

Guidance Document

G0054A Civil Engineering - Earth Structures

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1 Purpose

- 1.1** The purpose of this Guidance Document is to support LU Standard S1054 (Civil Engineering – Earth Structures) and give guidance on established good practice solutions that meet the requirements of that standard. Hereinafter in this Guidance Document any references to “the Standard” relate to that standard.
- 1.2** The Earth Structure assets comprise:
 - a)** embankments of soil with slopes more than 1m high;
 - b)** cutting slopes of soil and rock (chalk) more than 1m high.
- 1.3** LU guidance on established good practice solutions of a general nature applying to all civil engineering assets, including the Earth Structure assets, is provided in LU Guidance Document G050 (Civil Engineering – Common Requirements) that supports LU Standard S1050 (Civil Engineering – Common Requirements). Those documents should be consulted along with this Guidance Document.

2 Scope

- 2.1** The Scope of this Guidance Document covers all the Earth Structures assets owned by LU through the following life cycle stages:
 - a)** Inception and design
 - b)** Construction, installation, testing and commissioning
 - c)** Inspection
 - d)** Analytical assessment
 - e)** Condition assessment and certification
 - f)** Maintenance
 - g)** Strengthening and renewal
 - h)** Decommissioning
- 2.2** This Guidance Document mirrors the sub-section headings of LU standard S1054 (Civil Engineering – Earth Structures) at the start of each life cycle section, with additional sub-sections added at the back of each life-cycle section where there is further guidance material available to LU that does not specifically relate to the sub-section headings used in the Standard, or is better set out separately.
- 2.3** The knowledge for the guidance presented in this Guidance Document is derived substantially from historical information preserved in earlier LU documents and so pre-dates some important recent developments in provision and management of Earth Structures for transportation infrastructure. Nevertheless, given the age and characteristics of the LU surface railway the historical knowledge should be taken into account in applying current practice. Specific references to current good industry practice have been included in this Guidance Document where available.
- 2.4** Publications by CIRIA are a valuable source of guidance on current construction industry good practice. The following publications are of particular relevance to construction works at Earth Structures for transportation infrastructure:
 - C514 - Grouting for ground engineering
 - C515 - Groundwater control - design and practice
 - C516 - Modular gravity retaining walls - design guidance

C548 - Innovation at the cutting edge: the experience of three major infrastructure projects

C574 - Engineering in chalk

C580 - Embedded retaining walls - guidance for economic design

C591 - Infrastructure cuttings - condition appraisal and remedial treatment

C592 - Infrastructure embankments - condition appraisal and remedial treatment. 2nd edition

C637 - Soil nailing - best practice guidance.

2.5 This Guidance Document replaces 5-01304-005. The Guidance Document has been re formatted and re-numbered. There were no technical changes.

3 Guidance

Notes: Earth Structures form a fundamental part of the LU surface railway system. Of the approximate 463km of track in total of the system, 270km is above ground in surface sections and along these there are some 210km of Earth Structure assets, roughly evenly divided between embankments and cuttings. The remainder of the surface railway is track at grade or is on other structures such as bridges, viaducts and full-height retaining walls.

Approximately 90% of the surface system is now more than 80 years old, so that given the tendency of Earth Structures to deteriorate with time, many of these assets have shown signs of distress in recent years, with a corresponding requirement for increased maintenance to remain fit for duty.

LU have established by experience, and through research and analysis, a considerable knowledge of how to manage the Earth Structure assets along the railway. Much of this relates to maintenance, and methods of strengthening and renewal when maintenance is no longer an economic option for keeping the asset fit for duty.

As most LU Earth Structures were constructed at a time when knowledge of soil mechanics was at best rudimentary and before equipment for large scale fill compaction had been developed, the standard of original design and construction was poor. Much effort in the management of LU Earth Structures today results from those unsatisfactory practices. It is known from the investigation of the existing embankment sections that many local failures had occurred during and shortly after construction, but little useful contemporary information is available to understand and quantify the actual construction difficulties and failures that occurred. This leads to uncertainty in planning improvement works, for instance as to whether in situ materials can now develop their full intact strength, or whether they have been pre-sheared resulting in a lower strength, and what is the actual variation of strata within the fill.

A failure to manage the Earth Structures could allow their asset condition to fall below the minimum standard for them to remain fit for duty as defined in LU standard S1054 (Civil Engineering – Earth Structures). A reduction in factor of safety occurs and the collapse of a structure may follow. The consequences for the operation of the railway could be extremely serious.

Remedial works undertaken on an emergency basis are substantially more costly than Strengthening and Renewal works carried out within a planned management programme.

Maintenance and Strengthening and Renewal works on many railway Earth Structures are made more difficult by restricted access, especially in urban areas, and because of

limited clearance between the track and the operational boundary within which such works have to be carried out.

Good practice for dealing with Earth Structure instability is to identify and remedy the problem before it becomes an earthworks failure or leads to the imposition of mitigation measures e.g. emergency speed restrictions on track, in order to minimise the detrimental effect on the railway operation and safety. To achieve this requires effective communication between the parties responsible for railway operation, track maintenance and Earth Structures management, to ensure the timely exchange of information and guidance.

3.1 Inception and design

3.1.1 General

3.1.1.1 The Required Duty for Earth Structures is reconsidered annually and published in the Earth Structures Foundation Document.

3.1.1.2 Design and construction of Earth Structures for the LU railway will in some situations be equivalent to normal construction elsewhere; this would be the case for instance if a new embankment or cutting were to be constructed. The requirements for this class of work are fully covered within sections 3.1 and 3.2 of the Standard, and relevant guidance on those requirements is included within sections 3.1 and 3.2 of this Guidance Document.

3.1.1.3 There are other types of works at the Earth Structures that are peculiar to the management of the aging infrastructure of the LU surface railway. These works arise where Strengthening and Renewal is needed to stabilise deteriorating Earth Structure slopes. Such works give rise to specific additional design and construction issues outside the concerns covered in sections 3.1 and 3.2 of the Standard and this Guidance Document. Section 3.7 of the Standard contains the additional LU requirements for such works, and section 3.7 of this Guidance Document sets out some key accumulated knowledge of LU in this area of work.

3.1.1.4 Design for track-bed and formation is a civil engineering issue although the requirements are included within the track-bed standard - LU Standard S1160 (Permanent Way – Track Support). Historical considerations related to the trackbed and formation are therefore included in this Guidance Document.

3.1.2 Inception

The inception and subsequent design processes for Earth Structure assets follow the procedures set out in LU Standard S1538 (New or Altered Assets – Approvals Prior to Bringing Into Use). Guidance is given in LU Guidance Document G050 (Civil Engineering – Common Requirements).

3.1.3 Design process

3.1.3.1 Design concessions are required to cover any non-compliance of the submitted design with LU Standards and requirements. These design concessions are requested by the design organisation in accordance with LU Standard S1641 (Concessions to Standards) and need to be formally approved by LU before becoming part of the design.

3.1.3.2 Prior to starting detailed design for new construction or strengthening and renewal, the appointed design organisation is required to create a Conceptual Design Statement (CDS). The CDS is to set out the proposed design criteria, including design loadings, groundwater and soil parameters and design methods, to be adopted in the design of all aspects of the works. The required content and format for the CDS document is defined in S1538. The CDS document needs to include sufficient detail to enable the approval of the design proposals in principle.

- 3.1.3.3** The CDS design studies may establish a shortage of information on which to base the parameters for design. In that case a site investigation needs to be initiated to obtain the further geotechnical data required including the use of instrumentation where appropriate to provide information over a suitable period of time. The design CDS shall set out the requirements for the additional information to be acquired. The site investigation works require a separate investigation CDS and a CWS. The detailed design can not be completed until all the design information requirements set out in the design CDS have been addressed.
- 3.1.3.4** On completion of the detailed design, an independent design check needs to be undertaken by a separate design team in accordance with LU Standard S1538 (New or Altered Assets – Approval Prior to Bringing Into Use). Usually this will be a Category 2 check and can be carried out within the design organisation, provided it is carried out by suitable staff not involved in the original design. A check certificate endorsed by a partner, director or manager of the design organisation and by the independent checking organisation is required for the drawings and design. The check certificate shall confirm that the design has been carried out in accordance with the approved CDS.
- 3.1.3.5** Checking and certification of all aspects of Earth Structure design is undertaken in accordance with LU Standard S1538 (New or Altered Assets – Approval Prior to Bringing Into Use). The process may include a need for formal design reviews and approval from statutory bodies.
- 3.1.3.6** The Earth Structures standard requires that a Geotechnical Specialist, as defined by the Institution of Civil Engineers, should be in charge of the design of Earth Structures, and a separate Geotechnical Specialist should sign the check certificate. This reflects the special difficulties associated with the behaviour of natural ground and earthwork materials, including over time, and the consequent need for adequate experience in earthwork design in order to perform these roles.
- 3.1.4 Structure gauge**
No specific advice.
- 3.1.5 Geotechnical information and site investigation**
- 3.1.5.1** The information to be collected and the studies to be made in order to establish design parameters are extensively set out in the Standard. For most cases the critical design values occur in the long-term.
- 3.1.5.2** It is recognised in the Standard that an in depth examination of all the aspects, especially in the long-term, will not be justified by the scope of most projects, and therefore historically proven values for design parameters of the most common materials have been set out in section 5.5.1 of the Standard that should be adopted in normal design. It is recognised, however, that projects may arise with conditions sufficiently different to historic experience that alternative design parameters are appropriate provided they have been justified by adequate investigation and analysis.
- 3.1.5.3** The investigation of chalk should consider the information in CIRIA C574 Engineering in Chalk, 2002.
- 3.1.5.4** The Observational Method as described by Peck(1969) may be appropriate in circumstances where the actual behaviour of the ground during construction is observed and where in practice comparable previous experience has been substantially more favourable than was predicted by available conventional design procedures. The differences generally arise from the difficulty in obtaining realistic small strain deformation parameters and valid short term strength values for use in the analysis.
- 3.1.5.5** The observational method allows economy in temporary works design, but at the expense of extra monitoring and the provision of capability to add additional ground

support measures if they prove to be needed in practice. The method is not a substitute for investigation or design, and should be applied rigorously as described by Peck (1969) in order not to prejudice safety.

