TECHNICAL MANUAL

VERSION 10

3: FOUNDATIONS

3.

Foundations

Contents

Workmanship

1. 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 (applicable to: 'Engineered Fill' and Vibratory Ground Improvement' only).
2. The developer shall ensure that adequate quality control procedures are in place. The quality control and testing must identify that site work meets the design intention. All procedures should be auditable and available for inspection (applicable to: 'Engineered Fill' and 'Vibratory Ground Improvement' only).
3. Foundations should be of a suitable depth in order to achieve a satisfactory level of performance.
4. Excavations for foundations shall be accurate in line, width and depth, and suitable for the type of foundation which form the basis of the design.

Materials

No additional requirements.

Design

1. Site Investigation by an appropriately qualified person should be supplied and provide the following information (applicable to: 'Engineered Fill' and 'Vibratory Ground Improvement' only):
    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.
2. The ground improvement works must meet the Building Regulations (applicable to 'Engineered Fill' and 'Vibratory Ground Improvement' only).
3. Foundation type and depth must be suitable to resist movement due to the influence of nearby trees.
4. 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.
5. Raft foundation designs must be supported by structural calculations provided by a suitably qualified expert.
6. Foundation design must meet the requirements of Building Regulations

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3.1

Mass Fill

Limitations of guidance

The following situations are not covered by this guidance:
- Mass filled foundations for buildings other than dwellings.
- Buildings greater than three storeys.
- Foundations on filled ground.
- Mass fill foundations where foundation depths exceed 2.5m.

Design

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. Please see the ‘Ground Conditions’ section.

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).

Foundations: Trees and Clay

Foundation design should take into account influence from nearby trees. Where construction is to take place in cohesive soils and trees are/were/will be present:
- If the foundation depth is greater than 1.5m, heave protection will be required.
- Where foundation depths exceed 2m, short bored piles with ground beams are recommended. All pile designs should be undertaken by a Chartered structural engineer.
- Foundation depths required to exceed 2.5m are beyond the scope of the online foundation depth calculator and must be a piled engineered solution.

Minimum foundation dimensions

- Mass fill 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 ensuring that a 150mm projection either side of the internal wall is provided.
- Foundations should be situated centrally below the wall.

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 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.

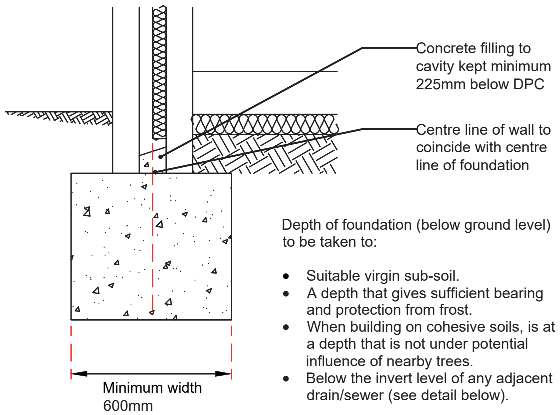
Where trees are situated close to a proposed building founded on a clay soil, the foundation depth/design will be affected; further guidance is available in the ‘Foundations - Trees and Clay’ section. In clay soils with a plasticity index greater than or equal to 10%, foundations should be taken to a 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.

For minimum depths of foundations in cohesive soils where trees are/were/will be present, please use the online foundation depth calculator. Further guidance can be found in the ‘Foundations - Trees and Clay’ section.

Minimum foundation depths

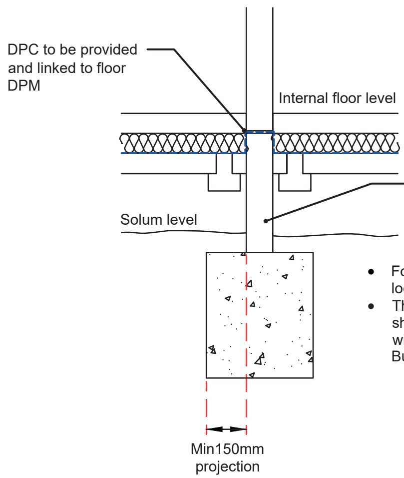
Modified plasticity index (x)	Volume change potential	Min foundation depth (m)
x ≥ 40%	High	1.00
40% > x ≥ 20%	Medium	0.9*
20% > x ≥ 10%	Low	0.75*
Note: *If the modified plasticity index is not confirmed, the minimum foundation depths should be 1m.		

Typical mass filled foundation



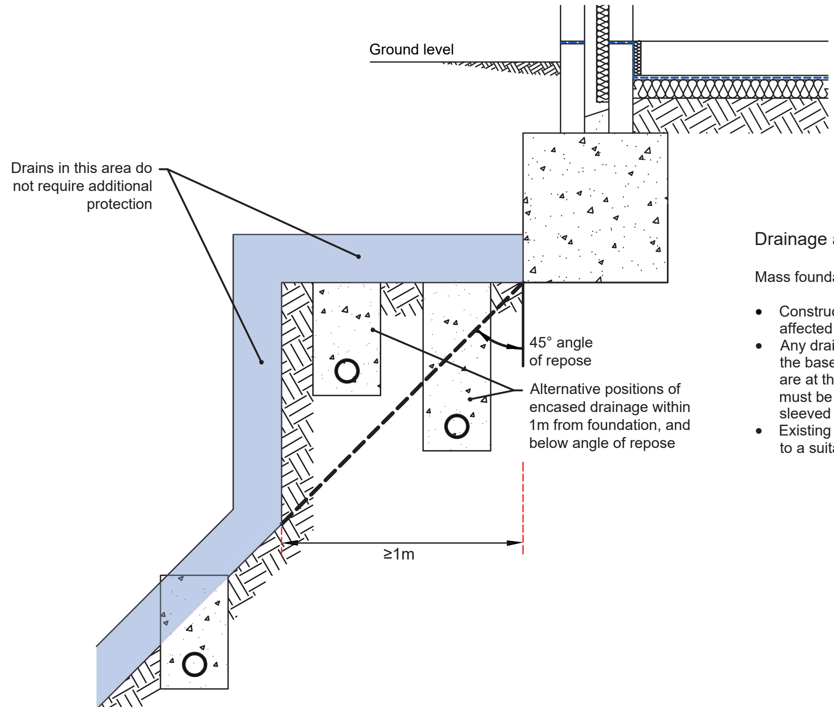
Depth of foundation (below ground level) to be taken to:
- Suitable virgin sub-soil.
- A depth that gives sufficient bearing and protection from frost.
- When building on cohesive soils, is at a depth that is not under potential influence of nearby trees.
- Below the invert level of any adjacent drain/sewer (see detail below).

Internal wall foundation



- Foundation to be centrally located under the wall.
- The foundation width should be in accordance with the relevant regional Building Regulations.

Drainage positions situated within angle of repose and adjacent to foundation by 1m



Drainage and other services:

Mass foundations must be:

- Constructed to a depth which will not be affected by nearby drainage or other services.
- Any drain or service pipe must not pass through the base of the foundation. Where such services are at the same level, the base of the foundation must be stepped below and the drain/services sleeved through the substructure wall above.
- Existing ground water drains should be diverted to a suitable outfall.

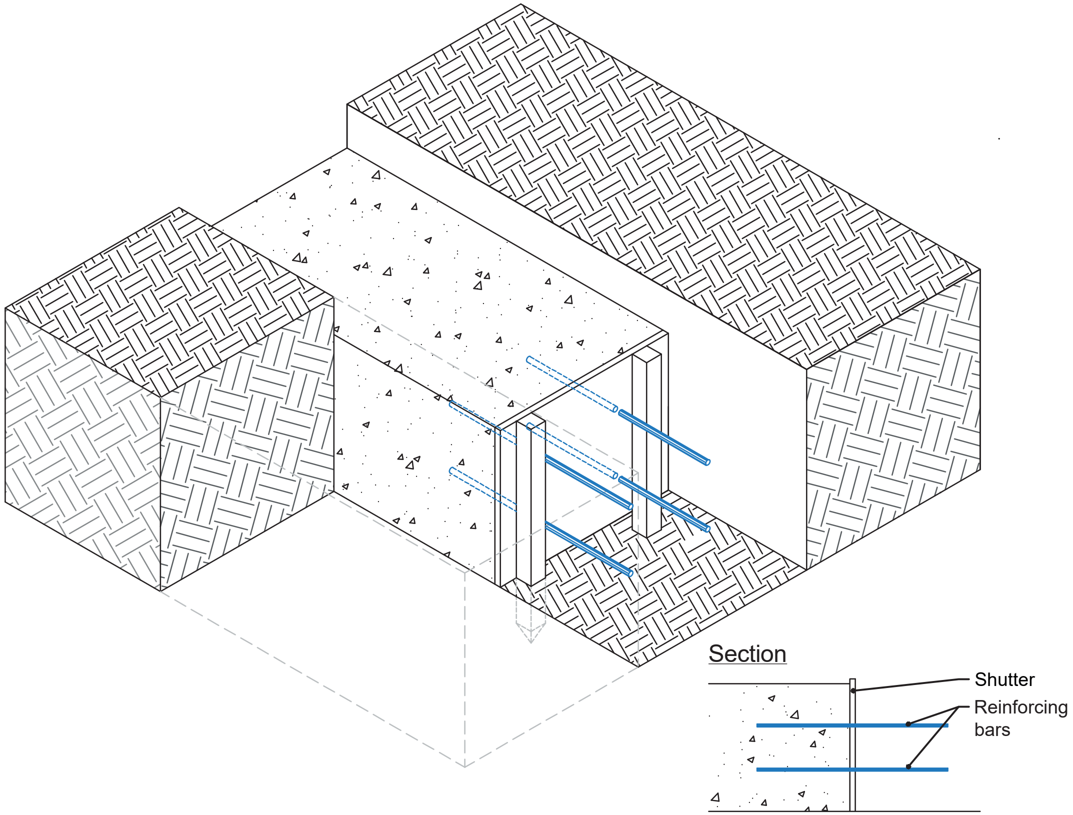
Reinforcing

Mass 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. If in doubt about any soft spots, the engineer's advice should be taken prior to placing the concrete.

Foundation joints

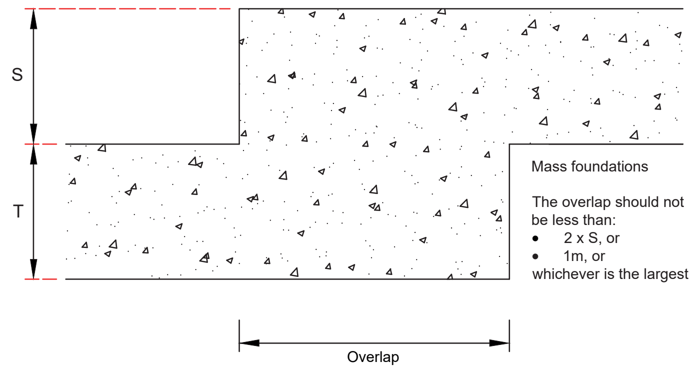
If construction joints are necessary, they should not be positioned within 2m of a corner or junction in the foundation. All shuttering should be removed before work progresses beyond the construction joint.

Using reinforcement bars across a joint



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, or 1m whichever is the largest.



