CHAPTER 5: Foundations

CONTENTS

FUNCTIONAL REQUIREMENTS

5.1 GROUND IMPROVEMENT

Workmanship

- **i.** All workmanship must be within defined tolerances as defined in Chapter 1 of this Manual.
- **ii.** All work to be carried out by a technically competent person in a workmanlike manner.
- **iii.** Ground improvement schemes should be appropriately tested to confirm that the completed works meet design specifications. The testing regime must be agreed with the Warranty Surveyor prior to commencement of work.
- **iv.** The Developer shall ensure that adequate quality control procedures are in place. The quality control must identify that site work meets the design intention. All procedures should be auditable and available for inspection.

Materials

- **i.** All materials should be stored correctly in a manner that will not cause damage or deterioration of the product.
- **ii.** All materials, products and building systems shall be appropriate and suitable for their intended purpose.
- **iii.** The structure shall, unless specifically agreed otherwise with the Warranty provider, have a life of not less than 60 years. Individual components and assemblies, not integral to the structure, may have a lesser durability, but not in any circumstances less than 15 years.

Design

- **i.** The design and specifications shall provide a clear indication of the design intent and demonstrate a satisfactory level of performance.
- **ii.** Site investigation by an appropriately qualified person should be supplied and provide the following information:
  - a. Depth of original soil types below the structure
  - b. Details of any filled ground and its suitability to accept ground improvements techniques
  - c. Gas generation or spontaneous combustion from ground conditions

  The investigation must be endorsed by the Specialist Foundations Contractor.
- **iii.** Structural elements outside the parameters of Approved Document A (England and Wales) must be supported by structural calculations provided by a suitably qualified expert.
- **iv.** The ground improvement works must meet the relevant Building Regulations, British Standards, Eurocodes and other statutory requirements.

5.1.1 Introduction

Ground improvement enables sites with poor load-bearing capacity to be strengthened; meaning the loadings of the proposed building can be adequately supported off suitable foundations. The guidance detailed in this Chapter will be accepted as a satisfactory method of meeting the Functional Requirements.

5.1.2 Limitations of guidance

The following situations are beyond the scope of the guidance in this Chapter:

- Where the original ground or sub-strata is unstable or will continue to settle.
- Sites with soft clays with a low bearing capacity (30kN/m^2 undrained).
- Filled ground where high levels of voids are anticipated.
- Clay fill, where the water will influence the foundation or where collapse may occur.

Each development site has its own specific characteristics, and where conditions do not clearly fall within the guidance given, clarification should be sought from the Warranty Surveyor or a suitably qualified and experienced expert.

5.1.3 Vibratory ground improvement

5.1.3.1 Introduction

Vibro displacement using vibro stone columns is a method of enhancing ground bearing capacity and limiting settlement. Typical applications include the support of foundations, slabs, hard standings, pavements, tanks or embankments. Soft soils can be reinforced to achieve improved specification requirements, whilst slopes can be treated to prevent slip failure. Both natural soils and made ground can be improved.

Vibro treatment should be carried out in accordance with Institute of Civil Engineers: 1987 Specification for ground treatment: Notes for guidance, and to a depth sufficient to reach an adequate bearing stratum.

5.1.3.2 Vibratory techniques

The vibratory process is applied to weak natural soils and filled ground with a view to improving the load-bearing capacity and providing an adequate bearing stratum for the building's foundations.

There are two vibratory techniques commonly used in the UK. These are known as the 'dry bottom feed' and 'dry top feed' methods; a third technique, less frequently used in the UK, is known as the 'wet bottom feed' method.

Dry bottom feed method

The dry bottom feed method is used in weaker soil conditions or where there is a high water table and the borehole is liable to collapse between vibroflot insertions. The vibroflot penetrates using its mass, air flush and vibration, but at design depth, the stone is introduced via a hopper into a pipe fixed to the side of the vibroflot. The stone, usually 40mm in size, exits the pipe at the tip of the vibroflot and reaches the bottom of the borehole. The stone is then compacted into the surrounding soil by repeated withdrawal and insertion of the vibroflot.

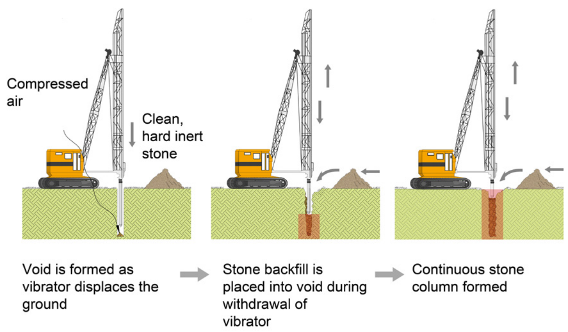


Figure 1: Vibratory techniques: dry bottom feed method

Dry top feed method

In the dry top feed method, the vibroflot penetrates the weak soil or fill again using its mass, air flush and vibration to form a borehole. Once refusal or design depth is reached, the vibroflot is removed and stone fill is introduced into the bore, with the 'charge' typically 500mm–800mm deep. The vibroflot is re-inserted and 'packs' the stone into the surrounding strata. Successive charges of stone are added and compacted, bringing the column up to working level. Typically, the stone grading is 40mm–75mm.

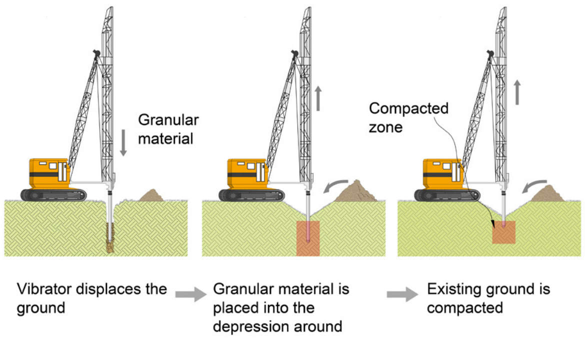


Figure 2: Vibratory techniques: dry top feed method

Wet bottom feed method

Where the ground contains fines and silts, water jetting from the tip of the vibroflot is used to remove loose materials and form a cavity for charges of stone to be added to replace and densify the soft ground. The carbon footprint of this activity is generally less than with comparable piling solutions.

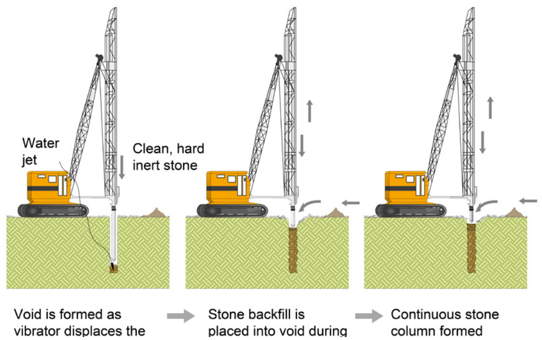


Figure 3: Vibratory techniques: wet bottom feed method

5.1.3.3 Suitability of ground conditions

Through the process of a site investigation, it should first be established by the appointed Engineer or suitably qualified specialist that the ground is capable of being improved by a vibratory ground improvement technique. The site investigation should determine the depths and properties of the natural materials under the site, including the presence of cavities, mines, rocks or soils that may dissolve or erode when water passes over them. It should also be established at an early stage whether the site has previously contained any buildings or structures, and whether they have been completely removed, including basement walls, floor slabs, etc. The presence and extent of any existing or redundant services and drains should be investigated, and the associated backfill to the excavations. In addition, the effect that any proposed sustainable drainage system (SuDS) might have on the ground conditions should be identified.

The Engineer should supervise the site investigation, taking account of the findings of the desk study, and first establish whether there are any contaminated substances or gases present. Data should be gathered using a suitable method for comparison with the site post treatment. Investigations should be made into the presence, level and nature of any ground water, and if it is likely to rise and cause heave or collapse by saturation.

The extent of any areas of made-up ground on the site should be established, including:

- The proportions, compaction and distribution of constituent materials throughout its depth.
- The grading and particle size distribution of fill materials.
- The potential for gas generation from fill materials, and the risk of combustion of natural deposits.

The appointed Specialist Contractor should be satisfied that the site investigation report provides adequate and representative information in order to design the ground improvement. The results of the investigation should be presented to the Warranty Surveyor prior to the commencement of the work.

The Developer shall obtain written confirmation from the Engineer and Specialist Contractor that the site is suitable for the proposed ground improvement system, and that all detrimental factors associated with the site and the proposed development have been taken into account. This is to be made available to the Warranty Surveyor prior to the commencement of any work on the site.

Site workmanship

The Specialist Contractor should appoint an Engineer to supervise the vibratory foundation works at all times and ensure that:

- The required depth and bearing capacity of stone columns are achieved.
- The stone columns are correctly located beneath the proposed foundation and in accordance with design drawings.

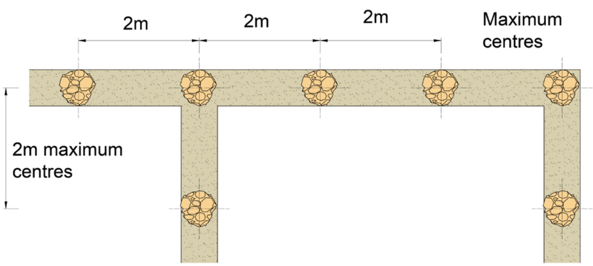


Figure 4: The intersection of adjacent reinforced concrete strips

5.1.4 Engineered Fill

5.1.4.1 Design of engineered fill

Careful selection of the material and controlled placement should ensure that the engineered fill forms an adequate foundation material; however, in some circumstances, significant ground movements can occur. Engineered fill should be designed and placed in accordance with recognised good practice, as noted in references at the end of this section.

