Part 4 Foundations

Chapter 4.6

Vibratory ground improvement techniques

4.6 Vibratory ground improvement techniques

CONTENTS

SCOPE

This Chapter gives guidance on meeting the Technical Requirements and recommendations for vibratory ground improvement techniques.

DESIGN STANDARDS

4.6 - D1 Design shall meet the Technical Requirements

Design that follows the guidance below will be acceptable for foundations on ground improved by vibratory techniques.

STATUTORY REQUIREMENTS AND OTHER STANDARDS

4.6 - D2 Design shall comply with statutory requirements

Design should be in accordance with relevant Building Regulations and other statutory requirements.

4.6 - D3 Design shall follow relevant Standards and Codes of Practice
Relevant British Standards, Codes of Practice and authoritative documents include:

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

ICE Specification for Ground Treatment

HAZARDOUS GROUND

4.6 - D4 The design of foundations shall be undertaken by an Engineer and take account of the characteristics of the site, its ground and any hazards

The foundation design should be carried out by an Engineer experienced with ground improvement techniques in accordance with Technical Requirement R5 - see Chapter 1.1.

In this Chapter, the term "Engineer" means an engineer who is independent of the specialist contractor responsible for the vibratory ground improvement techniques.

Details of ground hazards to be taken into consideration are given in Chapters:
4.1 'Land quality - managing ground conditions'
4.2 'Building near trees'

NOTIFICATION

4.6 - D5 NHBC shall be notified before work starts on site
NHBC Rules state: "If a Home is to be constructed on a Hazardous Site you (the Builder) must before making Application for Inspection notify the NHBC in writing of the particular hazards which arise. You (the Builder) must do this at least 8 weeks before work begins on the site." Early involvement of the specialist contractor and NHBC is encouraged.

DESK STUDY AND SITE INVESTIGATION

4.6 - D6 The Engineer shall ensure that a desk study and site investigation are commissioned and the interested parties are advised

The site investigation should take account of:

BS 10175	Investigation of potentially contaminated sites - Code ofpractice
BS EN14731	Execution of special geotechnical works. Ground treatmentby deep vibration
BS EN1997-2	Groundinvestigation and testing
BS ENISO 14688	Geotechnical investigation and testing- Identification andclassification of soil
BS ENISO 14689	Geotechnical investigationand testing- Identification and classificationof rock
BS EN ISO 22476	Geotechnical investigationand testing- Field testing
BR391	Specifying vibro stone columns

Chapter 4.1 'Land quality - managing ground conditions'

The desk study and site investigation should at least determine:

- the depths and properties of the natural materials under the site, including the presence of caves, workings, or natural phenomena such as rocks or soils which dissolve or erode when exposed to the passage of water. The Engineer should establish the scope of, and supervise, the site investigation, taking account of the findings of the desk study. Data for comparison with post treatment properties should be established
- the extent and nature of any areas of filled ground on the site, including:
  - the proportions and distribution of constituent materials
  - the state of compaction of the fill material throughout its depth
  - the grading and particle size distribution of fill materials
  - the potential for gas generation from fill materials
  - the potential for spontaneous combustion of fill and/or natural deposits
- the presence and extent of any existing or redundant services and drains, and what information is available regarding the extent and nature of the backfill to the excavations
- the effect that any sustainable drainage system (SUDS) may have on the geotechnical parameters of the site
- the presence, level and nature of any ground water, and if it is likely to rise and cause heave or collapse by saturation
- whether the site has been previously occupied by any structure, and whether these structures have left any potential underground obstructions or hardspots, eg basement walls, floor slabs etc
- whether there are any contaminated substances or gases present or suspected.

The Specialist Contractor should be satisfied that the site investigation provides adequate and representative information in order to design the ground improvements. The results of the investigation should be sent to NHBC prior to the commencement of the work.

SUITABILITY OF GROUND CONDITIONS

4.6 - D7 The ground shall be suitable for vibratory ground improvement

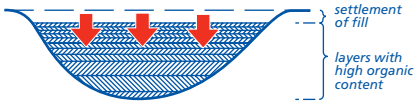
The Engineer should assess the ground and be satisfied that it is suitable for treatment. Vibratory ground improvement techniques suitable for various ground conditions are detailed in Appendix 4.6-A.

