS.601, section 2.8 (see note 1) save for in the following circumstances:
    i. <u>If geo-cellular unit assemblies as section 7 are incorporated into foundations:</u>
    See section 7.2. and 2.2 about additional validation requirements.
    ii. <u>If geo-confinement systems as section 8 are incorporated into foundations for thickness reduction purposes:</u>
    See section 8.2. See also section, 2.2 about additional validation requirements.

NOTE 1: Broadly, standard DS.601 permits simple material equivalence and condition factors to be used in most instances. The main exceptions to this are:
(a) Foundations to bituminous mixture surfaced pavements serving as main carriageway running lanes; and
(b) The two instances given in '2.1b.i-2.1b.ii'.

NOTE 2: The short and long term structural performance of geo-cellular unit products will vary significantly. Testing is vital to determine appropriate design values for analytical purposes.

NOTE 3: In some instances using geo-cellular unit assembly subbase replacement rafts may allow the thickness of the pavement upper layers to be reduced. However, this will depend upon the structural capacity of the product that is proposed.

c. For sections of main carriageway running lane pavement of a given type (e.g. bituminous mixture surfaced, precast concrete block surfaced etc.) the design of foundations should not vary between or within junctions. As such, the foundation design, materials and layer thickness selected for a length of a given type of pavement should be based upon the worst case conditions encountered.

2.2 Validating foundation layers

a. Immediately prior to overlaying a new or adjusted subbase with upper pavement layers, it should be checked for compaction density and wheelpath deformation in accordance with Southwark Highway Specification Clause 896. Density measurement will normally be carried out using a nuclear density gauge. However, this is not appropriate for coarse aggregates with a normal maximum particle size of >32mm. In such instances a sand or water replacement test will be required instead.

b. In addition, if a pavement;
    i. Forms part of a main carriageway running lane, is bituminous mixture surfaced and has foundations that have been designed using analytical or Performance Design; and/or
    ii. Includes a geo-cellular unit assembly

as within its foundations; and/or

iii. Includes a geo-confinement system as within foundations; and/or

iv. Spans a basement then, immediately prior to overlaying the subbase with upper pavement courses, it should be checked for subgrade and subbase surface modulus as Southwark Highway Specification Clauses 890-896.

2.3 Site investigation reports and associated other plans and reports

a. Depending upon the scale of works, site investigation reports may be needed to form the basis for design proposals.. The following provides a brief summary for guidance.

i. Basic site investigation information for simple refurbishment of existing streets

If existing streets and spaces are only being resurfaced and no fundamental change in the levels of traffic is anticipated, then:

- Records of visual inspection of pavement surfaces for defects.
- Assessments of subgrade stiffness modulus/CBR from regularly cores or trial pits to inform foundation layer thicknesses and the potential need for capping layer and/or sub-drainage.
- Condition surveys of existing retained pavement materials from regularly spaced cores or trial pits.
- Any as built information from previous schemes/constructions.
- Information about existing Statutory Undertakers apparatus and Highway drainage apparatus within the highway and horizontal radar location surveys (see note).
- Basement surveys.
- Other Desk Study information (e.g. well records, geological maps, historic maps, speleological society maps, aquifer protection maps, etc.).

ii. Geo-Technical and Geo-Environmental Site Investigation Report

If new streets or spaces are being created, or where more complex constructions (like under- pavement surface water reservoirs or rooting zones), then a Geo-Environmental and Geo-Technical Site Investigation Report as BS 5930 and BS 10175 is required.).

iii. Geo-Technical Design Reports

If it is proposed that a pavement include any geo-cellular unit assembly or is constructed over any basement then a Geo-Technical Design Report is required to validate the design proposals against the design parameters provided in the earlier Geo-Technical Site Investigation Reports.

iv. Tree Survey (TS), Arboriculture Implications Assessment (AIA), Arboriculture Methods Statement (AMS) and Tree Protection Plan (TPP)

These various studies and plans aim to minimise the impact of development works on existing trees (*the most significant cause of damage to trees during construction is compaction of soil to root limiting levels)*. Further information about them is provided in standard DS.501.

NOTE: See standard DS.501 for important requirements about providing detailed sub-surface utility location surveys to support proposals included in Applications for Town & Country Planning Consent to plant trees in existing Highways.

2.4 Frost susceptible soils

a. All materials within 450mm of the ultimate surface of the pavement should not be-frost susceptible. This includes the subgrade. The value may be reduced to 350mm by level 1 departure. If must be demonstrated to the satisfaction of approving officers that the mean annual frost index is less than 50. Materials are classified as non-frost susceptible if the mean heave is ≤ 15mm when tested in accordance with BS 812-124.

2.5 Sub drainage measures

2.5.1 Use requirements

a. Within new streets and spaces, sub-drainage measures as described in DMRB

HD 25 (see note 1) should be provided to pavements of all types, including modular unit surfaced pavements (see note 2). The proposed measures should be explained in submitted Pavement Design Statements

NOTE 1: Normally this will consist of a 150-220mm thick granular drainage blanket at formation level (the bottom of the subbase or capping layer) with associated carrier drainage lines. This may be omitted if sub-soil drainage is provided to the sub-grade.

NOTE 2: An exception is pavements that include under-pavement surface water infiltration reservoirs in their foundations.

b. Within existing streets and spaces, the adequacy of existing sub-drainage to any pavements that are being improved or refurbished should be reviewed and addressed in Pavement Design Statements

NOTE: Unless there are particular known drainage issue affecting the performance of a pavement then introducing sub-drains may not be necessary if only simple like-for-like resurfacing is being proposed.

c. Sub-soil drainage should always be introduced if:
   i. The subgrade stiffness is < 30MPA (CBR < 2.5%).
   ii. The seasonal high ground water level is within 600mm of pavement formation level or if capping layer is provided then it will be the top of that instead.
   iii. No granular drainage blanket is provided beneath the subbase.

2.5.2 Design requirements

a. Details of sub-drainage design requirements for both subbase and subgrade can be found in standard DS.705. The following serves as guidance only:
   i. Drainage for the subbase and sub-soil drainage for the subgrade (if required) should be kept separate.
   ii. Carrier drainage lines should be used to remove water from the drainage blanket. If no drainage blanket is used then the number of these may need to be increased. Thereafter the spacing of the lines will depend upon how heavy or free draining the subgrade material is (see note). The lines might be comprised of fin drains, narrow perforated pipe drains, cellular units or a number of other methods. Permeable carrier pipes should typically be of a double wall design, having a corrugated load-bearing outer and a smooth inner for increased hydraulic and load bearing performance. These should normally be located just beneath the level of the subgrade to provide added redundancy.
   iii. Encapsulating drainage blankets and carrier drainage lines with geotextile filters should be avoided where possible as these are likely to be blinded over time. Granular filter surrounds are preferred. Where this can be achieved then carrier drainage lines should be roddable so that the inevitable eventual build-up of fines can be removed. Care should be taken to set inverts to keep these lines self-cleansing so reducing the need for rodding.
   iv. Sub-drainage systems should pass via a catch pit manhole, silt trap or other approved solids filter chamber before out falling into public sewers.
   v. The ultimate outfalls from carrier drainage lines should typically be into the highway drainage system. However if necessary inverts cannot be achieved then outfalls to soakaways within soft landscaped areas may be permitted.
   vi. If sub-soil drainage is provided to the subgrade to improve its stability then it should be located ≥ 600mm beneath the top of the subgrade. The spacing of drain lines should be appropriate to how free draining the subgrade material is. If soils are relatively free draining, spacing can be wider than for less free draining soils (see note).

NOTE: This is because water will move laterally in the soil to saturation before it will begin to flow under gravity into drains. In heavy, fine grained soils (e.g. clays or loamy clays) drain lines should be placed at approximately 3m centres, increasing to 10m centres in lighter sandy soils.

