3.
Foundations

3.5
Vibratory Ground Improvement

Provision of information

A full set of design drawings, specifications, calculations and site investigation reports shall be made available to the Warranty Provider and all other interested parties. 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.

The Warranty Surveyor, at their discretion, may also request supporting information that demonstrates suitability for use of any materials or systems contained within the above.

Introduction

Vibratory ground improvement techniques are generally used to increase load-bearing capacity and reduce settlements to acceptable limits within undisturbed natural soils and filled ground.

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.

The ground must be suitable for vibratory ground improvement and designed in-accordance with recognised methods (e.g. Priebe). The treatment must extend through the full extent of the filled or poor ground and reach natural competent ground.

Foundations supported by vibratory ground improvement techniques require a coordinated design by an Engineer and specialists who are experienced with this type of construction.

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 (Undrained cohesion = 30kN/m^2 or less).
- 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.

Desk study and site investigation

All projects will require a site specific phase 1 desk study report (including Groundsure or similar) and a phase 2 geotechnical site investigation reports with appropriate geotechnical testing.

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.

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'

The foundations and vibro stone columns shall be designed in accordance with BS 8004:2020 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 Engineer.

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.

The results of the investigation should be presented to the Warranty Engineer prior to the commencement of work on site.

Desk study and site investigation results

Properties of the natural materials under the site
The site investigation should determine the depths and properties of the natural materials under the site, including the presence of geological hazards, cavities, mine-workings and associated features, rocks or soils that may dissolve or erode when water passes over them.

Through the process of a site investigation, it should first be established by the Engineer or suitably qualified specialist that the ground is capable of being improved by a vibratory ground improvement technique.

Extent of any areas of made ground on the site
The extent of any areas of made ground on the site should be established, including its history, composition and behaviour.

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.

Materials susceptible to heave or shrinkage
The extent of any shrinkable materials or materials susceptible to heave (clays, slag, burnt shale etc.) should be established. The necessary Atterberg tests and swelling tests should be conducted as appropriate.

Constituent materials
The proportions, compaction and distribution of the constituent materials throughout its depth should be established.

The investigation should include enough geotechnical testing to enable accurate geotechnical design of the vibro stone columns in accordance with proven design methods.

Fill materials
The grading and particle size distribution of fill materials should be established. See Conditions acceptable for treatment.

Existing or redundant services
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) or soakaways might have on the ground conditions should be identified.

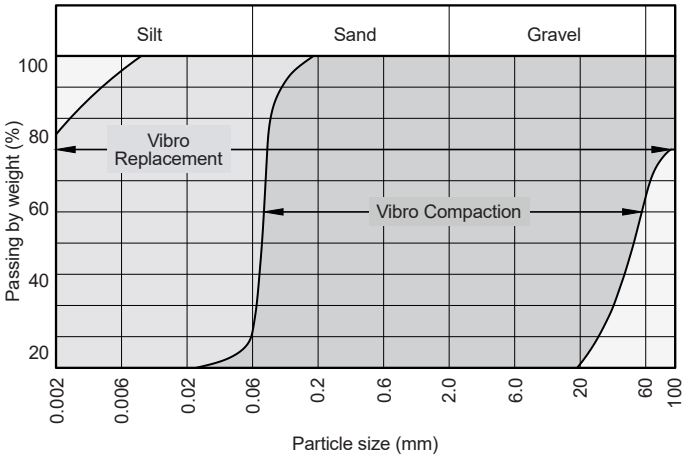
Ground water
The investigations should identify the presence, level and nature of any ground water, and if it is likely to rise and cause heave or collapse by saturation.

Contaminated substances
Contaminated substances including any potential for gas generation from fill materials such be identified. Any potential for combustion from contaminated substances should also 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.

Existing obstructions
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.

Conditions acceptable for treatment



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Unsuitable ground conditions

For Warranty purposes, the following ground conditions are not considered suitable for vibratory ground improvement.