Items to be taken into account include:

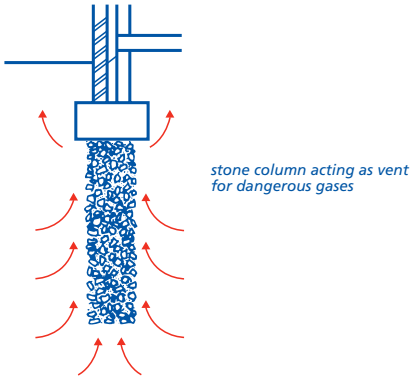
(a) ground conditions acceptable for treatment
Conditions acceptable for treatment are only those within zones A and B of the chart shown in Appendix 4.6-A.

(b) ground conditions not generally acceptable fortreatment
The following ground conditions are not generally acceptable for treatment:

- soft clays with an undrained shear strength less than 30kN/m² (Note; for clay strengths less than 30kN/m² additional consideration has to be given to group effects, ground heave and settlement due to installation and the proposal will be subject to NHBC agreement)
- ground with peat layers close to foundation level or the base of the stone column, or where intermediate layers of peat are thicker than 200mm either as a single layer or the sum of the thicknesses of individual layers throughout the length of the stone column
- voided filled ground, eg old water tanks, pottery, glass bottles, concrete rubble or brick fill of unsuitable grading
- any loose or non-engineered fill not previously subject to:
  - rising or fluctuating water levels
  - saturation
- filled ground still settling or expected to settle:
  - under its own weight or due to the effects of surcharging/upfilling
  - where there is a high organic content
  - where decay is continuing



- fill, containing degradable material where organic material forms more than 15% of fill by volume
- highly contaminated ground, eg toxic waste, or where inflammable, explosive or toxic gas generation will take place (stone columns may act as vertical vents). Note: Consideration will be given to proprietary systems which do not permit vertical venting (e.g. vibro concrete plug technology)

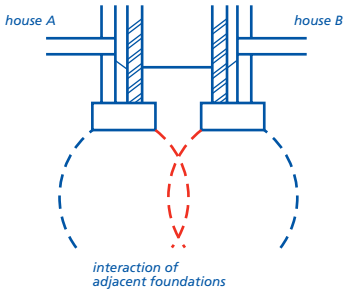


- clays with a plasticity index greater than 40%
- highly sensitive soils liable to collapse or remoulding

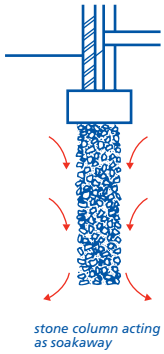
(c) detrimental factors

Factors to be considered include the following:

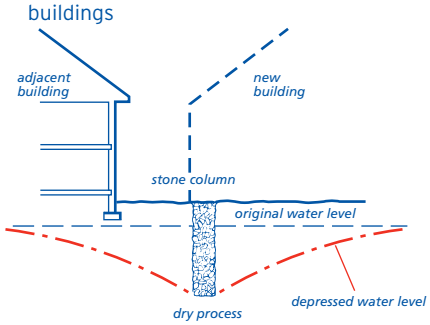
- where partial depth treatment of filled ground is proposed, the Engineer should be satisfied as to the anticipated performance of both the treated and untreated zones. The Specialist Contractor should take responsibility for the treated zone and the decision as to the depth of treatment
- the minimum depth of soil treated should allow for the interaction of adjacent foundations



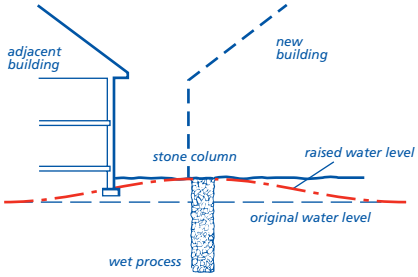
- stone columns may form vertical drains allowing the passage of water to a moisture susceptible strata, or provide seepage paths for gases