2.6 Capping layer and preparing subgrades

a. If the existing stiffness modulus of a subgrade is < 30MPa (CBR < 2.5%) then one of the following three improvement options should be used. These are stated in order of preference. Using lower preference options requires level 2 departure. It must be demonstrated to the satisfaction of approving officers that higher preference options have been considered and discounted.
   i. Cement and/or lime stabilisation of the existing subgrade through in-situ treatment as Southwark Highway Specification Clauses 613, 614, 615 or 643 (see *also 'd' about using geotextile separators to soft subgrades*). Notwithstanding this, the improved subgrade should be assumed to have a stiffness modulus of 30MPa (CBR 2.5%) for the purposes of subsequent pavement design
   ii. Removing the subgrade and replacing it with unbound or *stabilised* granular fill material. Notwithstanding the quality of the new material, it should be assumed to have a stiffness modulus of 30MPa (CBR 2.5%) for the purposes of subsequent pavement design.
   iii. Improving the existing subgrade by introducing sub-soil drainage. A method of monitoring must also be proposed. The resulting CBR value to be used for subsequent pavement design purposes will be agreed with approving officers.

b. If the existing subgrade stiffness modulus is ≥ 30MPa (CBR ≥2.5%) and capping is proposed (rather than an increased thickness subbase) then this may be composed of any of the following classes as Southwark Highway Specification series 600 clauses (though see 'c' below about using imported fill).
   i. Class 6A
   ii. Class 6B
   iii. Class 6C
   iv. Class 6D
   v. Class 6F1, Class 6F2, Class 6F3, Class 6F4, Class 6F5
   vi. Class 9A, Class 9B, Class 9C, Class 9D, Class 9E.

c. Notwithstanding 'a' and 'b', the following requirements apply in respect to using imported fill for capping or subgrade improvement (see notes).
   i. New streets and spaces
   Using imported fill material (see note) requires level 2 departure. It must be demonstrated to the satisfaction of approving officers that using materials from site is either impractical given constraints on site or less sustainable on balance than alternatives.
   ii. Existing streets and spaces,
   If the area of works within the Highway is > 250m^2 then using imported fill material requires level 2 departure (see note). It must be demonstrated to the satisfaction of approving officers that using materials from site is either impractical given constraints on site or less sustainable than alternatives
   However, if the area of works is ≤ 250m^2 then using imported materials requires only level 1 departure.

NOTE 1: Imported fills are as distinct from fills that have been won from the site. If existing site won materials found are unsuitable, then it may be possible to render them acceptable by processing. That processing may take place either on site or off of it.

NOTE 2: Imported fills include Class 6E (used to make Class 9A cement stabilised capping), Class 6F4 and Class 6F5.

d. If the subgrade bearing capacity is:
   i. <3% then, unless otherwise instructed by approving officers, a geotextile filter inter-layer should be used between the subgrade and the subbase (or capping layer where present) (see note 1).
   ii. ≥3 but ≤5.5% and an open graded unbound granular mixture subbase as sections 4 or 5 is used over this then - unless instructed otherwise by approving officers – for all carriageway pavements a ≥ 50mm thick filter layer composed of Class 6S selected granular fill should be provided between the two (see notes 2 and 3). This may be left out if using a geotextile filter interlayer is otherwise permitted or required.

NOTE 1: The above applies even if improvements to the subgrade are being carried out. If the subgrade has been stabilised *in-situ (so that it is not possible to access the unimproved subgrade below) then the geotextile should be located immediately on top of the stabilised material.*

NOTE 2: This is intended to prevent cohesive particles from the subgrade contaminating the open graded subbase mixture. Whilst it might seem sensible to provide a slightly increased thickness of sacrificial subbase (and assume that the additional thickness will become contaminated) research shows that the pumping action of water will continue to spread contamination up through the pavement.

NOTE 3: Subject to grading compatibility, the filter layer may not be necessary if a Class 6F capping layer or drainage blanket is provided beneath the subbase.

NOTE 4: Designers should protect subgrades and foundation layers from potential trafficking during construction.

2.7 Geotextiles

a. The Southwark Highway Specification includes material, installation and checking specifications for various types of geotextile separators, filters, membranes and protection fleeces. Refer to the SSDM/SER Engineering Materials palette for a quick lookup list.

b. Using geotextiles will complicate maintenance and reinstatement it requires level 1 departure.

NOTE 1: Legitimate uses of geotextiles are likely to include:
- *As encapsulating layers around under-pavement infiltration or attenuation reservoirs.*
- *As encapsulating layers around under-pavement geo-cellular unit 'soil vault' assemblies for street trees.*
- *To filter or separate weak subgrades.*

NOTE 2: This preference for avoiding geotextiles extends to sub-drainage blankets and filter drains also as, in the event of these being blinded, excavation to restore permeability can be difficult in urban areas given their likely buried depth. It also extends to use beneath the laying courses of modular pavements (including those with pervious block surfaces) since geotextiles can introduce a sheer/slip plane.

c. Any pavement containing geotextiles should be registered on the National Streets Gazetteer as having 'special engineering constraints'. Information about the nature of the construction should be provided as 'additional streets data' within the gazetteer and copies of as-built information retained so that this can be provided to Statutory Undertakers upon request.

2.8 Extent of pavement constructions and guidance on arranging foundations into zones

a. The carriageway pavement should normally extend beneath the footing of the edge carriageway restraint (e.g. the kerb). Unless a lateral retaining structure is provided, the sides of the construction should be set to repose slopes at a maximum gradient of 1:1 (else the layers should be similarly stepped with the carriageway subbase extending a minimum of 150mm beyond the limit of the kerb footing).

b. Within streets and spaces, the materials used to foundation layers are likely to vary due to inherited constraints. Important factors will include: the location of utilities and trees; sub grade conditions; levels of vehicle trafficking; the presence of basements and other vulnerable structures.

c. 'Simple' designs using a uniform foundation comprised of a single material over the entire width of the pavement is unlikely to be practical. Consequently subbases may consist of a series of materials within distinct zones. This might include for example:
   i. A corridor at the rear of the footway composed of conventional [U-Type 1] unbound granular mixture to accommodate utilities and provide structural buffering of adjoining properties.
   ii. A corridor in the centre or the front of the footway composed of [U-SMS] structural soil to serve as an under-pavement rooting zone for street trees.
   iii. A corridor at the front of the footway (or in the carriageway under Inset Parking Bays) composed of an empty [G-GW1] and [G-GW2] geo-cellular unit assembly to serve as an under-

pavement surface water infiltration or attenuation reservoir. Occasional transverse gaps of conventional unbound granular materials should be provided between specialist constructions for utilities to pass through from the carriageway.

iv. A corridor under the main carriageway running lanes composed of normal graded unbound granular material (e.g. [U-Type 1A]).

3 Normal graded unbound granular mixtures

3.1 Use requirements

3.1.1 Potential materials

a. Normal graded unbound granular mixtures that may be used to pavement foundation layers where permitted in section 3.1.2 include the following materials from the Southwark Highway Specification.

- [U-Type 1A]
- [U-Type 1A/F]
- [U-Type 1B]
- [U-Type 1B/F]
- [U-Type 2A]
- [U-Type 2B]

NOTE 1: The sub-designations A and B reflect different levels of asphalt content in the mixtures. However, other than where using gravel is permitted (for which see 'b' below) all mixtures are required to have a crushed and broken faces category of C90/3.

NOTE 2: The sub designation F reflects a requirement for a low fines content (≤ 3% passing by mass).

3.1.2 Permitted material options for different circumstances

General

a. As per Southwark Highway Specification, crushed gravel aggregate should not be used in any normal graded unbound granular mixtures.

b. None of the materials as section 3.1.1 may be used to a pavement foundation if either:

i. The pavement surface is designed to be fully pervious to surface water (e.g. with a pervious block, pervious asphalt or other pervious surface).

ii. The foundation will serve as a reservoir for infiltration or attenuation storage of surface water run-off.

Bituminous mixture surfaced pavements

c. For new and existing carriageway pavements, any of the normal graded unbound granular mixtures as section 3.1.1 may be used subject to the:

i. Restrictions on using unbound granular mixtures stated in the version of DMRB HD 25.

ii. Upper trafficking thresholds in Table 4.

Material	Upper use limit (million standard axles over design life)
[U-Type 1A]	None
[U-Type 1A/F]	
[U-Type 1B]	1.3msa
[U-Type 1B/F]	
[U-Type 2A]	5msa
[U-Type 2B]	1.3msa

Table 4. Trafficking limits for using different types of normal graded unbound granular mixture to pavement subbases

NOTE: HD 25/94 and HD25/06 include slightly different restrictions in respect to using unbound granular materials beneath Rigid-Composite and Rigid Pavements.

d. For new and existing footway and cycleway pavements, any of the materials as section 3.1.1 *may* be used.

Modular unit surfaced pavements

e. For flag and slab surfaced pavements, if the upper face plans area of an individual modular unit is ≥0.12m^2 then:

i. In new streets and spaces either [U-Type 1A] or [U-Type 1A/F] may be used (see note).

ii. In existing streets and spaces then any of the materials as section 3.1.1 may be used, subject to the trafficking limits stated in Table 1.

NOTE: If such pavements are being designed with unbound surfaces (e.g. as section 3 of standard DS.601) then - if regular high pressure water cleaning of the surface is likely - [U-Type 1A/F] or [U- Type 1B/F] should be used. Examples of locations where this may be the case include market streets. Specifying the subbase as such means that the modest quantities of surface water that will inevitably penetrate via joints can drain through the pavement (rather than remaining trapped in the laying course).

f. For precast concrete block, natural stone sett and clay paver surfaced pavements and smaller flag and slab surfaced pavements (see note 1) only [U-Type 1A/F] or [U-Type 1B/F] may be used (see note 2). However, using [U-Type 1B/F] is subject to the trafficking limits stated in Table 1.