Excavation

- Excavations 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, the foundation depth should be calculated from the existing, not finished, ground level.
- Where the depth of mass 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.

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.

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

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3.2
Strip

Limitations of guidance

The following situations are not covered by this guidance:
- Traditional strip foundations for buildings other than dwellings.
- Buildings greater than three storeys.
- Foundations on filled ground.
- Strip foundations where foundation depths exceed 2.5m.

Design

Strip 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. Please refer to the 'Ground Conditions' section.

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).

Foundations: Trees and clay

Foundation design should take into account influence from near-by trees.
- Where construction is to take place in cohesive soils and trees are/were/will be present, and the foundation depth is required (using the online foundation depth calculator) to exceed 1.5m, heave protection will be necessary and strip foundations will not be suitable. Mass fill or short bored piles should be adopted (see the 'Foundations - Mass Fill' and 'Foundations - Piles' guidance).

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 ensuring that a 150mm projection either side of the internal wall is provided.
- The minimum thickness of strip foundations should be 150mm.
- Foundations should be situated centrally below the wall.

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.

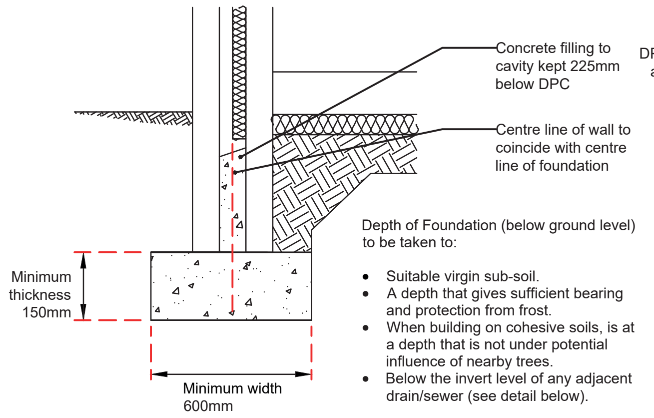
Where trees are situated close to a proposed building founded on a clay soil, the foundation depth/design will require to be assessed by following the recommendations available in the 'Foundations - Trees and Clay' section. In clay soils with a plasticity index greater than or equal to 10%, strip foundations 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.

Minimum foundation depths

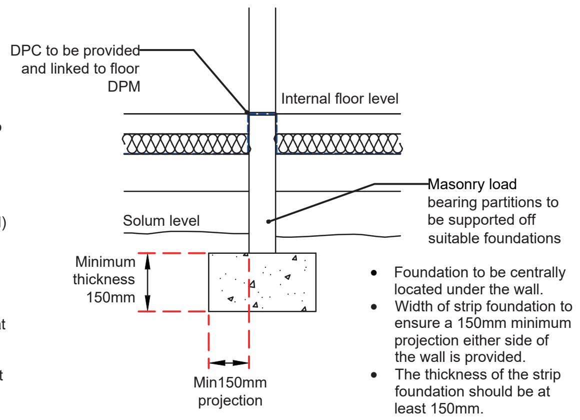
Modified plasticity index (x)	Volume change potential	Min foundation depth (m)
x ≥ 40%	High	1.00
40% > x ≥ 20%	Medium	0.9*
20% > x ≥ 10%	Low	0.75*
Note: *If the modified plasticity index is not confirmed, the minimum foundation depths should be 1m.		

The Plasticity Index may be used without modification; for soils comprising of pure clays, with 100% of particles less than 425μm, the Plasticity and Modified Plasticity Indexes will be the same. The adoption of the Modified Plasticity Index in mixed soils, such as glacial till, however, may result in a more economical design.

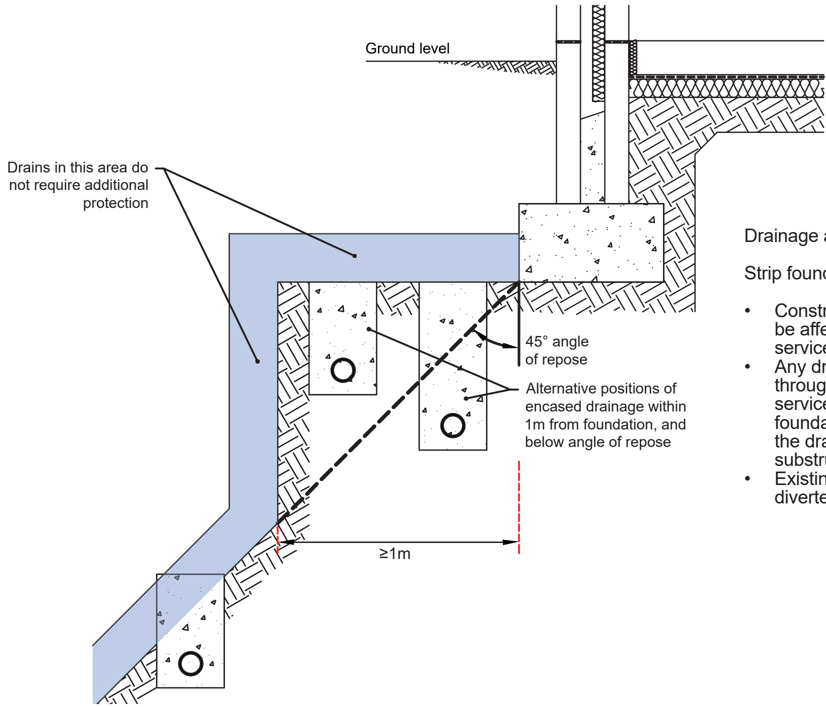
Typical strip foundation



Internal wall foundation



Drainage positions situated within angle of repose and adjacent to foundation by 1m



Drainage and other services:

Strip foundations must be:

- Constructed to a depth which will not be affected by nearby drainage or other services.
- Any drain or service pipe must not pass through the strip foundation. Where such services are at the same level, the strip foundation must be stepped below and the drain / services sleeved through the substructure wall above.
- Existing ground water drains should be diverted to a suitable outfall.

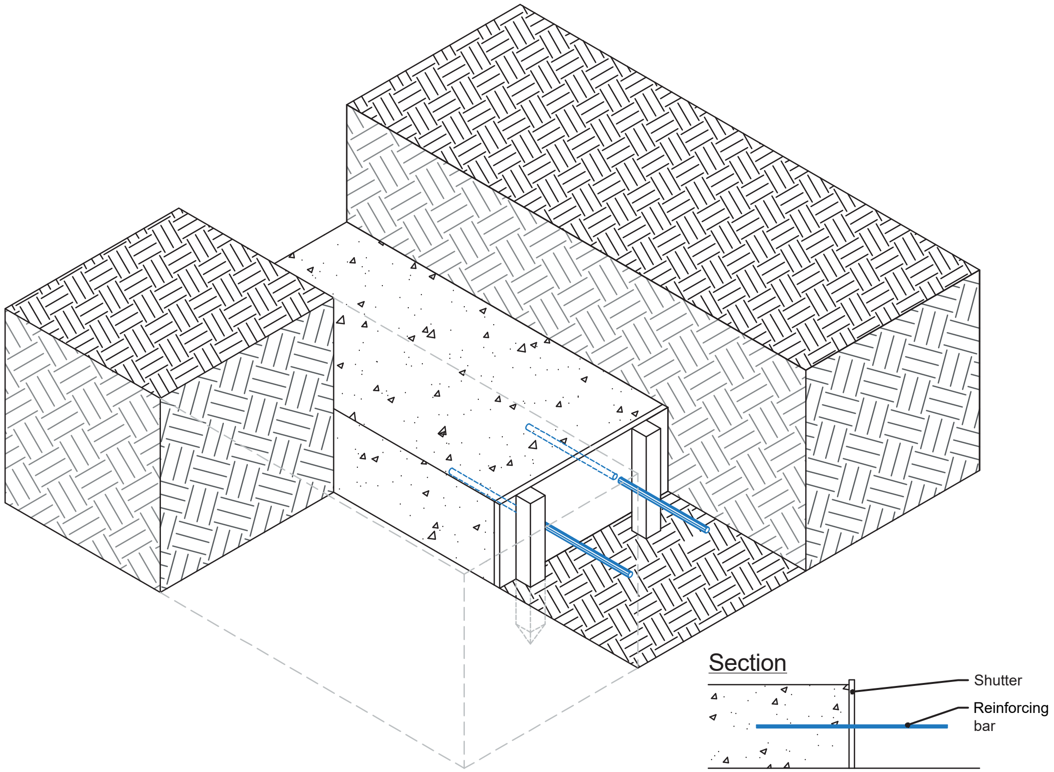
Reinforcing

Strip 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.

Foundation joints

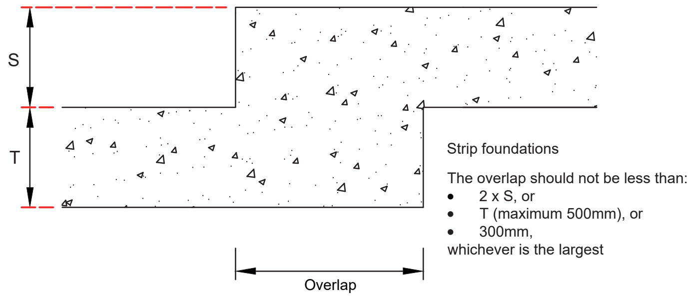
If construction joints are necessary, they should not be positioned within 2m of a corner or junction in the foundation. All shuttering should be removed before work progresses beyond the construction joint.

Using reinforcement bars across a joint



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, or 300mm, whichever is the largest.



Excavation

- 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, the foundation depth should be calculated from the existing, not finished, ground level.
- Where the depth of strip 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.
- 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.

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.

Standards referred to:

- BS 8004 Code of Practice for foundations
- BS 5950-1 Structural use of steelwork in buildings
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- BS 8110 Structural use of concrete

3.

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3.3

Piles

Piled Foundations

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.

Limitations of guidance

The following situations are beyond the scope of this guidance.

- 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.

Foundations: Trees and clay

Foundation design should take into account influence from nearby trees. Where construction is to take place in cohesive soils and trees are/were/will be present:

- Suitable heave precautions should be included in the design details for the protection of the piles and ground beams.
- The piles must be deep enough to cater for heave.

For more information on this, please see the ‘Foundations - Trees and Clay’ section.

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).

How piling systems work

There are 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.

