Chapter

4.6

NHBC

Engineered fill

This chapter gives guidance on meeting the Technical Requirements and recommendations for using engineered fill to support foundations to residential developments, external works and infrastructure.

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Introduction

On construction sites, filling or earthworks are often required for various purposes, such as preventing flooding, enhancing drainage, planning roads or establishing a suitable ground profile. Engineered fill may also be used to replace existing made ground overlying competent strata at shallow to moderate depths to form a new development platform, or be used below raft foundations on sites with shrinkable clays and trees in lieu of deep trench fill foundations.

This chapter details the information that NHBC requires to ensure that engineered fill is correctly placed to support low-rise residential building structures, external works, and infrastructure while avoiding potential risks of excessive settlement or ground failure.

Scope

This chapter gives guidance for engineered fill to be placed for the support of the proposed development.

The interaction between engineered fill, underlying ground conditions and the development are important and site-specific. The primary objectives of this chapter are to ensure that:

- the ground investigation is appropriate to the proposed development, site conditions and nature of the filling
- geotechnical ground model(s) are developed, taking into account the proposed development and underlying ground and groundwater conditions
- the engineered fill is placed to a suitable earthworks specification
- appropriate geotechnical laboratory acceptability testing and in-situ, compliance testing is undertaken and documented, and verification is provided to NHBC
- engineered fills do not settle excessively or have the potential to cause excessive differential settlement between properties founded upon the fill and external areas
- engineered fill and the underlying ground supporting building foundations shall limit building settlements to less than 25mm and minimise angular distortion or tilt to 1:400
- the design and detailing of foundations, infrastructure and external works suit the placed fill and underlying ground conditions, taking account of the overall ground model and any geohazards in the ground beneath or nearby.

The geotechnical and environmental suitability of historic fill, or fill placed without full verification reporting, should not be relied upon without appropriate site investigation, characterisation, compliance testing and assessment being undertaken like other made ground deposits would be assessed. This may need to include long-term settlement monitoring or loading trials to determine performance.

Assessment of historic fill within land reclamation schemes and marginal sites is generally outside the scope of this chapter. For sites with uncertainty about their suitability for future residential development, please consult NHBC or consider using NHBC Land Quality Service for a bespoke consultation. You can find details about this service at:

- www.nhbc.co.uk/builders/products-and-services/consultancy/land-quality-service
- Email: lqs@nhbc.co.uk

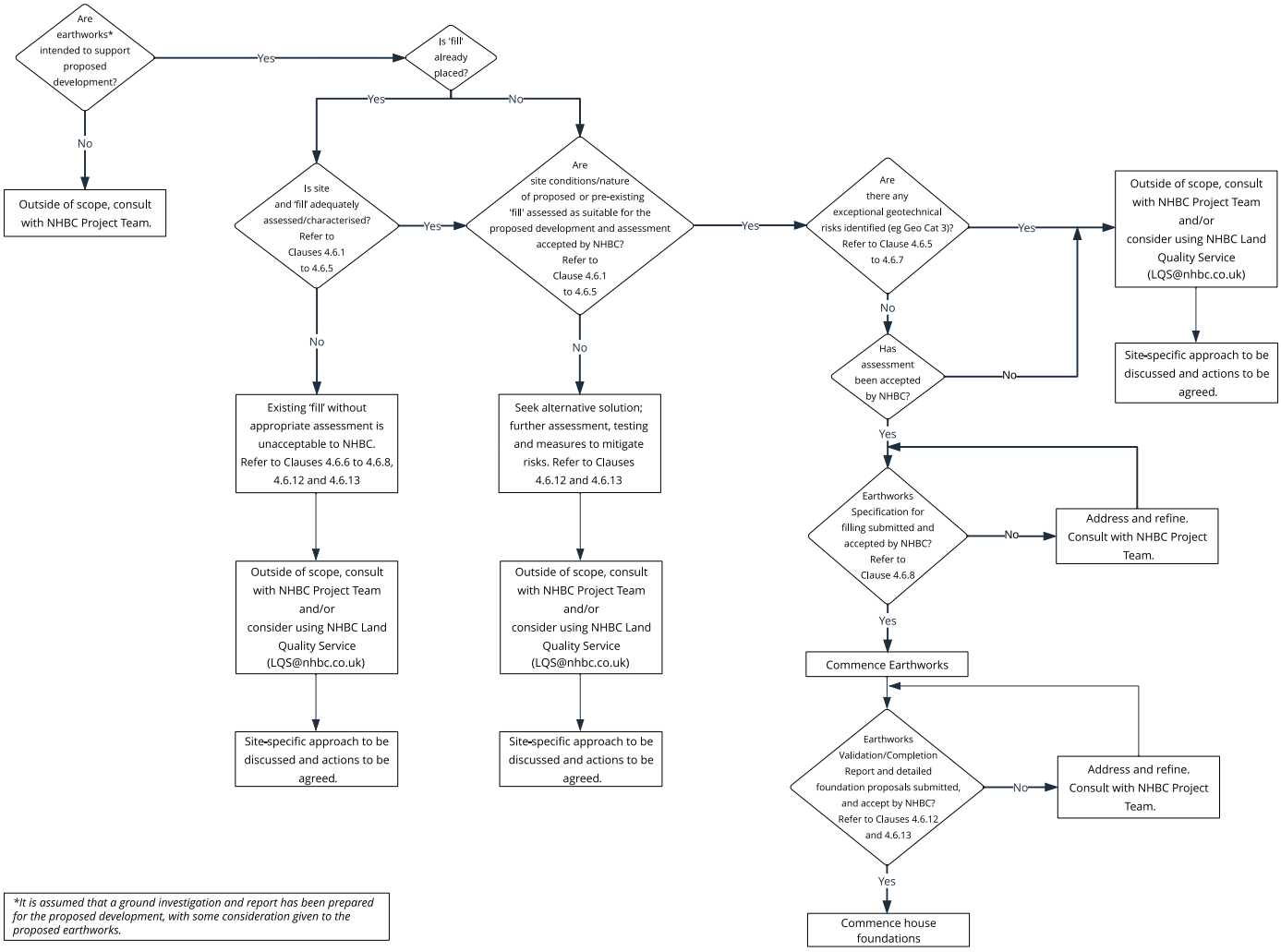
The following are not considered in this chapter and will require more specific guidance from other sources:

- backfilling to retaining walls, buried features such as culverts, services or access chambers
- capping and sub-bases to roads, drives, parking, and hardstanding areas
- filling beneath adoptable highways
- soil stabilisation or soil mixing
- piling mats or other specific forms of working surface for construction activities
- fill containing hazardous substances or required to provide mitigation against the presence of contamination, or to be placed on contaminated sites
- use of reinforcing geogrids.

The builder is responsible for ensuring that any earthworks filling proposals do not breach planning requirements or waste and environmental regulations.

The following Figure 1 is to assist users in navigating through this chapter and outlines how proposed or existing earthworks fit into the applicability and use of this standard.

Figure 1: Fill assessment and chapter applicability process



Definitions for this chapter

Acceptability testing	Geotechnical and chemical suitability testing of the source material(s) intended to be used as engineered fill.
Beam grillage	A reinforced concrete foundation designed to support load-bearing walls or structure, and to span a loss of support, and reinforced with traditionally cut and bent rebars and closed-loop links.
Buried batter	An inclined buried interface of natural soil and made ground, or between made ground and engineered fill, and potentially liable to cause differential settlement at the ground surface.
Cohesive fill	Containing clay of natural origin, comprising greater than 15% fines passing a 0.063mm sieve. Suitable for use as engineered fill but requires greater moisture control than granular material. Behaves in a plastic manner and can be deformed and remoulded by hand. Suitability is typically dependent on moisture content. Only clays with a plasticity index of less than 40% are acceptable as fill, where they are required to support building foundations. This includes Class 2 (general fill) and Class 7 (selected fill) in accordance with the name specified in Table 1 highway works: Series 600 — Earthworks.
Compliance testing	Geotechnical suitability testing of the engineered fill as it is being placed in layers on site
Differential settlement	Settlement of one part of a building or structure relative to another. While the total settlement of a structure may interfere with functions such as service connections, it is the differential settlement that causes structural damage.
Earthworks	Permanent change in ground profile and/or level, which may be due to the placement of fill to raise ground levels (filling) or the removal of material (cutting).
Earthworks specification	An earthworks specification describes the design requirements of proposed earthworks and includes how the earthworks should be undertaken and what acceptance criteria should be used to demonstrate their suitability.
End-use	The nature of the proposed final development located over the fill, including the buildings and their foundations, external works and infrastructure features, and associated activities in their normal use.
Engineered fill (also referred to as 'fill')	Fill that is selected, placed and compacted to an appropriate specification so that it will exhibit the required engineering behaviour to support structural loadings for buildings, external works (drives, paths and external walls) and infrastructure (roads, drains and services) without excessive settlement or risk of shear failure. Selected (structural) fill and general fill are examples of engineered fill.
Formation level	The prepared surface on which the engineered fill or the superstructure is built.
General fill	Suitable for the support of access roads, drainage, driveways and services buried within it or supported on it. Elements supported on general fill are usually less sensitive to differential ground movements than shallow foundations for residential buildings. Some degree of variability can be accepted in the completed fill, and fewer tests may be acceptable than for structural fill; however, it will still require a suitable regime of compliance and verification testing.
Geotechnical Design Report	A report that is used to develop a suitable and functional earthworks design for a proposed end use, which includes the full details on the interpretation of design data and justification for the design, including relevant layout drawings. They are produced for Geo Category 2 and 3 projects where engineered fill is being used to support building foundations.
Geotechnical Design Statement	A brief and abridged version of a Geotechnical Design Report for Geo Category 1 projects where engineered fill is not being used to support building foundations.
Granular fill	Free draining material predominantly comprising sands and/or gravels Good for use as engineered fill Having less than 15% fines (less than 0.063mm sieve size) Behaves in a non-plastic manner This includes Class 1 (general fill) and Class 6 (selected fill) in accordance with the Refer to title in Table 1 Specifications for highway works: Series 600 — Earthworks.
Ground improvement	Techniques used to stabilise or improve the strength of soils in situ. This includes dynamic compaction, rapid or high-energy impact compaction, surcharging and installation of vertical drains or vibro stone columns. These techniques may be applied to historic uncontrolled fill, loose native soils upon which engineered fills are to be placed or following placement of fill.
Highwall	The steep edge of quarry or opencast workings. Where the quarry is backfilled, it usually forms a zone of contrasting material behaviour where ground movements could be excessive and affected by significant differential settlement.
Historic fill	Comprises made ground and is not suitable for supporting building foundations, access roads, drainage, driveways and buried services without full investigation and assessment which should be provided in a ground investigation report.
Immediate settlement	Settlement which takes place during the application of a load as a result of elastic deformation without change in the water content.