3.1.6 Groundwater

3.1.6.1 The Standard requires that stability analyses be made for the most unfavourable anticipated conditions during the design life of the asset. Monitoring is recommended to establish site specific values over an annual seasonal cycle, which may be used if sufficiently comprehensive, to adjust the historically established moderately conservative values otherwise required by section 3.4 of the Standard.

3.1.6.2 Particular attention should be paid to potential water seepages at the faces of cutting slopes in side-long ground, where permeable and stratified soils may give rise to significant outflows following exceptional wet winter weather, especially from the up-slope if there is an extensive hinterland of high ground.

3.1.6.3 Clearance and modification of existing, or the construction of new, drainage systems including ditches, streams, rivers, lagoons and ponds including any protection, lining, revetment or other works may be required for the construction of the earthworks. These should be undertaken in accordance with LU Standard S1052 (Civil Engineering – Gravity Drainage Systems)

3.1.6.4 Reference should also be made to Guidance Document G052 (Civil Engineering – Gravity Drainage Systems). This document provides guidance and presents typical drawings detailing good practice for drainage design.

3.1.7 Design life

To achieve the required design life all elements embedded within the earthwork contributing to its stability, other than drainage covered by LU Standard S1052 (Civil Engineering – Gravity Drainage Systems), need to be designed for the full design life, i.e. 120 years.

3.1.8 Fire resistance

Conventional earthworks generally have minimal fire concerns. However, works involving ground improvement or reinforcement will need to address the risk of fire damage and include adequate protection. These concerns are specifically raised in the section of the Standard dealing with geosynthetics, and they clearly also apply to the possible use of certain light-weight materials such as polystyrene. Guidance is given in the relevant sections below.

3.1.9 Constructability and temporary works

3.1.9.1 Considerations with regard to temporary works play an important role in the planning of construction works for Earth Structures, including strengthening and renewal works. In general these considerations have much in common with those for other types of civil engineering assets and reference should be made to LU Standard S1050 (Civil Engineering – Common Requirements) and its associated Guidance Document.

3.1.9.2 Temporary works commonly installed include the construction of:

- a) site compounds;
- b) site access and haul roads;
- c) temporary bridges;
- d) scaffold access ramps and working platforms;
- e) earthwork haul roads and working platforms;
- f) protection and support of existing structures and services;
- g) support to excavations.

- 3.1.9.3** The extent of temporary works required for Earth Structure construction, maintenance and strengthening and renewal works is a function of the access difficulties, the longitudinal extent of the site and the need to access and work on steep Earth Structure slopes in limited working space on sites which are directly adjacent to a live working railway.
- 3.1.9.4** A CDS should be prepared for major temporary works that may have a significant impact on the railway e.g. a temporary bridge across the tracks (LU Standard S1538 New or Altered Assets – Approval Prior to Bringing Into Use).
- 3.1.9.5** Design calculations should be undertaken to demonstrate the adequacy of all temporary measures utilised during the works. In many Earth Structures projects these will involve establishing the short-term stability of temporary cut slopes that are needed to allow permanent works to be put in place. Such calculations may lead to time limits on the opening of temporary cuts before slope support is restored that form part of the project detailed design.
- 3.1.9.6** Reference should be made to LU Standard S1156 (Gauging and Clearance) for track clearance requirements when working on or adjacent to the railway.
- 3.1.10 Impact on the operational railway and adjacent structures**
- 3.1.10.1** The loading impact of railway Earth Structures on adjacent assets will rarely be significant, provided stability of slopes is maintained. However, due to the large plan area of earthworks, they often have substantial conflicts within existing and planned service lines in urban areas, and this is an aspect that needs to be addressed rigorously, even at the ground investigation stage.
- 3.1.10.2** The satisfactory performance of the Earth Structure embankments in supporting the railway within required movement tolerances is significantly related to the crest width arising from the proscribed clearance from the nearside running rail to the lineside services at the slope crest, and the additional crest width needed to adequately support and provide access to those services. A similar crest width is required for track performance even if no services are to be provided initially.
- 3.1.11 Provision for inspection and maintenance**
- 3.1.11.1** The design should generally involve minimum maintenance during the design life, which would normally be limited to control of vegetation and animals and the management of drainage. Any additional maintenance anticipated needs to be quantified and justified in the design.
- 3.1.11.2** Maintenance alongside a working railway is potentially a dangerous activity giving rise to the requirement in the Standard for design provision of an adequate unobstructed cess.
- 3.1.12 Design standards**
- 3.1.12.1** Modern design standards generally, and BS EN 1997-1 (Eurocode 7) in particular, make use of a number of partial factors in establishing minimum safety criteria for design of earthworks. The experience of LU on the requirements for their ageing accumulation of Earth Structures had been established based on the application of a single partial factor to the strength parameters and recording this as the factor of safety. In effect the other partial factors are considered equal to 1. However, more recently LU Standard S1054 (Civil Engineering – Earth Structures) has been updated to follow principles of BS EN 1997-1 as well as the principles of progressive failure for high plasticity overconsolidated clay soils. Guidance for slope stability analysis, soil parameters, pore pressures and partial factors is provided in LU Guidance Document G0054B.
- 3.1.13 Loading**
- No specific advice.

3.1.14 Stability

See section 3.1.12.1 and section 3.4 of this Guidance Document.

3.1.15 Ground improvement techniques

3.1.15.1 Ground improvement can be achieved by using dynamic compaction. This is achieved by dropping a free falling weight a number of times at predetermined spacing on the surface of the ground or fill. This aspect of the work should be completed before commencement of construction of any permanent works. This method of compaction is unlikely to be used close to a live railway. Other methods of ground improvement include:

- a) provision of drainage i.e. vertical drains;
- b) vibro-flotation techniques;
- c) installation of stone columns;
- d) installation of lime columns.

3.1.15.2 For advice and guidance on ground improvement techniques reference should be made to the following publications:

- a) British Geotechnical Society, 1997 Ground Improvement;
- b) ICE 'Specification for Ground Treatment';
- c) CIRIA C573, 2002 Guide to Ground Treatment;

3.1.16 Geosynthetics

Uses of geosynthetics

3.1.16.1 The strengthening of an Earth Structure slope by inter layering geogrids or geotextiles into an embankment will resist the tendency for the outer edges to soften and slip with time. The technique reduces future maintenance costs and enable steeper slopes to be built than normally possible with fill material. This allows embankments to be built to a greater height within a given base width.

3.1.16.2 Geosynthetics have the following functions when used in ground engineering works:

- a) separation - the geosynthetic forms a boundary between different soil or rock materials, thus segregating two or more particle sizes;
- b) reinforcement - the geosynthetic imparts tensile strength to a reinforced soil system;
- c) filtration - the geosynthetic effectively retains particles while allowing water to flow through with little or no increase in pore pressure;
- d) drainage - the geosynthetic effectively allows water to flow in the plane of the fabric, thus allowing drainage of water away from a structure or system.

3.1.16.3 Those primary functions stated above also serve as secondary functions to each other in given applications. In erosion control the primary function of a geosynthetic is filtration with the separation function playing a secondary role.

Design principles

3.1.16.4 Although relevant codes of practice for the use of geosynthetics are not yet available, research has been conducted into the properties of geosynthetic materials and literature is available detailing various aspects of design and construction using the materials (e.g. BD70/03 in the HA Design Guidance Document for Roads and Bridges). The important design considerations in the specification of geosynthetics for any civil engineering work include:

- a) properties relevant for adequate design and performance;

- b) standardised test methods for obtaining the relevant geosynthetic properties;
- c) construction methods to ensure minimal geosynthetic damage and guarantee that the design life is achieved.

3.1.16.5 Safety aspects need to be considered throughout the geosynthetic design process. The design and its amplification in the specification and conditions of contract should emphasise safety requirements; these should include, for all phases of the work, but not be limited to:

- a) the effect of work on neighbouring land and structures;
- b) demolition of existing structures;
- c) excavation and groundworks;
- d) support of soil, structures and services;
- e) protection of railway and construction workers and the public around the site;
- f) access for materials;
- g) access and manoeuvring space for plant;
- h) temporary works;
- i) materials in temporary and permanent works;
- j) construction sequence and stability;
- k) protection of trains and permanent way during all stages of the works.

3.1.16.6 It needs to be established that the materials and methods to be employed satisfy the requirements of COSHH and HASAWA.