Engineered fills used to produce suitably shaped landforms for structures should be constructed to high standards to minimise the risk of ground movements causing damage to property built on shallow foundations.

In designing and specifying a fill to form a foundation for buildings, the following technical requirements should be established:

- A well-constructed excavation, safely executed, with all soft and hard spots removed, and made reasonably dry and well drained.
- Sound fill without undesirable material and capable of compaction as specified, provided with starter and capping layers as necessary.
- Placement and compaction to ensure that the performance of the fill will meet required criteria as a foundation fill.
- Appropriate monitoring; the Designer must ensure that all work can be carried out safely as required by the Health and Safety Executive Construction Design and Management Regulations.

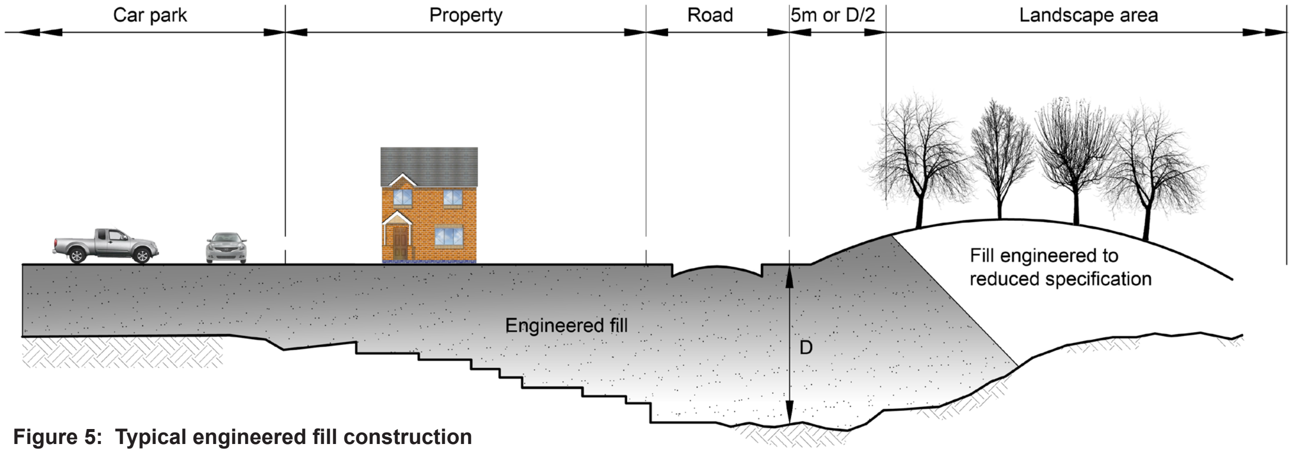


Figure 5: Typical engineered fill construction

5.1.4.2 Fill selection

Fill should be clearly categorised into material that may and may not be used: unsuitable fill, general fill, restricted fill and special fill. Fill materials must not present an environmental or health hazard.

Unsuitable fill should not be used at any location on the site.

General fill is all material except that which is unsuitable, restricted or special, and is normally the majority of the material used. It may include natural soils as well as some waste products.

Restricted fill is material that would be general fill except that it contains minerals hostile to the built environment. It can include natural materials such as pyritic shales, sulfate-bearing clays and waste materials, including burnt colliery discard and steel slag. Its use is precluded where ground water could rise to the underside of the deepest foundation, or where it is rejected for pollution reasons. For some developments, such as housing with gardens, restricted fills would include fills that are harmful to people.

Special fill is high-quality material, such as well-graded natural sands and gravels, crushed rock or clean demolition rubble. Its use will often have to be reserved for specifically defined purposes, such as a capping layer or backfill to retaining walls. Where possible though, granular soils should be used as general fill since these materials drain readily and consolidate quickly. The smaller the predominant particle size, the longer the potential time required for consolidation under the self-weight of the fill.

5.1.4.3 End product criteria

The greatest threats to successful in-service performance are:

- Collapse settlement due to inundation of dry or inadequately compacted fills.
- Excessive consolidation settlement of wet compressible fill.
- Heave or settlement of clay fills due to climatic changes or vegetation.

These ground movements depend on moisture movement, so by reducing the voids in a fill, the opportunities for excessive in-service movements should be restricted. A maximum allowable air-voids content of 5% is a suitable criterion for most clay fills. However, specifying a 5% air-voids content is insufficient, as this value may easily be achieved by adding water to the fill without increasing compactive effort. A suitable alternative control method is to specify a minimum acceptable density as a proportion of the maximum dry density measured in a standard laboratory compaction test. Limits on moisture content are required also.

If the fill is too wet, there could be excessive consolidation settlement, and if the fill is too dry, it might be vulnerable to collapse compression.

5.1.4.4 Placing engineered fill

A successful engineered fill requires not only an appropriate specification but also adequate control during placement. All the work must be carried out with due regard to safety, as required by the Construction Design and Management Regulations.

5.1.4.5 Site preparation and disposition of fill

The site should be cleared of all topsoil and other unsuitable material.

Soft spots and hard spots, such as derelict foundations, should be removed, together with ponds and surface water from depressions. Removing water by pumping may be necessary when filling some excavations below the ground water level.

When a variety of material types are used as fill, they should be deposited in horizontal layers across the site. If there is only a limited amount of good granular material, it will be best to use it in layers interspersed between layers of poorer cohesive fill.

The fill thicknesses should be reasonably constant beneath a structure to minimise differential settlement.

Feather-edges, resulting in foundations set partly on fill and partly on natural ground, should be avoided, and the site worked in such a way that structures are located either directly on natural ground or directly over fill of a consistent thickness.

If fill is to be placed over sloping natural ground, some stepping of the ground may be necessary. Construction over the face of a quarry or an opencast mining high wall should be avoided.

Special measures may have to be taken by providing flexible connections for services at the location of high walls and by thickening construction for service and estate roads.

If the natural ground on which the fill rests is soft and compressible (for example, layers of peat or soft clay), the surface of the fill may settle appreciably and unevenly as a result of the weight of the fill consolidating the soft layers below. This settlement will, of course, be additional to that resulting from the compression of the fill itself.

Sensitive structures may warrant a surface (or capping) layer formed from special fill compacted to more onerous standards than the underlying fill. This should help minimise the differential settlement suffered by the structure.

Where landscaped or other non-load bearing areas form part of a development, they need less compaction than the load-bearing areas. There should be a transition zone around the load-bearing area, as shown in Figure 5.

5.1.4.6 Fill placement

Fill should be placed in horizontal layers, with each layer separately compacted. For a given item of plant, compaction performance will be determined by fill layer thickness, fill moisture content and the number of passes of the compaction equipment. There are, however, other factors such as the need to avoid excessive handling.

Whenever possible, site trials should be undertaken to determine the correct criteria. Some general information about placing fills is given in BS 6031. Each layer should be of a thickness that allows the compactive energy to spread throughout the layer, producing the specified fill density and low air-voids content. Loose layers with a thickness greater than 250mm are unlikely to be satisfactory for earth fills compacted to support low rise structures.

It may be necessary to use layers of 200mm or less. Moisture content at the time of placing a fill is fundamental to subsequent performance, particularly where the fill contains a large proportion of fine grained cohesive material. If the fill is too dry, there is the possibility of heave or collapse settlement; if it is too wet, there is the possibility of insufficient strength and high compressibility. It will be difficult to achieve an air-voids content of 5% or less when the moisture content is low. In the same way that the addition of too much water can detract from the performance of engineered fill, soil can be over-compacted.

Granular soils and cohesive soils drier than optimum, when rolled excessively, become over-stressed, and what should have been a firm compacted surface becomes a loose tilth. This should be avoided whenever possible. Where a fill containing a large proportion of fine grained cohesive material (for example, clay) is used, filling during wet weather should be avoided.

5.1.4.7 Quality control

Quality control procedures should be implemented to ensure compliance with the specification. The nature of the control procedure will depend on the type of specification adopted. The end product specification requires an appropriate type and quantity of testing of the fill during placement to ensure that the desired end product is being achieved. Depending upon the type of contract, quality control may be the responsibility of the Engineer or of the Contractor working under the supervision of the Engineer. Control parameters should be the same as those determined during the site investigation stage. Both design and control parameters must be reproducible, a term that denotes the range within which measurements made on the same fill by different operators using different equipment should agree.

The following are the most significant control parameters:

- Moisture content, in respect of an optimum moisture content established at the site investigation stage.
- Dry density, in respect of the already established maximum dry density.
- Air-voids content, which depends on moisture content and dry density.
- Undrained shear strength, which is an alternative to monitoring moisture content and dry density for clay fills.

The laboratory compaction tests and the associated field control tests are suitable for a wide range of fill types, and form the most generally applicable approach. For cohesive soils, undrained shear strength forms an alternative basis for specification and control testing.

However, different methods of measuring the undrained shear strength, such as the unconfined compression test and the vane test, can give significantly different values. The measured value of cohesion can be sensitive to a detailed test procedure, such as the rate of shearing.

It is important for the method of testing to be strictly specified. Where a cohesive fill contains gravel, it may not be possible to obtain sufficiently undisturbed samples for strength tests. On larger sites, employing in-situ methods, such as the cone penetrometer (BS 1377: Part 9), could be considered.

Small sites are generally more difficult to work than large sites, as finished work may be damaged more easily in confined working areas and deficiencies in site preparation usually reflect more readily in poorer quality compaction than on larger sites. Consequently, it is necessary to test more frequently on a small site than on a large one.

A suggested minimum test frequency is presented in Figure 6. However, each site should be judged on its own merits, with careful note taken of any problems revealed during site investigation. In very variable or difficult conditions, more frequent testing may be required. Tests in visually doubtful areas, and re-tests of failed areas, should be carried out in addition to those recommended in Figure 6.