NOTE 1: Smaller flag or slab units are those where the surface area of the upper face of individual units is < 0.12m².

NOTE 2: The requirement to use lower-fines [Type 1A/F] or [Type 1B/F] mixtures means that the subbase will be modestly free draining.

Self-binding gravel surfaced pavements

g. [U-Type 1A/F] may be used as a subbase material to a self-binding gravel surface that is installed to an existing paved area that has been disturbed by trees. Other options as section 3.1.1 may not.

4 Open graded unbound granular mixtures

4.1 Use requirements

4.1.1 Permitted material options for different circumstances

Pavements with under-pavement surface water infiltration/attenuation reservoirs

a. Either [U-Type 3/40] or [U-Type 3/20] may be used as part of a subbase surface water infiltration or attenuation reservoir. It must be demonstrated that introducing a geo-cellular unit assembly reservoir is inappropriate.

NOTE: Beneath pavements that are trafficked by even a small number of commercial vehicles, where no separate bound base course is to be provided then the granular reservoir normally requires stabilisation or protection with another bound material. This effectively serves as the missing base course.

b. Any pavement containing a granular reservoir of [U-Type 3/40 or [U-Type 3/20] should be registered on the National Streets Gazetteer as having 'special engineering constraints'.

Conventional pavements

c. Both bituminous mixture and modular unit surfaced pavements that include bound base courses to their upper layers may use [U-Type 3/40] or [U-Type 3/20] to their subbase.

	Southwark Highway Specification	Description	Requirements for using material to upper subbase
A	[C-NF-C15]	No-fines concrete	Preferred. To be used unless agreed otherwise. Voids content to be specified on a case specific basis (see notes 1-3)
B	[U-Type 1A/F]	Normal graded unbound granular mixture as section 3.	Use requires level 1 departure. It must be demonstrated to the satisfaction of approving officers that only modest unintended surface water ingress is likely to occur (e.g. via the joints between modular surface units)
C	[C-WL3] [H-CBGM-B/R-C10] [H-CBGM-B/G-C10]	Wet lean concretes and cement bound granular materials (CBGMs)	Use requires level 1 departure. It must be demonstrated to the satisfaction of approving officers why both Options (A) and (B) above are inappropriate. See also notes 1 and 4
D	None. Upper 100-150mm of open graded base course strengthened by geo-confinement system as section 8		Within footways and other non-carriageway areas, subject to level 1 departure use may be permitted as part of a 'no-dig' solution over the rooting zones of street trees (see note 5). May not be used to carriageway pavement. However Design Pilot dispensations may be agreed in Workstage A3 *Briefing* to explore this (see note 6)

NOTES
1) See section 6.2 for further general design requirements about concretes and hydraulically bound mixtures.
2) See section 6 for general information about no-fines concrete, including how voids content influences both permeability and (along with a number of other factors) strength.
3) Where this material is used then a filter compatibility check should always be carried out to check that laying course materials will not migrate through. See standard DS.601 for further information.
4) As this material is impermeable then - in order to allow for dispersal of any surface water ingress – some method of perforation will be required. See section 2.8 of standard DS.601 for further information.
5) This is only likely to be feasible where underground utilities and other services are located at sufficient depth and the overlying surface and laying course is fully pervious. Where these layers are not pervious, roots may track to the surface in search of access to air and moisture. This may lead to disruption of the laying course and significant pavement heave.
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Table 5. Protective upper subbase overlay options for conventional unbound flag or slab surface pavements with an open graded unbound granular mixture subbase.

d. For unbound flag or slab surfaced pavements (see note) [U-Type 3/40] and [U-Type 3/20] may only be used for the subbase if a ≥ 110mm thickness of some other stiff material (effectively a base course) is introduced to the upper part of the subbase as a protective overlay. Table 5 explains permitted options for this overlay.

e. Within new streets and spaces, level 1 departure is required to use [U-Type 3/40] or [U-Type 3/20] to the subbases of footways (and other non-carriageway pavements). It must be demonstrated that adequate provision for rooting of trees within the pavement has been made using other materials and methods.

Self binding gravel surfaced pavements

f. [U-Type 3/20] may be used as a subbase material to a new self binding gravel surfaced pavement that is installed over existing tree roots within an existing unpaved area (effectively a no-dig construction).

4.2 Design requirements

a. Open graded unbound granular mixtures may need to be covered or encapsulated by a geotextile filter membrane to prevent migration of particles from the layers above. However, this should be avoided wherever possible by considering filter criteria and specifying appropriately graded laying course materials.

b. See '2.6d' about introducing filter inter-layers to prevent contamination by cohesive particles if open graded unbound granular mixtures are installed over weak subgrades.

5 Structural soils

5.1 Use requirements

5.1.1 Potential materials

a. Structural soils: [U-SMS] may be used to foundation layers where permitted as section 5.1.2 . [U-SMS] is a fully load bearing structural soil similar to CU Structural Soil. It is not the same thing as either:
- *'Amsterdam Tree Sand' (sometimes known as 'Metro Soil'). Amsterdam Tree Sand may not be used beneath Highway pavements (though it may occasionally have valid uses as a mineral subsoil within unpaved soft landscaped areas and under-pavement 'soil vaults').*
- *'Stockholm planting bed' soil and rock mixtures.*

5.1.2 Permitted material options for different circumstances

General

a. [U-SMS] structural soil should not be used as a subbase surface water attenuation or infiltration reservoir material (see note 1). However a Design Pilot to explore this may be agreed or instructed.

NOTE 1: Some use beneath pervious surfaces may be acceptable providing: (a) these are set to falls to shed the majority of surface water to conventional collector gullies; and (b) water from surrounding pavements/surfaces is not being intentionally directed towards them.

b. Any pavement containing [U-SMS] structural soil should be registered on the National Streets Gazetteer as having 'special engineering constraints'.

Footway and cycleway pavements

c. For bituminous mixture surfaced pavements, [U-SMS] structural soil may be used as a subbase material directly beneath the base course.

d. For modular unit surfaced pavements, requirements for using [U-SMS] structural soil are as follows:
   i. Unbound flag and slab surface pavements (see note 1)
   [U-SMS] structural soil may be used a subbase material. However, a minimum 110mm thick protective layer of one of the materials as Table 2 should be provided over it (see note 2).
   ii. Unbound precast concrete block and clay paver surfaces
   [U-SMS] structural soil may be used a subbase material so long as either:
   - ≥ 110mm thick base course composed of a material permitted as section 5 of standard DS.601.
   - ≥ 110mm thick protective layer of one of the materials as Table 2 is provided over it (see note 2). Note however that the second option

may not replace a formal base course if one is required to the pavement upper layers.

iii. All other types of modular unit surfaced pavement
[U-SMS] structural soil may be used as a subbase material directly beneath the bound upper layer base course.

NOTE 1: Such pavements do not require a bound base course to their upper layers. See section 3 of standard DS.601 for further information.

NOTE 2: This requirement is made for much the same reason as why protective layers are required over the open graded unbound granular mixture subbases discussed in section 4 (both materials being very similar in terms of mixture design and stiffness.

e. [U-SMS] may be used as a subbase material to a new self-binding gravel surfaced pavement that is installed over existing tree roots to an existing unpaved area (effectively a no-dig construction). However,
   i. ≥ 110mm thick interlayer of [U-Type 3/20] must be provided between it and the surface course.
   ii. It must be installed with associated geo-confinement systems

Carriageway pavements

f. [U-SMS] structural soil may only be used for subbases of sections of carriageway pavement if all the following apply.
   i. The street in question has a 20mph speed limit or forms part of a 20mph zone.
   ii. The structural soil is located under an Inset Parking Bay or other similar area protected from general over-run by vehicles moving at speeds > 15mph. However, it may not be used under loading bays or other areas that may be used by large numbers of commercial vehicles.
   iii. The pavement includes a bound base course to its upper layers.
   iv. (If the pavement has a bituminous mixture surface) it uses a Flexible or Flexible-Composite upper layer construction.

5.2 Design requirements

a. Wherever [U-SMS] structural soil is provided its depth should be ≥ 625mm.