Inundation settlement/ collapse compression	Occurs in poorly compacted made ground or fill placed dry of optimum moisture content and with high air voids. The failure mechanism is typically attributed to the subsequent rising of groundwater or surface water percolation, where the voids are filled with water and cause delamination. Burst pipes and leaking drains present a risk. It can occur in both cohesive and granular soils, with greater risk in cohesive soils.
Landscape fill	Unsuitable to support shallow foundations for buildings, ground floor slabs for buildings, other critical elements sensitive to differential ground movements, or any external works such as pavements, services or garden walls. Loading may be limited to construction equipment. There may be no geotechnical testing requirements for landscape fill other than for workability reasons. Landscape fill may be specified for garden areas alongside earthwork slopes and bunds in some developments.
Made ground	Material that has been placed but to an unknown or unrecorded filling specification. Its geotechnical and geo-environmental properties need to be established by appropriate ground investigation and testing for it to be reclassified and its suitability for reuse established.
Material classification	Assignment of materials into groups and classes for earthwork purposes. The groups and classes are established by testing the geotechnical properties of a material to determine its suitability for use as fill. The properties may include moisture content, grading, plasticity, compaction and recompacted CBR and shear strength, etc. Testing continues during earthworks placement to ensure material properties remain consistent and within defined limits to achieve the required compaction or fill performance.
Performance testing	Load-settlement testing of the completed engineered fill at its surface and ahead of building foundations.
Primary settlement or consolidation	Occurs after immediate settlement of material on loading. It occurs as pore water pressures dissipate and usually comprises the most significant element of the total settlement of a cohesive fill. Completion of primary settlement is most easily identified by graphical analysis of settlement data showing a 'levelling off' behaviour as secondary settlement then commences.
Raft foundation (semi-rigid raft)	A foundation consisting of continuous slab elements and down stand beams designed in accordance with Chapter 4.4 Raft, pile, pier and beam foundations to spread superstructure loads over the building footprint and provide a capacity to span a defined loss of support.
Reinforced strip	A reinforced concrete foundation designed to support load-bearing walls or structure, and to span a loss of support, and typically reinforced with two layers of mesh reinforcement.
Secondary settlement or consolidation	Occurs after primary settlement (ie, creep) and may continue for many years, including during the life of the development, depending on the soil types.
Selected and structural fill	Suitable for the support of shallow foundations for buildings and other critical elements sensitive to differential ground movements, or as backfill underneath ground-bearing slabs against earth-retaining structures. The completed fill is required to have a high degree of uniformity, high stiffness and low settlement potential, and requires a high degree of supervision and control and a high frequency of selection classification, compliance and verification testing.
Self-weight settlement	Settlement induced in a fill due to its own mass. The magnitude of self-weight settlement is a function of both the stiffness of the fill and its overall thickness. The contribution of self-weight settlement can be significant in cohesive soils.
Soil modification	Mechanical and/or chemical treatment of soils to create a suitable moisture content of an engineered fill to achieve the specified requirements of minimum relative compaction and maximum air voids. Processes include (non-exhaustively) destoning, formation of windrows with mechanical mixing or turning to promote air drying, addition of low-dosage (no greater than 2% by dry weight) binders such as lime and/or cement in order to moisture condition, lower plasticity and/or control silt fraction to promote optimal compactibility.
Soil stabilisation	Mechanical and/or chemical treatment of soils to create substantial gain in strength to produce structural soil layers contributing significantly towards the performance or stability of earthworks. This would include (non-exhaustively) soil mixing with high dosage chemical admixtures or grouts, hydraulically bound materials and reinforced soils overlying weaker strata. It is currently outside the scope of this chapter and not accepted for the support of foundations.
Specification for earthworks	Acceptable methods by which satisfactory compaction of fill materials can be achieved. The three main types of specification for earthworks used in the UK are Method, End Product and Performance.
Total settlement	The combined magnitude of immediate, primary and secondary settlements.

4.6.1 Compliance

Also see: Chapter 2.1

Engineered fill shall comply with the Technical Requirements and provide adequate support for the proposed end-use. A suitably qualified and experienced engineer shall be responsible for the design, specification, supervision and validation reporting to be submitted to NHBC for assessment.

Engineered fill placed to a suitable earthworks specification that complies with the guidance in this chapter will generally be acceptable to NHBC. Reference shall also be made to Chapter 4.1 Land quality — managing ground conditions, for both geotechnical and contamination risks.

This chapter gives guidance for a wide range of circumstances where engineered fill is required. It is not the intention to describe all combinations of site conditions, end-uses, fill material types and filling techniques. Where conditions fall outside those described and detailed within this chapter, it is recommended that early engagement with NHBC should be undertaken prior to preparation of the earthworks specification.

The earthworks specification should be produced by a suitably qualified and experienced person acceptable to NHBC. Where engineered fill is to support building foundations, the earthworks specification should be produced by a suitably qualified engineer — refer to Technical Requirement R5 for detail on requirements.

Where engineered fill is being used to support building foundations, the earthworks specification should be supported by a geotechnical design report. A geotechnical design statement is acceptable where engineered fill is not being used to support building foundations.

British Standards, codes of practice and authoritative documents relevant to engineered fill, earthworks and structures formed upon engineered fill are detailed in Table 1.

Table 1: British Standards, relevant codes of practice and authoritative documents

Relevant standard	Additional guidance
BS EN 1997-1	Geotechnical design. General rules
BS EN 1997-2	Geotechnical design — Ground investigation and testing
BS 6031	Code of practice for earthworks
BS EN 16907	Earthworks. All parts
BS EN ISO 14688	Geotechnical investigation and testing. Identification and classification of soil. Parts 1 and 2
BS EN ISO 14689	Geotechnical investigation and testing. Identification, description and classification of rock
BS EN ISO 17892	Geotechnical investigation and testing. Laboratory testing of soil
BS EN ISO 22476	Geotechnical investigation and testing. Field testing. All parts
BS 1377	Methods of test for soils for civil engineering purposes. All parts
BS 10175	Investigation of potentially contaminated sites. Code of practice
BRE FB 75	Building on fill: geotechnical aspects
BRE IP 5/97	Building on fill: collapse compression on inundation
BRE Digest 427	Low-rise buildings on fill. All parts
BRE Digest 433	Recycled aggregates
BRE SD1	Concrete in aggressive ground
ICE	Earthworks: a guide (by Paul Nowak and Peter Gilbert)
MCHW[1] Volume 1	Specification for highway works: Series 600 - Earthworks (SHW)
DMRB[2] Revision 1 CD 622	Managing geotechnical risk
CIRIA C574	Engineering in chalk
CIRIA C504	Engineering in glacial tills
CIRIA C570	Engineering in Mercia mudstone

Notes

1. Manual of Contract Documents for Highway Works.
2. Design Manual for Roads and Bridges.

4.6.2 Provision of information

Earthworks design and specifications shall be produced in a clearly understandable format, including all relevant information, and shall be distributed to all appropriate parties.

The earthworks specification and accompanying information, including relevant drawings, should be submitted to NHBC at least eight weeks prior to the commencement of filling or associated works. The earthworks specification should also be issued to site supervisors, the earthworks contractor and relevant specialist subcontractors (see Clause 4.6.7 for details of what should be included within an earthworks specification).

An earthworks method statement, from the earthworks contractor or equivalent, should be produced and issued to all relevant personnel. It describes how the requirements of the specification are to be delivered, the plant to be used and arrangements for supervision and reporting.

In addition, the following supporting information should be provided to NHBC:

- desk study and ground investigation report
- geotechnical design report or geotechnical design statement (depending on which is relevant)
- materials classification (acceptability) assessment
- earthworks verification report.

This list is not exhaustive, and additional content may be required depending on site-specific circumstances.

4.6.3 Hazardous sites and ground hazards

Also see: Chapters 2.1, 4.1 and 4.2

Placement of engineered fill on hazardous sites shall be reported to NHBC before work on site commences and shall be specified to take account of any ground hazards.

Hazardous sites, as defined in the NHBC Rules, should be reported to NHBC in writing at least eight weeks before earthworks begin.

Details of ground hazards to be taken into consideration are given in Chapter 4.1 Land quality — managing ground conditions and Chapter 4.2 Building near trees.

4.6.4 Desk study and ground investigation

Also see: Chapters 2.1, 4.1 and 4.2

A desk study and ground investigation shall be undertaken, and the findings used to inform the design of the filling and earthworks specification.

A desk study and sufficient ground investigations should have been undertaken to characterise the site and identify all the features and potential geotechnical and environmental ground hazards relevant to the earthworks, including classification of the fill material itself.

The ground investigation should take account of the findings of the desk study and relevant standards listed in Clause 4.6.1. Further guidance is given within Chapter 4.1 Land quality — managing ground conditions.

The desk study and ground investigation should determine the items listed in Table 2, as a minimum.

Table 2: Typical items to be covered by desk study and ground investigation

Item to be determined	Guidance
Site history and past usage (eg agricultural, residential, commercial or industrial)	To aid in determining a ground model for the site and potential areas of concern
Known areas of made ground	As shown on BGS GeoIndex, other geodata services, historical site investigations and their reports
The nature of the underlying geology	To determine the potential for soft, loose soils, instability, voids or highly compressible soils, and to allow an assessment of pre- or post-treatment of the existing ground
The proximity of any existing buildings, roads or services	To assess whether these could be affected by ground movement caused by filling
The strength/density, compressibility and stability of soils beneath the proposed fill and for the potential reuse as fill earthworks	To enable the level of risk to be determined, including settlement of the underlying soils and whether unsuitable material needs to be removed or if any form of pre-treatment is required. To assess the acceptability of site derived fills
The nature (presence and extent) of any groundwater and surface watercourses	To assess whether groundwater (or surface water) may affect the existing made ground/ natural soils or newly placed fill — for example by causing inundation settlement or washout of 'fines'
The geotechnical properties of soils, including sulfate content and pH	To determine the suitability of soils for use as engineered fill and for the design of buried concrete
The presence of any slopes, embankments, cuttings, quarry highwalls, buried batters or earth faces	To assess the potential negative effect of earthworks on existing ground stability and the potential effect of features on the performance of earthworks and foundations bearing upon the placed fill
The presence of any buried services, culverts, tunnels or other buried structures	To assess the effect of structural loading from placed earthworks and associated earthworks machinery, and whether protection or mitigation measures are required. To allow an assessment for potential effect of structural 'hardspots' on building foundations
The presence of contaminated substances or materials suspected to be contaminated	To assess whether cut earthworks and placement of filling may cause, or increase, the release of contaminants such as leachate, hazardous ground gases, etc (refer to Chapter 4.1 Land quality — managing ground conditions)
Geotechnical risks	An initial geotechnical risk register to ensure that all known or anticipated natural or man-made geohazards are identified and can be investigated and considered within evolving stages of investigation, design and earthworks placement

Other items to consider in addition to Table 2, but not repeated here, are listed in Table 1 of Chapter 4.5 Vibratory ground improvement techniques and in Chapter 4.2 Building near trees.