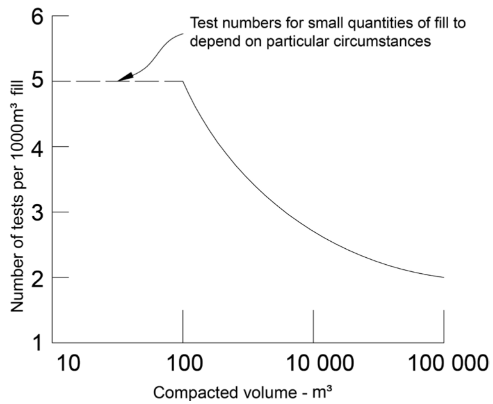


Figure 6: Number of tests

Modern compaction control requires laboratory and field testing during the site investigation, and during, and possibly following, the earthworks. The results of this work must be recorded, collated and presented to demonstrate the quality of the operation. The required documentation includes:

- Summary of the specification requirements and the end product in terms of the selected geotechnical parameters for the various fills (based on-site investigation information).

- List of the required suitability tests; one form to be completed for each borrow pit under investigation.
- Suitability test results for each borrow pit.
- List of the required control tests.
- Results of the control tests on each fill type, layer or area, as appropriate.
- A list of post-compaction monitoring requirements.
- The results of post-compaction monitoring; all completed forms should be signed and dated by the person responsible, and a list prepared of any required action or remedial work to be carried out.

5.1.4.8 Monitoring of fill performance

Monitoring provides a check on the performance of the fill after compaction, and is particularly important where vulnerable structures are to be built or foundation loading is unusually large. It is also required where the fill is relatively deep or substantial ground water rise within the fill is expected.

Monitoring techniques include:

- Surface levelling stations to measure the settlement of the fill surface.
- Magnet extensometers to measure the settlement of incremental depths of fill.
- Standpipe piezometers to measure the rise in the ground water table in the fill after placement.
- Load tests for direct estimation of settlement of surface layers produced by loadings.

Surface levelling stations are easy to install and very effective. By optical levelling of the stations, measurement can be made of the total vertical movement of the fill upon which they rest, together with any movement of the underlying natural ground, although this is unlikely to be large if all soft material has been removed prior to compaction.

Levelling stations should be sufficiently robust to resist damage due to construction traffic. A round headed bolt cast into a 1m concrete cube set 300mm into the fill has been found to be effective.

Magnet extensometers are unlikely to be necessary in shallow-depth fill. Standpipes or piezometers will be of advantage if there is reason to suspect that ground water will rise into the fill at any time in the future, with consequent settlement.

5.1.5 Testing

Testing is carried out to confirm that the ground improvement works meet the design criteria. The tests are usually completed to determine the ground bearing capacity.

The Engineer shall require the Specialist Contractor to verify that the ground treatment has been completed to a satisfactory standard. This will usually include carrying out suitable testing to establish the degree of ground improvement, its load-bearing characteristics and settlement potential. These tests may include:

5.1.5.1 Plate tests

This test will not determine the design but will allow for an assessment of the workmanship on the stone columns. Plate tests should be carried out on stone columns or treated ground at a frequency of at least one test per day per rig.

The plate tests should be carried out with a 600mm diameter plate and minimum test load of 11 tonnes.

5.1.5.2 Mini zone tests

A mini zone test (dummy footing) can be used as a limited substitute for zone tests. The test should be applied to at least two stone columns and the area of foundation they support. To be useful, mini zone tests should be continued for long enough to establish the presence of creep behaviour.

Mini zone tests (dummy footing) should be carried out at a rate of one test per 1000m^2–3000m^2 of treated ground, along with penetration tests at a rate of one test for 20–50 stone columns, or one test for not more than 500m^2 of treated ground, with a minimum of one test per structural unit.

Alternatively, in the absence of penetration tests, one test per ten houses (with a minimum of two tests per site) would suffice.

5.1.5.3 Zone tests

An isolated pad or strip footing is used to test up to eight stone columns and the intervening ground. Loadings, which should simulate the dwelling loads, are held for 24 hours at predetermined stages to examine creep behaviour.

5.1.5.4 In-situ tests

Where vibration will improve the ground itself, e.g. granular materials, then in-situ testing is appropriate. The improvement can be assessed when the test results are compared with the in-situ test results recorded during the pre-treatment investigation.

5.1.5.5 Trial pits

Trial pits can be excavated around trial stone columns to prove that they are fully formed and to the required depth and diameter. This is a destructive test, and allowance should be made accordingly.

On completion of the treatment, the Engineer is to confirm that the treated ground has achieved the anticipated condition assumed in the design, and provide evidence in writing to the Warranty Surveyor.

5.1.6 Fill materials

The following materials require testing to ensure their suitability for use as fill to support structural foundations and slabs, or as backfill to associated trenches:

- Acid wastes
- Reactive materials
- Materials that include sulphates (e.g. gypsum)
- Organic materials
- Toxic materials
- Materials that cause noxious fumes, rot, undue settlement or damage to surrounding materials

The sample tests should be carried out by a suitably qualified person, and it may be necessary to take a number of samples to identify the material characteristics of the fill accurately.

5.1.7 Sources of fill material

Where the material is of a stable and uniform type from one source, the testing regime may be reduced. However, if the material is variable or from a number of sources, regular inspections and/or testing may be required. Recycled aggregate or other building materials, such as crushed brick, should only be used following an inspection by the Warranty Surveyor. Colliery shale and any other residue from mineral extraction or industrial process bi-products should only be used with specialist approval.

5.1.8 Suitable foundations for sites with improved ground

Foundations on sites with improved ground should either be of a reinforced strip or raft type. Both foundations will require a full design by a Structural Engineer.

For 'low rise structures', the foundations should be designed to ensure a maximum settlement of 25mm is not exceeded. In relation to differential settlement, a design limit for maximum tilt of 1/500 is appropriate. More stringent values may be required due to the particular circumstances (e.g. medium and high rise structures).

Functional Requirement 5.2 must be met where the foundations are bearing on cohesive soils or cohesive fill materials and trees nearby.

5.1.9 Relevant British Standards and Guidance Documents

Relevant British Standards Codes of Practice and authoritative documents include:

- BS 6031 Code of Practice for earthworks
- BS 1377: Part 9 Methods of tests for soils for civil engineering purposes. In-situ tests
- BS 10175 Investigation of potentially contaminated sites – Code of Practice
- BS EN 1991 Actions on structures
- BS EN 14731 Execution of special geotechnical works. Ground treatment by deep vibration
- BS EN 1997-1 General rules
- BS EN 1997-2 Ground investigation and testing
- BS EN ISO 14688 Geotechnical investigation and testing – Identification and classification of soil
- BS EN ISO 14689 Geotechnical investigation and testing – Identification and classification of rock
- BS EN ISO 22476 Geotechnical investigation and testing – Field testing
- BR 391 Specifying vibro stone columns
- Institute of Civil Engineers (ICE) Specification for ground treatment: Notes for guidance, 1987

- CIRIA C572: Treated ground: Engineering properties and performance, 2002
- CIRIA C573: A guide to ground treatment, 2002
- BRE 424: Building on fill: Geotechnical aspects
- BRE Information Paper 5/97: Collapse compression on inundation

FUNCTIONAL REQUIREMENTS

5.2 FOUNDATIONS, TREES AND CLAY

Workmanship

i. All workmanship must be within the tolerances defined in Chapter 1 of this Manual.
ii. All work is to be carried out by a technically competent person in a workmanlike manner.
iii. Strip foundations should be of a suitable depth in order to achieve a satisfactory level of performance.

Materials

i. All materials should be stored correctly in a manner that will not cause damage or deterioration of the product.
ii. All materials, products and building systems shall be appropriate and suitable for their intended purpose.
iii. The structure shall, unless specifically agreed otherwise with the Warranty provider, have a life of not less than 60 years. Individual components and assemblies, not integral to the structure, may have a lesser durability, but not in any circumstances less than 15 years.

Design

i. The design and specifications shall provide a clear indication of the design intent and demonstrate a satisfactory level of performance;
ii. Foundation type and depth must be suitable to resist movement due to the influence of nearby trees.
iii. Structural elements outside the parameters of Approved Document A (England and Wales) must be supported by structural calculations provided by a suitably qualified expert.
iv. The design and construction of the foundations must meet the relevant Building Regulations, British Standards, Eurocodes and other statutory requirements.

5.2.1 Introduction

This Chapter gives guidance on foundation design when building near trees. The details described in Chapter 5 will be accepted as a satisfactory method of meeting the Functional Requirements.

5.2.2 Limitations of guidance

The following situations are beyond the scope of the guidance in this Chapter, and will require a site-specific assessment by a suitably qualified and experienced expert:

- Foundations with depths greater than 2.5m within the influence of trees
- Ground with a slope greater than 1:7
- Manmade slopes, such as embankments and cuttings
- Underpinning
- Engineered foundation designs

Each development site has its own specific characteristics, and where conditions do not clearly fall within the guidance given, clarification should be sought from the Warranty Surveyor or a suitably qualified expert.

5.2.3 The nature of the problem

The roots of all vegetation take water from the soil to make good the water lost from the leaves. If the soil contains clay, it will shrink as it is dried, or swell if it is allowed to rehydrate. If the shrinking or swelling extends below the foundations, they will subside or heave respectively. If the movements are in excess of those that can be tolerated by the building, damage is likely to occur.