NOTE: Though this is likely to exceed structural requirements, it is the minimum depth recommended by manufacturers in order for it to succeed as a growing media for trees. Lesser depth may be acceptable to limited areas when working around obstructions or to slopes at the edge of the pavement.

b. The pH of the material and nutrient levels will need to be specified on a case by case basis to suit proposed tree species. Interpretative testing of the proposed mixtures will need to be undertaken by a Soil Testing Laboratory. Subject to the recommendations of a Soil Scientist in that test, the mixture may need to be amended to better suit the needs of the proposed trees.

c. [U-SMS] structural soil subbase layers may need to be covered or encapsulated by a geotextile filter membrane to prevent migration of particles from the layers above. However, this should be avoided wherever possible by considering filter criteria and specifying appropriately graded laying course materials.

d. If the upper layer pavement construction over a [U-SMS] structural soil subbase is not fully pervious (see note) then some other method of allowing air and moisture to access the subbase will need to be provided. Failing this soil biology within the mixture may die, compromising its effectiveness as a growing medium for street trees.

NOTE: See standard DS.601 about situations where pervious upper layer constructions are likely to be permitted. Broadly, using pervious block surfaces is currently restricted to Inset Parking Bays that have under pavement rooting zones for street trees extending beneath them.

6 Hydraulically bound mixtures (HBM) and concretes

6.1 Use requirements

6.1.1 Potential materials

a. HBMs that may be used to pavement foundation layers where permitted in section 6.1.2 include the following materials from the Southwark Highway Specification.

i. Cement Bound Granular Materials (CBGMs)
- [H-CBGM-A/G-C4]
- [H-CBGM-B/R-C4]
- [H-CBGM-A/R-C4]
- [H-CBGM-B/G-C6]
- [H-CBGM-A/G-C6]
- [H-CBGM-B/R-C6]
- [H-CBGM-A/R-C6]
- [H-CBGM-B/G-C10]
- [H-CBGM-A/G-C10]
- [H-CBGM-B/R-C10]
- [H-CBGM-A/R-C10]
- [H-CBGM-B/R-C15]
- [H-CBGM-B/G-C4]
- [H-CBGM-B/R-C20]

ii. Other Hydraulically Bound Materials (HBMs)
- [H-SC840-C4]
- [H-SC840-C10]
- [H-SC840-C6]

NOTE 1: For CBGMs, if the initial grading code in the type reference is followed by an R (as in [CBGM-B/R-CX]) it denotes the need for the mixture to use crushed rock aggregate and have a coefficient of thermal expansion <10 x 10^{-6} per °C. If the grading code is followed by a G (as in [CBGM-A/G-CX] then this denotes that gravel aggregate is used.

NOTE 2: For both CBGMs, other HBMs and no-fines concretes (for which see 'b') the C figure at the end of the type designation code (as in [H-SC840-C6]) denotes the compressive strength class of the mixture.

NOTE 3: Though they typically provide a higher strength and performance than necessary for subbase layers, [H-CBGM-B/R-C15] and [H-CBGM-B/R-C20] CBGMs have been included here due to their occasional use to the subbases of modular footway pavements with unbound surfaces that do not include a separate base course. They may also occasionally be required if early trafficking is necessary or beneath CRCB/CRCR or CRCP rigid pavements

NOTE 4: [H-SC840-CX] is soil cement.

b. Concretes that may be used to pavement foundation layers where permitted as section 6.1.2 include the following materials from the Southwark Highway Specification.

i. Wet lean concretes
- [C-WL1]
- [C-WL3]
- [C-WL2]
- [C-WL4]

ii. No fines concretes
- [C-NF-C15]
- [C-NF-C20]

NOTE 1: Though [C-WL4] wet lean concrete provides a higher strength and performance than typically necessary for subbase layers, it has been included here due to its occasional use to the subbases of modular footway pavements with unbound surfaces that do not include a separate base course. It may also occasionally be required if early trafficking is necessary.

NOTE 2: [C-NF-C15] and [C-NF-C20] are porous 'no-fines' concrete mixes. Their voids content must be specified on a case specific basis. This will partly determine their strength. Though used primarily to the base courses of modular pavements (as standard DS.601) they have been included here since subbases to unbound flag and slab surfaced pavements sometimes require cement bound materials to be used. Being very different to the other concretes and HBMs specified here in performance, their actual strength is likely to be significantly less than the C15 and C20 compressive strength classes indicated in the type reference codes.

6.1.2 Permitted material options for different circumstances

Bituminous mixture surfaced pavements

a. For new and existing carriageway pavements, requirements for using the materials in section 6.1.1 to subbase layers are as follows.

i. Pavement with fully Flexible or Flexible-Composite upper layers

Using any of the materials as section 6.1.1 requires level 1 departure (see note 1). It must be demonstrated that some special engineering constraint exists that prevents any of the unbound granular mixtures as sections 3-5 from being used. Normally this will only be owing to limited cover or - in the case of existing pavements - the existing presence of such materials in such a way as to be incompatible with co-use of unbound granular mixtures. Neither of the no-fines concretes may be used.

ii. Pavements with EME2 base courses to their upper layers

One of the following CBGMs or HBMs should be used:

- [H-CBGM-A/G-C10]
- [H-CBGM-B/G-C10]
- [H-CBGM-A/R-C10]
- [H-CBGM-B/G-C20]

Using other stronger grades of CBGM or HBM as section 6.1.1 requires level 1 departure. Some special engineering constraint else a requirement as DMRB HD 26 will need to be demonstrated.

iii. Pavements with Rigid or Rigid-Composite upper layers

One of the following CBGMs or HBMs should be used to at least the upper 150mm of the subbase (note 2):

- [H-CBGM-A/G-C10]
- [H-CBGM-B/R-C10]
- [H-CBGM-A/R-C10]
- [H-SC840-C10]
- [H-CBGM-B/G-C10]
- [C-WL2]

Using other stronger grades of CBGM or HBM as section 6.1.1 requires level 1 departure. Some special engineering constraint else a requirement as DMRB HD 26 will need to be demonstrated.

NOTE 1: Normally only materials with a C4 or C6 compressive strength class will be permitted. Other higher strength grades will generally only be acceptable for small projects where early trafficking is unavoidable.

NOTE 2: This reflects DMRB HD 25 requirements that a cemented subbase should be provided to pavements with such upper layer constructions.

b. For new and existing footway and cycleway pavements, using any of the materials as section 6.1.1 to subbases requires level 1 departure (see note). It must be demonstrated that some special engineering constraint exists that prevents any of the unbound granular mixtures as sections 3-5 from being used. Normally this will only be permitted on account of limited cover or (in the case of existing pavements) the existing presence of such bound materials in such a way as to be incompatible with co-use of unbound granular mixtures.

NOTE: Normally only the following materials of weaker strength class will be permitted: [H-CBGM- A-C10], [H-CBGM-B-C10] or [C-WL1].

Modular unit surfaced pavements

c. For modular unit surfaced pavements, using unbound granular mixture subbases as sections 3-5 should be strongly preferred. Given this, except where it is expressly permitted in other design standards or SSDM/TDR detail drawings, using any of the concretes, CBGMs or other HBMs as section 6.1.1 requires level 2 departure (though see '4.1.2d' and '5.1.2d' about potential use as protective overlays to open graded unbound granular mixture subbases as sections 4 or 5).

NOTE: Normally only the following materials of weaker strength class will be permitted: [H-CBGM- A-C10], [H-CBGM-B-C10], [C-WL1] and [C-NF-C15].

Self-binding gravel surfaced pavements

d. None of the materials as section 6.1.1 may be used beneath self-binding gravel surfaces. If any are encountered when retro-fitting such a surface then they must be removed.

6.2 Design requirements

a. If [C-NF-C20] or [C-NF-C15] no-fines concretes are used beneath unbound granular laying courses to modular pavements, then a filter compatibility check as section 2.12 of standard DS.601 should be carried out to check that laying course materials will not migrate through the voids in the mixture. Where compatible materials cannot be sourced then - subject to the requirements of that standard - it is likely to be necessary to introduce a geotextile filter. Using geotextiles and/or granular filter layers may also be necessary where no-fines concrete immediately abuts subgrades and other soils.

b. If [C-NF-C20] or [C-NF-C15] no-fines concrete is specified then the voids content will be agreed on a case specific basis with approving officers (see note).

NOTE: Unless the pavement upper layers are to be intentionally pervious, a voids content of 12-16% is likely to be appropriate. Though much greater voids content are possible (and *this improves material sustainability and reduces linear expansion and contraction) this should generally be avoided as it will increase the likelihood of laying course migration. Mechanical strength will also decrease in inverse proportion to voids.*

c. Prior to trafficking, all concretes and hydraulically bound mixtures used to pavement courses (including where used to upper structural layers as standard DS.601) should achieve the early strength requirements of Highways Agency 'Design Manual for Roads and Bridges', HD 27/04 paragraphs 3.8-3.11.

d. If early trafficking of concrete, CBGM of other HBM materials is necessary then - as per Southwark Highway Specification sub-Clause 813.17 - a minimum of 50% by mass of aggregate in the mixture must have a crushed and broken faces category of C90/3.