- obstructions and variations in the density of fill and natural ground (hard spots)
- alterations to the oversite level before or after treatment or disturbance of ground by excavations after treatment
- the location of changes in the profile of the natural underlying ground eg edges of pits or quarries, slopes, or manmade obstructions such as soakaways or drainage runs
- long term lowering of water table causing settlement of existing adjacent buildings



- short term rise in local water table due to large volumes of water used in wet process during construction causing settlement or heave of existing adjacent buildings



- surface water sewers should be used for rainwater disposal where possible, but where soakaways are necessary, these should be positioned so that their construction and operation is not detrimental to the treated ground
- the effect of any new or existing sustainable drainage systems (SUDS) should be taken into account when vibro improvement techniques are proposed
- soils with a modified Plasticity Index of 10% or greater should have foundations designed to accommodate volume changes, and the depth of concrete foundation should be in accordance with Chapter 4.2 'Building near trees'.

CONFIRMATION OF SUITABILITY OF PROPOSED TREATMENT

4.6 - D8 The builder shall obtain written confirmation from the Engineer and Specialist Contractor that the site is suitable for the proposed ground improvement system

Confirmation that the site is suitable for the proposed system should be made available to NHBC prior to commencement of the work.

The Engineer and Specialist Contractor should agree the following in writing before work commences on site:

- design objectives
- a detailed schedule of work
- a programme of work
- what tests are to be carried out on completion of the work
- responsibility for procedures and tests.

For details of tests see Sitework clause S3.

The following should also be taken into account:

- the layout and depth of the stone columns and the accuracy to be achieved (see Sitework clause S2)
- what factors of safety have been incorporated into the design to allow for unforeseen contingencies
- the criteria for non acceptance of the vibrating poker work
- what calculations and case histories are required to justify the ground improvement proposals together with the layout of the stone columns and details of the equipment and process to be used on site.

These written agreements should be made available to NHBC before work commences on site.

COMPATIBILITY OF LAYOUT AND DESIGN FOR THE TREATED GROUND

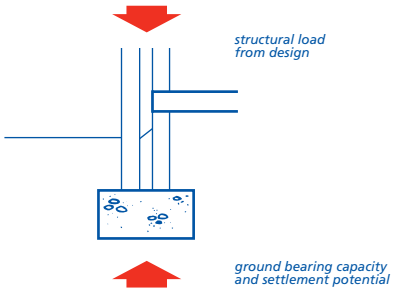
4.6 - D9 Design shall ensure that site layout and dwelling design are compatible with the treated ground

Items to be taken into account include:

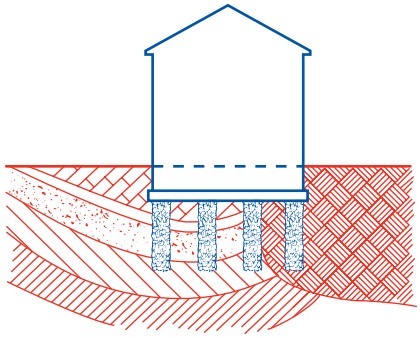
(a) limitations of the treated ground

The Engineer should:

- undertake discussion with the Specialist Contractor to confirm the feasibility of proposals
- determine the loads to be imposed by the buildings and assess against the results of the site investigation
- confirm the required load/settlement performance of the treated ground



- consider limitations of the configuration of the dwellings:
  - T-block and L-block vulnerable at junctions
  - vulnerability of long blocks
- avoid siting buildings in locations where major changes in ground conditions can be expected



- advise and discuss design criteria with NHBC at the design stage.

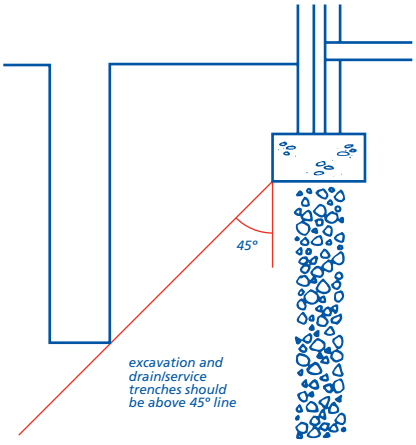
(b) limitations of ground support

The Engineer should:

- establish the likely limits of ground movement
- allow for ground movement in the design, including where appropriate:
  - position and spacing of movement joints
  - flexibility of masonry mortars
  - masonry reinforcement.