Although all vegetation can cause soil drying, the roots of trees extend deeper and further and are thus particularly prone to causing damage. Large shrubs can also root to considerable depths, but their influence is more localised. Herbaceous plants and grass can also cause soil drying down to 1.5m, and require some precautions.

Damage is best avoided by increasing foundation depth to below the level where significant changes in moisture content are likely to occur. This Chapter defines the depths that are required, and the most suitable types of foundations. The extent of soil drying can be variable and unpredictable. If all risk of damage is to be avoided, the required depths would be punitive; instead, the guidance seeks to minimise the risk by striking a balance between the extent of risk and the costs of increasing foundation depth.

The extent of risk depends on:

- The soil
- The potential for the tree species to cause soil drying
- The size of the tree
- The proximity of the tree to the foundations
- The likely climatic conditions in the locality

These factors are considered in greater detail in the following sections.

5.2.4 The soil

Soils may be broadly classified into two types:

- Cohesive soils comprise mainly of clay or fine silt particles. When moist they are plastic and can be moulded, and will remain intact if placed into water. As they dry, they will become stiffer, and will eventually crumble if dried beyond a certain point. These soils can potentially cause problems.
- Non-cohesive soils, comprised mainly of sand or with only a proportion of clay or silt, cannot be moulded and will break up if placed in water. They are not subject to significant swelling or shrinkage.

The clay component of cohesive soils can vary widely; very few soils are pure clay, but they contain varying quantities of sand or silt. Clay soils are defined by their particle size (less than two microns), and it is only these clay particles that will shrink or swell. The particles are made-up of a complex molecular lattice structure that is capable of absorbing water, and as it absorbs water the particles will swell, and vice versa. There are many different types of clay with different molecular structures, and all of which have different swelling characteristics. The extent of swelling and shrinkage that can occur will therefore depend on the type of clay particles and the proportion of clay, as opposed to silt or sand, within the soil.

The potential of soil to swell or shrink can be determined by simple tests to determine its plastic limit (the moisture content below which it changes from being plastic and mouldable, and starts to crumble) and liquid limit (the moisture content above which it changes from being plastic, and starts to flow like a liquid). The plastic and liquid limits can be determined by simple laboratory tests in accordance with BS 1377. The difference between the plastic and liquid limits is the plasticity index; the higher the plasticity index, the greater the potential volume changes.

5.2.5 Potential of the tree species to cause soil drying

Tree species differ in the ability of their roots to grow and exploit the available water in a cohesive soil, particularly if it has high clay content. This is commonly referred to as their 'water demand'. Species such as Oak, Poplar and Eucalyptus are deemed as high water demand as they are particularly efficient at exploiting clay soils, rooting to considerable depth. A few species only rarely cause damage and are deemed of low water demand, whilst the majority fall into the moderate category.

Hardwood species tend to have a broad spreading root system, extending considerable distances laterally as well as to depth. By contrast, the influence of most conifers is more localised, but just as deep. A few species (of both hardwoods and conifers) have intermediate characteristics. The guidance takes account of the different patterns of rooting, but it must be emphasised that the distribution of roots can be variable, meaning the guidance should not be taken as indicating a 'zone of influence' of a tree.

5.2.6 Size of tree

The amount of water taken by the roots relates to the leaf area and the vigour of the tree. With open grown trees, height is usually considered the best indicator of leaf area. The greatest water uptake occurs as the tree reaches maturity, and so 'mature height' is the determining factor. Individual trees within a group or row will have a smaller leaf area, but as they compete with each other, the mature height of the individual trees remains the relevant factor.

Although some trees are managed as pollards or are subject to periodic reduction to control their size, unless such treatment can be assured in the future, mature height should be used.

5.2.7 Proximity

The closer the tree, the deeper the potential influence, and the guidance indicates the required foundation depth at any distance. The parts of the foundations closest to the tree require the greatest depth, but if preferred can be stepped down for more distant parts.

5.2.8 Likely climatic conditions

Weather conditions play a major role in determining the extent of soil drying. Hot sunny weather will increase the rate of water uptake by the roots, whereas rainfall during the summer can restore the water that has been taken. As the hottest and driest conditions tend to be in South East England, it has the greatest risk. For other, wetter, parts of the country, the guidance allows for reducing the required foundation depth.

5.2.9 Information required for determining the foundation depth

5.2.9.1 Establishing ground conditions

The British Geological Survey website (www.bgs.ac.uk) can indicate the likely soil conditions in any locality. Enter the postcode to locate the site, and a left click on the location brings up a box that shows the bedrock geology and the superficial deposits (if present). The name of the bedrock or superficial deposits are often sufficient to indicate probable soil conditions (e.g. London Clay or Plateau Gravel), but if not, clicking on the name will bring up further details.

Unless there is clear evidence that a cohesive soil is not present, site investigations will be required to determine the soil type to at least the depth of potential influence of adjacent trees. Usually, trial holes are an acceptable method for determining the soil strata, but specialist site investigation reports are preferred if available.

Soil samples should be taken from at least two depths, at 1.5m and 2.5m (or the base of the trial hole, whichever is the shallower), and sent to a soil laboratory for determination of plastic and liquid limit (and thus plasticity index). In addition, the moisture content of the samples is usually determined. The highest value of plasticity index should be used for determining foundation depth.

5.2.9.2 Identification of trees

Many Local Authorities will require a Tree Survey and Arboricultural Method Statement as part of the planning application. This will usually serve to identify all relevant trees both on and off-site. If a tree survey is not available, assistance with identification of all of the more common trees can be obtained from various websites:

Natural History Museum

www.nhm.ac.uk/nature-online/british-natural-history/urban-tree-survey/identify-trees/tree-key/index.html

Royal Botanic Gardens, Kew

apps.kew.org/trees

Science and Plants for School
(particularly useful for winter identification, using twig characteristics)

www-saps.plantsci.cam.ac.uk/trees/index.htm

If a tree cannot be identified, it must be assumed to have high water demand (deep rooting).

5.2.9.3 Mature height of tree

The mature height of commoner tree species is obtained from Table 4 in Appendix A.

Mature height should be used unless:

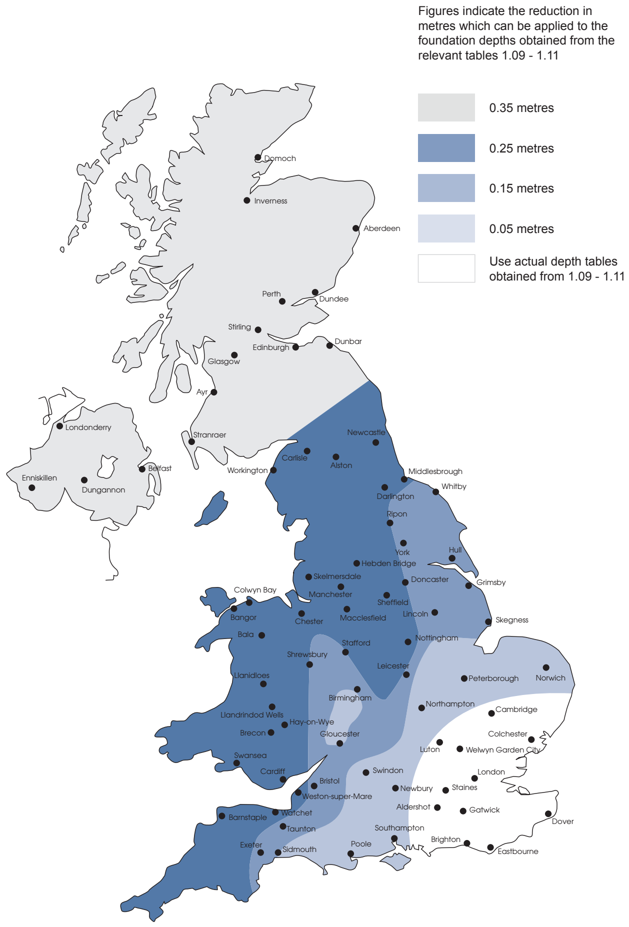
- An arboricultural report is obtained, indicating that a lesser height is appropriate for the conditions of the site.
- Assurance can be provided that the tree will be maintained at a lesser height at all times in future.

5.2.9.4 Proximity of tree

Measurement should be taken from the centre of the trunk to the nearest part of the foundations. If preferred, foundations depths can be stepped down at greater distances, in accordance with Chapter 5.5.4, by measurement to other locations around the building.

5.2.9.5 Climatic conditions

Determine from the map in Figure 7 whether the depth of foundations can be reduced for the relevant site location.



NOTE:

The minimum foundation depth for a foundation on a clay soil, where no trees are present or have been removed within 3 years is

- 0.9m (900mm) for low to medium volume change potential soils;
- 1.0m (1000mm) for high volume change potential soils (PI value > 40%); or
- in accordance with Building Control policy, whichever is greater.

Figure 7: Allowable reductions for geographical location

5.2.10 Determining foundation depth

5.2.10.1 Foundation Depth Calculator

Foundation depth can be determined using the Foundation Depth Calculator found on our website. The depth of foundation is determined by inputting the:

- plasticity index of soil (see Chapter 5.2.1)
- water demand of the tree (see Table 4)
- mature height of the tree (see Table 4), or alternative values being used (see Chapter 5.2.3)
- distance of relevant tree to nearest part of foundations, and distances elsewhere if stepping foundations (see Chapter 5.2.4)
- allowance for climatic conditions (see Chapter 5.2.5)

5.2.10.2 Foundation depths to allow for future tree planting

Where there is a landscape plan specifying future tree planting, foundation depths should be calculated on the basis of the proposed species of tree and its proximity. If no species has been specified, they should be assumed to be moderate water demand.

Even if no tree planting has been specified, it is advisable to allow for reasonable future tree or shrub planting, or for the growth of self-seeded trees or shrubs, as shown in column 2 of Table 1.