Where a ground investigation has been undertaken without considering the proposed earthworks, it may be necessary to carry out further supplementary investigation, sampling, testing and/or monitoring to inform the earthworks design and earthworks specification.

4.6.5 Suitability of ground conditions

Also see: Chapters 2.1, 4.1 and 4.5

The ground to be filled over shall be suitably stable and appropriate for the proposed earthworks and end-use. Issues to be taken into account include:

1) **unsuitable ground conditions**
2) **obstructions**
3) **compressible soils**
4) **unstable ground**
5) **groundwater conditions.**

The geotechnical design should be prepared by a suitably qualified and experienced engineer who should assess the ground and be satisfied that it is suitable for engineered fill. Prior to earthworks commencing, the formation level should be inspected and tested in accordance with the earthworks specification.

Engineered fill may be placed on natural ground or made ground — both need to have been appropriately investigated to assess their suitability to provide long-term support to the engineered fill and proposed end-use. Where engineered fill is to be placed on made ground, the made ground will be considered as a residual geotechnical risk for the purposes of geotechnical design.

It may be acceptable to partially excavate existing ground and recompact it in place in order to provide a stiffened layer with improved bearing capacity, settlement characteristics and reduced permeability (as required). Settlement of both the engineered fill layer and the ground beneath should be assessed.

4.6.5.1 Unsuitable ground conditions

Prior to the execution of earthworks filling, unsuitable materials should be removed from the formation level, including:

- topsoil, tree roots, highly organic matters or other degradable materials
- frozen soils
- excessively wet or soft soils, such as silty soils or clays, with an undrained shear strength of less than 40kPa, where untreated to adjust their soil properties
- contaminated soils, and soils containing slag or combustible materials.

Unsuitable materials may be treated, in some circumstances, to adjust and improve the soil properties. Further assessment would be required to determine their suitability after treatment and prior to any subsequent placement as engineered fill.

4.6.5.2 Obstructions

Obstructions, including oversized materials or relic foundations that may impede future works in the ground or adversely affect earthworks filling or drainage should be removed.

It may be impractical to remove some obstructions beneath engineered fill, such as former piles, etc. These should be adequately surveyed and their locations accurately recorded. Any retained relic structure or obstructions should be a minimum of 2m beneath the underside of proposed building foundations. Future building foundations should be assessed for potential effect of structural ‘hardspots’.

4.6.5.3 Compressible soils

Where compressible soils are present, such as soft clays, disturbed ground or peat, the effects of earthworks should be assessed, including the magnitude and duration of induced settlements.

Where significant settlements of the underlying soils are predicted, it may be necessary to remove and undertake additional earthworks or alternative ground improvement works, such as the installation of vertical drainage, or surcharging prior to filling of earthworks.

The effects of ‘drying out’ compressible soils, such as peat beneath engineered fill, should be assessed where earthworks may reduce water infiltration, or the development may cause lowering of groundwater levels.

4.6.5.4 Unstable ground

Voids that might collapse or cause excessive settlement (ie, dissolution features, mine workings and entries, sewers and drains) should be adequately investigated and suitably infilled or grouted prior to the commencement of any earthworks filling or building foundations.

Unstable natural deposits or materials susceptible to solifluction (materials that have undergone progressive, gravitation and downslope movement) should be adequately investigated and addressed by the geotechnical design.

4.6.5.5 Groundwater conditions

The following conditions may adversely affect the long-term performance of engineered fill, if not properly considered and allowed for within the design and specification:

- lowering of the water table to facilitate filling may cause settlement of existing adjacent buildings
- rising or recovery of groundwater levels after filling may cause inundation settlement of fill or wash-out of ‘fines’ and settlement
- falling groundwater levels could cause settlement of soft strata, including peat
- lack of surface water management (ie, non-provision of adequate capping and drainage) following earthworks to ensure no subsequent deterioration over time.

4.6.6 Materials for use as engineered fill

Also see: BRE SD 1-Part 1, BRE Digest 433, BS EN 771 and ICE's Earthworks: a guide

Engineered fill materials shall be suitable for the site conditions, proposed end-use, and techniques for placement and compaction. Issues to be taken into account include:

1) suitable sources of engineered fill materials

2) treatment of fill materials.

The earthworks specification should indicate the materials to be used for filling, including their geotechnical classification and range of properties that should be subject to monitoring and testing. Material classification should be clearly stated for example, Class 1C Coarse Granular General fill or a Class 6N Well Graded Selected Granular fill in accordance with Specification for highway works.

Materials that do not fully comply with the earthworks specification must not be used as engineered fill.

4.6.6.1 Suitable sources for engineered fill materials

Engineered fill material may be site-won or imported from appropriate suppliers or donor sites. Where differing engineered fill types are placed in subsequent layers or distinct zones, it is important to ensure compatibility — for example, to ensure that fines are not washed out of one material into a more coarsely graded material, geotextile separators may be required.

Where material is obtained from stockpiles, the homogeneity should be confirmed. Different forms of stockpiling can affect particle size and grading. The outside of a stockpile may be weathered and may not be the same as the unweathered material within. The use of recycled aggregate as fill should comply with BRE Digest 433 or other suitable guidance as agreed with NHBC.

Details of considerations regarding the acceptability of materials for reuse as engineered fill are provided in Table 3. Tests undertaken to confirm acceptability should be carried out by a UKAS and/or MCERT accredited laboratory (or other specialist laboratories) in accordance with the earthworks specification, appropriate standards and industry guidance, with a detailed knowledge of the materials to be tested and proposed end use. The samples which are tested must be representative of the true nature of the material.

Table 3: Acceptability of materials for reuse as engineered fill

Material description	Examples of material	Details on acceptability for reuse as fill
Suitable sources for fill materials	• natural sands and gravels • clays with a plasticity index of less than 40% and undrained shear strength in excess of 40kPa • chalk (structured chalk of grades C5 to A1 only) • crushed rock • crushed concrete, brick or stone	Typically, the material would be acceptable to NHBC for engineered fill, provided that it complies with appropriate classification criteria. For material that is solely crushed brick, further assessment of strength will be required to ensure its durability.
Hazardous materials	• reactive materials • materials that include sulphides or sulfates, eg gypsum • organic materials • materials that cause noxious fumes, rot, undue settlement or damage to surrounding materials	Appropriate testing required to demonstrate their suitability.
Fill material requiring NHBC acceptance	• unburnt colliery spoil or shale (carbonaceous mudstone) with excessive coal or pyrite content • colliery shale (ie, burnt shale or red blaze) • steel slags • furnace ashes and other products of combustion • material obtained from demolition without screening, crushing and processing • soils with a silt content greater than 20% and where it will alters the behaviour of the overall engineered fill • highly variable materials • on wet sites, or sites with a high-water table, crushed or broken bricks which have no limit on their soluble salt content (as defined in BS EN 771) • high plasticity site won clays with a plasticity index of greater than 40%.	Not to be used as engineered fill unless a written agreement has been obtained from NHBC (appropriate testing and supporting technical report to be provided to demonstrate their suitability).
Unsuitable fill materials	• soils containing topsoil or significant organic matter (such as leaves or wood) greater than 6% by volume • degradable, reactive or non-durable materials • expansive materials, (ie, steel slag and gypsum containing materials) where testing has not determined their risk • materials capable of releasing contaminants or hazardous gases • combustible materials (ie, materials with a high calorific value greater than 7MJ/kg) placed within the top 1m of the finished development platform • materials containing significant amounts of plaster, plastic or rubber over 2% by weight • materials containing harmful substances which pose a risk to human health and the environment • structureless chalk (with grades Dm and Dc) • materials that are not generally used as engineered fill on residential sites	Fill containing these constituents are **NOT** acceptable for use.

4.6.6.2 Treatment of fill materials

The following techniques may be used to modify the moisture content of materials to render them suitable for use as engineered fill:

- placement in windrows or layers with mechanical turning as required for drying purposes
- the addition of lime and/or cement, typically up to 2% by weight to reduce the moisture content to nearer the optimum moisture content (OMC) for maximum dry density
- the addition of water by spraying or similar to increase the moisture content to nearer the OMC for maximum dry density.

The following techniques are not acceptable to NHBC for the treatment of materials for use as engineered fill:

- stabilisation to improve strength by the addition of over 2% lime and/or the addition of any cement or other hydraulic materials
- the addition of chemical binders or grouts.

4.6.7 Design and specification of earthworks

Also see: BS EN 1997-1, BS EN 16907-1, BS 6031

A suitably qualified engineer shall be responsible for the design and specification of earthworks, taking into account future development and type of building foundations. Engineered fill shall be placed in accordance with a suitable earthworks specification. Issues to be taken into account include:

1) **geotechnical design**
2) **earthworks specification**
3) **types of specification.**

Engineered fill should be placed to a suitable earthworks specification — the scope, details and requirements of the specification should be appropriate to the site, the nature of the fill, the techniques of placement and the end-use of the site.

4.6.7.1 Geotechnical design

On engineered fill sites, an element of geotechnical design will be required by NHBC. The complexity of the design and its supporting earthworks specification should reflect the scope of works and the associated risk. Geotechnical design is covered in BS EN 1997 Geotechnical design, with earthworks specifically covered by the requirements set out in BS 6031 (Code of practice for earthworks) and BS EN 16907 Earthworks.

It is recognised that on certain residential developments, the level of earthworks required can be minimal, with a low to negligible risk associated with the project. Where the scope of the earthworks is defined as Geotechnical Category 1 (Geo Cat 1), based on Table 4, a Geotechnical design statement (GDS) shall be prepared and submitted to NHBC.