Choosing the right piled solution

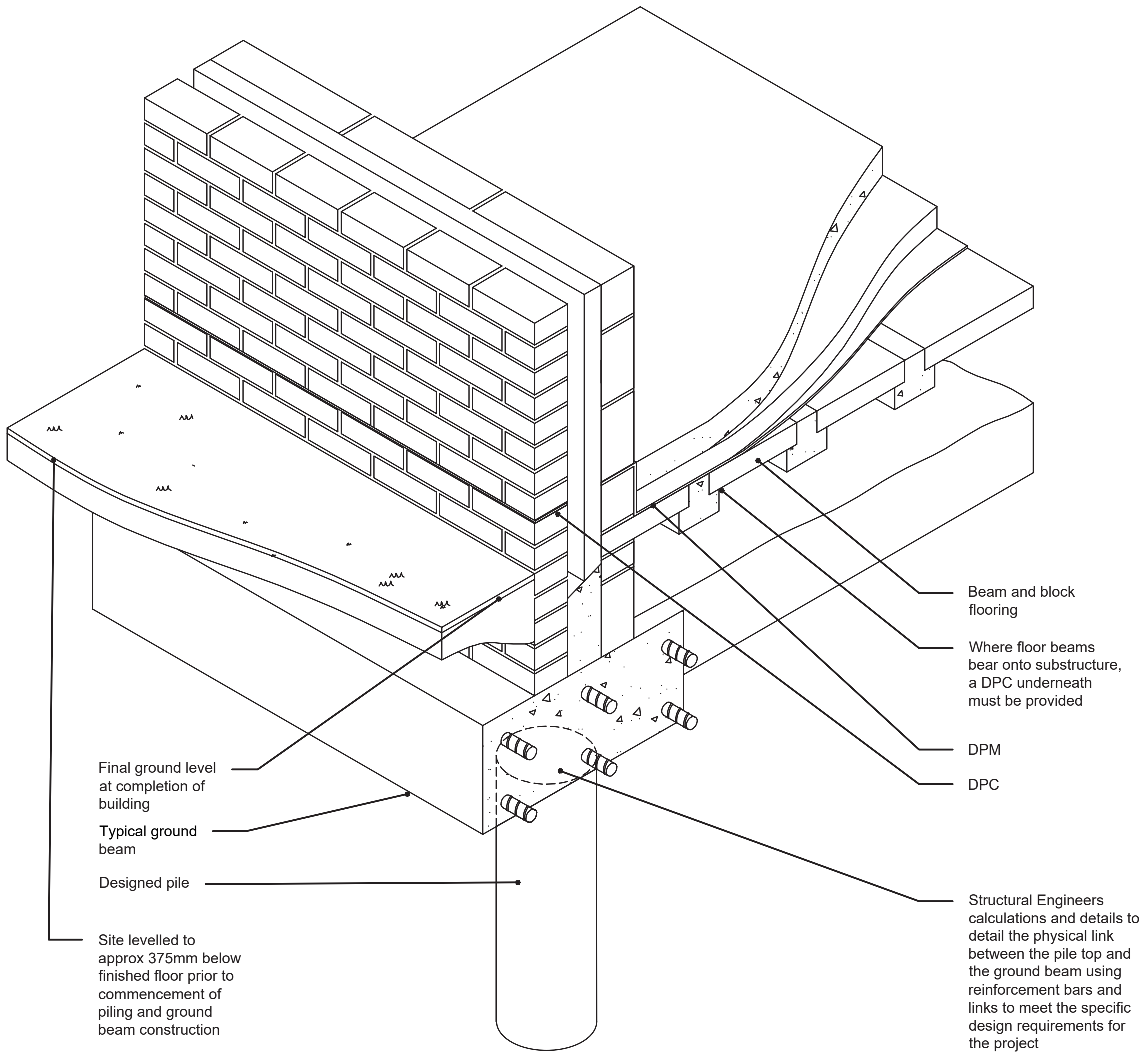
The choice of piling system to support the structure will depend entirely upon the ground conditions. It is important to have the appropriate site investigation works carried out to determine depths of filled ground, the bearing capacity of soils, soil type and any existing workings or services that may clash with pile locations.

Note: For further guidance on ground condition assessments, please refer to the ‘Ground Conditions’ section.

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.



Alignment 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).

Ground beams

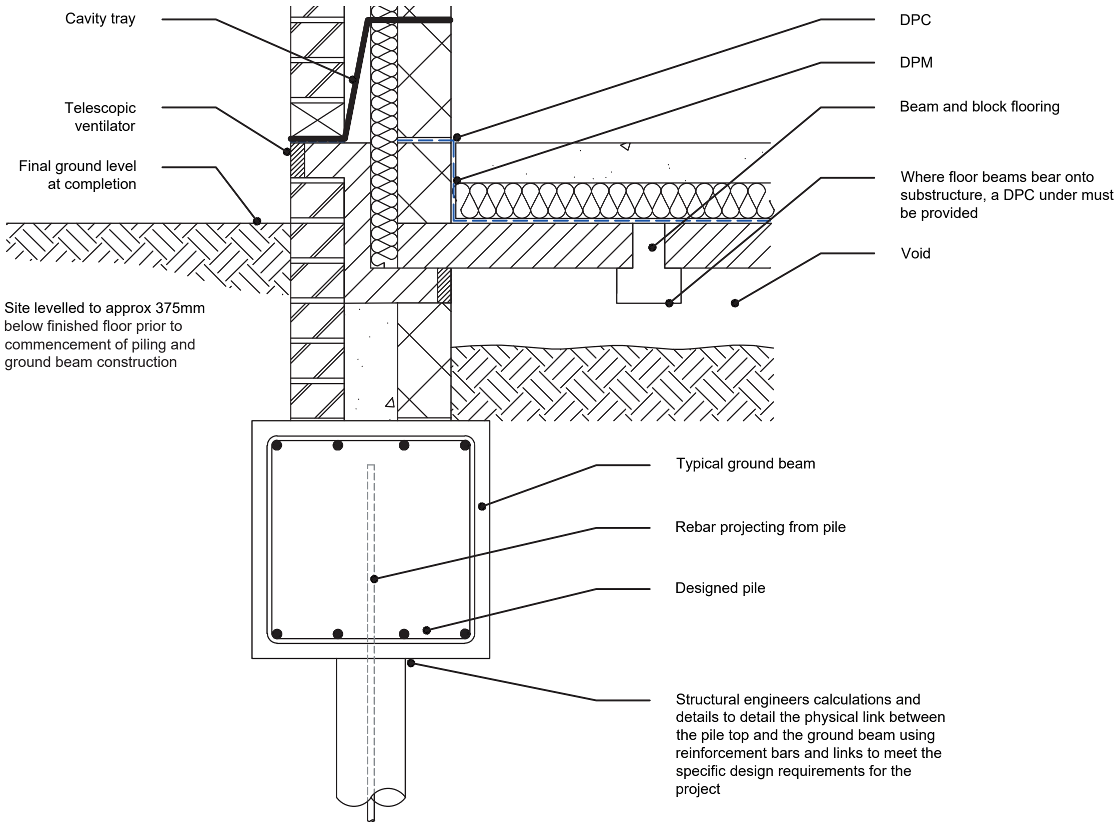
Piles should be capped with an appropriate ground beam system. There should be adequate connections between the beam and the pile to ensure that the loads are transmitted effectively, or that the beams are adequately restrained to the pile to resist uplift on sites that are susceptible to heave. All 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.

Pile construction records

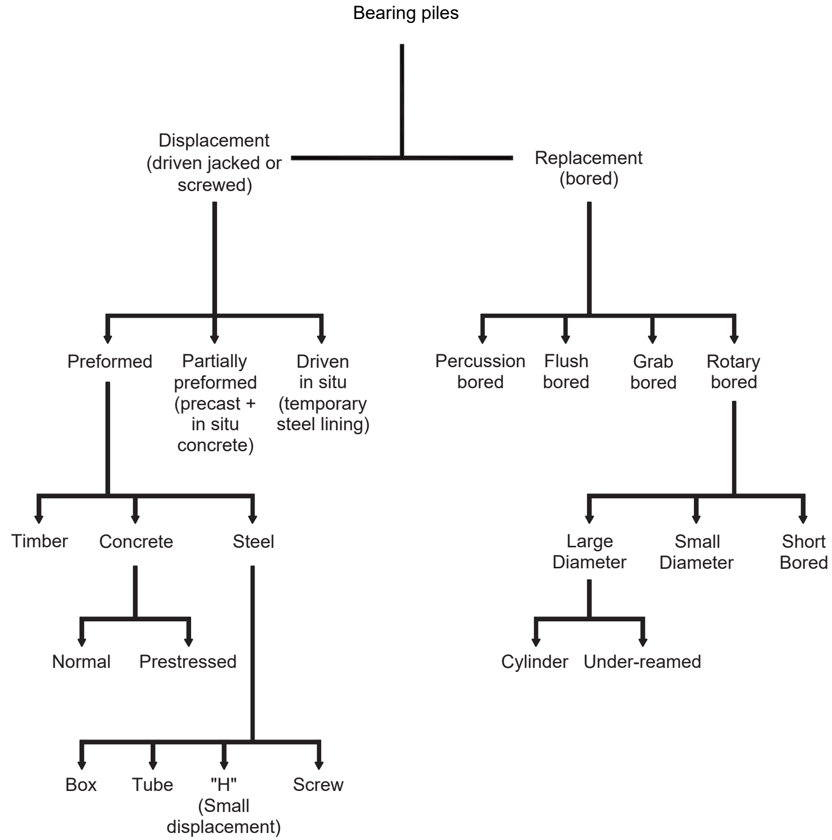
Pile construction records should be made available for all piles installed. The records should include the following information:

- 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, the Warranty Surveyor should be given the computer output for concrete volume and rig performance.



The range of piling types (BRE publication)



Key requirements

The piling scheme shall be designed to clearly demonstrate that the piles are capable of supporting and transferring the foundation design loads safely to known soil strata that are, in turn, capable of supporting the pile loads using the appropriate soil parameters obtained from geotechnical testing and contained in the appropriate site investigation report. The piles shall be designed in accordance with BS 8004:2015 and shall ensure that long term settlement does not exceed 10mm or 1:500 (differential, between adjacent piles) at working load and 15mm at 1.5 times working load, unless more stringent criteria are required by the Project Structural Engineer.

Pile installation record sheets shall show clearly that all piles installed have achieved sufficient depth with respect to the pile design calculations. Where there is any doubt concerning the depth of the piles, as a result of any encountered voids or boulders, or there is any other reason to suspect under-performance, the capacity of the questionable piles shall be demonstrated by means of static load testing and it shall be confirmed by the Project Structural Engineer that the piles are fit for purpose.

Technical documentation required

The following documentation shall be submitted to the Warranty Surveyor for assessment. Items 1-5 below should be submitted prior to commencement of piling on site. In the absence of approval, works are proceeding at the Developer’s own risk. Items 6-10 below shall be submitted as soon as they become available, prior to construction continuing over the piles.

Prior to commencement on site

1. Phase 1 Desk Study Report and Phase 2 Geotechnical, investigative and interpretive Site Investigation Report(s) (to at least 5m below the pile toe) with associated geotechnical testing sufficient for pile design including DS / ACEC requirements for buried concrete, heave and shrinkage.
2. Foundation drawings, pile layouts and pile schedule (with pile reference numbers and loadings).
3. Project Structural Engineer’s specification for piling works to include the allowable pile settlements and testing requirements.
4. Calculations for the substructure and for the derivation of the load on each pile.
5. Geotechnical pile design calculation (for compressive, horizontal, tensile and heave forces) to geotechnical parameters in Site Investigation Report, pile structural design and a copy of the pile set design (for driven piles, if applicable). This should include the pile designer’s written confirmation that the site investigation is adequate to ensure that the pile design complies with British Standards. This should also include confirmation, justification, type and number of any preliminary and/or working pile load tests required to satisfy the design. Note that an adhesion factor greater than 0.5 will not be acceptable unless supported by maintained static load tests on 1% of working piles.