- Highly shrinkable clays with a plasticity index greater than 40%.
- Soft clays with undrained shear strength less than CU = 30kPa.
- Ground with a peat layer greater than 200mm should be viewed as unsuitable. Multiple peat layers with a combined depth greater than stone column diameter are unsuitable. In addition, variations in peat thickness may cause differential settlements.
- Voided fill ground created by landfill or with concrete rubble or brick fill of unsuitable grading.
- Non-engineered fill material may result in the following:
  - Original ground or sub-strata is unstable or will continue to settle.
  - The location and mobility of ground water within or entering the fill – as this has the potential to trigger inundation settlement (if the fill has not been previously saturated).
  - Inundation settlement (also known as collapse compression) – associated with the permeation of water into poorly compacted fills and partially saturated fills with a high air voids ratio. Refer to BRE IP 5/97.
- Degradable material - organic material where the percentage per volume may cause excessive settlement to foundations.
- Ground gases including carbon dioxide and methane - Stone column installation will involve stone compaction, however, remaining voids can act as vertical vents to dangerous gases.

Ground conditions and other factors that may increase the complexity of vibratory ground improvement

- Shrinkable material with volume change potential (VCP). If the presence of shrinkable soils is suspected, and no testing data is available to verify the VCP then high volume change potential should be assumed.
- VCP Soils with a modified plasticity index greater than 10%. The installation of Stone Columns in cohesive material should consider any adverse effects on existing structures and site drainage.
- For all soil types, stone columns can transmit water down to lower fills causing softening and inundation of the fill materials.
- Deepening of foundations and heave precautions need to be assessed in accordance with the guidance within our 'Foundations' section of this Technical Manual regardless of the vibro treatment.
- Partial depth treatment of filled ground:
  - Sites designated for partial treatment will be considered on a case-by-case basis.
  - Engineer to consider the combined performance of both treated and untreated zones considering overall settlements.
  - Partial-depth treatment of loose/low-strength natural soils (SPT <10, cu < 40kPa) and partial-depth treatment of made ground/fill is not acceptable.
- Obstructions - buried structures including drainage.
- Variations in the density of material to be treated.
- Variations in ground water - long or short term alterations to ground water levels that may cause settlement or heave of existing buildings.

Limitations of treated ground

Buildings and long blocks with sensitive finishes should be avoided in areas with considerable variations in ground conditions.

In the case of stone columns, the un-cemented stone particles develop end bearing and skin frictional stresses. This process requires the soil surrounding the stone column to provide adequate lateral stresses to counter excessive bulging.

Soil types, such as peat and other weak materials, which include variations in thickness, may cause differential settlements.

Where the above limitations are found on site, the Engineer should:

- Determine foundation loads.
- Confirm the safe bearing pressure and settlement characteristics required.
- Compare design requirements with Interpretative Soil Investigation.
- Discuss viability of proposals and assess viable alternatives with specialist contractor.
- Submit proposals to the Warranty Provider at the earliest possible opportunity.

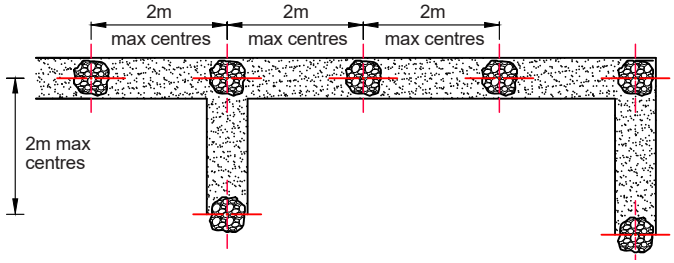
Installation

A suitably qualified competent person should ensure:

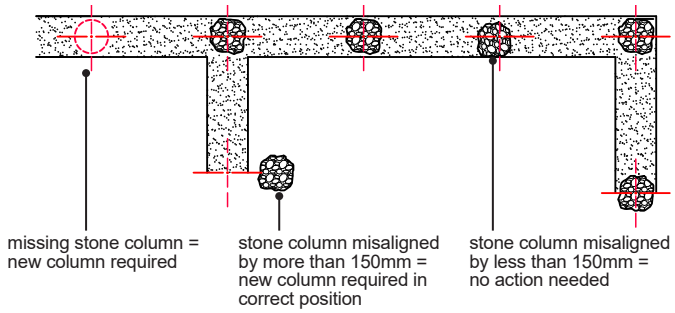
- There is appropriate site supervision and testing to achieve the required foundation design using vibro stone columns.
- Stone columns are located at the intersection of adjacent reinforced spread foundations.
- The minimum depth of stone columns is achieved.
- Any missing stone columns are replaced.

All installation criteria, including location and depth, are checked by suitably qualified competent person prior to the specialist plant leaving the site.

Stone columns can be centrally positioned under the foundation. For wider foundations, stone columns can be installed in a predetermined staggered arrangement under the spread foundation.