NOTE: In the case of CBGMs this is most easily achieved by using a mixture option with crushed rock aggregate (e.g. [CBGM-B/R-CX] with R denoting the crushed rock) since, as per relevant British Standards, crushed rock is always assumed to have a C90/3 category.

e. See standard DS.601 about the potential need to pre-crack and seal subbases composed of concrete, CBGM or other HBMs.

7 Geo-cellular unit (GCU) assemblies

7.1 Use requirements

7.1.1 Potential materials

a. GCU items that may be used to create assemblies where permitted in section 7.1.2 include the following materials from the Southwark Highway Specification.
   i. Under-pavement surface water infiltration/attenuation reservoir systems
      - [G-GW1]

NOTE1: [GW1] units are shallow, rectangular shaped grid-sided boxes with internal supports. They are approximately 350mm wide x 700mm long x 150mm deep. The units lock tightly together using both side and top connector pins to create extremely stiff composite constructions that resist sheer. They are mainly used to create surface water attenuation or infiltration reservoirs beneath pavements. They can be used to create anything from single unit depth vertical or horizontal rafts, hollow multi-sided tanks constructed from multiple rafts, or multi-layer tanks formed from full unit assemblies. Assemblies are normally encapsulated by geotextiles to prevent contamination, ingress or mingling with or by surrounding soils or engineering fill. Unlike many geo-cellular products they can be used to comparatively shallow depth beneath pavements, though they still typically require a minimum overlaying construction of around 300mm if the layers above are unbound. Depending upon the loads likely to be imposed, lesser depth might be achievable if other forms of upper layer pavement construction are used (e.g. pavement quality concrete base courses

   ii. Under-pavement 'soil vault' systems to provide secondary rooting zones for trees
      - [G-GT1]

NOTE 2: [GT1] assemblies consist of large hollow frame units with empty side faces. These are approximately 1200mm long by 600mm wide by 400mm high. The large open sides to the units provide substantial space to accommodate tree roots and underground utilities. They are designed so that columns of units can be created by stacking the frames one on top of the other, up to a maximum of 3 units. This structure, composed of multiple columns, can be filled with soil. Thereafter, a strong rigid grid plate is added on top of each column to support the pavement layers that will be added later. Normally the sides are encapsulated with a flexible geo-grid or other geotextile to prevent soils and neighbouring engineering materials from contaminating one another. An important difference to [G-GW1] units is in respect to the method of interlock. Whilst [G-GW1] units are designed to interlock tightly with neighbouring units to all sides to create a stiff composite structure, [G-GT1] units interlock only with the units above and below them in their individual columns. The columns themselves are designed to be independent. This has some advantage, in an emergency (such as a leaking water main) the pavement can be quickly excavated with heavy machinery without disturbing neighbouring columns. Like [G-GW1] assemblies, some depth of cover is required over the top of the assembly, but this is relatively shallow compared with other systems *and will depend upon the material used. However, designers should note that the system typically needs to be constructed on top of a further 100-150mm thick layer of unbound granular mixture for it to be effective in load bearing terms.*

iii. Ancillary units for general purposes
- [G-GW2]
- [G-GW3]

NOTE 3: [G-GW2] and [G-GW3] units are identical to the [G-GW1] units described above other than that they include special inserts within the internal void space of each unit. For [G-GW2] units the insert is a floating geosynthetic bio-matt that can be used to provide secondary bio-treatment of any hydrocarbons that may pass into the system from surface water that is allowed to enter. For [G- GW3] units the insert is an absorbent foam filling. This can be used to create hydraulic breaks where reservoirs are constructed on slopes (e.g. slowing flowing water down but letting it ultimately pass through) or to absorb water that might otherwise drain away for latter conveyance to adjoining soils. Whilst mainly designed to be used with [G-GW1] systems, these units can also be beneficially used in association with [G-GT1] rooting zone assemblies. For instance, if surface water is directed to pits, [G-GW2] units can provide pre-treatment of this to remove hydrocarbons that might damage some trees. Even in the most basic tree-pit designs, [G-GW3] units can prove beneficial in helping retain moisture that would otherwise naturally drain out of the soil – so helping to meet the rooting zone volume requirements that are explained in standard DS.501 more efficiently.

b. Any pavement containing GCUs should be registered on the National Streets Gazetteer as having 'special engineering constraints'.

7.1.2 Permitted material options for different circumstances

Under pavement rooting zones and surface water attenuation reservoirs

a. Under footway and cycleway pavements then, subject to geo-technical design and validation, [G- GT1] and [G- GW1] assemblies that are up to three units deep may be used to construct under-pavement 'soil vaults' serving as extended secondary rooting zones for street trees, or surface water infiltration/ attenuation reservoirs. Hollow water tanks formed by assembling single unit thick vertical and horizontal rafts of units (with a significant void space in the middle) may not be used.

b. Under carriageway pavements then, subject to geo-technical design and validation, [G-GT1] and [G- GW1] assemblies that are two to three units deep may be used to construct under-pavement 'soil vaults' or surface water infiltration/attenuation reservoirs, but only where:
   i. The street is:
      - Subject to a 20mph speed limit or is located in a 20mph zone.
      - Not a Classified Road (an A or B Road).
   ii. The level of projected commercial vehicle trafficking over the design life of the pavement does not exceed that for Road Category 3B as Table 3 of standard DS.601; and
   iii. The [G-GT1] units are located under Inset Parking Bays or other areas of the carriageway that are protected from general overrun from vehicles moving at speeds in excess of 15mph. These areas must also be surfaced in a material that clearly distinguishes them from the main carriageway running lanes. However, they may not be located under loading bays or other locations likely to be used by large numbers of commercial vehicles.

Additional potential uses

e. Subject to level 1 departure, any of the GCU items from section 7.1.1 may be used for additional purposes to those above. Potential examples include:
   i. As part of 'no-dig' pavement constructions.
   ii. As drainage blankets at formation level (or similar sub-drainage features).
   iii. As retaining walls to conventional tree pit constructions (albeit walls that might contain further soil and or ventilation paths).

7.2 Design requirements

a. Being geotechnical structures, the design of any pavement incorporating a GCU assembly should be informed by a Ground

Investigation Study. The resulting design should take an analytical approach and be supported by a Geo-Technical Design Report.

b. Unlike other subbase materials, the required thickness of a GCU subbase assembly will vary between products. Appropriate depths for all parts of the construction will need to be established as part of the analytical design.

c. If they are greater than a single unit deep, then GCU assemblies must be formed from contiguous rafts of units stacked one on top of the other. Hollow tanks formed by assembling multiple single-unit-thick vertical and horizontal rafts of units to create an effective box (with a significant void space in the middle) should not be used.

d. In existing streets and spaces, locating GCU assemblies where significant numbers of utilities will pass through them should be avoided. In the case of surface water infiltration and attenuation reservoirs, certain types of utilities may be fundamentally incompatible given the likely presence of large volumes of water in the construction from time to time.

NOTE 1: Generally, the above is likely to be of lesser concern in the case of under pavement rooting zones constructed out of [G-GT1] assemblies. The individual units in this system all have significant void spaces so as to accommodate the uninterrupted growth of tree roots and passage of underground services.

NOTE 2: If pipes and drains pass through assemblies then geo-technical design reports will also need to consider the loads exerted on these. In the absence of the granular fill to all sides usually found in pavement constructions, pipes may distort unacceptably when significant topsoil backfill is located over them with an assembly.

e. GCU assemblies should not be trafficked by site plant during construction.

f. If GCU assemblies are used to create substantial under-pavement soil vaults or infiltration/attenuation reservoirs then regular access chambers must be provided into the assembly to allow checking of soil conditions and/or water levels and to provide for future maintenance.

8 Geo-confinement systems

8.1 Use requirements

8.1.1 Potential materials

a. Geo-confinement systems for potential use to pavement foundations where permitted as section 8.1.2 include the following materials from the Southwark Highway Specification.

i. Cellular confinement systems
- [XCF-75]
- [XCF-200]
- [XCF-100]
- [XCF-300]
- [XCF-150]

NOTE: All the above items are fundamentally similar except for the thickness of the panel. This is indicated by the final figure in the item reference (e.g. [XCF-150] = 150mm thick).

ii. Geo-grids
- [X-G1]
- [X-G2]
- [X-G1(C)]

NOTE: [X-G1] is a heavy duty tri-axial geo-grid for use where a robust separator or stabilising geo- grid separator is required. [X-G1] is a composite of the same and a further geotextile filter or separator. The exact geotextile separator or filter will need to be specified on a case specific basis. [X-G2] is a weaker bi-axial geo-grid for where a more flexible separator is required. It's most common use is likely to be for encapsulating geo-cellular system rooting zones constructed out of [G-GT1] assemblies as discussed in section 7 for which [X-G1] would provide too rigid.