If the building design or location is such that no tree planting is likely at any time in the future, minimum foundation depths, as shown in column 3 of Table 1, should be used.

Plasticity index	Depth to allow for reasonable future tree /shrub planting (m)	Minimum depth if no future tree/shrub planting likely (m)
>40	1.5	1.0
20-40	1.25	0.9
10-20	1.0	0.75

Table 1: Minimum foundation depths

5.2.11 Woodlands, groups or rows with mixed species of trees

Foundation depth should be determined on the basis of the individual tree that requires the greatest depth.

5.2.12 Foundation design

5.2.12.1 Depths in excess of 2.5m

Where the required foundation depths, as determined in Chapter 5.3, are in excess of 2.5m, foundations must be designed by a suitable expert, i.e. a Chartered Structural Engineer, taking account of the likely effect of soil movement on the foundations and substructure. Short bored piles with ground beams are recommended, and may prove to be the most economical form of construction. Short bored piles are an essential requirement for depths in excess of 3m.

5.2.12.2 Foundation depths less than 2.5m

Conventional strip foundations may be constructed practically and economically to a maximum depth of 2.5m.

Trench fill foundations are likely to be most economic at depths below 1.5m, but can be economic to depths up to 2.5m.

For foundation depths in excess of 2m, short bored piles with ground beams are recommended. All pile designs should be undertaken by a suitable expert, i.e. a Chartered Structural Engineer.

Structural raft foundations are generally not accepted as a suitable foundation on sites with a high risk of shrinkage/heave due to adjacent trees.

5.2.12.3 Heave precautions

Allowance must be made for the probability that any existing tree is likely to die sometime during the life of the building. If the tree has dried the soil prior to the foundations being laid, when it dies (or becomes over-mature) the soil will rehydrate and swell, causing upward or lateral heave movement of the foundations. Severing roots within the footprint of a building foundation will also allow the soil to rehydrate.

If foundation depth is greater than 1m, a proprietary compressible material must be placed on all inside surfaces of the peripheral foundations to allow for lateral soil swelling, as shown in Figures 8–10. Material is not required on internal foundations (as swelling pressures are likely to be similar on both sides). The material must be capable of compressing to allow for lateral swelling, in accordance with column 3 of Table 2.

Ground bearing slabs should not be used if the foundation depth is greater than 1m. Under these circumstances, a suspended floor slab should be used, incorporating either a void or a proprietary compressible material on the underside.

The thickness of the void should be in accordance with Table 2, or if a compressible material is used, it should be capable of compressing to provide a void of this thickness. The manufacturer's specifications must be checked to establish the actual thickness of compressible material required to both accommodate movement and be able to compress to the dimensions in Table 2.

Plasticity index of soil	Required foundation depth (m)	Thickness of void against side of foundation or ground beam (mm)	Thickness of void on underside of edge beam and floor slabs (mm)
>40	>2.5	Engineer design	
	2.0–2.5	35	100
	1.5–2.0	25	75
20–40	> 2.5	Engineer design	
	2.0–2.5	25	75
	1.5–2.0	25	50
<20	2.0–2.5	-	50
	<2.0	No special precautions	

Table 2: Minimum void dimensions for foundations, ground beams and suspended floor slabs

A typical foundation designs to allow for heave are shown in Figures 8-10.

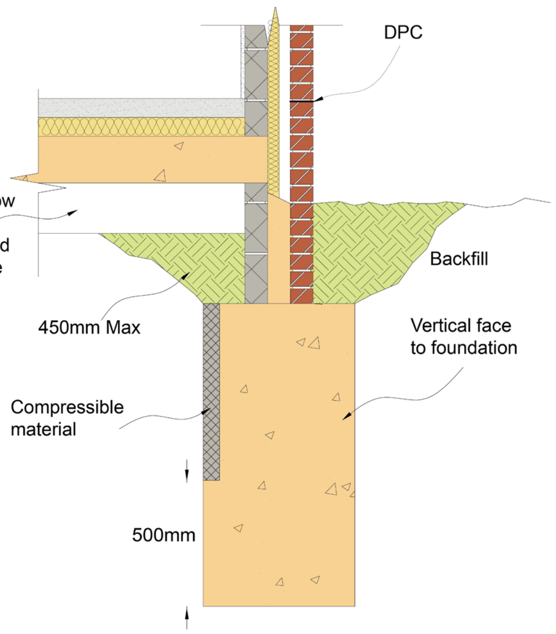


Figure 8: Heave protection: Section through a typical mass filled foundation

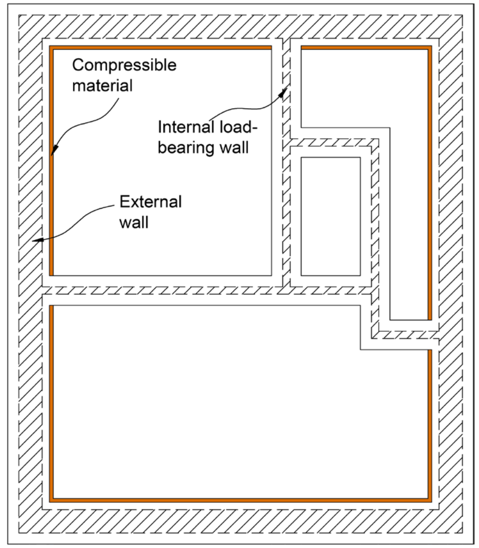


Figure 9: Plan of heave protection to a mass filled foundation

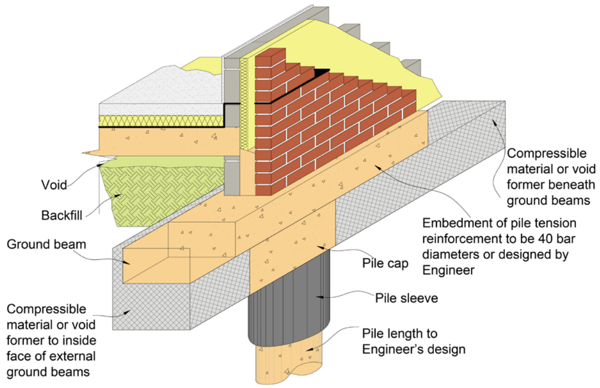


Figure 10: Heave protection: Section pile and beam foundation

5.2.13 Special situations

5.2.13.1 Trees removed prior to construction

If trees have been removed prior to construction, precautions must be taken against potential rehydration and swelling of the soil. If they have been removed within 12 months of the foundations being laid, the design should be drawn up as if the tree was still present. If the height of the former trees is known, the depth should be determined using actual height. If the identity is not known, it should be assumed to be of high water demand, and if height is not known, it should be assumed to be 20m.

If trees have been removed more than 12 months prior to construction, precautions should be taken in accordance with Table 3.

Plasticity index	Time since tree felled (years)	Thickness of void against side of foundation or ground beam (mm)	Thickness of void below slab (mm)
>40	2-3	35	100
	4-5	25	75
20-40	2-3	25	75

Table 3: Minimum void dimensions for foundations, ground beams and suspended floor slabs where trees have been removed

5.2.13.2 Sloping sites

If the slope is greater than 1:7, foundations should be Engineer designed (see Chapter 5.1.2). For slopes less than 1:7, distance should be measured down the angle of the slope. If there is a retaining wall, include the height of the retaining wall in the distance.

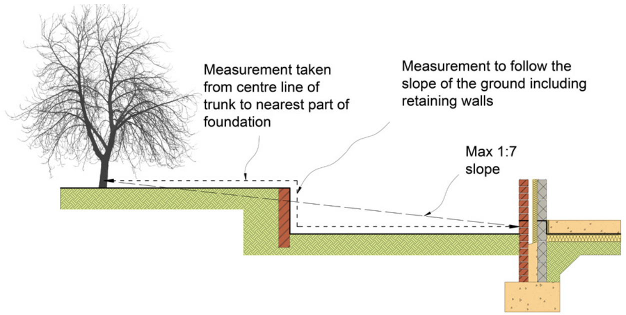


Figure 11: Measuring foundation distance on sloping sites

5.2.13.3 Changes in level

Changes in ground level (either raising or lowering soil levels) beneath the branch spread of the tree can damage the tree, and should be avoided if possible.

If ground levels are altered in proximity to existing trees that are to remain, foundation depth should be determined on the basis of the mature height of the tree and original ground level.

If ground levels are altered in proximity to trees that are to be removed, foundation depth should be determined on the basis of the existing height of the tree and original ground level.

5.2.13.4 Varying foundation depths

As foundation depth depends on the proximity of the tree, the depth can be reduced in steps with increasing distance. Steps should be in accordance with Chapter 5.2 of this Manual.

5.2.13.5 Protection for drains

In addition to the requirements of Chapter 9 of this Manual, drainage near trees should incorporate additional provisions. Where there is a volume change potential within the ground, the provisions include:

- Increased falls to cater for any ground movement.
- Deeper and wider backfill of granular material.
- A drainage system that is capable of movement should heave and shrinkage occur; drainage pipes should not be encased in concrete.
- Additional clearance is required where drains pass through the structure of a building to allow for additional movement.

5.2.14 Made-up ground

This refers to land or ground created by filling in a low area with non-original soils or other fill material. Often, such created land is not suitable for building without the use of specialist foundations. If there is high clay content within the made-up ground, specialist foundations may require additional heave protection. It is also important to establish the depth of the made-up ground, because if it is a relatively shallow depth, the original soil below may be cohesive and within the zone of influence of the tree.