Prior to construction continuing over the piles

6. Pile installation logs (with pile numbers cross-referenced to the pile layout drawing), including details of re-strikes, rock sockets, rig telemetry records, and concrete volume.
7. Concrete mix details and cube test results for the concrete used in the piles with tabulated results similar to that in Concrete Advice Note. No.30 (The Concrete Society) Tables 1 and 3. Delivery records, cross-referenced to the pile layout/numbers, should also be kept for possible future reference.
8. Integrity testing of all concrete piles with interpretive summary and conclusion.
9. Dynamic load testing results with analysis of long-term settlement, interpretive summary, and conclusion. The correlating static load test for each differing length, load and diameter must be included (and the relevant boreholes if the static testing was undertaken at a different site.)
10. Static load test results with interpretive summary and conclusion.

Reference documents

- BS EN 1997-1:2004 + A1:2013 - Eurocode 7: Geotechnical design (EC7)
- BS 8004:2015 + A1:2020 - Code of practice for foundations
- BS EN 1997-2:2007 - Ground investigation and testing
- BS 5930: 2015 + A1:2020 - Code of practice for ground investigations
- ICE Specification for piling and embedded retaining walls (3rd edition 2016)
- London district surveyors association (LDSA) - Guidance notes for the design of straight shafted bored piles in London clay (2017)

Geotechnical site investigation

A detailed, site specific, interpretive, Phase 2 Geotechnical Site Investigation should take place and be in accordance with BS 5930 / BS EN1997-2 and extend to depths beneath the pile toe of at least 3 x pile diameter or 5m or the smallest plan dimension encompassing the pile group (whichever is the greatest). Refer to ‘Published Minimum Requirements for Site Investigation’ by the Federation of Piling Specialists (July 2013). Generally, boreholes should be at centres of 10m to 30m for structures and at a minimum of 3 points, but closer borehole spacing’s should be used where there are site-specific hazards (e.g. soluble soils, mining features etc.) or where there are large variations in soil properties.
The investigation should include sufficient geotechnical testing throughout the length and beneath the pile to enable an accurate geotechnical design of the pile in accordance with proven design methods.

If the Site Investigation is found to contain insufficient information to verify the proposed design of the piles, the pile designer should request additional investigation and testing e.g. additional boreholes to the above depth, as considered necessary to establish the required geotechnical parameters.

Pile design

A pile layout drawing and pile load schedule should be prepared by the Project Structural Engineer, indicating the pile reference numbers, all loadings to which each pile will be subjected and details of connections between piles and the substructure. Calculations should clearly demonstrate how the load on each pile was derived.

The piles shall be designed in accordance with BS8004:2015/BSEN1997-1 and shall ensure that long term settlement does not exceed 10mm or 1:500 (differential, between adjacent piles) at working load and 15mm at 1.5 times working load, unless more stringent criteria are required by the Project Structural Engineer.

In all cases, a geotechnical and structural design should be carried out to current standards in order to produce a Geotechnical Design Report to confirm the required pile length, reinforcement etc. and to reflect the ground conditions as confirmed by the site specific Site Investigation Report. The pile design should prove that the pile can support all compressive, horizontal, tensile, heave and negative skin friction forces.

The skin friction adhesion factor (α) should be in accordance with BS 8004:2015 (clause 6.4.1.2.3). An adhesion factor greater than 0.5 will not be acceptable unless supported by maintained static load tests on 1% of working piles.

BS 8004:2015 (clause 6.1.1) and BS EN1997-1 (clause 7.4.1) permits pile design to carried out one of the following options:
1. Geotechnical/Static pile design based on soil parameters from the site investigation and appropriate safety factors.
2. The results of dynamic load tests (provided they have been verified by static load tests in comparable situations).
3. Pile driving formula (provided they have been verified by static tests in comparable situations).

If the results of appropriate static load testing are not available for the site, then only option 1 can be used as the basis of design. In this case, all driven piles should be installed to the lengths indicated in the static pile design calculation and representative dynamic tests with settlement analysis (e.g. CAPWAP) are carried out (typically 3% to 5% per static pile design), but this may need to be increased if there are any concerns regarding the pile installation or if required by the Project Structural Engineer.

However, if the piles cannot be driven to the lengths indicated in the static pile design (as is often the case), then reliance switches to dynamic tests and/or dynamic formulae, both of which need to be verified by previous evidence of acceptable performance in static load tests on the same type of pile, of similar length and cross section and in similar ground conditions (the static load tests don’t necessarily need to have been carried out on the particular site), as required by BS 8004:2015.

A pile schedule should be produced indicating the pile numbers (referenced to the drawings), pile loads, pile type and diameter, pile length, required rock socket length, and details of required reinforcement. Piles for new developments should be not less than 150mm diameter or equivalent.

Alternative pile types and design methods

If alternative pile types or non-standard design methods are being considered, please contact the Warranty Surveyor prior to commencement of piling.

Pile design factor of safety

The factor of safety is dependent on the extent of site investigation, design method/code/standard, confidence in the design, the proposed pile load testing regime, and should be in accordance with design method being used.

BS EN 1997-1 Partial factors depending upon load testing undertaken (for bored or continuous flight auger piles)

Direction of load	Load tests	Partial factor for shaft resistance	Partial factor for base resistance	Model factor
Compression	None	1.6	2.0	1.4
	WPT only	1.4	1.7	1.4
	PPT and WPT	1.4	1.7	1.2
Tension	None	2.0	-	1.4

BSEN1997-1 Partial Factors depending upon load testing undertaken (for driven piles):

Direction of load	Load tests	Partial factor for shaft resistance	Partial factor for base resistance	Model factor
Compression	None	1.5	1.7	1.4
	WPT only	1.3	1.5	1.4
	PPT and WPT	1.3	1.5	1.2
Tension	None	2.0	-	1.4

WPT: Working Pile Test.
PPT: Preliminary Pile Test.
Refer to BSEN1997-1 for full tables and commentary.

Note: It is not acceptable to adopt a higher factor of safety in place of an adequately detailed Site Investigation.
The guidelines contained in LDSA guidance should be used for the design of straight shafted bored piles in London clay.

Piling in rock/boulders

If rock sockets are required by the pile design, then the achievement of such sockets during pile installation should be demonstrated. Where there are boulders, it needs to be demonstrated that piles are not founded on, or partly on, boulders. It is advisable to ensure that piles are taken down through strata containing cobbles/boulders. Pre-drilling may be required.

“Rig refusal” will not be accepted in the event that design rock socket lengths are not achieved, In the event of this, static load testing and additional site investigation and geotechnical testing will be required.

Piling in chalk

Reference should be made to CIRIA PR86 and CIRIA C574 for pile design and installation. Where the risk of solution features as obtained from a Groundsure or Envirocheck hazard map is moderate or high (i.e. not low), probing should be carried out at each pile location in accordance with CIRIA PR86. Piles should be designed to take into account the risk of a solution feature around, adjacent or beneath the pile (refer to clause 7.10.2 of CIRIA C574). Should concrete flows significantly exceed the volume of the pile during installation (suggestive of a solution feature/void), measures should be taken immediately to mitigate the risk e.g. additional probing, deeper piles, relocation of piles, load testing etc.

On sites previously classified as low risk, should a potential solution feature be encountered during excavation/inspection/construction of the foundations, the foundation design should be amended accordingly to ensure that the soils within the feature are not required to provide long term support to the foundations. This will likely involve, as considered appropriate, those steps undertaken on sites with a moderate and high risk of the presence of solution features.

Piling in ground subject to cavitation

Where the ground is subject to potential cavitation as a result of gypsum dissolution, brine dissolution etc., the pile design and installation should take into account any existing and future cavitation. As such, some form of redundancy may need to be considered within the design to counteract any unknown conditions. As the presence of solution features cannot be readily identified during the installation of the piles, it is recommended that probing be undertaken at each pile location. Geophysical investigation or similar is recommended in order to locate existing cavities.

Piling over mine workings

With regard to piling over or near to historical mine workings reference should be made to CIRIA SP32 and CIRIA C758D. Piles are not generally suitable unless founded below the grouted horizons. When piling adjacent to existing mine entries, assurance needs to be provided that adequate competent rock is available, that stipulated rock sockets are achieved and that piles will not be affected by any potential future collapse or partial collapse of the mine entry.

Piling in made ground

Piles terminating in, or relying on, made ground/fill are not acceptable.

Pile installation and testing

Piles should be installed and tested to ensure that they meet the design requirements. The Project Structural Engineer shall review all pile installation records and testing results and advise on remedial works to address any unusual results or failures.

Pile installation records (logs)

Copies of the site-recorded pile installation records (logs) shall be provided for each pile indicating the pile number (correctly referenced to the drawing), pile load, pile length, reinforcement details and any sleeving requirements.
For driven piles, the first pile driven should record the number of blows for the first 100mm of each metre of depth, and the set (including dates) achieved during installation and on re-strike should be indicated.

Should driven piles vary considerably in length across short distances, then the pile installation should be immediately re-assessed and details (including subsequent results of further investigation and a plot of pile lengths on the pile layout drawing and sections) submitted to the Warranty Surveyor for review. Installing piles to “rig-refusal” or reference to the limitations of the piling rig shall not be accepted as the sole proof of adequacy of the pile length. If the pile static design lengths are not being achieved on site, then static pile load tests may be required in order to ensure compliance with the British Standards and/or carrying out additional site investigation to prove the adequacy of the pile.

Re-strikes shall be carried out on driven piles (typically at a rate of 10%) following a suitable time allowance. If sets have relaxed on re-strike, the adequacy of the piles shall be re-evaluated (e.g. by additional testing).

Rig telemetry should be recorded, stored and provided as a matter of course for projects with continuous flight auger (CFA), sectional flight auger (SFA) or continuous helical displacement (CHD) piles.

Concrete mix and cube test results

Concrete mix details and cube test results for the concrete used in the piles shall be provided with tabulated results, similar to that in Concrete Advice Note No.30 (The Concrete Society) Tables 1 and 3. Delivery records, cross referenced to the pile layout/numbers, should also be kept for possible future reference. The Project Structural Engineer shall review all concrete cube testing results and, in the case of any unusual results or failures, advise on any remedial works proposals necessary.

Pile integrity testing

The integrity of the full depth and cross-section of all CFA, SFA, CHD, bored piles (including retaining walls) should be established by integrity testing using recognised methods. Should integrity testing indicate anomalies, then the Project Structural Engineer should advise on the remedial measures proposed and seek agreement with us. It is recommended that such agreement is obtained prior to work continuing.

Note: Integrity testing should not be considered as replacement for sufficient site investigation or other types of testing, particularly static load testing. 100% of such piles shall be integrity tested.

Dynamic load testing

Dynamic load testing shall be carried out in accordance with BS 8004:2015 and shall include analysis of long term settlements. There should be adequate site investigation to 5m below the pile toe as required by the British Standards.

BS 8004:2015 (clause 6.1.1) & BS EN1997-1 (clause 7.4.1) permits pile design to be carried out by one of the following options:

1. Geotechnical/Static pile design based on soil parameters from the site investigation and appropriate safety factors.
2. The results of dynamic load tests (provided they have been verified by static load tests in comparable situations).
3. Pile driving formula (provided they have been verified by static load tests in comparable situations).