8.1.2 Permitted material options for different circumstances

a. There are a wide range of circumstances in which geo-confinement systems may be required. Using any of the geo-confinement systems as section 8.1.1 requires level 1 departure given the maintenance and reinstatement complexities they can introduce.

b. Any pavement containing geo-confinement panels should be registered on the National

Streets Gazetteer as having 'special engineering constraints'.

8.2 Design requirements

a. If using geo-confinement systems for foundation layer strengthening/thickness reduction purposes then the permitted reduction in layer thickness will be agreed based on research or empirical evidence for the proposed product outlined in the Pavement Design Statement.

b. Wherever geo-confinement systems are proposed, designers should demonstrate regard in design information to build-ability, for instance by showing the location of anchors, cuts to individual panels, and joints between panels. This is particularly important for cellular confinement panels as these cannot be lapped with one another.

Appendix A – Background

1 General introduction to pavement foundations

a. The lower foundation layers of a pavement construction perform several main roles.

i. Foundation for pavement upper layers
They create a stable foundation over the subgrade (the natural ground) on which the upper pavement layers that will perform the majority of load distributing functions can be constructed. This is almost always necessary since the subgrade is seldom sufficiently stiff in itself. Adequate compaction of materials and prevention of water saturation are both very important to the success of the foundation.

ii. Support for construction traffic
The foundations also serve to create a platform for construction traffic during the laying of the upper pavement layers. If not sufficiently stiff to withstand this trafficking then the foundations and the subgrade beneath will distort, preventing them from performing their other important roles in-service.

iii. Sub drainage path
Adequate drainage is critical to the long term performance of the foundation. Any surface water that is successful in penetrating the pavement from the layers above needs to be dispersed. Similarly, the pavement needs to be kept free from any ground water that might rise up from the subgrade. This might require either creating a 'drainage blanket' of very porous fill at the bottom of the foundation for surface water to disperse through, or introducing sub drains.

b. In recent years new design philosophies have been introduced that add to the roles that foundations may be expected to perform. These have often required changes to traditional design approaches.

i. Surface water attenuation and infiltration reservoirs
Concerns to reduce flood risk, recharge ground water and improve water quality at source have led to the development of subbase reservoirs within pavement foundations for the temporary storage of surface water. These may serve either to:
- temporarily detain ('attenuate') surface water that has infiltrated through the pavement for later controlled release into conventional drains (so slowing the passage of water into sewers).
- allow surface water to gradually soak into the subgrade

In either instance the foundation must be designed to hold this water in a way that will not undermine its stability.
The above challenges conventional pavement design in several respects. Firstly, it involves holding large amounts of water within a pavement (whereas minimisation and rapid dispersal were once key concerns). Secondly, it requires materials with large void spaces within them to be used in order to provide the necessary storage capacity (previously materials were closely graded to minimise gaps and maximise stiffness)

ii. Rooting zones for street trees
Concerns about the poor health, growth and survival rates of trees in urban streets have led to the development of specialist materials and construction systems that allow

rooting areas for trees to be extended under trafficked pavements. Spatial constraints in streets mean it is seldom possible to provide all the growing medium needed by a tree within a large, open tree pit. If everyday soil was used as a pavement foundation material then the high levels of compaction required for successful pavement design would make it useless to any tree. Popular systems include under-pavement 'soil vaults' housed within special assemblies made of hollow plastic crates (geo-cellular units) and specialist rock and soil mixtures (structural soils) that can be heavily compacted as per conventional engineering practice.

c. When engineers discuss foundation layers they typically refer to two distinct pavement courses:
   i. Subbase
   This provides the platform for constructing the pavement upper layers. It is typically made of smaller and higher quality material than the capping layer beneath. Where a base course is present above, or if the subbase itself is bound, then this material can be relatively low grade. A further consideration is permeability of the material and voids content. Using relatively permeable materials is the most effective way of providing for the downwards dispersal of any surface water that succeeds in penetrating the pavement layers above. If the level of permeability is high and the material also has a high voids content then it can serve as a surface water storage reservoir as part of a sustainable Urban Drainage System (SuDs) pavement construction
   ii. Capping (or subbase improvement) layer
   As discussed above, the purpose of a capping layer is to improve the bearing strength of the subgrade (the ground over which the pavement is constructed) where this is found to be too poor to build on.
   Capping can be achieved using a variety of methods. The most sustainable is often to increase the bearing strength of the existing ground through stabilisation with cement or lime. This can be ploughed into it whilst it remains in situ. Alternatively, a layer of unbound or bound fill can be introduced over the existing subgrade. It is most sustainable to utilise existing materials found on site. Much lower quality and more loosely graded materials can be used than higher up in the structure as stresses will be lower due to depth. However, where the bearing strength of the existing ground is very low (characterised by a stiffness modulus of < 30MPa or a CBR value of <2.5%) then covering it with fill alone will not be sufficient. Instead the subgrade must be removed altogether and replaced. In some instances it is possible to improve the stiffness modulus above 30MPa by inserting sub-soil drainage deep in the subgrade so enabling capping fill to be used.
   Unbound capping fill is also often used for regulating purposes (e.g. to make up pavement levels using a cheap material) else to provide a path for dispersal of surface water or ground water to keep this out of the main pavement construction above (sometimes referred to as a 'drainage blanket').

2 Discussion on common foundation layer materials

2.1 Normal graded unbound granular mixtures

a. Unbound granular mixtures are made up of carefully selected, graded, aggregates. Numerous qualities can affect the performance of the mixture, from the source materials used, the shape and number of broken faces on the particles (e.g. how flat, sharp or rounded they are) to their chemical composition, resistance to wear and susceptibility to frost. This will dictate everything from the stiffness (elastic modulus) that a mixture can achieve to its water permeability and resistance to chemical attack.

b. Mixtures described as 'normal graded' are those characterised by the absence of significant voids in the installed mix. This is achieved by ensuring the grading of the mixture (e.g. the proportion of particles of different sizes) is relatively close and even with a decent amount of very fine particles. If correctly specified then these mixtures can achieve reasonably high stiffness values. Generally, he greater the upper end of the grading range for the mixture (e.g. the larger the maximum nominal particle size permitted) then the more effective it will be at distributing loads. However, mixtures with larger aggregates make achieving surface tolerances at the top of the layer difficult due to their 'lumpiness'.

c. Though they contribute significantly to stiffness the 'fines' within a mixture can create problems. They may be washed out by any water that finds its way into the pavement and this can undermine stability. These same displaced fines also clog drainage elsewhere in the construction. Alternatively, if not washed out they may prevent the downwards dispersal of any water that has succeeded in penetrating the upper layers above. The trapped water may then stand in those layers. This could lead to damage to the pavement due to freezing and expansion of the water in cold weather and/or 'pumping' when the water is pressurised in pores by passing traffic. These problems are not necessarily a consequence of the mixture specification. Typically the permitted grading ranges within these are such that - by careful manufacture - a relatively free draining material with little fines could be produced (e.g. the mixture specification permits the fines content to be anywhere between 0-9%). However, reducing the amount of fines and other small particles within mixtures is more costly. As such, unless the permitted fines content is explicitly reduced by the specifier, then suppliers will typically produce and provide mixtures with fines contents towards the upper end of the grading range (e.g. they have 9% fines content rather than 0%).

d. Whilst mixtures have been traditionally manufactured from crushed rock or gravel, engineers are increasingly encouraged to accept those that use secondary and recycled materials such as crushed concrete, glass, furnace slag and asphalt planings. Providing these meet the same performance requirements as the virgin materials, this is encouraged. However, irrespective of whether the source material is virgin, secondary or recycled, designers need to be aware that different constituent materials may impart different qualities. For instance, mixtures with a high proportion of reclaimed crushed asphalt in the mixture are likely to drain slightly better having lower fines. On the other hand, they are likely to be less stiff and may suffer from secondary compaction. Different types of virgin rock will similarly vary in their qualities.

e. The majority of existing streets in Southwark will be constructed with normal graded unbound granular mixtures to their foundations. Often these consist of variants of mixtures specified by the Highways Agency (the Highway Authority for the nation's motorways and other trunk roads outside of London). These have names such as 'Type 1' and 'Type 2' and are familiar to all Highway engineers, being used extensively and therefore manufactured up and down the country in considerable volumes to meet demand. The names reflect different permitted mixture gradings, constituent materials and performance properties. Type 2 mixtures are somewhat less stiff than Type 1 mixtures and consequently need to be used to increased thicknesses in order to provide the same structural capacity.