(c) drainage and service trenches

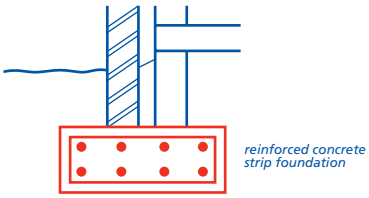
The Engineer should consider the influence of drainage and other service trenches on the stability of the complete design (see Sitework clause S4).



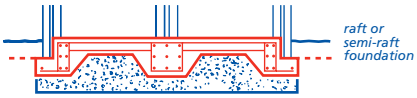
(d) suitable foundation types

The following criteria should be incorporated in the foundation design to ensure the compatibility and overall stability of the foundations and superstructure:

- only two types of foundations are suitable, both of which should comply with the minimum criteria for areas of reinforcement as defined in BS EN 1992-1-1. They are:
  - reinforced concrete strip foundation



  - reinforced concrete raft or semi-raft foundation positioned on a uniformly compacted bed of hardcore



- for both types of foundation, top and bottom reinforcement should be provided
- the depth of foundations to be a minimum of 600mm below the surface of the treated ground, and founded on firm material of adequate bearing capacity
- where the treated ground is of a granular nature, a reinforced concrete strip foundation will normally be acceptable provided that the full depth of all fill material is treated
- if the treated ground is of a cohesive nature, a suitably designed raft, semi-raft or reinforced concrete strip foundation will normally be acceptable
- the reinforced concrete foundation should be designed to span between the centres of adjacent stone columns unless a more rigorous structural analysis is carried out to show that an alternative detail is acceptable
- if partial depth treatment of filled ground is proposed then a suitably designed reinforced concrete raft or semi-raft foundation should be used
- if during excavations for foundations in treated ground it is found that excessive depths of concrete are required, then precautions should be taken to ensure overall stability of the foundations, and the Engineer should be satisfied that construction of the foundation will not be detrimental to the treated ground.

(e) use of suspended ground floors
Suspended ground floors should be provided for all dwellings where vibratory ground improvement has been carried out unless the Engineer can substantiate an alternative solution that is acceptable to NHBC.

(f) notice to NHBC
Notice of the proposed development should be forwarded to NHBC.

Inform NHBC of the appointment of the Specialist Contractor and of the anticipated commencement date for treatment.

MATERIALS STANDARDS

4.6 - M1 All materials shall:
(a) meet the Technical Requirements
(b) take account of the design

Materials that comply with the design and the guidance below will be acceptable for use in conjunction with vibratory ground improvement techniques.

Materials for use in conjunction with vibratory ground improvement techniques shall comply with all relevant standards, including those listed below. Where no standard exists, Technical Requirement R3 applies (see Chapter 1.1 'Introduction to the Standards and Technical Requirements').

References to British Standards and Codes of Practice include those made under the Construction Products Directive (89/106/EEC) and, in particular, appropriate EuropeanTechnical Specifications approved by a European Committee for Standardisation (CEN).

STONE FILL

4.6 - M2 Stone fill for forming columns shall be compatible with the ground conditions, and be suitable for the vibratory ground improvement process

Column fill should be clean, hard, inert material complying with the guidance given in Appendix 4.6-B.

In acidic ground conditions, limestone fill may not be acceptable.

The use of recycled aggregates should comply with the guidance in Appendix 4.6-B.

GRANULAR MATERIAL

4.6 - M3 Granular material for raising site levels before treatment or adding during deep compaction shall:
(a) be free from hazardous materials unless appropriate precautions are taken, and
(b) be suitable for compaction

The appropriate precautions to be taken where hazardous materials are present in fill are detailed in Appendix 4.6-B.

The test requirements for fill given in Appendix 4.6-B should be followed where appropriate.