Materials

3.1.16.7 There are six generic types of geosynthetics available for use in the civil engineering industry. These are as follows.

- a) Woven fabrics produced on looms. In the majority of these fabrics, the warp and weft threads lie at right angles to one another;
- b) Nonwoven fabrics produced on heat bonding or needle-punch machines. Both types are made from randomly laid fibres which are either heated between rollers until they partially melt together, or are agitated by barbed needles to produce an artificial felt;
- c) Directionally structured fabrics (DSF). Fabrics produced on warp knitting machines where rows of needles effectively knot the fibre intersections. Fibres are arranged in an orderly fashion, but can be orientated in a wide variety of directions;
- d) Open mesh textile grids and nets made by weaving or warp knitting, as well as geogrids;
- e) Impermeable geomembranes, particularly those made from HDPE;
- f) Geocomposite materials such as fin drains, DSF and nonwoven composites and the recently developed laminated multi-layer composites where nonwovens, wovens and membranes are bonded together.

3.1.16.8 Geosynthetics are manufactured from a variety of artificial polymers:

- a) polyamide;
- b) PETP;
- c) polyethylene (LDPE and HDPE);

- d) polypropylene;
- e) PVC;
- f) CPE.

3.1.16.9 Comparisons of the properties of the four main polymer families are shown in Table 1.

Polymer group Comparative properties	Polyester	Polyamide	Polypropylene	Polyethylene
Strength	●	+	#	#
Elastic modulus	●	+	#	#
Strain at failure	+	+	●	●
Creep	#	+	●	●
Unit weight	●	+	#	#
Cost	●	+	#	#
Resistance to				
Ultra violet light Stabilised	●	+	●	●
Unstabilised	●	+	+	#
Alkalis	#	●	●	●
Fungus, vermin, insects	+	+	+	●
Fuel	#	#	+	+
Detergents	●	●	●	●
● High + Medium # Low				

Table 1: Comparative properties of general polymer families

3.1.16.10 Geosynthetics supplied to LU or its suppliers for use in Earth Structures should have a current BBA Certificate, be fit for purpose and conform with the requirements of the standard

3.1.16.11 Consideration needs to be given to the minimum design life required for the geosynthetic. For permanent works the geosynthetic is to be sufficiently durable so as to maintain its integrity for a minimum period of 120 years when installed. Guidance on the assessment of geosynthetic durability properties is given in DD ISO/TS 13434:2008

3.1.16.12 In most cases the properties and suitability of a geosynthetic can be gained and assessed from the manufacturers data provided the tests have been performed in accordance with the relevant British and ASTM Standards.

3.1.16.13 For safety critical applications or where a special geosynthetic property is required, tests may need to be carried out to obtain the required property or to confirm the manufacturer's figures. The sampling and testing procedures should be in accordance with the following sections.

Sampling and testing

3.1.16.14 The relevant properties of the geosynthetic to be considered in design and the selection of a geosynthetic material will depend largely on the intended function and location of the material. However some of the common geosynthetic properties to be measured and the relevant British Standard (where available) and ASTM standards are included in Table 2.

Property to be measured	Test name	Suggested test method
Mass per unit area	Determination of mass per unit area	BS EN ISO 9864:2005
Nominal thickness/dimensions	Determination of thickness at specified pressure, single layers	BS EN ISO 9863-1:2005
Apparent pore size O_{90}	Determination of characteristic opening size	BS EN ISO 12956:2010
Per cent open area	Per cent open area for woven geotextiles	U.S. Waterways Experimental Station AD-745-085
Tensile creep	Determination of the tensile creep and creep rupture behaviour	BS EN ISO 13431:1990
Compressive creep	Determination of compressive creep properties	BS EN 1897:2001
Compressive strength	Determination of compression behaviour. Determination of short-term compression behaviour	BS EN ISO 25619-2:2008
Tensile Strength	Wide-width tensile test	BS EN ISO 10319:2008
Tensile Strength	Tensile test for joints/seams by wide-width strip method	BS EN ISO 10321:2008
Puncture resistance	Static puncture test (CBR test)	BS EN ISO 12236:1996
Tear resistance	Trapezoid tearing strength of geotextiles	ASTM Designation D 4533-85
Abrasion resistance	Abrasion resistance (sand/paper/sliding block method)	ASTM Designation D 4886-88
Friction (against standard sand)	Determination of pull out resistance in soil	BS EN 13738:2004
Flexibility (bending resistance)	Stiffness of geotextiles	ASTM Designation D 1388
Permittivity at 50 mm hydraulic head in-isolation	Determination of permeability of water flow	BS EN ISO 12958:2010
Transmissivity at hydraulic gradients 0.01, 0.1 and 1.0 and at confining stresses 25, 50, 100, 200 and 400 kN/m ² between rigid platens	Determination of water flow capacity in their plane	BS EN ISO 12958:2010
Durability	Guidelines for assessment of durability	DD ISO/TS 13434:2008

Table 2: Relevant geotechnical properties and test methods

3.1.16.15 For the purpose of sampling, consignments of geosynthetics should be separated into batches according to their material specification, physical characteristics (e.g. rolls or packages) and manufacturer or main supplier. The number of samples selected at random from each batch should be determined by taking the cube root of the number of items in the batch. If the cube root is a fraction, then the next higher integer should be taken, as set out in Table 3.

Number of rolls/ packages in batch	Number of rolls/packages in batch sample
1 - 2	1
3 - 8	2
9 - 27	3
28 - 64	4
65 - 125	5
126 - 216	6
217 - 343	7
344 - 512	8
513 - 729	9
730 - 1000	10

Table 3: Number of rolls or packages to be selected from a batch as batch sample

3.1.16.16 The method of determining the number of specimens to be tested from the sample rolls or packages will usually be contained within the specified test method (Table 3), however, the sampling technique used should be as follows.

- a) take samples from the whole width of each roll or package using an appropriate instrument which will not damage the material away from the cut edges;
- b) the length of each sample should be chosen according to the needs of the testing programme;
- c) the first two turns and last two metres of any rolled products should be excluded, but not any soiled or damaged material;
- d) the samples should be clearly marked to show the machine direction during manufacture then numbered and rolled in the direction of their smallest dimension;
- e) the samples should be stored away from ultra violet light, heat and dust;
- f) when required, test pieces in accordance with the specified test method (Table 2) should be carefully cut from the samples ensuring that no part of any test specimen is situated less than 100 mm from the edges of the sample. Also they should be taken from the general surface of the sample so that they are equally distributed each side of the median line of the sample, parallel to the machine direction during manufacture and so that their position is systematically different in the longitudinal and cross directions, (in the case of woven materials, this implies that no two test specimens should contain the same warp and weft yarns.

3.1.16.17 The test specimens should be conditioned for a minimum period of 24 hours prior to testing in accordance with either of the atmospheric conditions shown in Table 4.

Condition	Temperature	Relative humidity
A	23 ± 1°C	50 ± 5%
B	20 ± 1°C	65 ± 2%

Table 4: Conditioning

3.1.16.18 The factors which determine whether a geosynthetic will perform the functions required of it are its mechanical properties; its hydraulic properties and its performance within

the environment in which it is placed. Laboratory testing is the means by which these characteristics are assessed and evaluated. The designer should specify the required geosynthetic property tests from the following list.

- a) Index tests:
 - I. mass per unit area;
 - II. nominal thickness/dimensions;
 - III. apparent opening size;
 - IV. per cent open area;
 - V. tensile strength and strain;
 - VI. puncture resistance;
 - VII. tear resistance;
 - VIII. abrasion resistance;
 - IX. friction;
 - X. permittivity;
 - XI. joint load carrying efficiency and deformability.
- b) Performance tests:
 - I. friction;
 - II. permittivity in-soil.
- c) UV radiation resistance:
 - I. acid resistance;
 - II. alkali resistance;
 - III. biological resistance;
 - IV. tensile load-strain-time-temperature characteristics;
 - V. repeated loading characteristics.
- d) Testing of geosynthetic material should conform with the requirements of BS EN ISO 13431:1990, BS EN 1897:2001. Where a required geosynthetic property test method is not included, the suggested test method is indicated in Table 2.

Design considerations - General

3.1.16.19 The physical properties of a geosynthetic should be utilised appropriately in any civil engineering works. Since geosynthetics can have a variety of functions, design requirements are diverse. For reinforcement, the emphasis is on mechanical properties such as strength and modulus, for filters it is on properties such as water permeability and soil tightness. Geosynthetics must also fulfil secondary functional requirements e.g. a certain amount of ultra violet resistance is needed, or they must have resistance to mechanical wear and tear if construction equipment is to be driven over them. The suitability of a geosynthetic should be checked against these functional requirements during the design phase of a project.

3.1.16.20 Where a geosynthetic is incorporated into works for a permanent purpose, its properties, both beneficial and detrimental to the performance of the structure should be taken into account in the design of the works. A geosynthetic may also be used for a temporary purpose, such as to keep materials separate during construction, becoming redundant as construction proceeds. Having performed its temporary function the presence of a geosynthetic may be detrimental to the permanent works, e.g. forming a preferential slip surface or becoming clogged when good drainage is

required. Consideration of the use of geosynthetics for a temporary purpose should therefore consider their effect on the permanent works.