2.2 Open graded unbound granular mixtures

a. Open graded unbound granular mixtures are distinguished from the 'normal graded' mixtures by the fact that the sizes of the respective particles that make up the mixture are more remote from one another. The mixtures also include a significantly reduced proportion of very small particles ('fines'). This means there are more gaps between particles in the installed mixture. As a result they drain very freely and have much greater void space. The chances of them becoming destabilised at a later date by the gradual washing out of 'fines' is significantly reduced. However, the absence of fines reduces the stiffness. To compensate for this much greater attention must be paid to the shape of the particles. They must have angular edges (rather than rounded) and be close to square in shape (rather than flatter and more flake-like).

This helps them generate greater frictional interlock. Also, because they may be in contact with water for long periods of time, the source material must be resistant to chemical attack. In order to meet these requirements, appropriate virgin crushed rock aggregate is used rather than recycled secondary materials.

b. Because of their very free draining nature, these materials are often used to create subbase surface water reservoirs as part of infiltration or attenuation pavement designs. They may also be used if there is concern that there might be greater than usual unintended ingress of surface water into a conventional pavement. Using such a material will allow this to drain through for dispersal by sub- drains deeper in the pavement construction. This avoids the risk of water becoming trapped close to the surface where it might then cause damage.

c. A further application for open graded mixtures is where pavements are constructed over the existing rooting zones of trees where no altering of ground levels can take place. They are then often used as part of a 'no-dig' construction that distributes loads whilst allowing air and moisture to continue to reach the soil below.

d. Because of their lesser stiffness, open graded unbound granular mixtures need to be installed to a greater thickness than any of the 'normal graded' mixtures. However, where they are installed to create surface water attenuation or infiltration reservoirs, the depth required in order to provide necessary storage capacity is often likely to exceed that needed for structural reasons. Where depth is an issue then geo-confinement systems can be used to reinforce them so increasing the stiffness achieved and reducing the necessary depth.

e. When these materials are used to create granular subbase surface water reservoirs, it is normal practice in most instances for the upper 130-200mm to be hydraulically stabilised to protect it from sheer forces generated by vehicles passing over the pavement. Overlaying with a protective layer maybe required when open graded unbound mixtures are used to subbases of conventional modular surfaced pavements that may be for lightly trafficked unbound flag and slab surfaced pavements).

2.3 Structural soils

a. Structural soils are proprietary unbound granular mixtures in which open graded aggregates form a compacted load baring skeleton that provides full support to the pavement layers above. However, the mixture also includes topsoil which is suspended in the gaps in the aggregate skeleton. The skeleton prevents the soil from becoming over compacted. The top soil normally accounts for approximately 20% by dry weight of the mix. Save for when the aggregate is porous and able to absorb significant moisture, a tackifier agent (often a hydrogel) is typically used to prevent separation of the mix during transport, laying and compaction.

b. Structural soils should not be confused with tree sand (sometimes referred to 'Amsterdam Tree Sand' or 'Metro Sand') which is not a fully load bearing material. Tree sand may not be used as a foundation material to pavements in Southwark. They also differ somewhat from similar rock and soil mixtures that are used in 'Stockholm Planting Bed' designs. The aggregate component of Stockholm mixtures is typically much larger than in structural soil (so creating much greater void space for soil and space for large root development) whilst the soil component is washed in after placing the aggregate (rather than the two being mixed together then placed as with structural soil). These factors raise quality control and structural validation concerns.

c. Unlike conventional normal graded and open graded unbound granular mixtures structural soils provide a growing medium through which tree roots can successfully grow, gaining access to water and essential elements without causing pavement heave. Manufacturers also suggest that the material can be used within under-pavement surface water infiltration/attenuation reservoirs as part of a SuDs pavement, having a water holding capacity of approximately 15-20% of their total volume when properly compacted and roots have occupied pore space. However, such claims should be treated cautiously given the open graded nature of the mix, its high permeability (>60cm/hour) and consequent potential for blinding of geotextiles resulting from migration of fines from the soil component.

d. The main alternative to structural soils for providing adequate rooting conditions for trees beneath pavements is to create 'soil vaults' from geo-cellular unit assemblies. Structural soil has a few advantages over this. It is not a geo-technical structure. Safety and maintenance are therefore lesser concerns and design is significantly simplified. Structural soils are similar to conventional unbound granular subbase mixtures and perhaps therefore at reduced risk of accidental damage as a result of reinstatement or other works (as well as being more familiar to construction workers). Lastly, structural soils are also much easier to install around underground utilities and other obstructions that tend to proliferate in existing streets and spaces.

e. However, research shows that 'soil vaults' constructed from geo-cellular system assemblies obtain substantially superior results in respect to tree growth and health. This is interesting since manufacturers suggest that the plant available water holding content of structural soils should be too dissimilar to that of a good loamy sand or sandy loam soil (~7-9% by volume compared with ~9-11% for a loamy sand soil). The reason for the poorer performance may be that roots growing through the mixture have to travel greater distances to divert around the immoveable aggregate skeleton which will also restrict the extent of their expansion. Given the low soil content, this effort will be rewarded with little moisture or essential elements. It may also be that the water holding capacity of the mixture is reduced once it is occupied by roots.

2.4 Hydraulically Bound Mixtures (HBM) and concretes

<u>Hydraulically Bound Mixtures (HBM)</u>

a. HBM is a term used to refer to granular materials that have been bound with an agent that is activated by water. That agent is often cement but may also be (partly or wholly) a number of more sustainable alternatives. These include by-products of other industrial processes, such as pulverised fuel ash or blast furnace slag. Where the binder in the HBM is cement then the sub-term CBGM (cement bound granular mixture) is often used. Whatever the binder used, HBM may be created by importing and laying material from elsewhere or by 'hydraulically stabilising' existing materials found on site (e.g. by ploughing the binder agent into them). Even soils can be used for HBMs. Either way, the strength of CBGMs and other HBMs is not always the same. As stronger materials cost more, engineers specify the strength and other performance aspects to meet the requirements for a particular application. This may range from very low to moderate. When specified at moderate strengths and where quality aggregates are used, CBGMs and other HBMs may be suitable for use to pavement base courses forming part of the upper pavement levels (but never surfaces). They are most likely to be used within the foundation layers.

b. CBGMs and other HBMs often create confusion amongst engineers. This is due to uncertainty about their relationship with CBMs – the acronym used for the material that was often specified in the past when a cement bound material was required (and remains so in many older design documents that have yet to be updated). Broadly, CBM used to be specified in the main document that engineers refer to for pavement materials. This is known as the Specification for Highways Works (SHW - which forms the basis of the Southwark Highway Specification). The SHW was updated some years ago to conform with European Standards aimed at increasing the sustainability of construction. This resulted in the replacement of CBM clauses with CBGM and other HBM clauses that support using less prescriptive mixture designs (and so potentially the incorporation of materials from more sustainable sources). To complicate things further, it is not always appreciated that CBGMs and other HBMs may not be directly equivalent to the old CBMs of similar strength grade. Whilst they cure to a similar value in the very short term, that in the medium term (e.g. at 28 days) is considerably lower. Because of this, when

CBGMs and HBMs are used in place of the CBM mixtures in older standards, they need to be specified with a slightly higher strength class to compensate.

d. Because of their variable potential mixture contents, CBGMs and other HBMs require extensive testing both before and after use to confirm that they provide the intended structural performance. Given the time and effort this takes, they are typically only cost effective when they can be mixed and used in large volumes. This is generally only likely to be the case on large trunk road and motorway schemes and where used as part of major new development works when entire new streets are being created.