If the results of appropriate static load testing are not available for the site, then only option 1 above can be used as the basis of design. In this case, all driven piles should be installed to the lengths indicated in the static pile design and representative dynamic tests with settlement analysis (e.g. CAPWAP) are carried out (typically 3% to 5% per static pile design but this may need to be increased if there are any concerns regarding the pile installation or if required by the Project Structural Engineer).

However, if the piles cannot be driven to the lengths indicated in the static design (as is often the case), then reliance switches to dynamic tests and/or dynamic formulae, both of which need to be verified by previous evidence of acceptable performance in static load tests on the same type of pile, of similar length and cross section and in similar ground conditions (the static tests don’t necessarily need to have been carried out on the particular site), as required by BS 8004:2015.

Static load testing

Preliminary Pile Tests (PPT): Maintained load (ML) testing up to the unfactored ultimate resistance (commonly defined as settlement equivalent to 10% of the pile diameter) in accordance with BS 8004, SPERW, or other accepted standards; normally carried out before work starts on site or at the very beginning of a project.

Working Pile Tests (WPT): Maintained load (ML) testing up to at least 1.5 times working load in accordance with BS 8004, SPERW, or other accepted standards. Working Pile Tests shall be carried out at a rate of 1 per 100 piles or part thereof (not less than 1%).

Note: Where there are large variations in substrata revealed either by the Site Investigation or during the construction of piles, load tests should be carried out in each zone and the level of testing reassessed accordingly for each design situation. Similarly, load testing should reflect the various pile lengths and loadings.

If there are queries with regard to anything not covered within this document and/or it is intended that the Site Investigation, pile design, installation or testing is to deviate from the above guidance, then please contact the Warranty Surveyor for agreement prior to commencement.

3.

Foundations

3.4
Raft

Raft foundations

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.

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). For further clarification, please refer to the 'Foundations Trees and Clay' section.

Materials
Materials and workmanship should meet the requirements set out in the 'Appendix C - Materials, Products, and Building Systems' section.

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 the 'Ground Conditions' section and ascertain the bearing capacity and suitability of the ground.

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.

Key requirements

The raft foundations shall be designed to clearly demonstrate that the rafts, insulation and any treated ground are capable of supporting and transferring the foundation design loads safely to known soil strata that are, in turn, capable of supporting the loads, using the appropriate soil properties obtained from geotechnical testing and contained in the appropriate Site Investigation report. The rafts shall be designed in accordance with BS 8004:2015 and shall ensure that long term settlement does not exceed 25mm or 1:500 (differential), unless more stringent criteria are required by the Project Structural Engineer.

Technical documentation required

The following documentation shall be submitted to the Warranty Surveyor for assessment. Please Note: In the absence of approval, works proceed at the Developer's own risk.

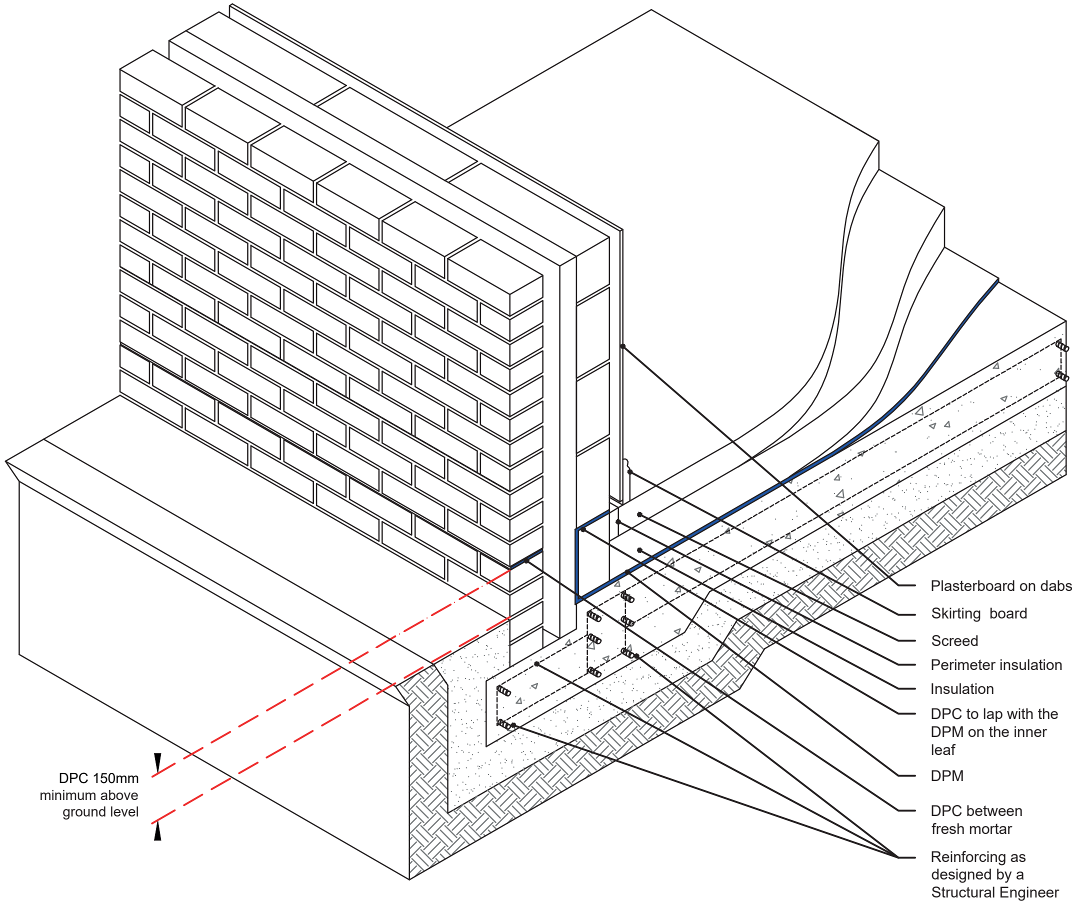
1. Phase 1 Desk Study Report and Phase 2 Geotechnical Site Investigation Reports including site-specific recommendations for raft foundations (and allowable bearing pressures) to ensure long term settlement does not exceed 25mm or 1/500 (differential)
2. Structural drawings:
   a) GA and RC drawings, including a drawing register sheet.
   b) Details of internal and external thickening to cater for loadings and the effects of frost.
   c) Details of any insulation beneath the raft.
3. Structural calculations:
   a) Demonstrating that the ground bearing pressure does not exceed the allowable value specified in the Site investigation report. Localised areas of higher bearing pressures (e.g. beneath load-bearing walls, thickening or point loads) should be considered.
   b) Demonstrating that the raft (i.e. the thickening, slab and beams) can span a 3.0 metre 'soft spot' and cantilever 1.5 metres.
   c) Demonstrating the adequacy of any insulation beneath the raft (in relation to loadings, creep and groundwater). The insulation must have appropriate 3rd party approval certification and compressive creep must be limited to a maximum 2% reduction for a 50/60 year period.
4. Confirmation that all made ground and organic matter beneath the foundation has been or shall be removed/replaced with appropriate material, or treated.
5. Details of engineered granular fill below the raft (including its depth and lateral extent, ensuring a 45 degree spread from the edge), along with its compaction specification, testing and Geotechnical Engineer's validation. Where Manual for Highway Works (MHW) specification for engineered granular fill is indicated, details shall conform with MHW Volume 1 Series 600 Earthworks Cl:610 'Fill to Structures'
6. Calculations demonstrating how the depth of granular fill has been determined to cater for the effects of heave and shrinkage (if shrinkable soils are present).
7. Details of any ground treatment (e.g. vibro treatment, cement-lime stabilisation etc.).

If there are queries with regard to anything not covered or it is intended to deviate from the above guidance, then please contact the Warranty Surveyor for agreement prior to commencement. Following acceptance of the proposals, please refer back to the Warranty Surveyor if anything is subsequently discovered on site, which affects the design and/or construction of the raft.

Where thermal insulation products are used below the structural raft they should:
- Meet the requirements of BS EN 1606 Thermal insulation products for building applications.
- Meet BS EN 13163 (for EPS insulation).
- Meet BS EN 13164 (for XPS insulation).
- The Structural Engineer should ensure that the design limits 'compressive creep' to a maximum 2% reduction for a 50/60 years period.
- The insulation product must have third party product approval certification for use below a structural raft foundation (including below external walls).

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.

Typical raft foundation



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.

Stepped membranes

DPM should be continuous where floors are stepped, a waterproof specialist must select an approved waterproof membrane to meet the requirements of BS 8120 to provide a continuous barrier that is compatible with the floor DPM/DPC.

Damp proofing

Damp proof courses (DPC)

DPC's should be of a flexible material that is suitable for its intended use and the DPC should have appropriate third-party certification. Blue brick or slates will not be accepted as a DPC.

DPC's should be laid on a mortar bed and correctly lapped at junctions and corners. The depth of lap should be the same as the width of the DPC.

DPC's should not bridge any cavities unless it is acting as a cavity tray. Where a cavity tray is required (e.g. over a telescopic floor vent) please refer to the 'External Walls' section for cavity tray, weep holes and stop end requirements.

Damp proof membranes (DPM)

A DPM should be provided beneath all ground-supported slabs or cast in-situ reinforced slabs. DPM's should be linked to the DPC and be a minimum 1200g polythene. Other DPM's may be considered if they have appropriate third-party certification and are installed in accordance with the manufacturer's instructions.

Concreting of floors

Prior to concreting, any water or debris that may have collected on top of the DPM should be removed. Expansion joints should be provided and constructed in accordance with the Structural Engineers design.

Bricks and blocks below ground

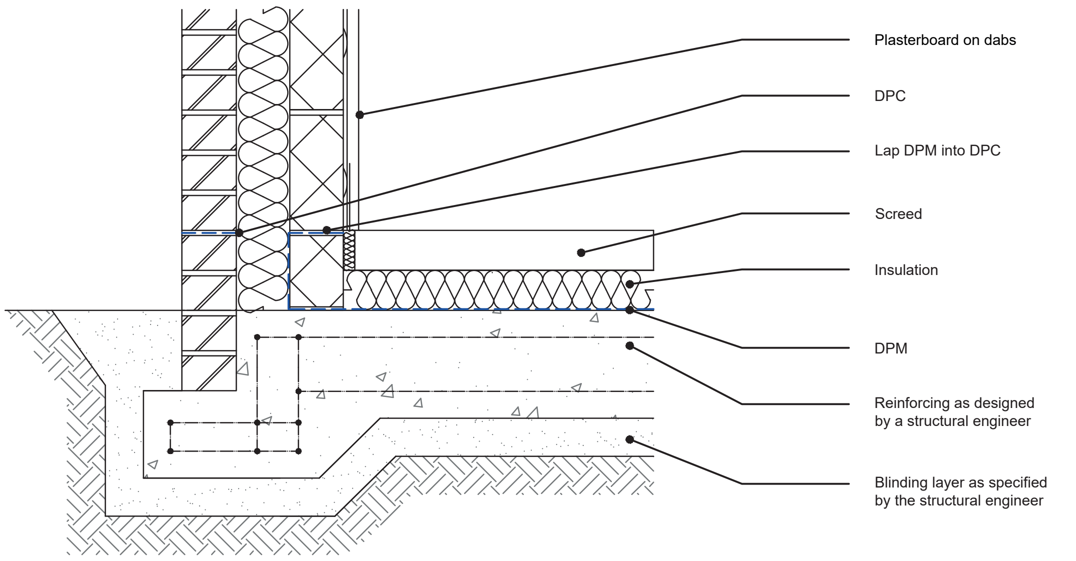
The selected bricks should be appropriately durable against saturation. See 'Appendix C - Materials, Products, and Building Systems' for further guidance.