Design considerations - Reinforcement applications

- 3.1.16.21** HA Advice Note HA 68/94 is to be used for the design of reinforced soil to strengthen earthworks. This applies to the construction of new earthworks, the widening of existing embankments, the steepening of existing cuttings and the repair of failed slopes.
- 3.1.16.22** The geosynthetic material is to possess adequate tensile strength to withstand all external forces on the reinforcement. The design tensile strength needs to take into consideration all necessary partial safety factors in respect of conditions that could lead to strength deterioration in the geosynthetic material. These conditions will include temperature, soil environment, mechanical damage and any other situation that could lead to deterioration during the design life of the structure.
- 3.1.16.23** For permanent structures, where a design life of 120 years is required, the creep properties of the geosynthetic material is to be taken into consideration. An adequate factor of safety needs to be applied to the tensile strength to take account of creep. In order for a geosynthetic to perform adequately for the design life of a structure, only a fraction of the short term tensile strength value of the material can be applied as a sustained long term load. The permissible long term load for polyester is 50% of the tensile strength, for polyamide 40% and for polyethylene and polypropylene below 25%.
- 3.1.16.24** Where a geosynthetic material is used for slope reinforcement the material needs to possess adequate frictional properties to prevent sliding between the material and the surrounding soil. Where the material is used in reinforced walls it needs to possess adequate frictional properties to provide sufficient bonding with the retained soil in order to prevent wall deformation.
- 3.1.16.25** Where the geosynthetic is required to perform a dual role of reinforcement and drainage, the permeability properties of the material needs to be adequate for performing the drainage function.
- 3.1.16.26** The geosynthetic material used is to possess adequate chemical and biological resistance with regard to the soil and water environment. Adequate partial factors of safety needs to be applied to the ultimate tensile strength to allow for chemical and biological degradation in aggressive environments.
- 3.1.16.27** HA Technical Memorandum BD 70/03 provides design criteria and construction requirements for reinforced and anchored earth retaining walls.

Design considerations - Drainage, separation, filtration and erosion control applications

- 3.1.16.28** In drainage applications the geosynthetic allows water to flow in the plane, or normal to the plane of the material thus allowing drainage of water away from a structure or system. For separation the geosynthetic is used to form a boundary between different soil or rock materials thus segregating two or more particle sizes. In filtration the geosynthetic retains soil particles while allowing water to flow through with little or no increase in pore pressure to the surrounding soil. All the functions of the geosynthetic material of drainage, separation and filtration are utilised in achieving erosion control.
- 3.1.16.29** The design criteria for geosynthetics in drainage applications should specify the appropriate pore structure to eliminate (or reduce to the minimum) the passage of soil through the material, to provide an adequate seepage rate, and to ensure clogging resistance. For a geosynthetic to act as a filter it is essential that a condition of equilibrium is established at the soil/geosynthetic interface as soon as possible after installation to prevent soil particles from being piped indefinitely through the

geosynthetic; if this were to happen drainage would eventually become blocked. Some requirements of the geosynthetic material for adequate performance are given below.

3.1.16.30 The geosynthetic material chosen must possess adequate hydraulic properties to perform the required functions. It is important to note that, where the geosynthetic material is expected to be subjected to field stress, the hydraulic properties quoted may need to be obtained from tests performed under the anticipated stress conditions. This is particularly required where compression of the pores, from the applied stress, is likely in a material where in-plane flow is essential.

3.1.16.31 For soils with predominantly granular fractions the following formula for geotextile filter criteria should be used:

a) piping limit: $O_{90} \leq D_{85 \text{ Soil}}$;

b) permeability limit: $O_{90} \geq D_{15 \text{ Soil}}$ and $O_{90} \geq 0.05 \text{ mm}$.

where O_{90} is the required AOS of the geosynthetic filter. $D_{85 \text{ Soil}}$ and $D_{15 \text{ Soil}}$ are specific particle fractions of the soil to be filtered.

3.1.16.32 For soils with significant cohesive fractions the following formulae should be used:

a) piping limit: $O_{90} \leq 0.12 \text{ mm}$;

b) permeability limit: $O_{90} \geq 0.05 \text{ mm}$ and minimum volume water permeability = 30 litres/m²/sec (BS 6906 Part 3, 1989).

where O_{90} , $D_{85 \text{ Soil}}$ and $D_{15 \text{ Soil}}$ are as above.

3.1.16.33 The geosynthetic material is to possess adequate chemical and biological resistance with respect to the soil and water environment. In the railway environment the effect of chemicals such as carriage cleaning acids and de-icing salts (from roads at bridges) need to be considered.

3.1.16.34 The geosynthetic material is to possess adequate resistance to ultra violet light degradation to ensure that deterioration does not occur when the material is exposed during installation and construction and, in the case where the material is to be exposed for most or all of its design life.

3.1.16.35 The geosynthetic material is to possess adequate strength to withstand installation and construction forces and to withstand stresses from any applied load without damage to the material.

3.1.16.36 Fin-drains should be durable, resistant to damage during installation and should be correctly designed to possess adequate long term in-plane flow characteristics when subject to both normal and shear stresses from the adjacent soil or fill. Due to problems with crushing, the present application of fin-drains is mainly restricted to smaller structures with lower applied stresses.

Properties	Filtration		Erosion		Separation/reinforcement			
	U	P	U	P	Very high	High	Moderate	Low
Grab strength, kg (ASTM D 1682)	80	36	89	40	120	80	58	40
Puncture strength, kg (ASTM D 751-79)	36	11	36	18	49	33.5	18	13
Burst strength, kg (ASTM D 751-79)	20	9	22	10	30	20	14.5	10
Trapezoidal tear, kg (ASTM D 4533-85)	22	11	22	13.4	33.5	22	18	13.4
Elongation at failure, (ASTM D 1682)	-	-	20 %	20%	-	-	-	-
U - Unprotected drainage trenches	Protection criteria - Fabric is protected when used in							
P - Protected	or below concrete or cushioned by a layer of sand							

Table 5: Minimum geosynthetic properties required to ensure survivability in different applications

3.1.16.37 Details giving minimum geosynthetic strength to ensure survival in different types of applications are shown in Table 5.

3.1.16.38 Some manufacturers' brochures also quote partial factors of safety related to the fill material which are based on loss in tensile strength following performance tests. These partial factors lie between 1.0 for clay and 1.7 for a sharp angular limestone and can be used for preliminary design and choice of geosynthetic material.

Guarantees and warranties

3.1.16.39 Manufacturers, materials suppliers and fixers should be required to provide guarantees for materials and workmanship commensurate to the predicted design life as appropriate.

3.1.17 Instrumentation and monitoring

Monitoring

3.1.17.1 Monitoring is an essential aspect of any Earth Structure construction, maintenance and strengthening and renewal works, and should be addressed at the design stage. Monitoring is specifically included in a contract for collection of information important to verifying the successful completion and design life achieved in the construction. It should be capable of providing the data to verify the satisfactory achievement of the contract requirements and to monitor track and embankment deformation to confirm the performance of the works in accordance with contract requirements and LU Standards. Monitoring is particularly important where new innovative techniques have been adopted as part of the works. The instrumentation should be installed, checked and maintained as consistently as any other element of the works.

3.1.17.2 Post construction monitoring can provide valuable information on the performance of stabilisation measures and can verify their effectiveness at reducing Earth Structure and track deformation. The effectiveness of novel and innovative remedial works solutions should be monitored. Where possible instruments should be installed on structural elements to measure loads, bending moments and shear forces generated on the structure. Analysis of these results from a number of sites where different techniques have been adopted would help to determine optimum design solutions for

various Earth Structure construction, maintenance and strengthening and renewal situations.

3.1.17.3 Following on from a programme of investigations into the behaviour of Earth Structures, some contracts for strengthening and renewal were let with the level of performance required by the stabilisation measures included in the contract in the form of a 'performance statement'. The criteria defined in this performance statement specified the magnitude of deformation allowable both along and across the track after substantial completion of the works. The works had to achieve the requirements of the performance criteria or re-treatment of the Earth Structure was required by the contractor.

3.1.17.4 Additional monitoring instrumentation is usually installed after completion of the works to complement any existing instrumentation installed during the initial site investigation and assessment of the Earth Structure. Care should be taken by the contractor during the works to ensure existing instrumentation is not detrimentally affected by the works. The contract should make provisions for the replacement of any existing instrumentation damaged during the construction, maintenance or strengthening and renewals works.

3.1.17.5 Furthermore, the instrumentation enables enhanced understanding of the Earth Structure behaviour and enables the performance of the works to be monitored to check compliance with the agreed performance criteria.

3.1.17.6 The types of monitoring instrumentation typically installed include:

- a) precise levelling points;
- b) inclinometers;
- c) magnetic extensometers;
- d) rod extensometers;
- e) vibrating wire piezometers;
- f) standpipe piezometers;
- g) Geopiezometers.

Positioning of instrumentation

3.1.17.7 The location of precise levelling monitoring points and instrumentation within the track area should be considered carefully to ensure that the instruments installed are not affected by track maintenance operations such as placement of ballast or ash, or by Guidance Document or mechanical track tamping operations.