5.2.15 Strip or trench fill foundations in non-shrinkable soils overlying shrinkable soils

If non-shrinkable soils such as sand and gravels overlie shrinkable clays, increased foundation depths are not required if the depth of the non-shrinkable soil is greater than 0.8 of the depth which would be required for the underlying shrinkable soil. See Figures 12 and 13 for further clarification.

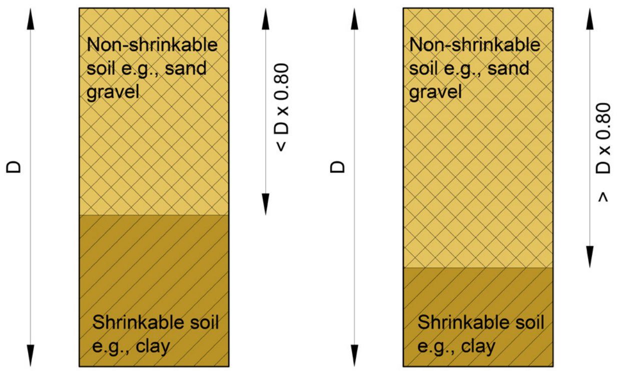


Figure 12 and 13: Foundation depth required to be taken down using foundation calculator and plasticity index of underlying clay

Broad leafed tree		H	Conifer		H
High water demand					
Elm, English	Ulmus procera	24	Cypress, Lawson	Chamaecyparis lawsoniana	18
Elm, Wych	Ulmus glabra	18	Cypress, Leyland	X Cupressocyparis leylandii	20
Gum tree	Eucalyptus Spp.	24	Cypress, Monterey	Cupressus macrocarpa	20
Hawthorn	Crataegus monogyna	10	Cypress, Smooth	Cupressus glabra	15
Oak, English	Quercus robur	24			
Oak, Holm	Quercus ilex	16			
Oak, Red	Quercus rubra	20			
Oak, Turkey	Quercus cerris	24			
Poplar, Hybrid black	Populus x euramericana	28			
Poplar, Grey	Populus canescens	18			
Willow, Srack	Salix fragilis	24			
Willow, White	Salix alba	24			
Willow, Weeping	Salix alba 'Tristis'	16			
Whitebeam	Sorbus aria	14			
Moderate water demand					
Elm, Wheatley	Ulmus carpinifolia 'Sarniensis'	20	Cedar	Cedrus spp.	20
Lime	Tilia spp.	24	Cypress, Italian	Cupressus sempervirens	12
Oak, Fastigiate	Quercus robur 'Fastigiata'	20	Wellingtonia	Sequoiadendron giganteum	24
Poplar, Lombardy	Populus nigra 'Italica'	25	Western red cedar	Thuja plicata	18
Poplar, Aspen	Populus tremula	18			

Low water demand					
Acacia, False	Robinia pseudoacacia	16	Honey locust	Gledistsia triacanathos	14
Apple	Malus spp.	10	Hornbeam	Carpinus betulus	16
Ash	Fraxinus spp.	24	Indian bean tree	Catalpa bignonioides	16
Beech	Fagus sylvatica	20	Laburnum	Laburnum spp.	12
Cherry, Japanese	Prunus serrulata	9	Magnolia	Magnolia spp.	10
Cherry, Fruit	Prunus cerasus	12	Mulberry	Morus spp.	12
Cherry, Plum	Prunus cerasifera	10	Sweet gum	Liquidambar styraciflua	14
Cherry, Wild	Prunus avium	16	Tree of Heaven	Ailanthus altissima	20
Chestnut, Horse	Aesculus hippocastanum	20	Tulip tree	Liriodendron tulipifera	18
Chestnut, Sweet	Castanea sativa	18	Walnut	Juglans regia	16
Maple, Japanese	Acer palmatum	8	Dawn redwood	Metasequoia glyptostroboides	16
Maple, Norway	Acer platanoides	18	Douglas fir	Pseudotsuga menziesii	18
Mountain ash	Sorbus aucuparia	10	Fir	Abies spp.	18
Pear	Pyrus spp.	12	Hemlock	Tsuga heterophylla	16
Plane	Platanus spp.	22	Juniper	Juniperus communis	6
Plum	Prunus domestica	12	Larch	Larix spp..	16
Sycamore	Acer pseudoplatanus	20	Maidenhair tree	Ginkgo biloba	16
Birch	Betula spp.	14	Monkey puzzle	Auracaria auracana	14
Elder	Sambucus nigra	10	Pine	Pinus spp.	16
Fig	Ficus carica	8	Spruce	Picea spp.	16
Hazel	Corylus avellana	8	Yew	Taxus baccata	12
Holly	Ilex aquifolium	12			

Table 4: Water demand (rooting depth) and mature heights (H) of common trees

FUNCTIONAL REQUIREMENTS

5.3 STRIP AND MASS FILL FOUNDATIONS

Workmanship

i. All workmanship must be within the tolerances defined in Chapter 1 of this Manual.
ii. All work is to be carried out by a technically competent person in a workmanlike manner.
iii. Strip foundations should be of a suitable depth in order to achieve a satisfactory level of performance.

Materials

i. All materials should be stored correctly in a manner that will not cause damage or deterioration of the product.
ii. All materials, products and building systems shall be appropriate and suitable for their intended purpose.
iii. The structure shall, unless specifically agreed otherwise with the Warranty provider, have a life of not less than 60 years. Individual components and assemblies, not integral to the structure, may have a lesser durability, but not in any circumstances less than 15 years.

Design

i. The design and specifications shall provide a clear indication of the design intent and demonstrate a satisfactory level of performance.
ii. Structural elements outside the parameters of regional Approved Documents must be supported by structural calculations provided by a suitably qualified expert.
iii. Strip foundations must meet the relevant Building Regulations, British Standards, Eurocodes and other statutory requirements.

5.3.1 Introduction

Strip and mass filled foundations are usually the most simplistic and cost-effective foundation for low rise buildings on original ground, and the guidance in Chapter 5.3 provides details of how to meet the Functional Requirements.

5.3.2 Limitations of guidance

The following situations are beyond the scope of the guidance in this Chapter:

- Traditional strip and mass filled foundations for buildings other than dwellings.
- Dwellings greater than three storeys.
- Foundations on filled ground.
- Strip and mass filled foundations where foundation depths exceed 2.5m.

5.3.3 Design

Strip and mass filled foundations shall be designed to ensure that the building is appropriately supported at all times without excessive settlement. This foundation type should only bear onto original ground if the foundation has been designed by a Structural Engineer and is appropriately reinforced. It is therefore important that site conditions are appropriately assessed prior to the building design. Further guidance on ground condition assessment can be found in Chapter 4 – Site Investigation.

For 'low rise structures', the foundations should be designed to ensure a maximum settlement of 25mm is not exceeded. In relation to differential settlements, a design limit for maximum tilt of 1/500 is appropriate. More stringent values may be required due to the particular circumstances (e.g. medium and high rise structures).

5.3.4 Minimum foundation dimensions

Strip foundations should be of a 600mm minimum width for external walls. For single leaf internal walls up to 150mm thick, foundations may be reduced in width to 450mm. The minimum thickness of strip foundations should be 150mm. Foundations should be situated centrally below the wall.

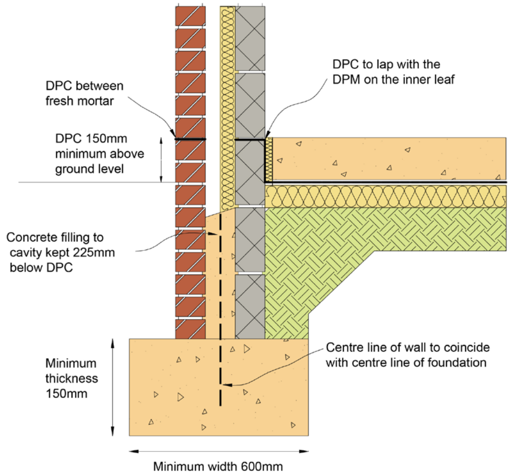


Figure 14: Typical strip foundation

5.3.5 Foundation depths

The depth of all foundations should be determined by specific site conditions. All foundations must bear onto virgin stable subsoil and, except where strip foundations are founded on rock, the strip foundations should have a minimum depth of 450mm, measured from finished ground level to their underside, to avoid the action of frost. This depth, however, will commonly need to be increased in areas subject to long periods of frost or in order that loads are transferred to suitable ground. Where trees are situated close to a proposed building founded on a clay soil, the foundation depth/design will be affected; further guidance is available in Chapter 5.2.3.

In clay soils with a plasticity index greater than or equal to 10%, strip foundations should be taken to a depth where anticipated ground movement will not impair the stability of any part of the building, taking into account the influence of vegetation and trees on or adjacent to the site. The depth to the underside of foundations on clay soils should not be less than 750mm, as measured from finished ground level, and depths may need to be increased in order that loads are transferred to suitable ground. Table 1 gives details of minimum foundation depths, which can be found in Chapter 5.2.10.2.

Modified plasticity index	Volume change potential 40% and greater	Minimum foundation depth (m)
40% and greater	High	1.0
>20% - <40%	Medium	0.9*
<20%	Low	0.75
Note: *If the modified plasticity index is not confirmed minimum foundation depths should be 1m.		