Well graded, inert fill which passes a 100mm x 100mm screen in all directions and contains less than 10% fine material of silt or clay size will normally be acceptable for raising site levels.

The grading of material for adding during deep compaction should be within Zone A of the chart shown in Design clause D7 and Appendix 4.6-A.

SITEWORK STANDARDS

4.6 - S1 All sitework shall:
(a) meet the Technical Requirements
(b) take account of the design
(c) follow established good practice and workmanship

Sitework that complies with the design and the guidance below will be acceptable for vibratory ground improvement.

SITE SUPERVISION

4.6 - S2 The Builder shall ensure that the Engineer visits the site and provides competent supervision throughout the ground treatment process

The Engineer should provide competent site supervision at critical stages (e.g:

- inspection of setting out and materials
- column installations during early stage of the work
- where installation data differ from design assumptions
- if changes in treatment layout are required)

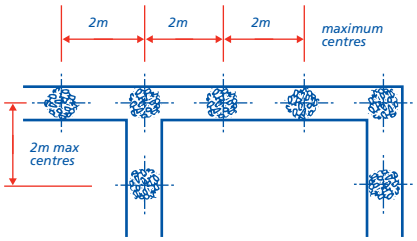
throughout the period of the ground treatment process.

Some aspects of sitework may be the responsibility of the Engineer or his representative, or of the Specialist Contractor, rather than of the Builder.

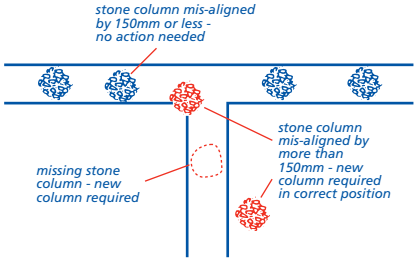
Items to be taken into account include:

(a) location, depth and alignment of columns
Supervision should be provided to ensure that:

- the minimum required depth of the stone columns is achieved, and they are correctly located. The Builder should provide sufficient profiles to enable locations to be checked
- the stone columns are located either centrally under the foundations they are to support or in the predetermined staggered arrangement, at a maximum of 2 metres centre to centre and at the intersection of adjacent reinforced concrete strips



- missing stone columns are replaced
- stone columns which are misaligned by more than 150mm in any direction are replaced

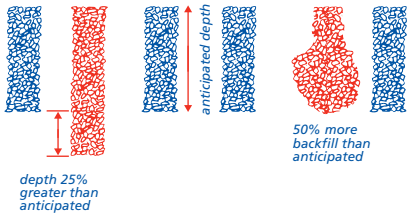


- a check on the location of all stone columns is made by the Engineer's representative prior to the specialist plant leaving the site.

(b) unforeseen circumstances
Allowance should be made for:

- unforeseen changes in the site conditions, or trends which may affect site conditions. Changes should be recorded and reported to the Engineer immediately they become apparent
- changes in the anticipated depth of the compaction point in excess of 25% should be recorded and reported to the Engineer and Specialist Contractor as soon as possible but no later than the end of the day on which they occur
- variations of over 50% in the quantity of backfill used in compaction points of the same length. Variations should be recorded and reported to the Engineer and Specialist Contractor at the end of the day on which they occur
- unforeseen obstructions requiring either local removal and backfilling prior to treatment, or realignment of, and additional columns, coupled with local amendment of foundation design
- the effects of any of the above on the final efficiency of the treatment. These are to be fully considered by the

Engineer and the Specialist Contractor. The Builder and NHBC are to be advised immediately about proposed remedial measures.



VERIFICATION OF COMPLETED TREATMENT

4.6 - S3 The Engineer shall require the Specialist Contractor to verify that the ground treatment is satisfactory

Items to be taken into account include:

(a) suitable testing

Tests should be carried out to establish the degree of ground improvement, its load-bearing characteristics and settlement potential.

The types of test that can be used are described in the following clauses. The Specialist Contractor should predict the results from his experience of work on the type of ground, prior to the test taking place. Prediction of the results and the degree of tolerance within those results is to be agreed with the Engineer prior to testing, and compared with the test results.