3.1.17.8 Precise levelling has in the past typically been undertaken using Hilti nails (with referenced plastic discs) fixed to both ends of the sleeper but the preferred location for precise levelling points is on the top of the running rails. Levels taken on top of the running rails can be referenced by permanent markings on the side of the rails. Levels taken on the running rails are generally considered more consistent than levels taken on the sleeper ends and less likely to be damaged by track maintenance activities. Levels should be taken on both running rails at intervals of typically every third sleeper. When sites are greater than 200m in length this interval can be increased to every sixth sleeper. All precise levelling points should be related to a stable datum or deep borehole datum where necessary.

3.1.17.9 To help minimise the risk of damage to other types of instrumentation installed the following points should be considered:

- a) all instrument locations should be marked on site using bright visible paint or protective cap;

- b) the local Section Track Manager (STM) and Line Track Manager should be informed of the instrument locations and of the necessary precautions to be taken when working adjacent to the instruments;
- c) where possible arrangements should be made for a representative from the contractor to be present when track fettling and ballasting works are undertaken adjacent to instrument locations to ensure that the integrity of all the instruments is maintained.

3.1.17.10 Although these precautions will help minimise risk of damage, the best approach to ensure the instruments are not damaged would be to position the monitoring instrumentation outside the lineside cable run or as far from the track area as is practicable whilst still being able to monitor the required Earth Structure and track movements.

3.1.17.11 In situations where ballast is deposited on the track which covers the instrumentation and levelling points, arrangements should be immediately made with the local STM for the track to clear the ballast from the instrumentation locations. The STM should keep the contractor informed of when track fettling work is planned and undertaken so that any resulting disturbance to the instrumentation can be allowed for when presenting the monitoring results.

Frequency of monitoring

3.1.17.12 Base readings should be taken from all instrumentation prior to site works commencing and when construction works begin readings should be taken at weekly intervals. On completion of the site works, during the defects correction period, the frequency of readings can be reduced to monthly intervals.

Presentation of monitoring results

3.1.17.13 All instrumentation data should be processed by the contractor and submitted in both tabular and graphical form. All displacements should be presented in millimetres and all plots should be in colour.

3.1.17.14 All levels should be related to the LU tunnel datum and chainages should be referenced in accordance with LU's Location Coding System. Longitudinal precise levelling plots should be produced with negative movements relating to settlement and positive movements representing heave. For transverse precise levelling plots a negative cross level should represent a situation where the outer sleeper is below the inner sleeper.

3.1.18 Landscaping and planting

3.1.18.1 The use of vegetation on Earth Structure slopes can be both aesthetically pleasing and can also serve a major engineering function. Vegetation is essential to the aesthetics of the railway and also has the additional benefits of providing a habitat for wildlife, providing an effective barrier which reduces noise and screens the railway from adjacent properties.

3.1.18.2 Vegetation for slope stabilisation can be used in isolation or in combination with other strengthening and renewal solutions to provide the required stability and aesthetics. An environmental impact assessment should be undertaken to assess the impact of Earth Structures works on the landscape. The design of the works should seek to conserve and enhance the landscape e.g. by encouraging biodiversity.

3.1.18.3 CIRIA organised a research project into the use of vegetation in civil engineering which started in 1986. The findings of this research project were published in CIRIA Use of Vegetation in Civil Engineering, 1990. This document provides practical guidance and sections are dedicated to the topic of the use of vegetation for slope stabilisation. Reference should be made to this document regarding good practice on the use of vegetation for slope stabilisation.

3.1.18.4 Vegetation can have a significant effect on the stability of Earth Structure slopes. The vegetation can act to stabilise the slope in a number of ways including:

- a) reducing water runoff
- b) increasing shear strength by mechanical action of the roots;
- c) increasing shear strength by generating pore suctions in cohesive materials;
- d) trees acting as buttresses against down slope soil movement;
- e) surcharge the bottom of the Earth Structure slope.

3.1.18.5 The most significant contributions to stability come from increases in shear strength due to roots and soil pore suctions.

3.1.18.6 The vegetation can also act to destabilise the slope in a number of ways including:

- a) wind loading on vegetation
- b) surcharge of vegetation;
- c) generation of vertical cracking after dry periods.

3.1.18.7 Factors other than Earth Structure slope stability must also be considered including:

- a) risk of trees falling onto the track
- b) maintenance problems associated with leaf fall;
- c) damage to adjacent properties by settlement and heave associated with trees
- d) seasonal shrinkage or swelling of clay soils;
- e) appearance of the slope.

3.1.18.8 Slope stabilisation techniques using solely vegetation can act to stabilise shallow failure surfaces within the slope which occur within the depth of the root matrix of trees and shrubs. Vegetation can be also used in combination with geotextiles, geogrids, gabions, crib, concrete block and segment walls in a variety of ways ranging from the vegetation providing the integral structural elements of the solution to providing a purely aesthetic function.

3.1.18.9 Generally during the construction of strengthening and renewal works large amounts of vegetation need to be removed to enable construction to take place. In addition all trees within 3m of any new structures installed need to be felled and the remaining roots poisoned with a selective herbicide. Any other trees within the site which are unstable should also be felled as part of the works.

3.1.18.10 Care should be taken during tree felling that no material falls onto the railway track. Any trees which require removing should be felled during engineering hours to reduce risks and so as to not unduly alarm passing railway traffic. Trees away from the track can be felled during traffic hours at the discretion of the Head of Earth Structures asset engineer.

3.1.18.11 The roots of felled trees should be left in place if they do not interfere with the construction of the strengthening and renewal works so that their stabilising effect is available until the new trees or shrubs are fully established.

3.1.18.12 After completion of the strengthening and renewal works re-vegetation and re-grassing of the Earth Structure slopes is required. All landscaping should be undertaken using selected species in accordance with LU Standard S1165 (Landscaping and Vegetation). The aim of the landscaping is to evenly distribute vegetation on the Earth Structure slope to provide a consistent water demand throughout the slope, and minimise variations in seasonal water demand. The planting scheme adopted and plant species selected should reflect this requirement.

3.1.18.13 Trees, shrubs and plants supplied should be fit for purpose and conform with BS 3936 and LU Standard S1165 (Landscaping and Vegetation). The site preparation process prior to planting should include the following procedures:

- a) clear area and apply selective herbicide
- b) excavate a hole larger than the root ball;
- c) incorporate compost into planting hole;
- d) mulch immediate area around the plant with either compost or mulch mat;
- e) apply base fertiliser at the recommended rate of application.

3.1.18.14 The minimum age of whips supplied should be two years; 1 year in seed bed and 1 year transplanted. Acceptable species are defined in LU Standard S1165 (Landscaping and Vegetation). Trees and shrubs planted should be planted in the autumn if possible, reducing the requirements for watering. Tree and shrub saplings when planted should be protected against bark stripping by vermin, by the provision of protective collars where this is appropriate.

3.1.18.15 Completed Earth Structure slopes should be topsoiled where appropriate and grass seeded. Treatment where appropriate for weed control should be carried out during a period of active growth before commencement of seeding. Weed control should not take place at times when rain is forecast during the next 24 hours. Grass seeding should be undertaken in all areas and as specified in LU Standard S1165 (Landscaping and Vegetation). The seed mixture should be low maintenance and adhere to the HA, Series 600 Table 6/5, plus 20% wild flower mix. Grass seeding should generally be undertaken either in the spring or autumn.

3.1.18.16 Planting should be undertaken during the appropriate season to ensure the survival of the plants. Plants that die before the end of the maintenance period should be replaced by the contractor.

3.1.18.17 All landscaping should be undertaken by experienced, qualified and competent staff. It is generally recommended that a specialist sub-contractor be used to undertake this element of the work.

3.1.18.18 The landscaping and vegetation scheme should be designed such as to minimise future maintenance requirements.

3.1.19 Design documents

Specification of earthworks – General

3.1.19.1 Construction documentation for new Earth Structure construction can generally be based on the Highways Agency (HA), Specification for Highways Works (HA), Series 600, 'Earthworks', and relevant sections of the Design Guidance Document for Roads and Bridges. Reference should also be made to the Institution of Civil Engineers (ICE) specification for piling and embedded retaining walls and CIRIA Report C580.

Specification of earthworks – Selection of materials

3.1.19.2 For new construction earthworks on the LU railway, only material deemed acceptable by the Head of Earth Structures may be used as fill. Earthworks materials are classified in Table 6/1 of the HA specification documents into 9 principal classes according to material type. Classes are sub-divided for compaction purposes or due to particular properties or applications. The acceptability of material in each class depends on whether it has a moisture content in the range in which effective compaction is possible. Unacceptable material can be made acceptable by adding water or drying out, but this increases the cost compared to using as dug material.

3.1.19.3 Classes 1 and 2 are general fills which are satisfactory as bulk fill for most embankment construction purposes. They incorporate chalk except when it is likely to be degraded by normal construction plant so that it can not be trafficked; in which case it is designated separately as Class 3, general fill, and restrictions on working methods and seasonal working apply.

3.1.19.4 Classes 4 and 5 are generally used as fill to landscaped areas and for topsoiling and turfing respectively.

3.1.19.5 Classes 6 to 9, are selected or processed fill materials which have special roles

Specification of earthworks – Topsoil

3.1.19.6 Existing topsoil material should be stripped from areas of cutting, and from areas to be covered by fill unless it is an important part of a thin crust over very weak material, when it is best left in place. Wherever practicable topsoil should be immediately used after its stripping and if not should be stored in suitable low stockpiles.