If there are sulphates in the ground and/or there is ground water present, confirmation by the manufacturer that the brick or block is suitable for use below ground should be provided.

Reference Documents

- BS EN 1997-1:2004 + A1:2013 - Eurocode 7: Geotechnical design (EC7).
- BS 8004:2015 + A1:2020 - Code of practice for foundations.
- BS EN 1997-2:2007 - Ground investigation and testing.
- BS 5930: 2015 + A1:2020 - Code of practice for ground investigations.
- Manual for Highway Works Volume 1 Series 600 Earthworks

Typical raft foundation design



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.

3.

Foundations

3.5

Engineered Fill

Limitations of guidance

The following situations are beyond the scope of this guidance:

- Where the original ground or sub-strata is unstable or will continue to settle.
- Sites with soft clays with a low bearing capacity (30kN/m2 un-drained).
- 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.

Fill or made ground can be divided into 2 main types:

1. Engineered Fill: When placed as part of the construction process and carried out to an engineered specification to high standards with good quality control and adequate engineering supervision, then risks can be assessed and may be quite small.
2. Non-Engineered Fill/Made Ground: Risks associated with sites covered with existing fill are more difficult to assess and short of complete excavation, the risks cannot be fully quantified. Therefore, alternative foundation solutions where loads can be transferred to competent strata are required.

Engineered fill

Generally cohesive/granular homogeneous material specifically selected to replace either made ground or infill voids left by other processes is adopted. Fill has been divided into 2 further categories. These are:

- Shallow fill (i.e. less than 2.5m depth below ground level).
- Deep fill (i.e. greater than 2.5m).

For further guidance on foundation types suitable for building on 'Shallow' and 'Deep' fill, please refer to our Warranty good practice guide 'Building on Fill' which can be found on the website.

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 the 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.

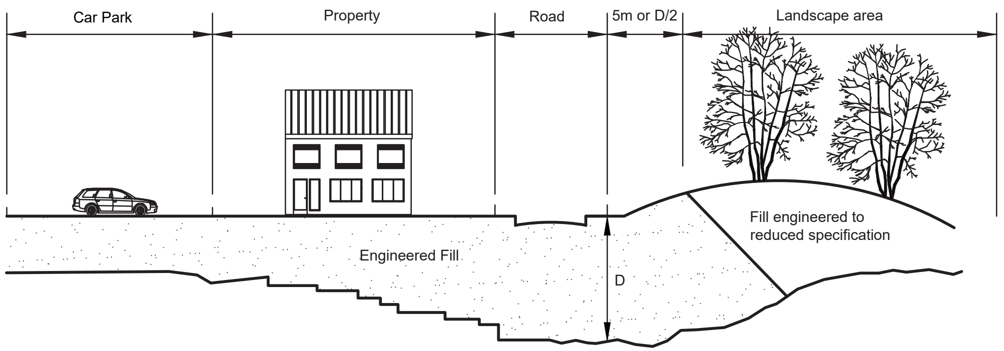
Fill selection

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.

Typical engineered fill construction - Figure 1



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, sulphate-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.

Materials considered to be unsuitable for use as fill are:

- Swamp or marsh land materials.
- All organic or part organic materials.
- Materials subject to spontaneous combustion.
- Colliery shales, ironstone shales and similar materials which have the potential for expansion due to oxidation of pyrites.
- Frozen materials or materials which are frost susceptible.
- Any materials which have a higher moisture content than the maximum permitted for such materials as defined in the specification.
- Clays with high plasticity index exceeding 55%.

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.

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 fill 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 also required.

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.

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.

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 thickness 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 1.

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 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.

Quality control and testing of fill during placement

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.
- Un-drained 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, un-drained shear strength forms an alternative basis for specification and control testing. However, different methods of measuring the un-drained 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.

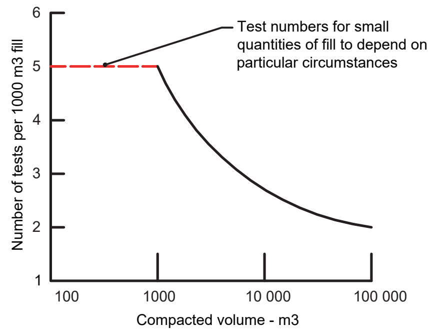
Small sites are generally more difficult to work than large sites, as finished work may be damaged more easily in confined working areas and deficiencies in site preparation usually reflect more readily in poorer quality compaction than on larger sites. Consequently, it is necessary to test more frequently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

A suggested minimum test frequency is presented in Figure 2. 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 2.

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.

Number of tests - Figure 2



Monitoring of fill performance - post compaction

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.

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

Introduction

The following guidance outlines recognised good practice in relation to building on fill. The structural design and construction should be in accordance with the Functional Requirements of this Technical Manual and recognised publications from British Standards, Eurocodes, CIRIA, BRE and ICE.

Key requirements

The foundation scheme shall be designed to clearly demonstrate that the foundations are capable of supporting and transferring the design loads safely to known soil strata that can be demonstrated from the appropriate project site investigation reports to be capable of carrying the load, using the appropriate soil properties obtained from geotechnical and load testing.

Groundwork shall be designed and validated by a suitably qualified Chartered Geotechnical Engineer to ensure that settlement will not exceed 25 mm (10mm for piles) or differential settlement tilt greater than 1:500 for low-rise buildings unless more stringent criteria are required by the Project Structural Engineer.

Partial depth foundation solutions where either piles or ground improvement techniques (i.e. vibro stone columns, vibro concrete columns etc.) terminate in the fill material, and do not penetrate to naturally occurring competent strata below, are not acceptable.

Made ground/fill material is inherently variable in nature and unpredictable when considering its settlement properties. Foundations proposing to bear upon made ground /fill as a formation for strip, trench or raft type foundations are unacceptable.

Technical documentation required

The following documentation shall be submitted to the Warranty surveyor for assessment. In the absence of approval, works proceed at the Developer's own risk.

1. Site Investigation Reports including site-specific recommendations for foundations to ensure long term settlement does not exceed 25mm (10mm for piles) or 1/500 (differential).
2. Structural drawings:
   a) Site layout plan including proposed finished floor levels for all plots.
   b) Topographical survey confirming existing ground levels. Subsequent site level surveys indicating areas where earthworks are required to achieve final construction levels. If piling or ground improvement techniques are to be adopted, piling platform and/or vibro platform levels are required.
   c) GA and RC drawings, including a drawing register sheet.
   d) Piling & Vibro layout drawings (if applicable), including a drawing register sheet.
   e) The design of the dwellings should allow a degree of articulation with movement joints sufficient to accommodate the maximum allowable differential settlement above, also at thresholds and service entries.
3. Structural calculations:
   a) Demonstrating that the ground bearing pressure does not exceed the allowable value specified in the Site Investigation Report.
   b) Piled foundation calculations (please refer to the 'Piling Good Practice Guide' available on our website).
   c) Vibro foundation calculations (please refer to the 'Piling Good Practice Guide' available on our website).
4. Earthworks Specification including:
   a) Confirmation that works are supervised by a suitably experienced independent Chartered Geotechnical Engineer.
   b) Proposals for load testing to determine the expected long-term settlement and differential settlement of the fill. Please note: We consider that plate load tests do not confirm the expected long-term performance of the ground.
   c) Allowable bearing pressures, expected settlement and differential settlement.
   d) Consideration of the effects of slag, burnt shale and expansive soils.
   e) Consideration of self-weight settlement of the fill.
   f) Collapse compression analysis in accordance with BRE IP5/97.
   g) Details of any ground treatment (e.g. vibro treatment, cement-lime stabilisation etc.).
5. Geotechnical validation report including:
   a) Confirmation that all made ground and organic matter was removed.
   b) Details of formation levels prior to filling works.
   c) Depths of all cut and fill carried out across the site with levels linked to the original site investigation.
   d) Details demonstrating compliance with Clause 610 of the Specification for Highway Works (for structural fills).
   e) Details and locations of all tests and interpretation by the Geotechnical Engineer.
   f) Confirmation of the bearing capacity achieved by the earthworks and confirmation that long-term settlement will not exceed 25 mm or 1:500 differential settlement.

If there are queries with regard to anything not covered within this document and/or it is intended to deviate from the above guidance, then please contact the Warranty Engineers for agreement prior to commencement. Following acceptance of the proposals, if anything is subsequently discovered on site, which affects the design and/or construction, please contact the Warranty Surveyor immediately.

Reference Documents

- Current Regional Building Regulations
- BS EN 1997-1:2004 + A1:2013 - Eurocode 7: Geotechnical Design (EC7)
- BS 8004:2015 - Code of Practice for Foundations
- BS EN 1997-2:2007 - Ground Investigation and testing
- BS 5930: 2015 - Code of Practice for Ground Investigations
- BS 1377-9:1990 - Methods of test for soils for civil engineering purposes. In-situ tests
- BRE IP 5/97 - Building on Fill: collapse compression on inundation
- BRE Building on Fill 3rd edition: geotechnical aspects
- Department of Transport Specification for Highway Works, Part 2, Series 600 Earthworks
- Warranty Good practice guides, to ensure long term and differential settlement criteria remain compliant:
  - Raft Foundations (Long term settlement 25mm and 1/500 differential)
  - Piling (Long term settlement 10mm and 1/500 differential)
  - Vibro ground improvement (Long term settlement 25mm and 1/500 differential)

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:

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.

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 1000m²-3000m² 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 500m² 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.

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 building loads, are held for 24 hours at predetermined stages to examine creep behaviour.

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.

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.

3.
Foundations

3.6
Vibratory Ground Improvement

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 following guidance will be accepted as a satisfactory method of meeting the Functional Requirements of this Technical Manual.

Limitations of guidance

The following situations are beyond the scope of this guidance:

- 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 un-drained).
- 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.

Vibratory ground improvement

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.

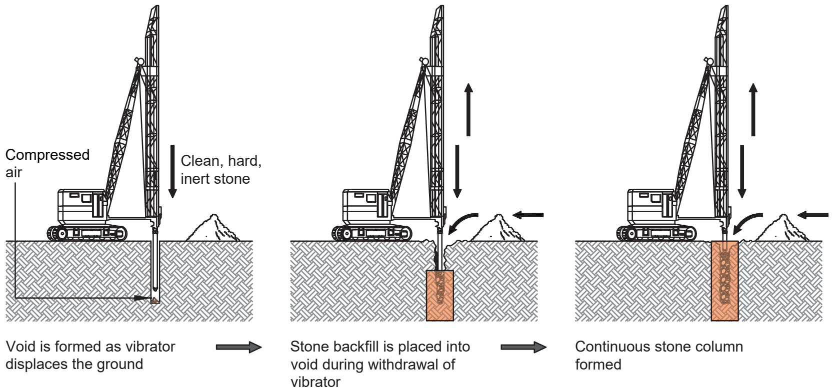
Soft soils can be reinforced to achieve improved specification requirements, whilst slopes can be treated to prevent slip failure, both natural soils and made ground can be improved.