If for example a threefold improvement were predicted and only a twofold improvement achieved, this could mean that the ground was different to that indicated by the investigation, or that the treatment carried out differed from the specified treatment. In such a case, further investigation would be necessary.

Tests on ground containing clay soils may need to be delayed for a few days after the completion of treatment to allow excess pore pressures to dissipate.

The Engineer may choose any appropriate combination of the following tests with the agreement of NHBC:

- 600mm diameter plate tests
- dummy footing/mini zone test
- zone test
- in situ test
- trial pits

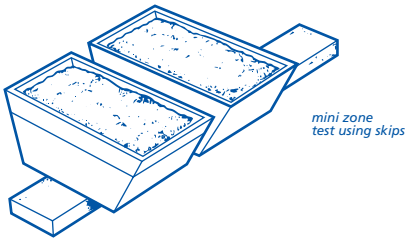
600MM DIAMETER PLATE TESTS

This test will not determine the design but will allow for an assessment to be made 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.

DUMMY FOOTING TEST/MINI ZONE TEST

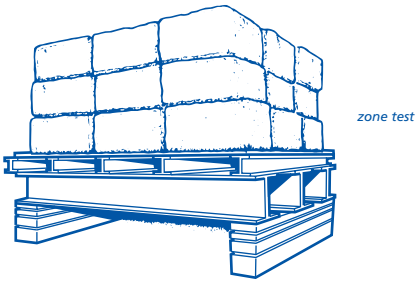
A mini zone test can be used as a limited substitute for zone tests. The test should be applied to at least two stone columns and the area of foundation which they support. The load may be applied through a rigid beam or stiffened plate using skips or other known loads arranged to give a uniform distribution of the load.

To be useful, mini zone tests should be continued for sufficient time for creep behaviour to be quantified and allowances for this time should be made in the overall project programme.



ZONE TEST

An isolated pad or strip footing is used, and up to 8 stone columns and the intervening ground can be tested. Loadings, which should simulate the dwelling loads, are held for 24 hours at pre-determined stages to examine creep behaviour.



IN-SITU TEST

Where vibration will improve the ground itself, eg 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.

(b) written confirmation of completed treatment

On completion of the treatment the Engineer should:

- from the results of the tests carried out satisfy himself that the treated ground has achieved the anticipated condition assumed in his design
- once satisfied with the effectiveness of the treatment in relation to the design, advise the Builder and NHBC accordingly in writing
- advise the Builder of any special precautions which should be taken for the positioning of services both beneath the dwelling and adjacent to it.

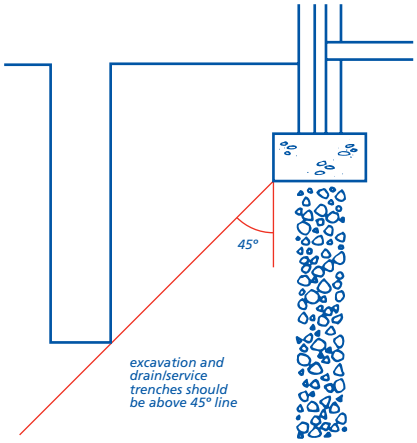
(c) record of the work

A comprehensive record of all works including information concerning the treatment, depth of fill, volume of stone used, on-site changes and all other relevant information, should be made available to NHBC.

4.6 - S4 The Builder shall ensure that treated ground is not disturbed by subsequent excavations

Ensure that the minimum clearance between excavations and foundations is not less than the depth of excavation minus the depth of the structural foundation.