Specification of earthworks – Excavations and cuttings

3.1.19.7 Excavations for foundations and trenches should be adequately supported at all times. Where excavations are permitted to be battered they should be suitably benched prior to backfilling and compaction. Excavations requiring backfilling should remain open only for the minimum period necessary. The contractor should keep all earthworks free from water. Where materials are designated as hazardous material, the contractor should carry out all necessary requirements for safe handling and disposal.

3.1.19.8 Cutting slopes or toes of cuttings may occasionally need to be undercut for trench or other excavations. Such excavations are to be restricted in extent and carefully monitored and should remain open only for the minimum period necessary, so as to prevent risk to the stability of the permanent works.

3.1.19.9 Soft or wet areas on slopes apparent after excavation should generally be improved by trench drains. Effective track drainage through cuttings is required to avoid pumping problems.

Specification of earthworks – Embankments and other fills

3.1.19.10 Embankments and other fills should be constructed of acceptable materials deposited in layers and compacted as appropriate for the class of material in accordance with the requirements of the HA Series 600 or equivalent. To avoid acceptable material becoming unacceptable double handling of cohesive soils should be avoided, and compaction should follow as soon as possible after spreading.

3.1.19.11 Unless otherwise required fills should be constructed evenly over their full width and their fullest possible extent and the contractor should control and direct construction plant and other vehicular traffic uniformly over them.

3.1.19.12 Staged construction of cohesive fills may be required in some situations to ensure that excess pore water pressures within the placed fill and also within any underlying low permeability subgrade are dissipated to ensure sufficient soil strength to maintain stability. Earthwork design details and proposed rates of controlled fill need to be submitted to the asset engineer for approval prior to commencing the work and sufficient instrumentation should be installed to provide data on the pore pressures achieved during construction so informed decisions can be made as regards the rate of construction.

3.1.19.13 Where the subgrade is very compressible, for instance a clayey alluvium perhaps with some peat, it may be necessary to install wick drains or apply a surcharge load, or both, to reduce construction time. Surcharging design details to accelerate dissipation of pore pressures and enhance stability including period of time, type of surcharge

material and initial level of top of surcharge should be in the Conceptual Design Statement (CDS).

3.1.19.14 Whenever fill is to be deposited against the face of the natural slope or sloping earthworks face including embankments, cuttings or other fills and excavations, such faces should be benched or otherwise shaped before placing the fill. Alternatively the interface may be mixed with grader blade or similar and the compaction extended over the reworked zone.

3.1.19.15 Earth Structures should not be constructed with oversteepened slopes unless they are appropriately reinforced. Geosynthetics can be used to enable near vertical slopes to be constructed with standard fill materials.

Specification of earthworks – Fill to structures

3.1.19.16 Class 6N, 6P, 7A or 7B fill materials as defined in HA Series 600, or equivalent materials should generally be used as fill materials to structures. These materials exert comparatively low pressures on the wall and will not settle differentially in relation to the structure. The fill material should be placed and compacted in accordance with the requirements of Table 6/4 of HA Series 600, or equivalent. Where a buried structure is not designed for differential loading, backfilling should be closely uniform on both sides.

3.1.19.17 The contractor should restrict the use of compaction plant used on fill to structures, within 2m of a structure. The design of structures against which fills are compacted should address elevated earth pressures due to this compaction process (Clayton, Militisky and Woods, 1996).

Specification of earthworks – Compaction of fills

3.1.19.18 All compaction of fills should comply with the requirements of HA Series 600, which defines how compaction should be conducted in terms of the type of compaction plant, method of operation of plant, number of passes of plant required and the final thickness of the compacted layer. The soil and the compactor plant should be classified and the number of passes and depth of layer determined from Table 6/4 of the HA. It is implicit in the HA that compaction should achieve a minimum 95% of the optimum dry density.

3.1.19.19 Earthmoving plant should not be accepted as compaction equipment and there should be recognition that materials placed dry, especially clayey sands, appear very strong with little compaction when placed but soften and collapse later if they become wet.

3.1.19.20 If more than one class of fill material is used, compaction should be as required for the class of material requiring the greater compactive effort.

3.1.19.21 The compaction plant is categorised in terms of its static mass and its mode of densifying the soil, including:

- a) smooth wheeled roller;
- b) grid roller;
- c) dead weight tamping roller;
- d) pneumatic-tyred roller;
- e) vibrating tamping roller;
- f) vibratory roller;
- g) vibrating plate compactor;
- h) vibro tamper;

i) power rammer;

j) dropping weight compactor.

3.1.19.22 Placing of fill materials must not commence until the compaction plant is available and the depth of compacted layer should be checked regularly where appropriate testing for in-situ density should be undertaken in accordance with the HA.

3.1.19.23 It is necessary to ensure the correct layer thickness of deposited material is achieved, that the spreading and compaction machinery are operating continuously, systematically and efficiently, and that the rate of input of material for compaction does not exceed the output of the compaction plant.

3.1.19.24 The objective of compaction is to drive soil blocks or particles together, expelling the air introduced by excavation and spreading. If the soil is very wet the air can be expelled easily, but the compacted soil is then soft. If the soil is too dry the clay blocks cannot be moulded to fit together, and granular soil is held in a loose state by capillary action. The limits at which these factors prevent compaction are the acceptability limits.

3.1.19.25 Incomplete compaction of material is difficult to identify as the surface will generally appear to be well compacted after very few passes. However low densities will be present deeper in the layer and large voids can occur near the bottom. As for material placed dry, the fill will take up available water causing the particle contacts to weaken with resulting surface settlement.

Specification of earthworks – Sub-formation and capping

3.1.19.26 The working life of a road base or of track ballast can be greatly improved by placing a capping layer on the sub-formation soils. This is especially true for sub-formations of plastic clay soils as mostly found along the LU surface railway.

3.1.19.27 Construction plant and other vehicular traffic should not be operated on the formation or sub formation unless adequate protection is provided, weather protection should be provided where necessary.

3.1.20 Construction Documents

Refer to LU Guidance Document G050 (Civil Engineering – Common Requirements) that supports LU Standard S1050 (Civil Engineering – Common Requirements).

3.1.21 Additional design considerations

3.1.21.1 Excavations for foundation construction - When undertaking excavations for foundation construction, additional excavation may be required to remove any pockets of soft soil or loose rock so as to achieve the design bearing capacity requirements. Resulting voids and any over break should be filled with lean mix concrete.

3.1.21.2 Swallow holes and naturally occurring cavities – Swallow holes are naturally occurring cavities which are commonly found in chalk. Probing can be used to determine the location and extent of swallow holes or other natural cavities. Clearing of rubbish and flushing of soft in-fill material needs to be undertaken prior to filling with grout, mass concrete or reinforced concrete. Infilled swallow holes and other naturally occurring cavities should be excavated, filled and capped as appropriate.

3.1.21.3 For construction over areas where potential swallow holes are not identifiable at the surface, the potential migration of the void and distress to the Earth Structure needs to be addressed in the long term, for example by design and placement of layer of geotextile within the base of the embankment to span potential voids.

Track formation (sub-grade)

- 3.1.21.4** Track formation needs to maintain sufficient strength and stiffness to provide the required load carrying capacity for supporting the track. The detailed requirements for formation design are outlined in LU Standard S1160 (Track Bed). The Network Rail strength requirement for track bed is for a formation (undrained) modulus of between 80MPa and 130 MPa. These values are also considered applicable to LU track. Since direct determination of stiffness modulus is not always practical the CBR is frequently used as an index test (HA25/94). The following equation has been derived empirically for typical UK soils: $E = 17.6 (\text{CBR})^{0.64}$ MPa.
- 3.1.21.5** Ballast placed on the formation is used to distribute load across the formation and provides a drainage medium. Adequate depths of ballast need to be provided to spread the train loads evenly over the formation and avoid distortion of the formation surface. If the depth of ballast provided is insufficient local excessive pressure will be placed on the formation creating irregularities in its surface. Pockets will develop in the formation which in turn fill with water, the continued passage of trains causes poorly supported ballast to break up, producing fines which have the effect of sealing off any drainage, thus leading to water retention. Further passage of trains is then accompanied by pumping and it becomes onerous to maintain track alignment.
- 3.1.21.6** In the majority of instances, formation problems are due to inadequate drainage. If wet spots occur it is possible to treat them by digging out the affected material and replacing it with competent material reinforced with a geotextile and drained by a sand blanket to create a stable long lasting repair. The source of any water needs to be identified and measures taken to ensure it is removed from the track formation.
- 3.1.21.7** When designing or undertaking track formation maintenance works reference should be made to LU Standard S1160 (Track Bed). Reference should also be made to [Selig and Waters, 1994](#) and [UIC719R, 1994](#), [Earthworks and track-bed layers for railway lines](#) for guidance on subgrade improvement alternatives.