Most earthworks are classified as Geotechnical Category 2 (Geo Cat 2) in accordance with BS EN 1997-1 and are required to be designed by an appropriately qualified and experienced person. Where the scope of the earthworks is defined as Geo Cat 2 or 3, a Geotechnical design report (GDR) shall be prepared and submitted to NHBC.

The content lists of a GDS or GDR may be prepared using outline from Managing Geotechnical Risks DMRB CD 622, as a guide. Both the GDS and GDR should be prepared by a suitably qualified engineer.

Table 4 should be used to attribute a geotechnical category to projects, and the subsequent requirements for GDS or GDR.

Table 4: Geotechnical design categories

Assessment of the site and proposals
Geohazards — legacy of mining/quarrying, un-engineered fill, low strength/bearing capacity, slope stability, etc
Preparatory works — removal of remnant foundations, obstructions, settlement monitoring, mining treatment, etc
Requirement for ground improvement — preloading, surcharging, dynamic compaction, etc

Category	Scale and extent of earthworks and end-use	Required information
Geo Cat 1 SIMPLE	Considered to have negligible geotechnical risk and may be designed adopting a qualifiable approach. The Geotechnical design statement (GDS) and earthworks specification should clearly define the scope of works covered by the Geo Cat 1 design and can be presented on drawings, accompanied by appropriate risk assessment. Typical sites would include: • greenfield sites • no geotechnical hazards • suitable existing ground conditions, no or minimal preparatory works and ground improvement measures • placement of engineered fill limited to proposed infrastructure, external works and earthworks slopes no steeper than 1V:5H • use of general fill only.	A GDS Summary based on good local experience and ground conditions that are well known and uncomplicated
Geo Cat 2 CONVENTIONAL	Considered to have no exceptional geotechnical risk associated with them, either during or post-construction. The records of the quantifiable design shall be presented in the Geotechnical design report (GDR), which should be accompanied by the earthworks specification. Typical sites would include: • brownfield sites • some or many geotechnical hazards to be removed or suitably mitigated • some or many preparatory works to be undertaken, the requirement for one or more ground improvement measures • placement of engineered fill limited to proposed infrastructure, external works and earthworks slopes steeper than 1V:5H • placement of engineered fill supporting building foundations and settlement sensitive elements • use of selected fill and general fill.	A GDR Based on the current BS EN 1997-1
Geo Cat 3 COMPLEX	Considered to have exceptional geotechnical risk with unstable ground conditions. Geo Cat 3 designs require an independent third-party check and are not covered by the requirements of this chapter. Typical characteristics include: • mostly brownfield sites • many geotechnical hazards to be removed or suitability mitigated • requiring a wide range of preparatory works to be undertaken • exceptionally difficult ground conditions with ongoing instability, ground movements or requiring investigation and special measures • placement of engineered fill supporting very large or unusual structures/buildings.	A GDR Typically, outside the scope of this standard Consultation with the NHBC and/or the Land Quality Service lqs@nhbc.co.uk

4.6.7.2 Earthworks specification

The earthworks specification should be prepared once the earthworks design has been undertaken and the properties of the proposed fill material have been established. It should clearly describe the design requirements to be satisfied ie, detail how the engineered fill is to be placed and what criteria will apply to prove its compliance, and include the information detailed below. An earthworks specification should be practicable and capable of both measurement and enforcement, and should be capable of being monitored by an effective form of quality assurance procedure.

A typical earthworks specification should include the following:

1. Description of scope and aims of the earthworks including reference and brief summaries of supporting documents:
   a. Desk study and ground investigation report
   b. Geotechnical Design Report (GDR) or Geotechnical Design Statement (GDS)
   c. Materials classification (acceptability) assessment
2. The intended end-use of the engineered fill should be defined
3. Details of any site preparation works required prior to earthworks filling and the treatment of exposed surfaces to prevent deterioration
4. Types of materials permitted for use together with material properties, including arrangements to prevent the deterioration of cohesive materials
5. Classification testing may include particle size distribution, plasticity (Atterberg Limits), compaction tests or moisture content tests should be undertaken to confirm that the fill materials remain within the earthworks specification
6. Types and frequency of classification tests should be site and material specific and confirmed in the specification. Acceptable test methods and frequencies of classification tests given in Tables 9 and 10 of BS 6031: 2009
7. Requirements for the placement, spreading and compaction of earthwork materials, including compliance criteria
8. Requirements for the disposal of unsuitable material
9. Testing proposals for the verification of compliance criteria and performance requirements to be met for end product and performance specifications, including load-settlement testing
10. Arrangements for supervision
11. Proposed as-built records to reflect the completed works
12. Construction drawings showing the proposed extent of the filling works (including thickness)
13. All other site-specific requirements and relevant construction drawings showing retained features, constraints, etc
14. The form and proposed content of an earthworks validation report

4.6.7.3 Types of specification

Three types of standard Specifications for Earthworks are acceptable to NHBC:

- method
- end product
- performance.

Method specification defines how compaction should be conducted in terms of the types of compaction plant, method of operation, number of passes of the plant and the final thickness of the compacted layer.

The end product specification defines the degree of compaction necessary and, if appropriate, stiffness requirement for the given material by reference to criteria linked to either serviceability or ultimate limit states. The level of compaction required is normally expressed in terms of selected geotechnical properties eg percentage of maximum dry density or prescribed minimum stiffness and is supported by on-site earthworks testing. Where an end product specification is used, the requirements normally define overall targets to be achieved without detailing the methods to be used to achieve the targets.

Performance specifications require the works to be defined relative to long-term project requirements, which are commonly set at a relatively high level. For example, the criteria may be defined based on the long-term fitness for use of a building that is to be formed upon the completed earthwork. NHBC requires a performance specification to be used in combination with an end product specification.

NHBC specification requirements for use on residential development are summarised in Tables 5 and 6.

Table 5: Types of specification for earthworks acceptable to NHBC

Specification	Specification requirements
Method	• the thickness of fill layers to be compacted • type of compaction plant • number of passes required • compaction requirements (typically 90% maximum dry density and <10% air voids)
End product	• the geotechnical properties to be achieved following placement of engineered fill — typically dry density, moisture content and air voids • the criteria for acceptable compliance and compaction requirements (see Table 6) • proposals in the event of non-compliance
Performance	• Defined by relative long-term projects requirements eg engineered fill and the underlying ground dupporting building foundations shall limit building settlements to less than 25mm and minimise angular distortion or tilt to 1:400 for 60-year design life • NHBC requires a performance specification to be used in combination with an end product specification • the behaviour the completed engineered fill is required to achieve under testing — usually limits of settlement under specified load and/or over time • details of the performance testing to be undertaken, including testing frequency • proposals in the event of non-compliance during placement and of performance testing

Table 6 provides the minimum level of compaction required throughout the placement of all engineered fill for both the support of building foundations and external and infrastructure works.

Table 6: End product acceptance criteria

End use	Acceptance criteria
Building foundations	>95% MDD* and <5% air voids (4.5kg or vibrating rammer) >98% MDD* and <5% air voids (2.5kg rammer)
External/infrastructure	>95% MDD and <5% air voids where fill >5m thick (2.5kg/4.5kg rammer)

*MDD = Maximum Dry Density

It may be appropriate for a project technical specification to incorporate different forms of earthworks specification for different types of fill material, eg method compaction for general fills and end product compaction for coarse granular fills.

The earthworks specification shall include relevant conditions to be satisfied during construction to ensure the following are met:

- materials are chemically suitable for the project and the surrounding environment
- materials should be durable, and not prone to deterioration or non-biodegradable
- earthworks should provide a stable finished surface that will limit post-construction settlement or movement within the engineered fill
- the earthworks should provide a surface of sufficient stiffness and/or shear strength for the intended use.

Once agreed with NHBC, the earthworks specification should not be amended on site without prior agreement with NHBC.

The earthworks specification should be based on industry guidance, such as the Specification for Highway Works, BS EN 16907 Earthworks, ICE Publishing — Earthworks: A Guide 2nd Edition, or on trials/previous experience, that is acceptable to NHBC.

The earthworks specification should outline if placing, testing and verification of earthworks fill is to be completed on the whole site, or undertaken and presented in a phased approach to facilitate the build programme.

Table 7 shows the types of earthworks specification that are acceptable to NHBC for different types of engineered fill and subsequent end-use, considering the starting ground (formation) level has been assessed as suitably stable and appropriate for the proposed earthworks and end-use (as per Clause 4.6.5).

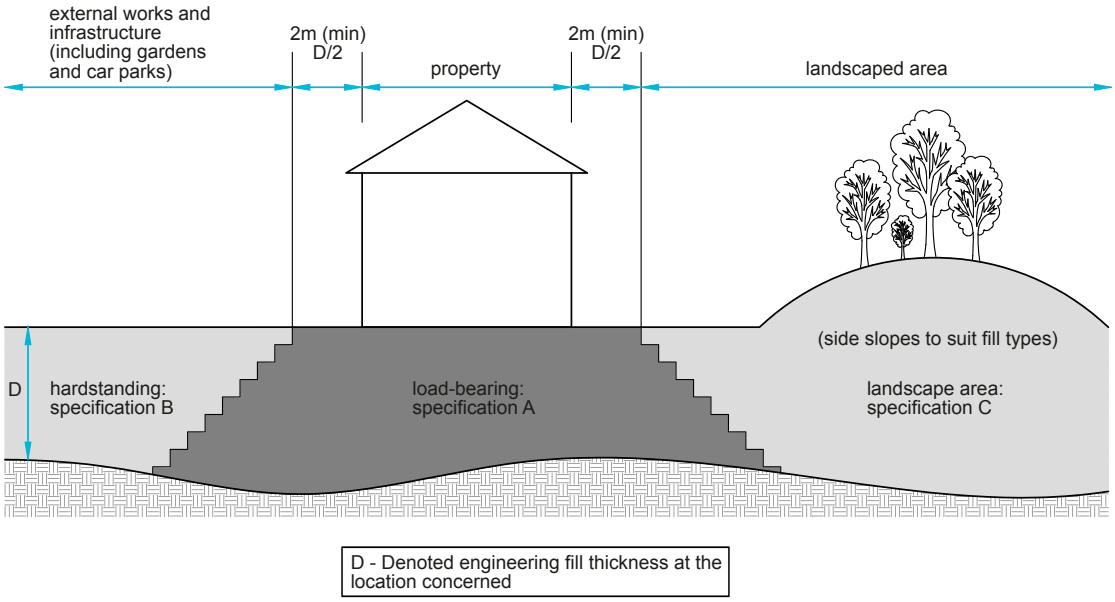
Table 7: Matrix for determining appropriate types of earthworks specification

End-use	Support of foundations	Support of external works	
Depth of fill	N/A(1)	<5m	>5m
Granular and cohesive fill types (including mixed fills)	End product plus performance (reinforced strip and beam grillage)	Method	End product
	End product (semi-raft)		

Note
1. Acceptable minimum depth of engineered fill beneath building foundations = 600mm.