Table 5: Minimum foundation depths

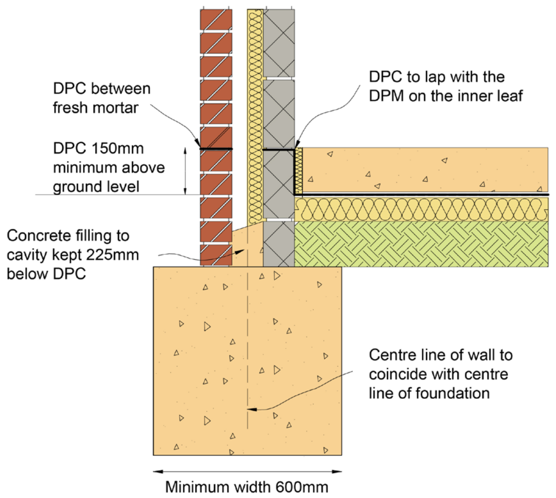


Figure 15: Typical mass fill foundation

5.3.6 Setting out foundations

The accuracy of setting out foundations should be checked by set controlled trench measurements, including their location relative to site borders and neighbouring buildings. Levels should be checked against benchmarks, where appropriate. In particular, for excavations check:

- Trench widths
- Trench lengths
- Length of diagonals between external corners

Walls should be located centrally upon the foundation, unless specifically designed otherwise. Any discrepancy in dimensions should be reported promptly to the Designer. Resulting variations should be distributed to all concerned with site works, including the Warranty Surveyor.

5.3.7 Excavations

Excavation should be to a depth that gives sufficient bearing and protection from frost damage. To avoid damage caused by frost, the depth of the foundation(s) in frost-susceptible ground should be at a minimum of 450mm below ground level. If the finished ground level will be above the existing ground level then, in cold conditions when freezing is expected, the foundation depth should be calculated from the existing, not finished, ground level.

Where the depth of trench fill foundations is in excess of 2.5m, they must be designed by a Chartered Structural Engineer in accordance with current British Standards and Codes of Practice. For trench fill, it is imperative to check that the finished foundation level is correct and horizontal. It will be difficult to adjust for discrepancies in the small number of brick courses between foundation and DPC level.

Prior to concreting, excavations should be ‘bottomed out’ to remove any debris that may have fallen into the trench; the excavations should be free from water, and if it has been left open for a long period of time, further excavation may be required to a non-weathered strata.

Note: It is important that Health and Safety obligations are met and that excavations are appropriately supported to prevent collapse.

5.3.8 Reinforcing

Strip and trench fill foundations should be reinforced where necessary to suit localised ground conditions. Reinforcement, if needed, should be clean and free from loose rust, and should also be placed correctly. Bars, of an appropriate size, should be supported to guarantee that they are 75mm above the base of the foundation, or as indicated in the design. They should be secured at laps and crossings, and, if in doubt about any soft spots, the Engineer’s advice should be taken prior to placing the concrete.

5.3.9 Foundation joints

If construction joints are necessary, they should not be positioned within 2m of a corner or junction in the foundation. All shuttering should be removed before work progresses beyond the construction joint.

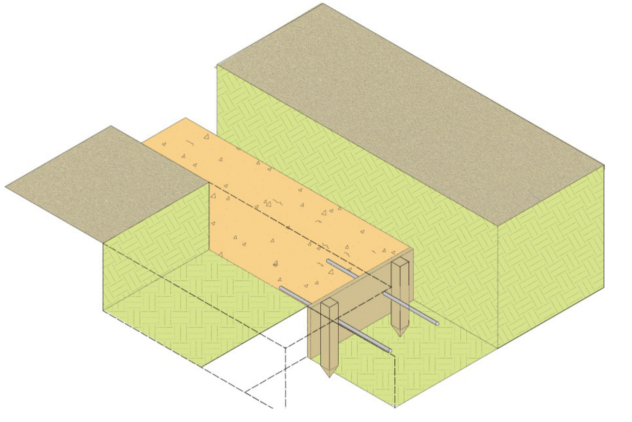
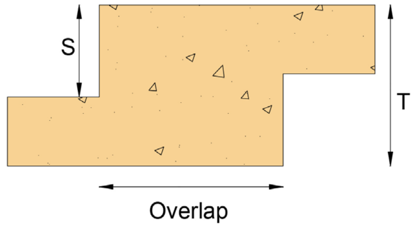


Figure 16: Using reinforcement bars across a joint

5.3.10 Steps in foundations

Steps in foundations must not be of a greater dimension than the thickness of the foundation. Where foundations are stepped (on elevation), they should overlap by twice the height of the step, by the dimension of the foundation or by 300mm, whichever is the greater, as shown in Figure 17.

Strip foundations
The overlap should be not less than:
- 2 x S, or
- T (maximum 500mm), or
- 300mm,
whichever is the largest.



Trench fill foundations
The overlap should be not less than:
- 2 x S, or
- 1m, or
whichever is the largest.

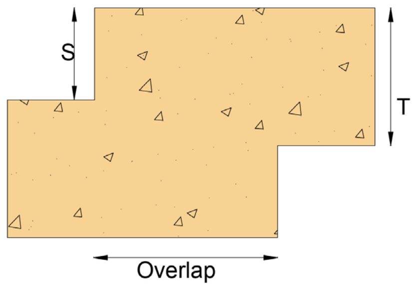


Figure 17: Steps in foundations

5.3.11 Standards referred to

- BS 8004 Code of Practice for foundations
- BS 5950-1 Structural use of steelwork in buildings
- BS 6399 Loadings for buildings
- BS 8103 Structural design of low rise buildings
- BS 8110 Structural use of concrete

FUNCTIONAL REQUIREMENTS

5.4 PILED FOUNDATIONS

Workmanship

i. All workmanship must be within the tolerances defined in Chapter 1 of this Manual.
ii. All work is to be carried out by a technically competent person in a workmanlike manner.
iii. Pile foundations schemes must be tested to confirm that the installation meets the design requirements.

Materials

i. All materials should be stored correctly in a manner that will not cause damage or deterioration of the product.
ii. All materials, products and building systems shall be appropriate and suitable for their intended purpose.
iii. The structure shall, unless specifically agreed otherwise with the Warranty provider, have a life of not less than 60 years. Individual components and assemblies, not integral to the structure, may have a lesser durability, but not in any circumstances less than 15 years.

Design

i. The design and specifications shall provide a clear indication of the design intent and demonstrate a satisfactory level of performance.
ii. Piled foundation designs must be supported by structural calculations provided by a suitably qualified expert. Calculations for full piling systems must be provided by, or endorsed by, the piling manufacturer.
iii. Piled foundations must meet the relevant Building Regulations, British Standards, Eurocodes and other statutory requirements.

5.4.1 Introduction

Piles are used to transfer loads from buildings to the supporting ground, and are utilised in a wide range of applications where conventional strip footings are inappropriate. They are particularly employed where soft or loose soils overlay strong soils or rocks at depths that can be reached conveniently by driving or boring. They are often the most economical type of foundation when very heavy loads must be supported or uplift forces need to be resisted. Large piles are extremely useful for limiting the settlements of large structures on deep stiff clays; smaller versions can provide appropriate foundations for houses and other small buildings on stiff clays liable to shrinkage and swelling. The technique has been in use for many years.

5.4.2 Limitations of guidance

The following situations are beyond the scope of the guidance in this Chapter:

- Innovative foundation systems that do not have third-party approval or accreditation
- Piling systems where the structural design is not endorsed by the Specialist Piling Contractor

5.4.3 Pile classification

Piles of many different types and methods of installation have been developed to suit the wide variety of soils. Piles generally fall into two main types:

- Bored and dug, including short bored and secant (replacement piles).
- Driven and jacked piles, steel, concrete and timber (displacement piles).

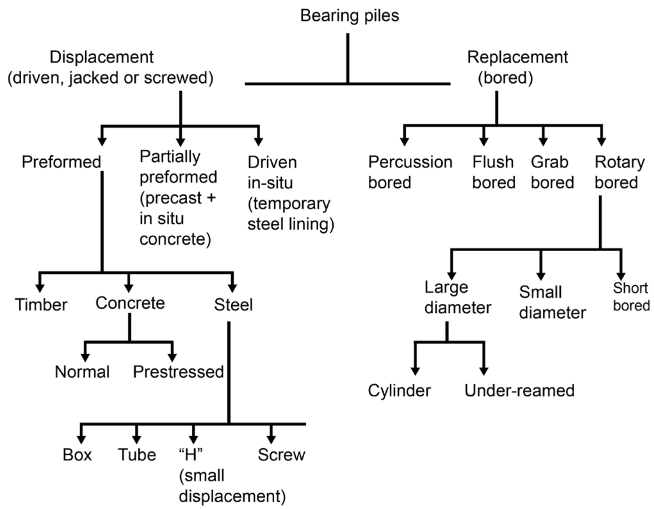


Figure 18: The range of piling types (BRE publication)

5.4.4 How piling systems work

There are basically two groupings of piles, based on the way that they transfer loads to the ground:

- End bearing piles derive the greater part of their support from bearing forces at the base. They act largely as columns transferring loads through soft deposits, usually to dense granular soil or rock at the foot of the pile.
- Friction piles, on the other hand, develop most of their support from friction between the shaft and the soil, usually firm clay.

5.4.5 Choosing the right piled solution

The choice of piling system to support the structure will depend entirely upon the ground conditions. It is important to have the appropriate site investigation works carried out to determine depths of filled ground, the bearing capacity of soils, soil type and any existing workings or services that may clash with pile locations. Further guidance for ground condition assessment can be found in Chapter 4 – Site Investigation.

Analysis of the site investigation report should be completed by a Specialist Piling Contractor and Structural Engineer, as they are best placed to design the most economical piling system.

Piles are particularly appropriate for heave sites (trees removed), for which they are strongly recommended.

Pile layouts can be readily designed to accommodate an individual plot. A good design will seek to achieve cost savings in foundation excavation and materials through incorporation of large ground beam spans between piles and a small number of piles.