3.2 Construction, installation, testing and commissioning

3.2.1 General

- 3.2.1.1** The guidance in LU Guidance Document G050 (Civil Engineering – Common Requirements) that supports LU Standard S1050 (Civil Engineering – Common Requirements) is of particular importance to this section.
- 3.2.1.2** When undertaking new construction, strengthening and renewal or maintenance works all necessary measures should be undertaken to ensure that the work does not detrimentally affect the railway and adjacent structures or services.
- 3.2.1.3** The asset engineer should be informed of any work which may affect other engineering assets and detailed method statements should be prepared and approved by suitably experienced persons, fully detailing the protection measures to be implemented. Utility companies should also be advised of any work undertaken adjacent to their services.
- 3.2.1.4** The provision for unobstructed movement at the cess is a clear safety requirement for works to be carried out while trains are running.
- 3.2.1.5** When working adjacent to the LU cable posts which carry signals, compressed air and high voltage cables, the relevant parties within LU should be informed in advance of the proposed works commencing. Prior to any work, an inspection of the existing cable condition should be undertaken. Details of the work to be undertaken adjacent to the lineside cables and of the proposed protection measures need to be submitted to LU signals and to LU high voltage cables division for approval before works can commence. When work is undertaken adjacent to high voltage cables reference should be made to LU Standard S1114 (Safe systems of work on or near electrical equipment).

3.2.1.6 In view of their frequent use in conjunction with Earth Structure slopes, guidance on gabion basket construction has been retained within this Guidance Document even though the gabion walls themselves are structural assets covered by LU Standard S1051 (Civil Engineering – Bridge Structures).

3.2.2 Work sites and access

No separate guidance for Earth Structure assets.

3.2.3 Construction methods

Gabions

3.2.3.1 Gabions need to be tightly filled with hard durable stone such as limestone or granite complying with the requirements of Class 6G material (Highways Agency (HA) Specification for Highway Works). Soft friable material should not be used. The maximum size of the fill material should not exceed two thirds of the gabion compartment or 200 mm whichever is smaller and the minimum size should be 100 mm or the aperture size of the containing mesh whichever is the greater.

3.2.3.2 The construction sequence and excavation for a gabion retaining wall is to be such that it can be undertaken without the risk of a slope failure, the accumulation of water or the generation of other conditions likely to affect the nature and stability of the ground. The method used should not jeopardise the safety of the railway, the stability of adjacent buildings, structures and utilities or mar their appearance.

3.2.3.3 Excavation, compaction of backfill and construction of a gabion retaining wall should be in accordance with the HA Specification for Highway Works.

3.2.3.4 The assembly and erection of gabion units needs to be in accordance with the manufacturers requirements for the particular system specified. Bundles of gabions need to be handled with due care to avoid damage to the PVC coating.

3.2.3.5 The stone filling should be placed by hand so as to achieve minimum voids. Gabion units should be maintained square and with vertical sides during filling. Internal tie wires are to be inserted and units tensioned in accordance with the manufacturers instructions. Gabion units are to be constructed so as to maintain tightness of mesh and laced securely with wire. The tolerance of the gabion wall line and level should be ± 50 mm with no undue distortion in individual units.

3.2.3.6 The top surface of the woven wire gabions are to be overfilled by a minimum level of 50 mm to accommodate subsequent settlement and improve shear resistance between successive courses. Gabion tops require to be tensioned and securely tied down.

3.2.3.7 Adjacent gabion boxes are to be fastened together using binding wire complying with the manufacturer's installation instructions.

3.2.3.8 Vertical joints of gabion baskets should be staggered as in running bond brickwork to give a better appearance and to prevent the formation of weak vertical shear planes.

3.2.3.9 The lifting of filled gabions by crane into position should not be permitted.

3.2.4 Materials

Geosynthetics

3.2.4.1 Geosynthetics will normally be supplied in the form of rolls or packages. The wrapping should:

- a)** ensure the geosynthetic is supplied dry and remains dry;
- b)** protect the geosynthetic from abrasion and damage;

- c) protect the geosynthetic from contamination;
- d) protect the geosynthetic from exposure to sunlight (ultra-violet radiation in particular).

3.2.4.2 Items within consignments of geosynthetics should be supplied clearly marked with the name of the product and its grade or code number, in order that it will easily be identified both before and after removal of any wrapping (BS EN 30320)

3.2.4.3 Geosynthetics are to be stored in a safe, secure environment, not subject to temperature extremes or other harmful conditions.

Installation of geosynthetics

3.2.4.4 Geosynthetics should be installed and lapped in accordance with the requirements of the SHW and manufacturer's instructions. Care should be taken to ensure continuity of the geosynthetic at connections.

3.2.4.5 The layer of material on which the geosynthetic is to be placed should not have protrusions or sharp projections which are likely to damage the geosynthetic during installation or in service.

3.2.4.6 The method of installation needs to ensure the geosynthetic is in continuous contact with the surface on which it is to be placed and the geosynthetic is not being stretched or bridged over hollows or humps. Unless the geosynthetic has been specifically designed for plant loading, construction plant is not permitted directly on the installed geosynthetic and covering with an adequate protective layer of fill material should take place immediately after its laying.

3.2.4.7 Geosynthetics should be cut using appropriate cutting equipment which minimises the risk of tearing or fraying.

3.2.4.8 Joints may be sewed, glued, stapled or heat bonded. Where jointing is unnecessary, geosynthetics may be simply overlapped by a specified amount. Joints usually form the weakest link in geosynthetic construction and key properties for the joint or overlap must be specified by the designer. Any engineering properties or durability requirements specific to the joint seam or overlap, as opposed to the geosynthetic should also be specified for each application.

3.2.5 Instrumentation and monitoring

No specific advice.

3.2.6 Pumping

3.2.6.1 Pumping, if required, can cause widespread impact on adjacent properties and the infrastructure therein. Consolidation settlement and the removal of fines are the primary mechanisms of concern.

3.2.7 Temporary works

3.2.7.1 For temporary structures a CDS, design calculations and design checks will be required. Clearance approval will also be required from LU for structures that are adjacent to or over the track in accordance with the requirements of LU Standard S1156 (Gauging and Clearances).

Site compounds

3.2.7.2 Prior to works commencing a site compound is typically established to locate the site offices and welfare facilities and to provide storage for plant, materials. On long sites or on sites where access is particularly difficult there may be a requirement for a number of smaller satellite compounds to be established during the works to serve different areas of the site.

Access and haul roads

- 3.2.7.3** The access onto the site is generally the responsibility of the contractor to arrange. Any temporary access or haul roads that have been installed to provide access routes onto the site need to be reinstated to their original condition at the end of the contract. The original condition of access roads and adjacent fence lines on and adjacent to the site should be recorded by undertaking a condition survey prior to any works commencing.

Temporary bridges

- 3.2.7.4** Temporary bridges are commonly required for works on railway Earth Structures to provide access to areas of the site that are isolated from the rest of the works by natural or man-made barriers including rivers, canals, roads and paths. These access bridges can vary in scale from large temporary 'Mabey' type bridge structures for supporting haul roads to relatively small scaffold bridges for carrying personnel and smaller plant.

Scaffold platforms

- 3.2.7.5** When undertaking work on Earth Structure slopes temporary scaffold ramps and platforms are commonly used to provide access and a stable working platform. The majority of work undertaken on Earth Structure slopes requires personnel and plant to work at some location on the slope. These Earth Structure slopes are typically very steep and are often of marginal stability. Most plant cannot work safely on such steep inclines particularly in wet weather, therefore horizontal working platforms and access to these platforms are required to enable plant to undertake work safely.
- 3.2.7.6** Scaffold platforms of this type need to be designed to provide the required capacity to enable site plant to operate from them. They also need to have foundations of sufficient capacity to support the required loading. Given that the Earth Structure slopes will have low factors of safety, slope stability calculations should be undertaken to confirm the Global Stability of the Earth Structure slope with the additional loading from the working platforms and plant. Care should be taken when founding these working platforms on ash which is commonly found at the shoulder of the railway embankments, this material is unstable and working platform foundations need to be founded on stable material.
- 3.2.7.7** When constructing scaffold platforms close to the track work should be undertaken during engineering hours to minimise the risks to the scaffolders constructing the working platform and trains operating on the track.
- 3.2.7.8** Reference should be made to LU Standard S1050 (Civil Engineering – Common Requirements) for the requirements to be met when erecting, using and dismantling scaffold on or near the railway.

Earthwork haul roads and working platforms.

- 3.2.7.9** An alternative to scaffold working platforms where access, working space and slope stability allow, is to use earthwork haul roads constructed against the existing face of the Earth Structure slope to provide access and a stable working platform for plant.
- 3.2.7.10** The construction of these working platforms involves the importation of large amounts of fill material so good access is essential. Also sufficient working space at the toe of the slope is required to ensure that the adjacent land and Global Stability of the Earth Structure slope is not affected by the construction of these platforms.
- 3.2.7.11** When constructed these earthworks provide good working platforms and can typically support large items of plant. During construction large amounts of vegetation are required to be cleared from the Earth Structure slope but care must be taken so that the removal of vegetation does not lead to an Earth Structure failure.

- 3.2.7.12** The fill material should be benched into the existing embankment and compacted in layers in accordance with the requirements of the Specification for Highway Works Series 600.
- 3.2.7.13** After the works are complete these earthwork haul roads and working platforms can be incorporated into the final slope stabilisation solution to provide earthwork berms to enhance further the stability of the Earth Structure slopes.

Support of excavations

- 3.2.7.14** Wherever temporary excavations are required during the works, sufficient temporary support should be provided to the excavations to ensure stability. This is particularly relevant when excavating close to the track and the lineside services or at the toe of the Earth Structure slope.
- 3.2.7.15** When undertaking excavations through the ash shoulders of embankments, it should be noted that the ash is particularly susceptible to deformation under live train loading.