Figure 2 illustrates the guidelines for the use of differing earthwork specification for different end-use, located in close proximity.

Figure 2: Compaction and differing end use



Notes:
1. Specifications A and B to be Table 3
2. Specifications C may be method or end product or no defined compaction regime

4.6.8 Compatibility of fill with foundations, infrastructure and external works

Placed engineered fill shall support foundations, infrastructure and external works as required without excessive settlement. Issues to be taken into account include:

1) building and foundation types
2) engineered fill performance and foundation options
3) building settlements and relative movements
4) external works and infrastucture.

This section provides guidance on building foundations that will generally be acceptable to NHBC. Where more rigorous structural or geotechnical analysis is carried out, alternative solutions may be acceptable, but these must be agreed with NHBC in advance of development.

4.6.8.1 Building and foundation types

Engineered fill covered within this chapter should be capable of supporting foundation loads from buildings of three storeys or equivalent weight.

Where compliance testing of engineered fill demonstrates a high level of consistency and quality in combination with a high level of supervision and control, a suitably structurally designed reinforced strip foundation may be acceptable. This can only be so in conjunction with ground hazards and risks associated with excessive settlements being suitably addressed. A suitably structurally designed beam grillage will also be acceptable.

Where engineered fill has been placed to a suitable earthworks specification with a satisfactory verification testing, a semi-rigid raft foundation in accordance with Chapter 4.4 Raft, pile, pier and beam foundations will be acceptable to support buildings.

Reference should also be made to the requirements of Chapter 4.2 Building near trees and Chapter 4.3 Strip and trench fill foundations as appropriate. Cohesive fill material should be taken as having a similar volume change potential (and requirement for minimum foundation depths) as natural clays of the same plasticity index.

4.6.8.2 Engineered fill performance and foundation options

Residential developments founded on engineered fill are more sensitive than other structures or infrastructure founded on the same material, and require foundation solutions that will mitigate the potential for both aesthetic and structural damage over the design life of the building. Any foundation solution adopted should be sufficiently robust to accommodate the predicted future settlements and prevent damage to building superstructures. To provide the required stiffness, rigidity and robustness against unwanted movements, all foundations on engineered fills should be reinforced. Unreinforced strip foundations would not be acceptable to NHBC under any circumstances.

Table 8 indicates the minimum requirements necessary for a shallow foundation to be used on engineered fill and considers different foundation types that may be used based on the achieved compaction of the engineered fill only. The table should only be used where no other residual geotechnical risks are present, and assumes that the engineered fill is placed on competent natural ground.

The foundation specified should consider the holistic geotechnical design (eg bearing capacity and settlement) and also allow for any retained geotechnical risks outside or below the engineered fill. Table 8 should not be used to justify a less robust foundation where unresolved geotechnical risks remain.

Where the requirements of Table 8 have not been significantly achieved, for example poor execution or poor site supervision, or inadequate testing or reporting, or where the verification of the earthworks falls outside the minimum requirements given below, an alternative foundation solution outside this chapter will need to be considered — ie, solutions from Chapter 4.4 Raft, pile, pier and beam foundations or Chapter 4.5 Vibratory ground improvement techniques. Where piles are considered, the potential for negative skin friction on the piles due to creep settlement of the placed engineered fill and/or the consolidation of any underlying soils should be assessed.

Table 8: Engineered fill performance and acceptable foundation options

Proposed outcome	Reinforced strip	Beam grillage	Semi-raft
Minimum relative compaction (% maximum dry density) [1]	>95	Majority of results >95 However, results show some variability and non-compliances (see Figure 7) No results <90	Majority of results >95 However, results show some variability and non-compliances (see Figure 7) No results <90
Maximum air voids (%)	<5	Majority of results <5 However, results show some variability and non-compliances (see Figure 7) No results >10	Majority of results <5 However, results show some variability and non-compliances (see Figure 7) No results >10
Supervision	A very high degree of independent supervision Full-time independent resident geotechnical engineer dedicated to inspection, supervision and testing of the fill	A high degree of independent supervision Full-time inspection of the filling by an independent resident geotechnical engineer	Good/normal supervision Part-time inspection of the filling by an independent geotechnical engineer
Contractor	Experienced/specialist earthworks contractor	Experienced earthworks contractor	Suitably experienced groundworker or earthworks contractor
Engineered fill	Fill generally of consistent depth and properties throughout Fill behaviour should have been proven by precedent or trials	Fill generally of consistent or steadily varying depth Little variation in fill properties	Effects of variations in fill depth and properties should be assessed with predicted settlements established
Foundation performance testing	Zone load tests and/or mini zone load tests and plate load tests across fill depth and at surface[2]	Mini zone load tests and plate load tests across fill depth and at surface[2]	Plate load tests across fill depth and at surface[2]
Verification	Earthworks verification report produced by a third-party organisation	Earthworks verification report produced by an experienced earthworks contractor	Earthworks verification report produced by an experienced earthworks contractor/ groundworker
Foundation design	Design by a suitably qualified engineer to relevant British Standards Designed for moment to span 2m as simply supported and 1.0m as a cantilever[3]	Design by a suitably qualified engineer to relevant British Standards Designed to span 3m as simply supported and 1.5m as a cantilever	Design by a suitably qualified engineer to Chapter 4.4 Raft, pile, pier and beam foundations

Notes

1. Modified Proctor hammer (4.5kg).
2. Minimum 600mm diameter.
3. Foundations to be typically reinforced with mesh reinforcement at top and bottom.

In circumstances where there is a potential increased or significant geotechnical residual risk of long-term creep settlements, for example as a result of the type or thickness of placed engineered fill or underlying thickness of made ground beneath the engineered fill, a stiff reinforced concrete raft or stiff beam grillage foundation may be required.

4.6.8.3 Building settlement and relative movements

The total settlement between any part of the building foundation and the surrounding ground or external area should not normally exceed 25mm over the 60-year design life.

Where engineered fill or the underlying ground is undergoing steady uniform settlement, a total foundation settlement of over 25mm may be acceptable, provided the differential settlement is compliant with the guidance below and the foundation solution is sufficiently robust.

The tilt or distortion (differential settlement) of any part of the foundation should not exceed 1 in 400. The potential differential settlement of any foundation should be assessed where:

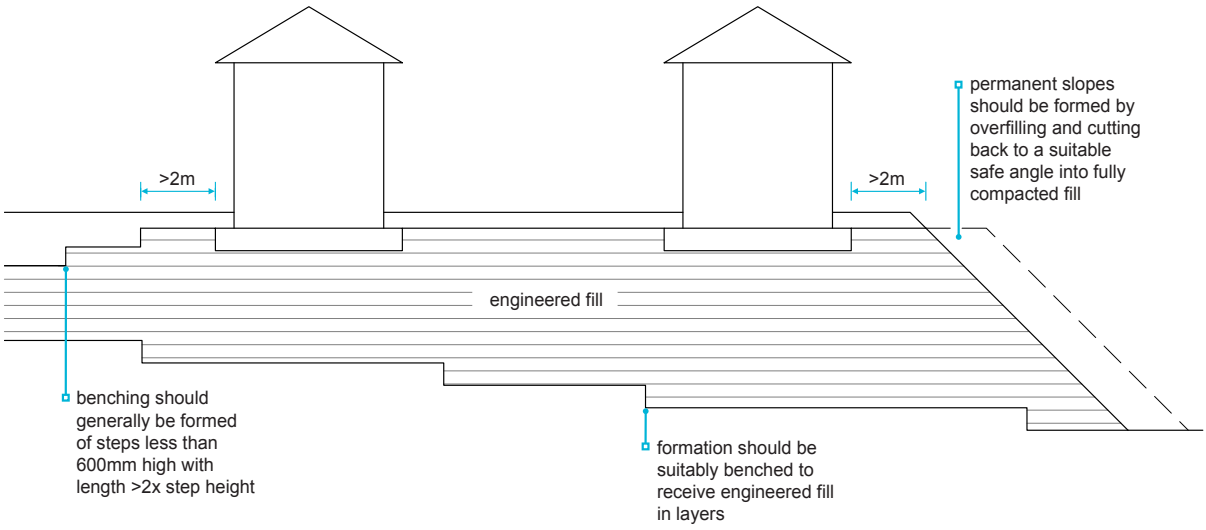
- the depth of fill significantly varies
- there is a tapered layer of compressible material
- a quarry highwall or buried batter is present.

Where predicted total or differential settlements of any part of the building foundation exceed the above criteria, further assessment will be required to determine suitable alternative foundation solutions. The presence of highwalls in particular will require rigorous assessment, including their location, geometry and observed load-settlement behaviour of the engineered fill following remediation, if they are to be considered by NHBC to be suitable to build residential development upon.

The effects of differential settlement between external areas and buildings should be assessed; in particular, where they are piled or supported on vibro columns. Additional means of support or measures to mitigate ground movement may be required where excessive settlements could be realised ie, the use of flexible drainage and/or surcharging.