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

Vibratory techniques

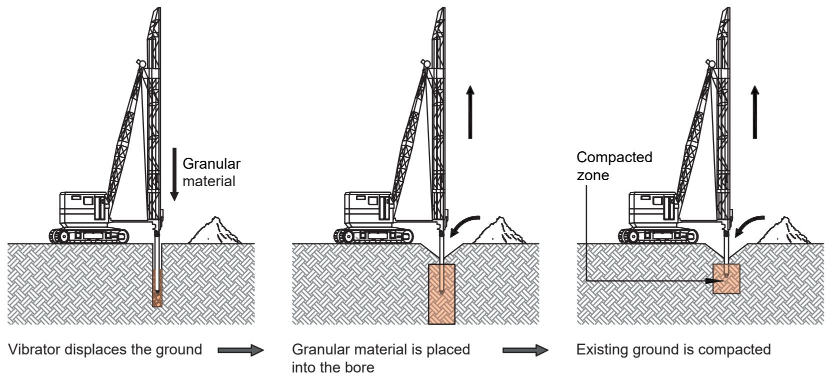
The vibratory process is applied to weak natural soils and filled ground with a view to improving the load-bearing capacity and providing an adequate bearing stratum for the building’s foundations. There are two vibratory techniques commonly used in the UK. These are known as the ‘dry bottom feed’ and ‘dry top feed’ methods; a third technique, less frequently used in the UK, is known as the ‘wet bottom feed’ method.

Vibratory techniques: dry bottom feed method



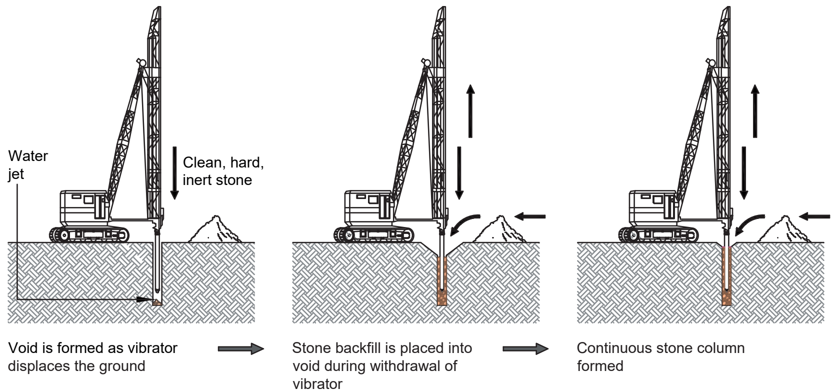
The dry bottom feed method is used in weaker soil conditions or where there is a high water table and the borehole is liable to collapse between vibroflot insertions. The vibroflot penetrates using its mass, air flush and vibration, but at design depth, the stone is introduced via a hopper into a pipe 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.

Vibratory techniques: 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.

Vibratory techniques: dry top 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.

Key requirements

The scheme shall be designed to clearly demonstrate that the foundations and treatment of the ground with vibro stone columns are capable of supporting and transferring the foundation design loads safely to known natural soil strata that are, in turn, capable of supporting the foundation loads using the appropriate soil properties obtained from geotechnical testing and contained in the appropriate Site Investigation report. The foundations and vibro stone columns shall be designed in accordance with BS 8004:2015 and shall ensure that long term settlement does not exceed 25mm or 1:500 (differential) at working load, unless more stringent criteria are required by the Project Structural Engineer. Partial-depth treatment of loose/low-strength natural soils (SPT <10) and partial-depth treatment of made ground/fill is not acceptable.

Technical documentation required

The following documentation shall be submitted to the Warranty Surveyor for assessment. Items 1-3d should be submitted prior to commencement of vibro treatment on site. In the absence of approval, works are proceeding at the Developer's own risk. Items 3e-3g shall be submitted as soon as they become available, prior to construction continuing over the vibro stone columns.

1. Phase 1 Desk Study Report (including Groundsure) and Phase 2 Geotechnical site investigation reports with appropriate geotechnical testing.
2. Structural Engineers foundation drawings and design calculations. Strip footings should be designed for the specified bearing pressures and be designed to span between vibro stone columns.
3. Vibro stone columns:
    a) Written confirmation from the vibro designer that the ground conditions are suitable for vibro treatment and that the Site Investigation report is adequate for the purposes of the design and installation of stone columns. Deepening of foundations in respect of trees/clay soils to be taken into account.
    b) Vibro stone column layout drawings.
    c) Vibro design calculations confirming full-depth of made ground and soft/loose natural strata.
    d) Confirmation of proposed testing regime (i.e. plate and dummy footing tests etc., see notes below). A minimum of 1% of stone columns should be subject to dummy footing test.
    e) Vibro installation logs (with vibro column numbers referenced to the vibro layout drawing). Logs should include date, column number, depth, diameter, weight of stone, confirmation of the platform level in relation to the finished floor levels and site investigations and details demonstrating that all low-strength/loose natural strata (SPT<10) and all made ground/fill have been suitably treated.
    f) Copies of all testing carried out (with the locations referenced to the drawings) and interpretation of test results.
    g) Written confirmation from the vibro designer that the as-built installation has achieved the required bearing capacity and settlement characteristics.

Reference Documents

- BS EN 1997-1:2004 + A1:2013 - Eurocode 7: Geotechnical Design (EC7)
- BS 8004:2015 + A1:2020 - Code of Practice for Foundations
- BS EN 1997-2:2007 - Ground Investigation and testing
- BS 5930: 2015 + A1:2020 - Code of Practice for Ground Investigations
- BR 391 – Specifying vibro stone columns (BRE)

Geotechnical Site Investigation Report

A site specific geotechnical Site Investigation should take place and be in accordance with BS 5930/EC7 and extend into adequate strata beneath the filled or poor-strength strata above. The investigation should include enough geotechnical testing to enable accurate geotechnical design of the vibro stone columns in accordance with proven design methods. In general, ground with a peat layer greater than the column diameter should be viewed as unsuitable.

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.

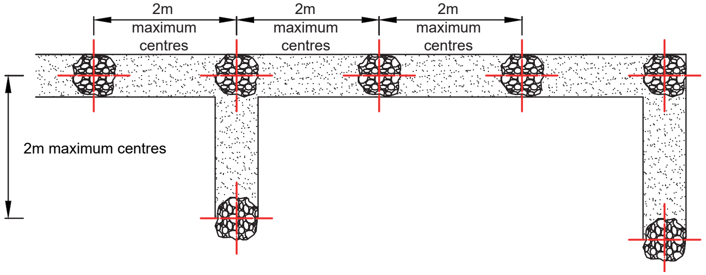
The developer shall obtain written confirmation from the engineer and specialist contractor that the site is suitable for the proposed ground improvement system, and that all detrimental factors associated with the site and the proposed development have been taken into account.

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.

The intersection of adjacent reinforced concrete strips



Strip foundations

Foundation drawings and calculations should be prepared by the Structural Engineer indicating the required bearing capacity and settlement characteristics for the purposes of design of vibro stone columns. In general foundations should be designed for maximum settlements of 25mm or differential settlement of 1 in 500 unless more stringent measures are required by the Structural Engineer. Strip foundations shall be designed to span between vibro stone columns and must incorporate top and bottom reinforcement. Irrespective of the provision of vibro stone columns, foundation depths and heave precautions must be in accordance with this Technical Manual, in respect of trees/clays, whilst ensuring that the vibro treatment is not detrimentally affected by deepening of the foundations.

Vibro Design

The ground must be suitable for vibro treatment (refer to the above mentioned references for details). Vibro stone columns should be designed in accordance with recognised methods (e.g. Priebe) and must extend through the full extent of filled or poor ground and reach natural competent ground. Partial-depth treatment of loose/low-strength natural soils (SPT <10) and partial-depth treatment of made ground/fill is not acceptable.

Vibro Testing

Testing should be carried out across the full site and cover all of the various ground conditions 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.

Plate Tests should be carried out

- With 600mm diameter plates loaded to 3 times working load or 11 tonnes, whichever is greater.
- At a minimum rate of 1 per 100 vibro stone columns or 1 per rig per day, or a minimum of 2 tests, whichever is greater.
- Note that plate tests do not provide a direct indication of the anticipated settlement of the completed structure and therefore can't be considered as the sole means of load testing.

Dummy Footing Tests should be carried out

- With 1500 x 600mm plates, loaded to at least 1.5 times working load (kN/m^2) for a minimum period of 13 hours.
- At a minimum rate of 1 per 100 stone columns or 1 per 10 houses, whichever is greater.

Penetration Tests should be carried out

- At a rate of 1 per 20-50 stone columns or 1 test for not more than 500m^2, with a minimum of 1 test for each structural unit.
- Penetration tests will not be required if dummy footing tests are carried out at the above rate.

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.

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.

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, then 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.

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).

Where foundations bear on cohesive soils or cohesive fill materials, the functional requirements regarding foundations trees and clay should be met. Further guidance can be found in the ‘Foundations - Trees and Clay’ section.

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.

3.
Foundations

3.7
Trees and Clay

Introduction

The following guidance is provided for foundation design when building near trees.

Limitations of guidance

Heave precautions must be incorporated into the foundation design as detailed in this Technical Manual.

The following situations are beyond the scope of this guidance, 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 in cohesive soils (note: Mass Fill or Piled Foundations should be adopted).
- Ground with a slope greater than 1:7.
- Man-made 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.

Raft foundations

Where a raft foundation is proposed, it must meet the following:

- The foundation depth should be determined using the guidance in this document and the online foundation depth calculator, and;
- If the resulting foundation depth is less than 1.5m deep and no foundation heave protection is required, a raft can be deemed suitable in this location and;
- The raft toe must be at least 600mm below the ground and there should be at least 500mm of compacted stone beneath the toe (i.e. total depth for excavation would be 1100mm or greater).

Note: If the resulting foundation depth required is 1.5m or greater, structural raft foundations are not accepted as a suitable foundation. An alternative foundation design will be required.

Please use the following guidance to determine the required depth of foundations.

Strip foundations

Conventional strip foundations may be constructed practically and economically to a maximum depth of 1.5m. However, strip foundations will not be suitable where heave precautions are required.

Please note: Where building near trees in clay soils; If a required foundation depth is greater than 1.5m, 'heave precautions' in the form of a proprietary compressible material must be placed on all inside surfaces of the peripheral foundations to allow for lateral soil swelling. In this instance strip foundations will not be acceptable and another foundation type should be selected.

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. Root barriers are not acceptable as an alternative solution.

This guidance 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.

The pile depth required to meet the Structural Engineers design requirements may well exceed the minimum depth required by the foundation depth calculator.

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

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.

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.

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.

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.

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.

TREES AND CLAY: Determining foundation depth in clay soils near trees

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*. Also see ‘Limitations of guidance’ at the start of this section.

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).

Mature height of tree

The mature heights of common tree species are provided in our online foundation depth calculator. Mature height should be used unless an
Arboricultural report is obtained, indicating that a lesser height is appropriate for the conditions of the site.