Using cranes and other plant on or adjacent to the LU railway

- 3.2.7.16** When using cranes and other plant on or adjacent to the LU railway the contractor should use all necessary skill, care and diligence to ensure that the operation and use of any crane or other plant can be controlled such that it does not constitute a risk to the railway.
- 3.2.7.17** For guidance on safe working procedures when using cranes and other plant on or adjacent to the LU railway reference should be made to LU Standard S1050 (Civil Engineering – Common Requirements).

3.3 Inspection

3.3.1 General

- 3.3.1.1** In order to ascertain and prioritise the condition of the Earth Structure assets, a comprehensive inspection of the LU surface railway at 100m transects was carried out in 1993, and the results were recorded in an Earth Structures database. A mandated ongoing regime for re-inspection as part of an asset management strategy was introduced at that time into the Engineering Standards for Earth Structures, and the inspection requirement continues in LU Standard S1054 (Civil Engineering – Earth Structures).
- 3.3.1.2** The inspection regime is of prime importance to the asset condition assessment and certification process, and subsequent management of the Earth Structure assets. In view of the importance of consistency in the results, a single comprehensive procedure for Principal Inspection based on the original experience has been established by LU and is set out in LU Standard S1054 (Civil Engineering – Earth Structures). The single procedure results in a common structure and quality of the recorded data across the network that is consistent with the historical record.
- 3.3.1.3** The standard requires all inspectors to be fully trained and their ability to carry out inspections consistent with past records to be proven before they undertake inspection work.
- 3.3.1.4** The Standard places emphasis on the response to reports from inspections in assuring that appropriate actions follow the new information, in particular with regard to the asset being safe and fulfilling its required duty.
- 3.3.1.5** The nature of the Earth structures is that not all the factors of importance can be quantified by inspections at set 100m intervals. The inspection regime therefore also calls for intermediate inspections where there are features that would not otherwise be recorded for evaluation. Only if a full Principal Inspection is made at a Feature can an

asset condition rating be determined directly at that location. Nevertheless the information on Features should contribute to the evaluation of the overall condition rating for an asset.

3.3.2 Types of inspection

The inspection categories of superficial and inspections carried out after an incident in superseded standard E3735 have been combined under the title defect advice inspections in LU Standard S1054 (Civil Engineering – Earth Structures).

3.3.3 Principal Inspections

See section 3.3.1.1 above and the following sections.

3.3.4 Reduced scope of principal inspection

The Standard allows a reduced scope of Principal Inspection where the Earth Structure no longer has a safety implication for the railway or others and long-term changes in condition are not anticipated. The reduced scope should be sufficient to identify any significant alteration in condition in time to schedule a full inspection before deterioration can become serious.

3.3.5 Special Inspections

No specific advice.

3.3.6 Defect Advice Inspections

Defect advice inspections follow any report that may indicate development of a defect or occurrence of an incident or event that may have triggered an adverse change in previous behaviour.

3.3.7 General inspections

No specific advice.

3.3.8 Preparation for inspections

3.3.8.1 The Standard requires effective training of Earth Structure inspectors to achieve consistent sets of results across the network.

3.3.8.2 Review of earlier records is particularly important where an Earth Structure contains existing support measures, as the inspector needs to know the required function of those works in order that he can judge in the field what signs are visible to quantify their performance in fulfilling that task.

3.3.9 Maximum inspection intervals

The intervals have been established from the historical record of deterioration of the assets.

3.3.10 Information from inspections

3.3.10.1 The information to be recorded in a full Principal Inspection is set out within Attachments 7.1 and 7.2 of the Standard.

3.3.10.2 An example of an Earth Structures Defect Advice Inspection reporting form is included in Attachment 7.1 of this Guidance Document.

3.3.10.3 The mandated structure of the data to be acquired from a principal inspection was adopted in the design of the LU Earth Structures database, established to hold the results from the original series of comprehensive earthworks inspections carried out in the 1990's. To enable automated analysis of the database record, a procedure for rating the conditions of Earth Structures from the inspection observations was coded in a set of modules within the database termed the LU Earth Structures Condition Rating

Tool algorithm. The database and associated algorithm were coded at that time using MS Access software.

- 3.3.10.4** An important benefit of entering the Principal Inspection results in a maintained database is that significant changes from the previous record are instantly apparent and it will generally be clear whether these result from isolated random errors in field recording or data manipulation, or whether a pattern of change is occurring.
- 3.3.10.5** Earth Structures standard S1054 (Civil Engineering – Earth Structures) recognises that Suppliers have needed to establish common software systems for asset data management across their asset types that are not directly compatible with the LU Earth Structures database. Nevertheless the historic data structure is to be retained, following as it does from the inspection procedure, which will allow a suitably recoded version of the Condition Rating Tool algorithm to be applied to the data, so maintaining the integrity of the established condition rating procedure for the Earth Structure assets

3.3.11 Determination of condition rating

- 3.3.11.1** The overall condition ratings for Earth Structures derived from the Condition Rating Tool are a measure of their current state compared with Earth Structures in a notional perfect condition, i.e. 100% represents a structure in perfect condition and 0% represents a structure in very poor condition. Previous grouting of slopes, installed slope drainage and the use of simple retaining walls are allowed for in the rating tool.
- 3.3.11.2** The coding for the Condition Rating Tool is presented in a separate volume as Appendix A to this Guidance Document.

3.3.12 Inspection reports

- 3.3.12.1** The assessor of the inspection should pay special attention to the underlying geology assumptions as made by the inspector from his observations. These assumptions have a major impact on the condition rating from the Condition Rating Tool at the inspection stage. Information from previous assessment at the site or at adjacent sites or other ground investigation data sources should be used to verify the assumptions and where justified they should be amended in the database record.

3.4 Analytical assessment

3.4.1 General

No specific advice.

3.4.2 Desk study

- 3.4.2.1** For advice and guidance on the stability of cuttings and embankments reference should be made to the following publications:
 - a)** A survey of slope condition on motorway earthworks in England and Wales, Transport and Road Research Laboratory Report 199, 1989;
 - b)** Chalk Cutting Stability Assessment – Metropolitan Line, Deliverable E3, 33950/F&G/REP/04/B GEO3590, Mott MacDonald, 1996;
 - c)** CIRIA C574 2002 Engineering in chalk;
 - d)** CIRIA C591 2003 Infrastructure cuttings condition appraisal and remedial treatment;
 - e)** CIRIA C592 2003 Infrastructure embankments condition appraisal and remedial treatment;
 - f)** Progressive failure in motorway slopes of clay, Potts, D.M, Kovacevic, N and Vaughan, P R, Transport Research Laboratory Contract Report, 1994.
 - g)** LU Guidance Document G0054B, Earth Structures – Guide for Slope Stability Analysis

- h) Metropolitan Line Chalk Cuttings – Technical Review, London Underground, Document Number RPT-EST-M001-5201037
- i) Effects of Inclement Weather on Earth Structures – Phase II Report. London Underground, Document Number RPT-EST-KA00-0539196, November 2010

3.4.3 Site investigation for assessment

No specific advice.

3.4.4 Soil properties

3.4.4.1

For advice and guidance on the soil properties for cuttings and embankments reference should be made to the following publications. However, the most up to date and most recent research findings are summarised in the LU Guidance document G0054B

- a) LU Guidance Document G0054B, Earth Structures – Guide for Slope Stability Analysis, A1, December 2014;
- b) LU, Ground investigation of Central and Metropolitan Lines FLAC analysis, 45354/F&G/REP/360/A;
- c) LU, Ground investigation of Central and Metropolitan Lines advanced laboratory testing interpretative report, 45354/F&G/REP/350/B;
- d) LU, Ground investigation of Central and Metropolitan Lines advanced laboratory testing factual report, 45354/F&G/REP/351A, 352A, 353A;
- e) LU, Ground investigation of Central and Metropolitan lines Flac analyses, 45581/F&G/REP/100/A;
- f) London Clay Embankment Centrifuge Tests: LU-1, LU-2 and LU-3, MDB/SPGM/WAT/AJV/LUREPORT-3.2, Cambridge University, May 1999;
- g) LU Centifuge Testing of Embankments Post Test Report, 45660/REP/F&G/200/A, Mott MacDonald, 1999;
- h) LU Research Stage II Assessment of Clay Fill, 51683/F&G/REP/100/B, Mott MacDonald, 1999;
- i) LU Research Stage II Assessment of Embankments, 51683/F&G/200/B, Mott MacDonald, 1999;
- j) LU Research Stage II Assessment of Cuttings, 51683/F&G/REP/300/B, Mott MacDonald, 1999;
- k) LU Research Stage II Strength and Dilatancy of Railway Ash, 51683/REP/400/B, Mott MacDonald, 1999;
- l) Properties of Material, Soil Mechanics Group, Civil Engineering, Imperial College, London Contract E3, Report D, 1997;
- m) Advances in geotechnical engineering, The Skempton Conference, Institution of Civil Engineers, 2004.
- n) Report on geotechnical observations of LU railway slopes 2000-2001, Andrew Ridley, Imperial College, for LU Civil Engineer

3.4.5 Pore Pressures

Refer to section 3.4.4 of this Guidance Document.

3.4.6 Loadings

Refer to section 3.4.6 of the Standard.