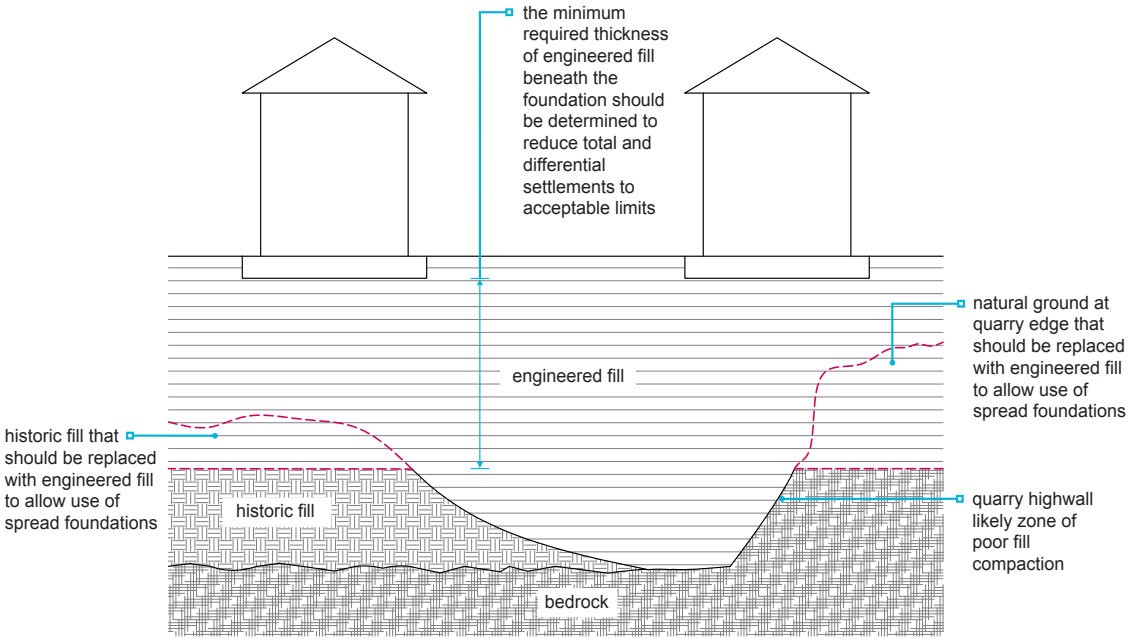
Figures 3 and 4 show examples of engineered fill over rolling landscape and over buried features where part removal of the feature was necessary to mitigate excessive tilts.

Figure 3: Engineered fill over gentle rolling landscape



land raising areas should be sufficiently large on plan to permit plant and fill movements and for benching and trimming at edges.

Figure 4: Engineered fill over buried features



4.6.8.4 External works and infrastructure

It will generally be acceptable to support low height retaining walls and boundary walls on mass concrete or reinforced foundations placed on engineered fill. Walls should be provided with joints and/or reinforcement as considered appropriate to provide flexibility and structural integrity while accommodating ground movements, particularly at locations where depths of engineered fill and settlements may vary. Geotechnical and structural designs are required where retaining walls are in excess of 0.6m in height.

Wall foundations, hardstandings and roads should be designed according to appropriate guidance and achieved geotechnical properties of the engineered fill.

Where external works and infrastructure pass from engineered fill to the natural ground, or where the depth of engineered fill varies significantly, the potential for differential ground movements should be assessed and catered for. Additional measures should be provided as necessary, eg the use of geogrid or futureproofing drains by potentially laying to steeper falls and the use of flexible jointing.

For areas not within the influence of building foundations (ie, hardstanding, gardens, infrastructure or external works areas), a maximum total long-term settlement of over 25mm would generally be acceptable subject to serviceability design limits (see Figure 2 for an approximate delineation of these areas).

4.6.9 Acceptable methods of earthworks filling

Also see: SHW Series 600

Earthworks filling shall only be undertaken using methods acceptable to NHBC that are appropriate to the materials, site conditions and end-use. Issues to be taken into account include:

1) **conventional compaction**
2) **non-standard compaction**
3) **preloading and surcharging.**

4.6.9.1 Conventional compaction

Placement and compaction of engineered fill should be undertaken in layers of controlled depth using appropriate plant. Acceptable methods are considered to be those based on the recommendations from the Specification for highway works (SHW) Table 6/4.

The type and size of the compaction plant should be based on the volume or depth of engineered fill to be placed, the classification of the fill to be compacted, and the specification requirements.

4.6.9.2 Non-standard compaction

This aspect covers all methods of compaction which are not covered by SHW Table 6/4. Details of non-standard plant and techniques should be submitted to NHBC in writing at least eight weeks before site works begin. Non-standard techniques include, but are not limited to:

- rapid impact compaction (RIC), using a rammer
- high energy impact compaction (HEIC), using polygon or triangular rollers
- dynamic compaction, using heavy drop weights dropped from a crane.

NHBC will require evidence of the effectiveness of non-standard plant or techniques, or demonstration of the suitability of proposals for the site conditions by trials as appropriate, particularly for large or complex projects. Site trials, including testing requirements, should be designed and agreed with NHBC prior to commencement. Trials must accurately reflect the proposed filling techniques and achieve specified performance requirements, and may require post-treatment investigation and load testing.

4.6.9.3 Preloading / surcharging

Placement of a surcharge may be an acceptable form of ground improvement but should not be used in place of the compaction techniques described previously. The design of the surcharge, including its magnitude and duration of surcharge requires careful analysis.

The effectiveness of surcharging should be demonstrated by monitoring or by trials. The requirements for monitoring and supervision are outlined in BS EN 1997-1 and BS 6031 and should be presented in the GDR. The surcharge load should be maintained until the achievement of the design requirements has been demonstrated. Refer to BRE FB 75 for further guidance.

4.6.10 Site work

Also see: BS EN 16907-5 and BS 6031

The developer or builder shall ensure suitable supervision, sampling and testing are performed throughout the entire duration of the earthworks. Filling shall be undertaken by a competent contractor using materials, personnel and plant appropriate for the nature of the site conditions and proposed end-use. Issues to be taken into account include:

1) **supervision and records**
2) **site preparation**
3) **material handling**
4) **material acceptability and compliance testing**
5) **actions in respect of non-compliant fill**
6) **protection of fill.**

4.6.10.1 Supervision and records

The developer or builder must arrange for a suitable site supervision and recording of the works appropriate to the scale and complexity of the project and proposed end-use of the fill. The recording of the site works should be in accordance with the requirements of the earthworks specification. Guidance on the level of information that is required to demonstrate the quality of the works is available in BS EN 16907-5.

4.6.10.2 Site preparation

The site should be prepared in accordance with the earthworks specification, with all vegetation, topsoil, fly tipped and unsuitable materials removed prior to filling. If suitable, topsoil should be placed in segregated stockpiles for reuse onsite or elsewhere. Where excess topsoil is present, this may be removed under the Material Management Plan (MMP).

The formation should be prepared by proof rolling, with any hard or soft spots identified and remediated in accordance with the earthworks specification. Temporary drainage may be required to keep the formation dry.

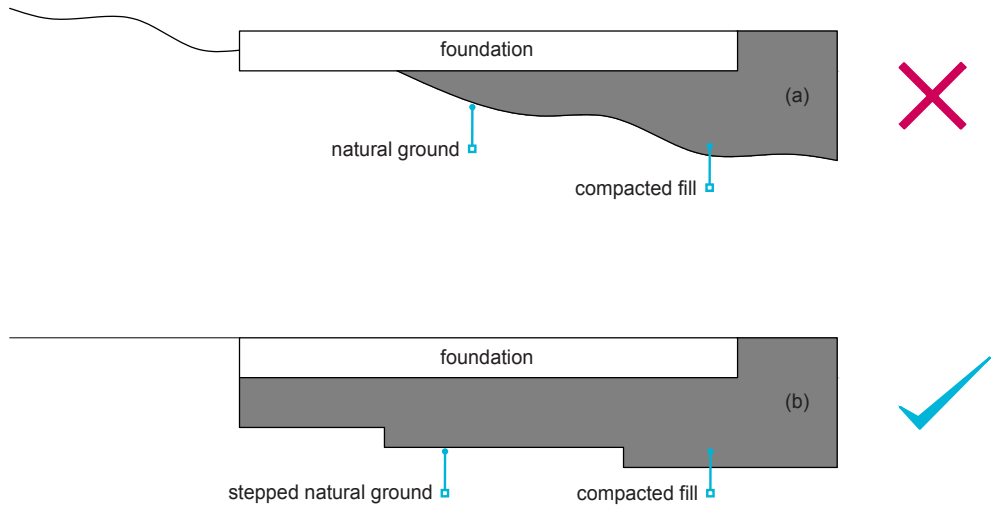
Relic structures, for example old foundations and hard standings, should be removed from below engineered fill areas in their entirety wherever practicable. As a minimum, relic structures and obstructions should be removed to at least 2m below any proposed foundation. All structures or uncharacteristic elements (including boulders) greater than 1m in diameter/length left in the ground at formation should be surveyed and their positions recorded.

When recording the depth of engineered fill, it is essential (eg for use in subsequent pile designs) that the formation should be surveyed prior to filling on a maximum 10m grid arrangement.

Site constraints and features to be preserved (for example monitoring wells, public rights of way, watercourses and trees to be retained) must be clearly identified, and all necessary protection and safety measures implemented. Alternatively, their removal or any reinstatement measures should be specified as appropriate.

Where the sub-formation is sloped, the sides should be stepped at a maximum height of 600mm to allow the engineered fill to be benched into the existing natural ground or achieved otherwise as stated in the earthworks specification. Figure 5 shows what may be required on a sloping site close to the development platform where filling is required.

Figure 5: Benching of sloping natural ground



Notes

a. Proposed development platform straddling over natural and fill areas
b. Preferred development platform with well-prepared and stepped fill area beneath

4.6.10.3 Material handling

In addition to the required classification testing, site-derived materials should be routinely inspected during excavation to ensure consistency and correlation with the expected ground model.

Imported fill should be subject to periodic inspection from the donor site prior to arrival at the site and regular inspections once delivered. Classification testing should be undertaken as required prior to placement, particularly where the material is not provided with independent certification and where visual assessment suggests the material classification varies.

Engineered filling should not be undertaken in inclement weather conditions. Where the engineered fill is cohesive, placement and filling should be paused during extended periods of rain. For sensitive materials like chalk, care should be taken not to over-compact the fill further than specified.

Engineered fill must be placed and compacted in accordance with the specification, within a defined moisture content range close to the optimum moisture content (OMC) as derived from relevant laboratory testing.

For cohesive fill materials, the moisture content is critical in achieving the desired dry density. Engineered fill that is compacted too dry of the OMC risks being vulnerable to collapse settlement or heave when wetted. Engineered fill that is compacted too wet of the OMC risks being too weak to provide adequate support without excessive settlement.

Engineered fill should proceed in near horizontal layers (to assist in shedding surface waters), with each layer fully compacted before commencing the following layer. The maximum layer thickness for method compaction should be based on the type of fill material, the classification of the fill material, placement, and the method and plant employed.

For end product compaction, an uncompacted layer thickness of up to 250mm, subject to site-specific requirements, would be acceptable. The maximum particle size should not be greater than 1/3 of the compacted layer thickness or 75mm, whichever is lower.