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.

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, by measurement to other locations around the building.

Regional and climatic conditions

The foundation depth calculator will allow for regional and climatic conditions by entering the details of the post code of the proposed site.

Foundation Depth Calculator

Foundation depth* (see also ‘Limitations of guidance’ at the start of this section) 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.
- Tree type (this will determine the water demand of the tree).
- Mature height of the tree will automatically be determined.
- Distance of the relevant tree to the nearest part of foundations and distances elsewhere if stepping foundations.
- Allowance for climatic conditions.

Internal walls should also be taken to a suitable depth to avoid the effects of heave.

Where the foundation depth calculator identifies a minimum depth exceeding 1.5m, raft foundations and strip foundations must not be used. Mass fill or piled foundations must be adopted.

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 the table below, should be used.

Table 1: Minimum foundation depths

Plasticity index	Minimum depth to allow for reasonable future tree/shrub planting (m)	Minimum depth if no future tree/shrub planting likely (m)
>40	1.50	1.00
20-40	1.25	0.90
10-20	1.00	0.75

* Note: Where a minimum depth of 1.5m or greater is required: Strip foundations must not be used. Mass fill or Piled foundations must be adopted.

Foundation design

Depths in excess of 2.5m

Where the required foundation depths, 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. See the ‘Foundations - Piles’ section for further information.

Foundation depths less than 2.5m

Mass fill foundations are likely to be most economic at depths below 1.5m, but can be economic to depths up to 2.5m. However, shored bored piles are recommended.

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. See the ‘Foundations - Piles’ section for further information.

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 1.5m, a proprietary compressible material must be placed on all inside surfaces of the peripheral foundations to allow for lateral soil swelling, as shown in the details on the next page. Material is not required on internal foundations (as swelling pressures are likely to be similar on both sides).

For piled foundations greater than 1.5m, a proprietary compressible material must be placed on:

- All inside faces of the external ground beams and,
- The underside face of external and internal ground beams.

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 in ground conditions where heave can occur or where the foundation depth is greater than 1.5m. Under these circumstances, a suspended floor construction should be used (e.g. cast in-situ concrete, precast concrete or timber). This must incorporate either a clear minimum void of a specified depth under the suspended floor or a proprietary compressible material/void former below the underside of the floor construction.

Note: the compressible material/void former must have a third party approval for use in this situation.

The depth 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.

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

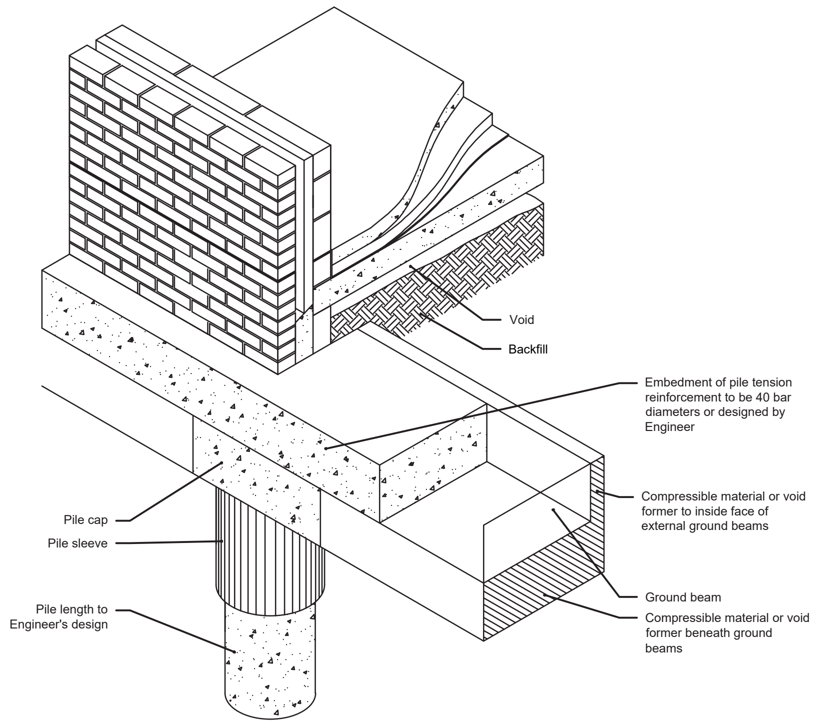
Volume change potential	Plasticity index	Void dimension against side of ground beam and foundation	Void dimension under ground beams, and suspended in-situ concrete ground floor	Void dimension under suspended precast concrete and timber floors(1)
High	>40	35mm	150mm	300mm
Medium	20-40	25mm	100mm	250mm
Low	10-20	0mm	50mm	200mm

(1) Under suspended floors, the void dimension is measured from the underside of beam or joist to ground level and includes 150mm ventilation allowance.

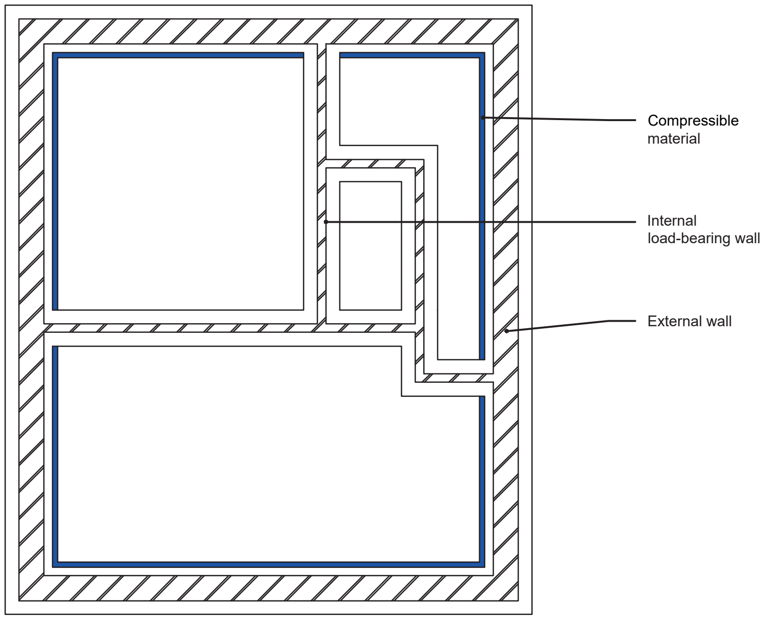
Please note: Void formers consist of materials that collapse to form a void into which the clay can swell. The compressible material/ Void former should have appropriate third party certification demonstrating their suitability as specified. The void dimension is the 'remaining void' after collapse. The thickness of the void former should be in accordance with the manufacturer's recommendations.

Typical foundation designs to allow for heave are shown in the following details.

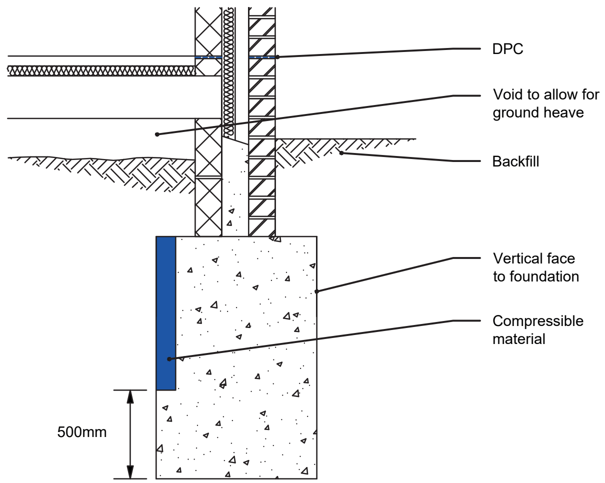
Heave protection - Section through pile and beam foundation



Plan of heave protection to a mass filled foundation



Heave protection - Section through a typical mass filled foundation



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 and the design should be drawn up as if the tree was still present.

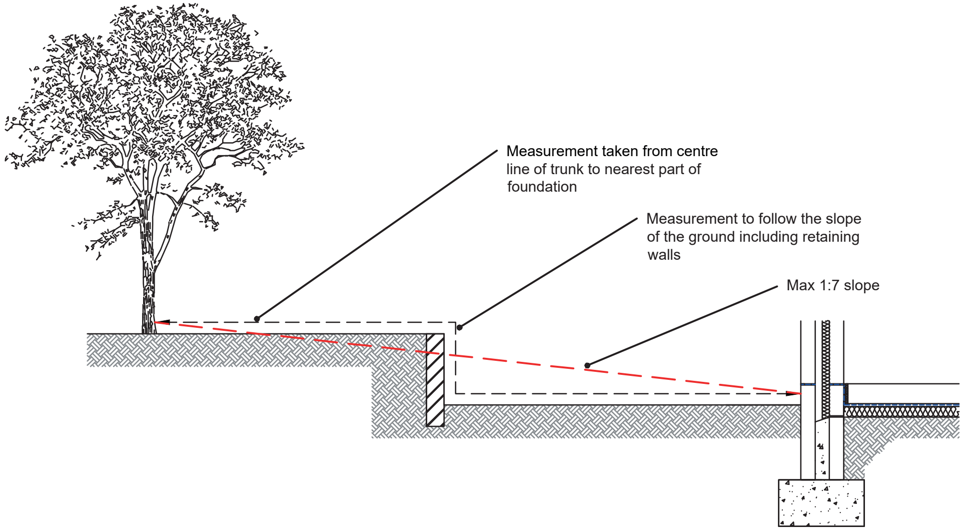
- If the height of the former trees is known, the foundation depth should be determined using actual height.
- If the identity is not known, it should be assumed the trees were of high water demand, and if actual height is not known, it should be assumed to be 20m.
- Heave protection should be provided as per the guidance where trees remain.

Alternatively, the foundations and heave protection should be designed by a suitably qualified structural engineer taking into account the recommendations of this guidance, the site investigation report conclusions and recommendations incorporated from both a registered arboriculturalist and geo technical consultant reports. The design should be submitted before work commences on site.

Sloping sites

If the slope is greater than 1:7, foundations should be engineer designed. 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.

Measuring foundation distance on sloping sites



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, the 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.

Varying foundation depths

As foundation depth depends on the proximity of the tree, the depth* (see also 'Limitations of guidance' at the start of this section) can be reduced in steps with increasing distance. Steps should be in accordance with the 'Foundations - Mass Fill' section.

Protection for drains

In addition to the requirements of the 'Drainage' section, 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.

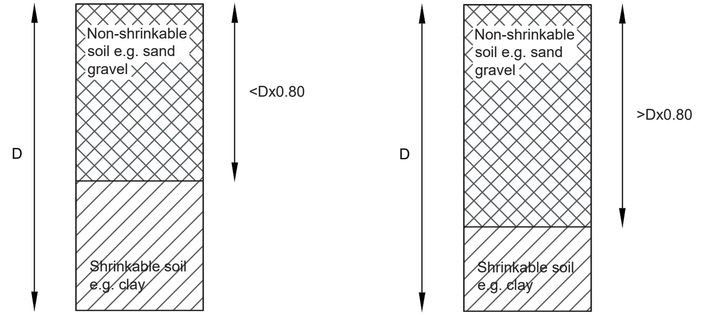
Made-up ground

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.

Mass 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 details below for further clarification.

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



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