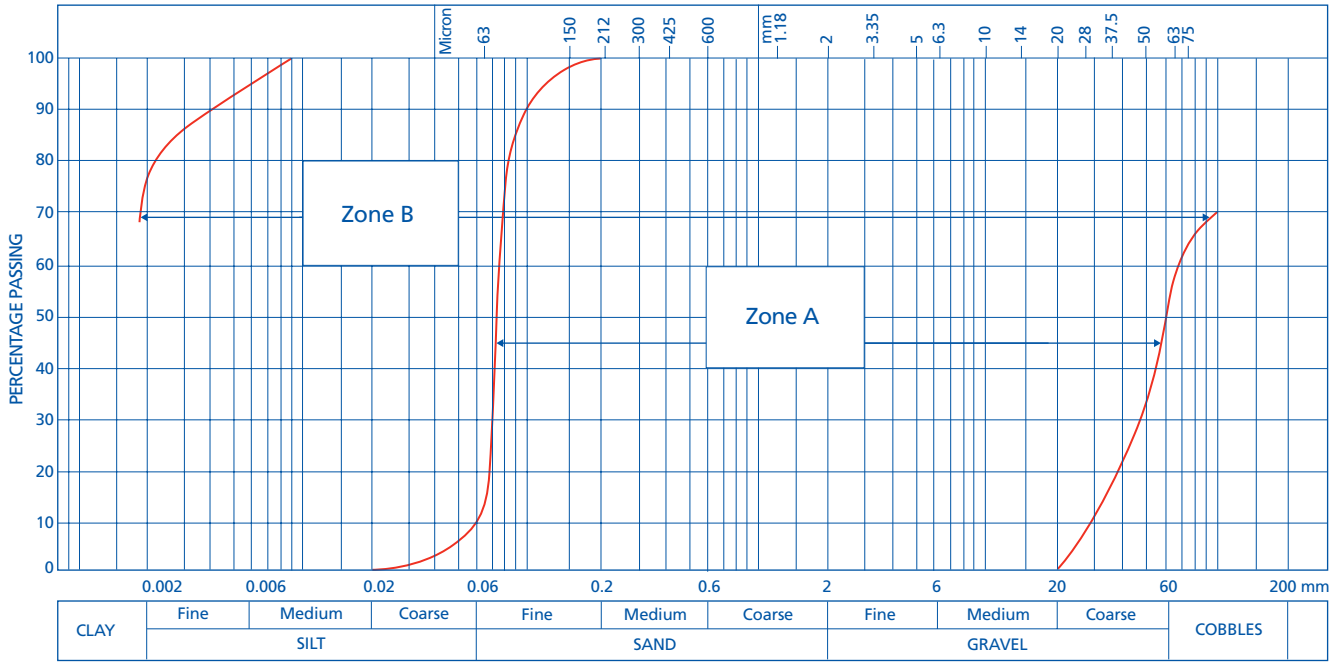
Particular attention is needed for excavation below the water table.



APPENDIX 4.6-A

SOIL CLASSIFICATION CHART

Conditions acceptable for treatment are only those within zones A and B of the chart.



Zone A Range of materials suitable for deep compaction (vibro-compaction) techniques

Zone B Range of materials suitable for stone column (vibro-replacement) techniques

Vibratory techniques

The vibratory process is applied usually to weak natural soils and filled ground. The purpose is to improve the load bearing capacity, reduce settlement and provide an adequate bearing stratum for the foundation supporting the dwelling.

A decision to buy a hazardous site is an acceptance by the builder/developer of the risks involved. It is important that the ground hazards are assessed before buying the site, and that allowance is made in foundation design for any consequences of this assessment.

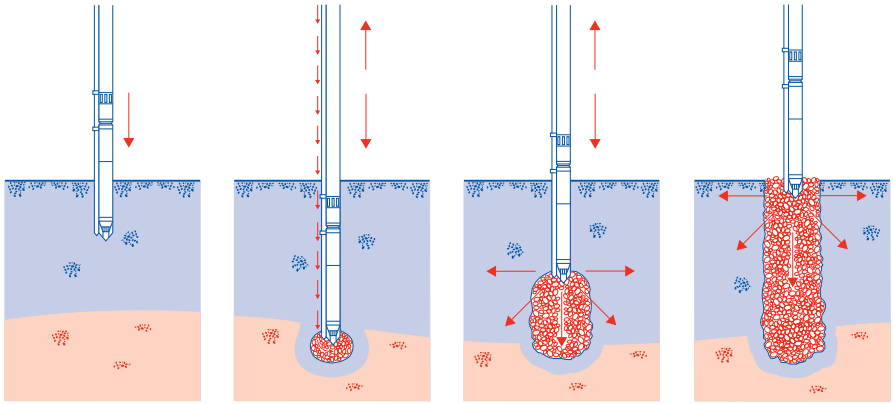
Hazardous sites are defined in NHBC Rules.