Differing engineered fill material types should not be placed in the same layer. They should be placed at predetermined layers and defined depths appropriate to their properties and the proposed end-use.

Filling activities should be planned and carried out so that:

- vibrations do not disturb existing or nearby properties, excavations, slopes, buildings, services or infrastructure
- filling and earthwork machinery does not overload retaining features, slopes, buried services or infrastructure
- ground movement, including around the area of filling, does not harm adjacent buildings, services or infrastructure
- temporary slopes (filled or in cut) are safe and stable
- under-compaction and over-compaction are avoided
- the rate of placement of fill does not result in excess pore water pressure leading to failure of the underlying ground.

4.6.10.4 Material acceptability and compliance testing

Classification and compliance testing should be in accordance with BS EN 16907-5 and BS 6031:2009. Laboratory testing should be undertaken by a UKAS and/or MCERTS accredited specialist. All testing should be to a current British Standards or European Standards, eg BS 1377, using appropriately calibrated equipment. Testing should be undertaken throughout the duration of the fill placement in accordance with the guidance in Clause 4.6.12.

4.6.10.5 Actions in respect of non-compliant fill

Where testing indicates compacted engineered fill does not fully comply with the requirements of the earthworks specification, appropriate action should be agreed as soon as possible with NHBC. Possible actions include:

- drying of engineered fill material prior to further placement of subsequent layers
- excavation and replacement of the engineered fill represented by the test failure
- additional compaction (if the failure is shallow or at the surface) and retesting
- undertaking appropriate performance testing.

If the non-compliant engineered fill is regarded as a marginal outlier and represents part of a normal spread of test data, it may potentially be deemed acceptable without further action. It should be recorded in the Earthworks Verification Report.

The possible extent of non-compliant engineered fill needs to be carefully assessed, as well as whether the non-compliance may indicate unsuitable placement and compaction techniques, or poor site conditions, excessively variable fill or unsuitable material. Where there is a divergence from the earthworks specification, the designer should be notified and advice sought.

Remedial action needs to be carefully undertaken and recorded, avoiding disturbance to previously placed compliant engineered fill.

4.6.10.6 Protection of fill

Compacted engineered fill should be protected from deterioration due to trafficking, poor weather and pooling surface water. Suitable measures include laying the surface to falls to assist drainage or use of a durable granular sealing layer or sacrificial layer.

4.6.11 Adjacent excavations

The builder shall ensure that foundations within engineered fill are not disturbed by adjacent excavations.

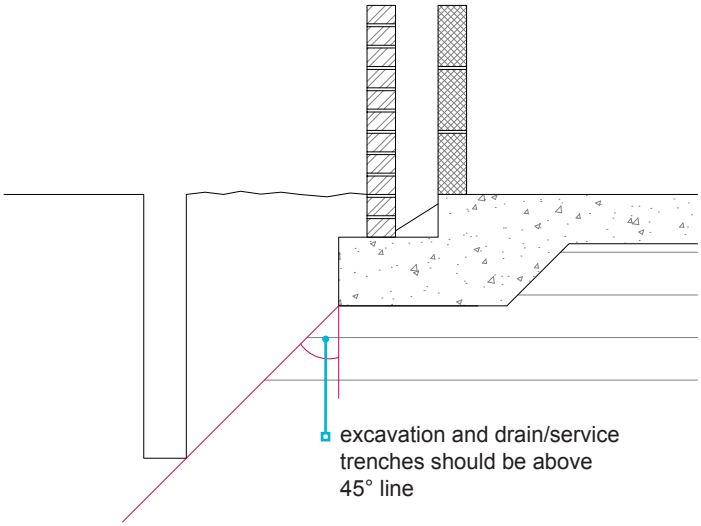
The engineer should consider the influence of drainage and other service trenches on the stability of the complete works.

Excavations in engineered fill may require additional trench support, even at relatively shallow depths. Health and Safety Executive (HSE) advice with respect to the design and management of below ground temporary works, including those for excavations, man-entry, etc must be adhered to.

The earthworks verification report should identify and duly reference any constraints to excavation because of buried features, contamination or unusual ground conditions.

The minimum horizontal clearance between excavations and foundations must not be less than the depth of excavation minus the depth of the structural foundation. Particular attention is needed for excavation below the water table, where encountered.

Figure 6: Placement of excavation adjacent foundation on engineered fill



4.6.12 Verification of engineered fill

Also see: BS EN 16907-5, BS 6031 and BRE Digest 427

Verification testing of engineered fill shall be undertaken to confirm compliance with the earthworks specification and its fitness for purpose. Issues to be taken into account include:

1) **fill classification**
2) **end product testing**
3) **performance testing**
4) **settlement measurement**
5) **testing frequency.**

Validation and verification of the filling should be in accordance with BS EN 16907-5 and BS 6031:2009. Laboratory testing should be undertaken by a UKAS and/or MCERTS accredited specialist. All testing should be to a current British Standards or European EN Standards, eg BS 1377, using appropriately calibrated equipment.

Testing should be undertaken on a combination of random and targeted locations through the full depth of the fill to ensure consistency across the site. Higher-risk locations (for example deeper engineered fill, heavier/larger buildings, or where engineered fill was placed in less suitable conditions) should have a robust data set to confirm that fill has achieved the required geotechnical compliance criteria.

The testing frequency should be set out in advance of the works in the earthworks specification.

4.6.12.1 Fill classification

Classification testing, including particle size distribution (grading), plasticity (Atterberg Limits), 4.5kg rammer compaction tests or moisture content tests, should be undertaken throughout the earthworks to confirm that the engineered fill materials remain within the acceptability limits set out in the earthworks specification.

The type and frequency of classification tests should be site and material specific and should be confirmed in the earthworks specification. Acceptable test methods and frequencies of classification tests are given in Tables 9 and 10 of BS 6031:2009.

4.6.12.2 End product testing

Fill compaction is most commonly established by comparing the in-situ dry densities and moisture contents with the laboratory-determined maximum dry density and optimum moisture content. NHBC will normally accept engineered fill verified to achieve the criteria given in Table 6. There may be variation to these requirements where differing material types or foundations are adopted, or where there is a risk of future inundation of the fill.

The in-situ densities of engineered fill may be measured using sand replacement tests (SRTs), nuclear density tests (NDTs) or electromagnetic density gauges (EDGs). Where NDTs or EDGs are used, the results should be regularly calibrated against SRTs. Where there is variation in the fill materials, the use of NDT results to assess compaction may not be reliable.

4.6.12.3 Performance testing

Table 9 indicates suitable tests to assess earthworks performance. The type and frequency of testing should be appropriate for specific site conditions and the proposed end-use. It is recommended that a minimum of three tests of each type are undertaken, so that a trend can be observed from the results, with the exception of preloading by surcharge.

Table 9: Types of performance testing

Test/parameter	Description	Application
Preloading by surcharge	An area usually greater than 50m^2 raised above the proposed development level with soils or fill to model the proposed development loadings	For large sites or areas of deep fill (over 5m deep) or where highly compressible soils exist at depth, usually in conjunction with other performance tests such as zone tests, plate tests or probing
Zone load	A rigid base (usually made up of concrete) with areas related to the width of the proposed foundations, typically between 4-10m^2 Suited to modelling the loading and depth of influence of a building on raft foundation The test duration to be sufficient to identify the magnitude and timescale for completion of primary settlement, the clear trend of any secondary settlement (creep) and to confirm that load-settlement behaviour is in accordance with calculated predictions	For large sites or areas of deep fill usually in conjunction with other performance tests such as plate tests or probing undertaken to identify suitable locations for the zone test Care must be exercised during the zone tests, pads/ bases are susceptible to ground vibrations/movement resulting from machinery/plant
Mini zone load/ pad	Smaller than a zone test — with an area less than 4m^2 and designed to model a typical (or heaviest) part of a spread (beam grillage or reinforced strip) foundation The test duration to be sufficient to identify the magnitude and timescale for completion of primary settlement, the clear trend of any creep and to confirm that load-settlement behaviour is in accordance with calculated predictions	Usually in conjunction with other performance tests such as plate tests or probing to identify suitable locations for the zone test Care must be exercised during the mini zone load tests, pads/bases are susceptible to ground vibrations/movement resulting from machinery/plant
Surface points settlement	A stable concrete or steel level monitoring point set at the surface or at shallow depth to determine the nature of any fill settlement without applied loading — usually over a prolonged period to model self-weight consolidation and creep settlement as required	Where self-weight consolidation or creep settlement may be significant — usually associated with deep cohesive fill
Settlement rods	Plates placed at the underside of engineered fill to measure settlement caused by the placement of fill	Usually in conjunction with other performance tests such as zone tests and mini zone load tests
Magnetic extensometers	Can be placed at varying depths within engineered fill or underlying made ground in deep fill sites to record settlement from targeted zones	Usually in conjunction with other performance tests such as zone tests and mini zone load tests
Plate test	Usually 600-900mm diameter plate and loaded incrementally to 1.5-3.0 times the highest proposed bearing pressure The peak load is held for up to 1 hour or until the rate of settlement does not exceed an agreed limit The use of dual cycle plate load tests can provide a significant improvement on the assessment and interpretation of the data. Wherever possible, dual cycle plate testing should be employed	Inexpensive but may not load the fill as deeply as a foundation, limited to approximately 1.5x the plate diameter Most suitable during fill placement
Probing	A range of techniques are available	Static cone testing can provide data on the surface to depth of soil, including soil stiffness and other important soil properties Shallow techniques (including hand-held) may be limited in data quality
Permeability	Infiltration testing in boreholes or trial pits at the depth of interest	Where low permeability is required to limit groundwater (or ground gas) movement
Inundation	Similar to permeability testing but with added settlement monitoring	To assess the susceptibility of fill to settlement when it becomes saturated (from surface water, service trenches or rising groundwater)
Hand vane	Undrained shear strength of cohesive fill; quick and easy but of limited reliability and accuracy	For cohesive fill Any gravel within the soil matrix that comes into contact with the cruciform pattern of the 4 vanes can significantly alter the results. It should only be used in conjunction with other tests as a confirmatory tool

Proposals for testing should be agreed in advance of the works and should be set out in the earthworks specification with supporting test plan(s). Test locations should be selected to allow a satisfactory spatial and lateral spread of results.