<u>Concretes</u>

d. Concretes are similar to CBGMs and other HBMs but tend to be better mixed and to use higher grade materials that achieve improved mechanical performance and durability. They can be broadly broken into three types: Pavement quality concretes; lean concretes; and no-fines concretes.

e. Pavement quality concretes use large amounts of cement binder and are produced to very high standards and consequent strength. Because of this they are sometimes referred to as 'rich mix concretes'. Pavement quality concrete is the same sort of material that is used to construct bridge decks and the floors of new office buildings. For pavement purposes they are most typically used within the upper pavement layers discussed in standard DS.601 – either to create cast concrete surface slabs or where an extremely strong base slab is required. Though used elsewhere in the country neither of these design approaches are common in London. Only in exceptional circumstances (e.g. when spanning a large void) is pavement quality concrete likely to be used to the foundation levels of pavement. The low stresses at such depths simply don't justify it.

f. Lean concretes use a lower proportion of cement binder than pavement quality concrete and are consequently much weaker. They are produced to what is known as a standardised prescribed mix (a simple recipe using consistent readily available materials). Though they are likely to be less sustainable than CBGMs and other HBMs this can serve to make them more cost effective since less extensive testing and validation is generally required. Consequently they are often the material of choice for work in urban streets wherever the applications permits. However, though their strength grading may appear superficially similar to CBGMs and other HBMs, their overall quality is much lower. This generally limits their use to the pavement foundation layers. They cannot be reliably used to upper pavement layers.

g. Though used extensively in some other European countries, no-fines concrete is a relatively new material for UK pavement construction. It first originated here for housing design. It behaves very differently from conventional concretes and HBMs and requires different mixing, testing and installation methods. It is produced by mixing a single-size gap graded aggregate (not so dissimilar to the open graded unbound granular mixtures described in section 2.2 of this appendix) with small amounts of a cement binder paste. The result is something akin to hard toffee popcorn - the aggregates being bound to one another at contact points, so leaving large gaps in between (there not having been enough binder or small aggregate in the mixture to fill these). The resulting material has a number of advantages. Firstly, cast slabs are pervious to water. Unsurprisingly this makes no-fines concrete a popular material for use in pervious pavement constructions. However, the same qualities also make it useful as part of more conventional block surfaced pavement constructions where it will allow surface water that will inevitably penetrate the surface between joints to drain through – so avoiding the many issues trapped water can cause higher in the construction. This is one of the reasons for its use in other European countries. Next, its porosity also allows it to breath, permitting heat that may otherwise build up in it or the underlying ground to dissipate. This may seem trivial but increasing temperatures in urban areas (the 'urban heat island effect') are a major public health concern and pavements a significant contributor to these. Trees and other plants also fare less well in hot ground and - as the trees themselves are potential further atmospheric coolers - there is an escalator effect. Next, the significantly decreased density of no-fines concrete means it consumes far fewer raw materials, whilst it is also less prone to contraction and expansion, so avoiding the need for extensive joints.

h. Unlike other concretes, there are few common national or international standards in respect to how to mix, test and install no-fines concrete (though this problem is increasingly being addressed). It is therefore mostly produced as a 'proprietary product' by suppliers who keep their own guarded recipes and methods for successful use. They may often install and validate it themselves. In general, the higher the voids content that can be achieved in the mixture, the greater its permeability to water will be. However, with increasing voids content - strength is reduced. Other factors also affect strength, such as: the proportion of sand included in the otherwise singled size 'large' aggregate mixture; just how wet the cement paste is; and the degree of compaction achieved during placement. Until mixing, testing and installation methods can be further standardised to create more consistently durable mixtures, using no fines concrete is likely to be confined to low trafficked pavements only. Notwithstanding this, the particular advantages of the material are such that it is much more likely to be used to construct pavement base courses than it is the foundations levels. Two notable exceptions to this are lightly trafficked conventional modular flag and slab surfaced footways and pervious block pavements which sometimes require hydraulically bound materials to be used to the upper part of their subbase.

<u>Issues affecting all concretes and HBMs</u>

i. All concretes, CBGMs, and other HBMs (other than no-fines concretes) suffer from problems caused by expansion and contraction when they are cast into larger slabs. This can occur both as the material initially cures (causing contraction) and much later, because of temperature loading from the sun. Given the UK's climate, the former of these is the greater concern. Either way, the result can be cracking or buckling of the material. This serves to significantly reduce the longevity of the pavement. Generally speaking, the stronger, quicker setting and less flexible the material is, the more significant these effects are. As such pavement quality concretes suffer the most whilst weaker HBMs that use slow setting binders suffer the least. To overcome these issues engineers intentional split slabs into smaller bays, introducing special joints between these to allow for the expansion and contraction. This effectively pre-empts the cracks and allows them to install other preventative measures in the layers above rather than having to guess where the cracks will occur. It also means that the joints can be designed to mitigate some of problems that untreated cracks create by filling them with materials that prevent water ingress or casting in steel rods to transfer loads between the slabs of adjoining bays. In the case of pavement quality concrete, engineers may also reinforce slabs with steel mesh grids or special fibres to resist the significant contracting forces in the concrete as it cures. However, all the above is of much less concern when these materials are used to the pavement foundation levels that are the subject of this standard. Given that using pavement quality concrete will next-to-never be justified to foundation layers and that, for other concretes and HBMs, the consequences of cracking are far less severe at such depths, cracking is often just accepted and allowed to take place.

j. Finally, designers must consider the rate at which strength in these materials develops in relation to when they need to open them for trafficking – either by construction vehicles or upon full opening of the street. All materials take considerable time to develop full strength - typically many weeks. Whilst full strength isn't necessarily required in order for trafficking to begin and special additives can be used to speed up strength development, the minimum necessary ultimate strength may still take much longer to harden sufficiently. In such instances designers may choose to use mixtures that have an ultimate strength greater than they require in order that that lower strength required for trafficking can be reached earlier.

2.5 Geo-cellular unit (GCU) assemblies

a. A GCU assembly consists of individual or interlocking load bearing boxes, each of which may be up to 95% void (empty space). Assemblies are typically able to incorporate gaps in their structure (sometimes using special bridge components) to permit the passage of underground utilities through them. Where designed to robustly inter-lock and create a 'raft' they can serve as 'subbase replacement systems' for trafficked pavements. There are many different products available that come in all sorts of depths from 85mm upwards. As the structural performance will vary from product to product, not all are appropriate for shallow use close to the surface of trafficked pavements where imposed loads are greatest.

b. There are three typical instances in which GCU assemblies may be used to pavement foundations. In all of these, the assembly effectively serves to 'suspend' the pavement over the structure it creates.
   i. To create under-pavement reservoirs for infiltration or attenuation storage of surface water by leaving the units empty
   ii. To create under-pavement rooting zones for street trees (sometimes referred to as 'soil vaults') by filling the assembly with soil.
   iii. As part of a 'no-dig' construction when it is necessary to construct a pavement over the rooting zone of an existing tree and it is not possible to significantly alter ground levels.

c. They may also be used for a wide range of less common purposes including as drainage blankets above subgrades at the very bottom of the pavement structure or as part of 'break out corridors' for roots under pavements that link tree pits to gardens and other nearby soil resources.

2.6 Geo-confinement systems

a. Geo-confinement systems are open lattice-like sheets or panels of high tensile strength synthetic material. Though similar to geo-cellular units they are not designed to form large box-like void structures that can replace other pavement layers; they are designed to be used in conjunction with unbound granular mixture layers, strengthening them in the process. The aggregate is filled into the open lattice. The cells created by the lattice confine the aggregate and so prevent it spreading sideways. This improves the stiffness of the aggregate layer and may mean that the depth of this can be reduced. A good example of how this works in practice is to consider a pyramid made out snooker or pool balls. Were you to push down on the top of the pyramid, it would quickly collapse. However, were you to confine the bottom layer of the pyramid by placing the setting up triangle around it, it would be much stiffer and less likely to collapse.

b. There are two principle types of geo-confinement systems.
   i. Geo-grids are relatively flat sheets of material with the lattice being made up of individual ribs. The grid formed by the ribs could be square, triangular or any number of shapes (though triangular grids often perform best).
   ii. Cellular confinement systems are similar to geo-grids but the lattice is extruded upwards so that the geosynthetic confines the aggregate fill to a greater depth.

   Both geo-grids and cellular confinement systems may sometimes be combined with other geo- synthetics (such as geotextile filters) to create geo-composites that can perform the functions of both materials in a single product.

c. Geo-confinement systems may be used for a number of reasons. These include to:
   i. Increase the stiffness of capping layer when a subgrade is very weak (and where used as part of geo-composite to prevent the subgrade from contaminating foundation layers).
   ii. Prevent the migration of unbound aggregate courses when they need to be trafficked by site vehicles during construction works.
   iii. Reduce the required thickness of unbound aggregate courses where there are limitations on available cover (e.g. when a deep pavement construction is not possible because of constraints). A common example is where lightly trafficked surfaces need to be installed over vulnerable tree

roots that are close to surface but which cannot be cut.

2.7 Fill for filter drains and other sub-drains

a. Filter drains are gravel filled trenches that collect and move water. They may also treat pollution. The trench is filled with free draining granular material. It often has a perforated pipe in the bottom to collect water.

b. In urban areas, filter drains are generally unseen, being located either beneath of or within pavement constructions (or soft landscaped areas) to collect and remove any water that might be accumulating there as ‘sub drains’. This water could have got in from the surface (having percolated down through the materials above – either intentionally or accidently) or it might have risen up from the ground beneath (ground water). Were it not removed it could undermine constructions. However, filter drains can also be used to collect and remove water directly from the surface. Where this is the case then the gravel trench is left open so that surface water can drain into it. This is a common site along the hard shoulders of rural roads and motorways.

c. In order to function correctly, the gravel used within the drain must be carefully graded to be sufficiently permeable whilst at the same time performing its important filtration role and supporting any materials above.