ACCEPTABLE METHODS

There are two vibratory techniques commonly used in the UK. These are known as the 'dry bottom feed' and 'dry top feed' methods, and are illustrated. A third technique, infrequently used in the UK, and known as the 'wet bottom feed' method is also acceptable to NHBC. This method is not illustrated.

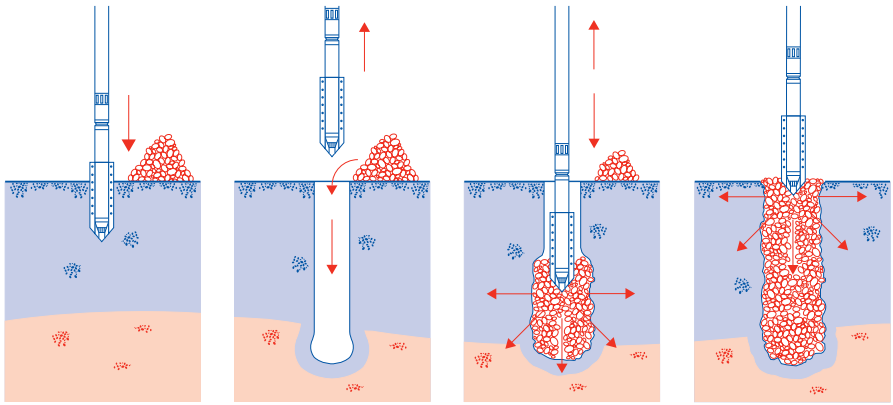
Dry bottom feed method

In weaker soils or situations where there is a high water table and the bore hole is liable to collapse between vibrator insertions, the dry bottom feed method is adopted. The vibrator penetrates by 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 a vibrator. The stone, usually of 40mm size, exits the pipe at the tip of the vibrator and in to the bottom of the bore hole. The stone is then compacted into the surrounding soil by repeated withdrawal and insertion of the vibrator.



Dry top feed method

In the dry top feed method the vibrator penetrates the weak soil or fill by its mass, air flush and vibration to form a bore hole. Once refusal or design depth is reached the vibrator is removed and stone fill introduced into the bore, the 'charge' is typically 500-800mm deep. The vibrator 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 40-75mm.



Appendix 4.6-B

MATERIALS FOR USE AS FILL

Hazardous 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 sulfates (eg gypsum)
- organic materials
- toxic materials
- materials that cause noxious fumes, rot,undue settlement or damage to surrounding materials.

Test requirements
Tests should be carried out by a suitably qualified person with a detailed knowledge of:
- the material to be tested, and
- the proposed conditions of use.

The samples tested must be representative of the true nature of the material. It may be necessary to take a number of samples to find out the material characteristics of the fill.

Sulfate content should be expressed as a percentage SO_4 by weight on the basis of acid soluble testing, taking full account of the recommendations of BRE Special Digest 1 Part 1.

Sources of fill material
Where the material is of a stable and uniform type from one source, it may only be necessary to check its suitability once. If material is variable, or from a number of sources, it should all be suitable. Regular inspections and/or testing may be required.

Where material is obtained from stockpiles, check the material is uniform. Different forms of stockpiling can affect particle size/grading. The outside of a stockpile may be weathered and may not be the same as unweathered material.

The use of recycled aggregate as fill should comply with BRE Digest 433 or other suitable guidance as agreed with NHBC.

Fill requiring NHBC approval
The following types of fill should not be used unless written permission has been obtained from NHBC:
- colliery shale and any other residue from mineral extraction
- slags
- furnace ashes and other products of combustion
- material obtained from demolition
- on wet sites, or sites with a high water table, crushed or broken bricks which have no limit on their soluble salt content (as defined in BS EN 771).

Expansive materials
Fill containing expansive materials is not acceptable for use as support to structural foundations and slabs or as backfill to associated trenches.

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