The pass criteria for the performance tests should be detailed in the earthworks specification and geotechnical design report/ geotechnical design statement and should be appropriate for the proposed end use and foundation type. Load-settlement zone load tests should be a minimum of 1.2 times the anticipated design load of the foundations and with the loaded area of a comparable scale.

4.6.12.4 Settlement measurement

Settlement measurement of load tests or surface points should be undertaken by a suitably qualified land surveyor to a suitable accuracy, no greater than to the millimetre and less where site conditions are considered appropriate or are likely to reduce uncertainty and the required duration of monitoring. It is critical that, over the long term, survey points are not damaged, disturbed, or affected by other activities. Additionally, the data should be related to stable datum outside the influence of any earthworks, or made ground or existing unstable ground. A minimum of two datum points should be established to provide redundancy in case one is lost or damaged.

Extensometers in boreholes can be effective at determining the depth at which settlements are occurring, where preloading or surcharge mounds are positioned upon underlying ground and self-weight consolidation is being assessed.

Plates with extension rods also provide means of measurement of settlement at sub-formation and the underlying ground.

Settlement data should be plotted at both natural time and logarithm time to aid assessment of the data.

4.6.12.5 Testing frequency

The frequency of testing for classification, compliance and performance purposes should be determined according to site conditions, fill materials and their consistency, filling techniques and the proposed end use as stated in the earthworks specification. Testing frequencies should be specified in accordance with industry guidance such as BRE Digest 427 and also see additional guidance within Clause 4.6.1.

Where a method specification is used, in-situ testing is required but typically would be based on the total volume of engineered fill to confirm that the degree of compaction achieved by the adopted method on site is as expected. When end product specification is used, in-situ testing should be based on a minimum number and grid, with each and every layer tested, eg 1 per 25m x 25m grid per layer and a minimum of three per layer per day. Where a performance specification is adopted, it will be necessary to undertake performance testing during fill placement, as well as upon completion, to ensure compliance with the earthworks specification.

The testing frequency based on Table 10 is generally considered as an acceptable minimum requirement.

Table 10: End product compliance testing of placed engineered fill*

Fill volume (m^3)	Minimum number of tests required
>100,000	2 per 1,000m^3
10,000 to 100,000	3 per 1,000m^3
<10,000	5 per 1,000m^3

*Note: Variation to the above may be necessary where differing material types or foundations are to be used.

Test types and frequencies should be reviewed according to the results obtained and site conditions. Where there is greater variation in site conditions or results than anticipated, an increased frequency of testing will be required. Conversely, and where agreed with NHBC, a decrease in test frequency may be acceptable where consistency in test results is being achieved.

4.6.13 Reporting

Also see: BS EN 16907-5 and BS 6031

A detailed earthworks verification report shall be provided to NHBC on completion of the earthworks filling and testing. Where appropriate, the contents shall be agreed with NHBC prior to the work being done.

A comprehensive earthworks verification report for the filling works should be provided to NHBC as soon as practicable. It should provide an interpretation and assessment of the factual data contained within the report, as well as a detailed summary of the works undertaken, including testing. A site-wide or phased reporting approach is acceptable.

Where reinforced strip foundations are proposed, the report should be produced by a third-party organisation separate from those undertaking the works ie, by the overseeing supervising engineer, with all factual information made available. The report, where beam grillage or semi-raft foundations are proposed, can be produced solely by a suitably experienced earthworks contractor.

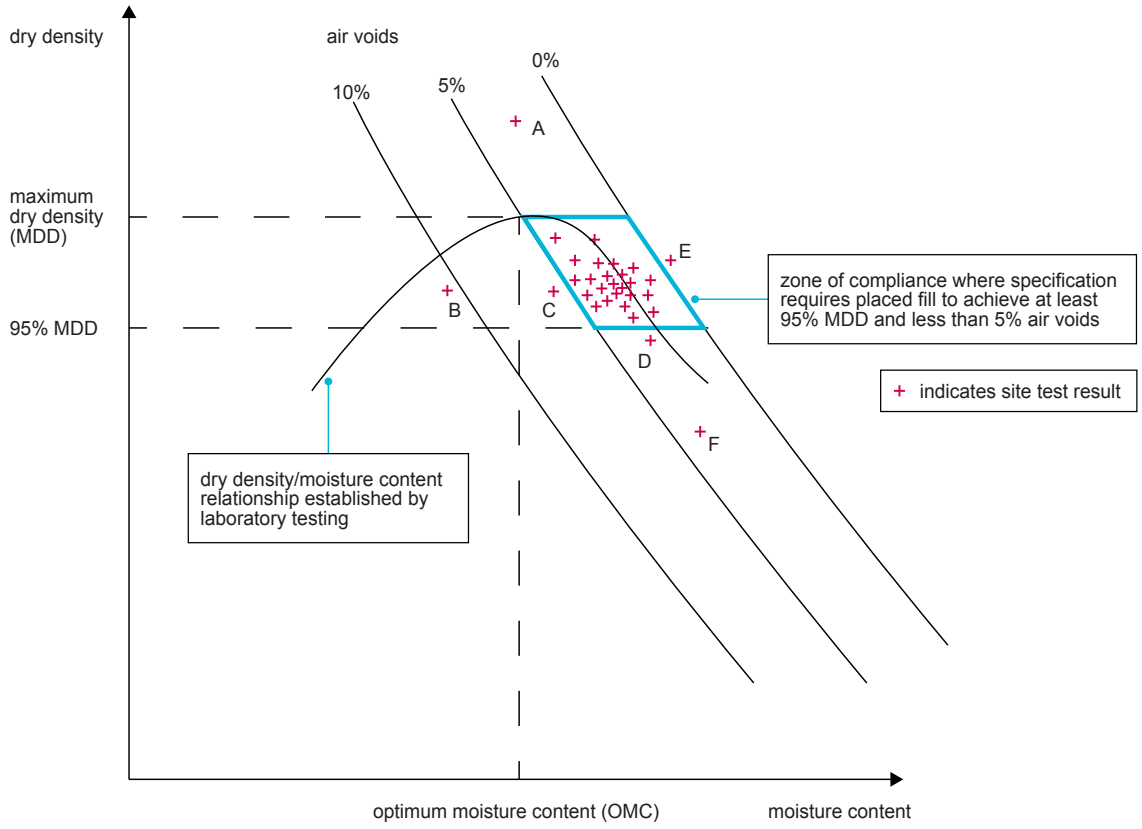
The content of the earthworks verification report shall be defined within the earthworks specification. Guidance on the contents and structure of the detailed report may be based on information within DMRB CD 622, where it is termed a geotechnical feedback report.

It is important that the report is in an appropriate format. Test results should be suitably summarised and presented to provide clear understanding using graphs and charts as necessary.

The earthworks verification report should give details as appropriate of the following:

1. The contractors and personnel responsible for the filling work, including details of supervision and testing
2. Preparation works prior to earthworks filling
3. Reference to the earthworks specification and method statement(s)
4. Sources of material used as engineered fill and their material classification
5. Any treatment, reconditioning or remediation of proposed engineered fill
6. Plant and methods used
7. As built survey records, including post-topsoil strip level or formation level for the earthworks, reduced levels following earthworks cuttings, final as-built or post-earthworks filling formation level, plan(s) and other drawings as appropriate that show the extent and depth of earthworks filling
8. All test results and certificates
9. Progress photographs and surveys
10. Progress reports and site diaries, with details of weather/site conditions and any agreed variations or changes to the specification
11. Graphical representation of the classification and compliance test data as show in Figure 7
12. Changes and amendments to design and earthworks specification
13. Records of remedial actions in areas of non-compliance
14. Problems experienced, and solutions and methods used to overcome the issues
15. Confirmation that the works comply with the earthworks specification and are suitable to support the proposed foundation types, where applicable (all non-compliances or departures from the earthworks specification should be clearly identified and suitably assessed)
16. Drawings showing known obstructions and any relevant features under or within the engineered fill
17. Graphical representation of the load-settlement tests, surcharge trials or post-completion monitoring over time with plots of settlement versus natural and logarithm presented to demonstrate that primary settlements are complete, with a clear trend of any remaining creep settlement projected to allow for a satisfactory building performance over a 60-year design life
18. Information required by the builder to safely undertake follow-on works in the ground, including any special precautions which should be undertaken or unusual constraints that exist, and any residual risks (for example further measures may be required where upfilling or an increase in ground levels post-remediation are likely to be proposed)

Figure 7: Basis for design: plot of moisture contents vs. dry densities for each fill type



Notes

A – Indicates placed fill is of significantly higher density than achieved in the laboratory – the fill classification is likely not complying with the specification. Repeated results higher than the MDD indicates the laboratory testing was not on representative material or the method of laboratory compaction was too light.

B – Indicates placed fill has been compacted too dry of optimum and may therefore, where cohesive fill has been used, be liable to settlement when wetted.

C, D and E – Marginally outside of the compliance zone. As part of a large set of results that are otherwise compliant, these marginal failures may be acceptable, provided they are not part of non-compliant clusters.

F – Indicates fill placed wet of optimum and may be liable to settlement under load or over time.

Results of type A, B and F should be assessed further, and explanation provided of remedial actions, further testing or reasons for acceptance.

Further guidance on acceptability testing of proposed source fills and compliance testing of placed engineered fill is are provided in BS 6031:2009. In setting the compliance curve of dry density/moisture content relationship, all tests should be presented or made available such that the target basis of design (for each fill type) can be agreed with NHBC, noting the degree of interpretation and assessment, including outliers. Updated targets may be appropriate in variable materials and should be detailed and agreed with the NHBC.

Compliance test results should be summarised and presented so that any non-compliances can be easily identified.

If the site has been filled some years before the intended construction works, or for an alternative end use such as commercial buildings, a retrospective validation may be appropriate. Assessment of historic fill within land reclamation schemes and marginal sites are generally outside the scope of this chapter. Consult NHBC or consider using the NHBC Land Quality Service for a bespoke consultation.

4.6.14 Further information

- *BRE Special Digest 1 — Concrete in aggressive ground. 3rd edition*
- *BRE Digest 427 — Low-rise buildings on fill (parts 1-3)*
- *BRE Digest 433 — Recycled aggregates*
- *BS EN 771 — Specification for masonry units*
- *BS EN 16907-1 — Earthworks. Principles and general rules*
- *BS EN 16907-5 — Earthworks. Quality control*
- *ICE Earthworks — A guide (by Nowak & Gilbert)*
- *SHW Series 600 — Manual of Contract Documents for Highway works. Specification for highway works. Series 600*

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