The Piling Contractor should take care to ensure that the piles are inserted vertically and pile tops are correctly aligned to support the foundation beams. An acceptable level of tolerance is for a pile to be offset in plan from the theoretical position by no more than 75mm, with vertical alignment no worse than 1m in every 75m (1:75).

5.4.6 Ground beams

Piles should be capped with an appropriate ground beam system. There should be adequate connections between the beam and the pile to ensure that the loads are transmitted effectively or that the beams are adequately restrained to the pile to resist uplift on sites that are susceptible to heave. All external, internal, partition and party walls can be accommodated using this system. The ring beam and its connections should be part of the piled foundation design, and should be supported by structural calculations provided by a Structural Engineer.

5.4.7 Pile construction records

Pile construction records should be made available for all piles installed. The records should include the following information:

- Pile type (driven tube, Continuous Flight Auger (CFA), auger bored, etc.).
- Pile dimensions (diameter or width/breadth).
- Pile depth.
- Driving records from driven piles, including hammer type, weight, drop height, sets, hammer efficiency.
- Pile verticality confirmation, which should be no more than 1:75 from vertical.

For CFA and concrete screw piles, we should be given the computer output for concrete volume and rig performance.

5.4.8 Testing

Piled foundation installation should be appropriately tested to ensure that the installed foundations meet the design requirement. A testing strategy plan should be agreed at the design stage that is representative of the complexity of the piling system. Further guidance is available from the Federation of Piling Specialists, which has produced the Handbook on Pile Load Testing.

Static load testing of preliminary and working piles should be undertaken. Working pile testing is to be carried out at a rate of not less than 1 working pile per 100 piles or part thereof (not less than 1%). However, additional tests may be required on sites with more unstable ground or where workmanship has been an issue.

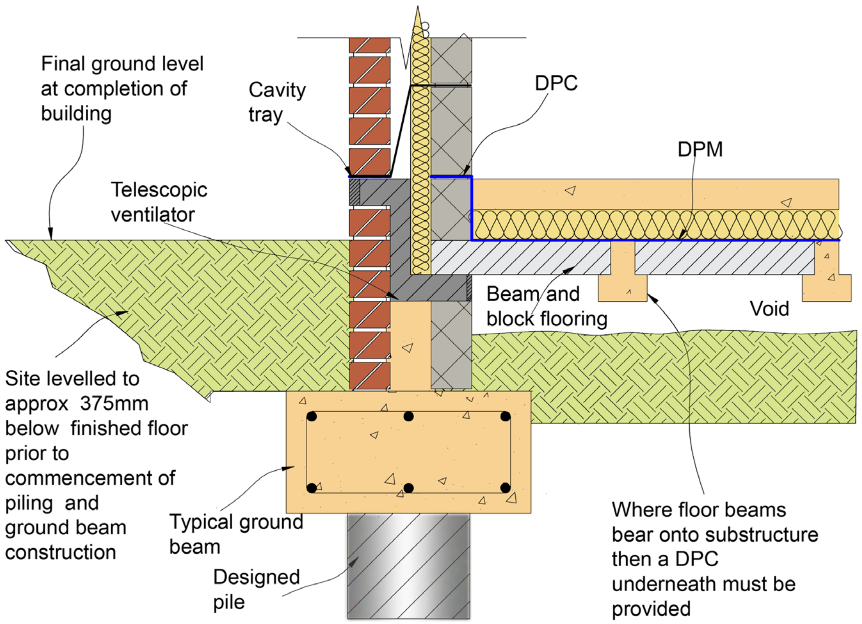


Figure 19: Pile and beam detail

5.4.9 Test methods

The Engineer shall require the Specialist Contractor to verify that the piling works have been completed to a satisfactory standard. This will usually include carrying out suitable testing to establish the degree of ground improvement, its load-bearing characteristics and settlement potential. These tests may include:

5.4.9.1 Dynamic tests

Also known as large strain testing, this technique is most commonly used for assessing the dynamic pile capacity of driven piles. Dynamic testing should be undertaken to reflect the detail of the site investigation report, the ground conditions and the factor of safety applied to the pile design. Please submit this information at the time of the Warranty application and prior to commencement on site.

5.4.9.2 Integrity tests

Also known as low strain testing, there are two types of tests used solely for assessing pile integrity:

- Cross hole sonic logging
- Pulse echo

For integrity testing of continuous Flight Auger Piles, 100% of the piles should be tested.

5.4.9.3 Negative skin friction

Where piles pass through ground that may consolidate or change in volume (e.g. due to a change in water table or loading due to the raising of levels), the effects of negative skin friction should be taken into account. The capacity of the pile to resist the additional compressive and tensile stresses should be checked at critical cross sections.

5.4.10 Relevant Standards and Guidance Documents:

- BS 8004 Code of Practice for foundations
- BS EN 1997 – 1 Eurocode 7
- BS EN 1997 – 2 Eurocode 7
- BS 5950-1 Structural use of steelwork in buildings
- BS 6399 Loadings for buildings
- BS 8103 Structural design of low rise buildings
- BS 8110 Structural use of concrete
- Piling Good Practice Guide (please refer to our website for further details)

FUNCTIONAL REQUIREMENTS

5.5 RAFT FOUNDATIONS

Workmanship

i. All workmanship must be within the tolerances defined in Chapter 1 of this Manual.
ii. All work is to be carried out by a technically competent person in a workmanlike manner.

Materials

i. All materials should be stored correctly in a manner that will not cause damage or deterioration of the product.
ii. All materials, products and building systems shall be appropriate and suitable for their intended purpose.
iii. The structure shall, unless specifically agreed otherwise with the Warranty provider, have a life of not less than 60 years. Individual components and assemblies, not integral to the structure, may have a lesser durability, but not in any circumstances less than 15 years.

Design

i. The design and specifications shall provide a clear indication of the design intent and demonstrate a satisfactory level of performance.
ii. Raft foundation designs must be supported by structural calculations provided by a suitably qualified expert.
iii. Raft foundation design and construction must meet the relevant Building Regulations, British Standards, Eurocodes and other statutory requirements.

5.5.1 Introduction

A raft foundation consists of a reinforced concrete slab, whose thickness and stiffness are designed to spread the applied wall and column loads over a large area. For domestic applications, rafts are often built with thickened perimeters to provide protection against frost heave, in which case they are effectively trench fill foundations with integral ground bearing floor slabs. Down stand edge beams also serve to stiffen the foundation's structure.

Rafts are used where it is necessary to limit the load applied to the underlying soil or to reduce the effects of differential foundation movements due to variable soil conditions or variations in loading.

5.5.2 Limitations of guidance

Rafts are not considered an accepted method of foundations where the ground conditions are susceptible to heave or shrinkage (e.g. where trees are present or have been removed).

5.5.3 Materials

Materials and workmanship should meet the requirements set out in Chapters 1 and 2 of this Manual.

5.5.4 Ground conditions

Raft foundations are usually designed for sites with ground conditions with low ground bearing capacity or where there are pockets of filled ground. It is therefore important to complete a suitable site investigation to meet the requirements of Chapter 4 of this Manual and ascertain the bearing capacity and suitability of the ground.

5.5.5 Structural design

Structural calculations should be provided by a suitably qualified Structural Engineer, confirming that the raft design is suitable for bearing onto the ground and that the ground bearing capacity safely supports the structure. For 'low rise structures', the foundations should be designed to ensure a maximum settlement of 25mm is not exceeded. In relation to differential settlement, a design limit for maximum tilt of 1/500 is appropriate. More stringent values may be required due to the particular circumstances (e.g. medium and high rise structures).

The design should provide sufficient information to ensure correct installation of the raft and its reinforcing. The minimum recommended information is as follows:

- Plans and details of the proposed raft showing reinforcing positions, etc.
- Structural calculations confirming that the raft is suitable for the proposed loads applied.
- A bar schedule, to be used by the reinforcing steel supplier and installer.

5.5.6 Ducts and sleeving

Any service penetrations that pass through the raft should be appropriately sleeved to protect the service duct. Service duct positions should be planned and indicated on drawings to prevent reinforcing bars from being cut, unless the structural design has catered for this.

5.5.7 Damp Proof Membranes (DPM), Damp Proof Courses (DPC) and floor finishes

The raft foundation and the junction with the wall should be appropriately constructed to resist ground moisture penetration. A DPM can be placed beneath the raft, wrapped around the external toe and lapped into the internal DPC; however, this detail can be difficult to implement on-site, and puncturing of the membrane can commonly occur when placing reinforcing. The preferred method is to place the DPM on top of the raft slab beneath the floor insulation or screed, as indicated in Figure 20.

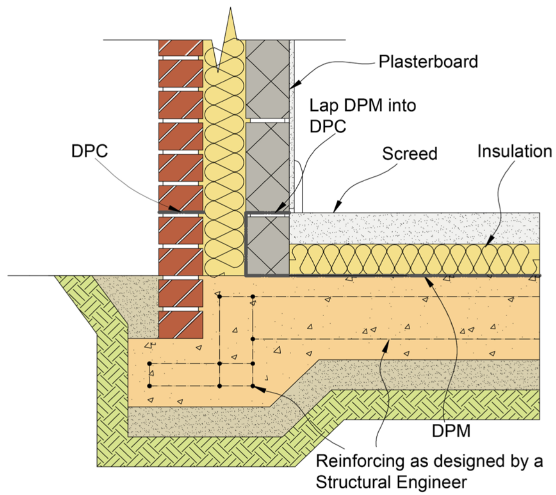


Figure 20: Typical raft foundation design

5.5.8 Standards referred to

- BS 8004 Code of Practice for foundations
- BS 5950-1 Structural use of steelwork in buildings
- BS 6399 Loadings for buildings
- BS 8103 Structural design of low rise buildings
- BS 8110 Structural use of concrete