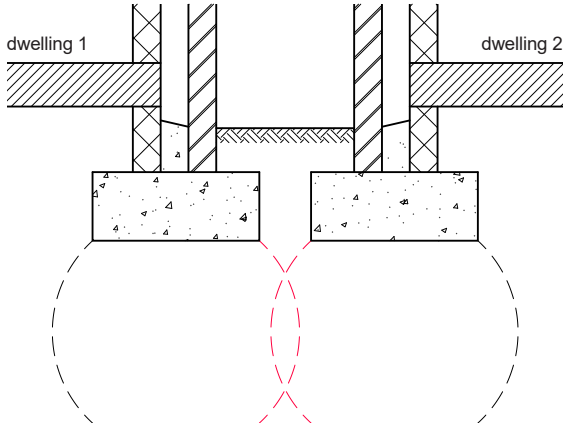


Stone columns which are misaligned by more than 150mm (centre to centre) in any direction should be replaced.



Adjacent foundations and services

- Design of vibratory ground improvement should consider adjacent foundations. Volume of soil treated should allow for the interaction of pressure bulbs and the resulting combined stresses.
- Service or drainage trenches - minimum clearance between foundations and excavations should be greater than depth of trench excavation minus the depth to the bottom of the concrete spread footing.

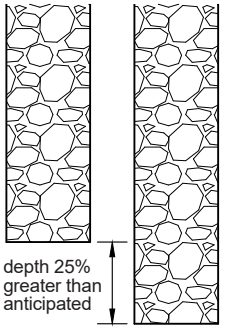


interaction of adjacent foundations

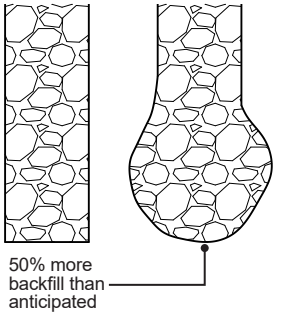
Actions on unforeseen events

The following events should be reported to the design team/specialist contractor and Warranty provider as soon as possible.

Where there is a reduction in treated depth in excess of 25%.



Where there is a significant increase in the quantity of backfill in comparison with similar treated depths.



Design team/specialist contractor should submit recommendations to the builder and Warranty provider.

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 Engineer.

Foundations

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

Foundation drawings and calculations should be prepared by the Engineer indicating the required bearing capacity and settlement characteristics for the purposes of design of vibro stone columns.

Foundations should be sized for the specified safe bearing pressures and be designed to span between the centres of the vibro stone columns.

The designer/engineer should ensure the following:

- RC foundations must be a minimum RC25/30 or FND concrete.
- Foundations shall be designed to span between vibro stone columns and must incorporate top and bottom reinforcement.
- Bottom profile of concrete foundations is located a minimum 600mm bgl and founded on firm material of adequate bearing capacity.
- For 'low rise structures' foundations should be designed for maximum settlements of 25mm.
- 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).

Irrespective of the provision of vibro stone columns, foundation depths and heave precautions must be in-accordance with the guidance provided in this Technical Manual, in respect of trees/clays, whilst ensuring that the vibro treatment is not detrimentally affected by deepening of the foundations. Further guidance can be found in the 'Foundations - Trees and Clay' section.

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.

Testing and validation of vibratory ground improvement techniques

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. The testing also needs to be compatible with the following:

- Ground composition.
- Quality of the site investigation.
- Foundation design and depth of treatment.

Testing foundation performance

Plates tests and any combination of the following - zone tests, dummy footing tests and/or pre- and post-treatment investigation - should be used on sites where any of the following apply:

- The treated ground consists of variable types of fill.
- The treated ground includes either peat, silt or clay.
- The ground water level is less than 1.5 x the foundation width below the bearing level.
- Partial depth treatment of fill.
- Variable depth of ground beneath each building.
- The ground to be treated exceeds 6m in depth.

The combination of testing requirements maybe reduced (with prior agreement with the Warranty provider) where the following criteria apply:

- The ground to be improved is well graded and granular.
- There is a low static ground water level that is greater than 1.5 x the foundation width below bearing level.
- The treatment has been taken to a depth below the foundation that is greater than 1.5 x the foundation width and this depth is confirmed with site logs.
- The ground is fill, and is treated to its full depth.
- Uniform ground beneath each building.
- Installation Site logging including print outs from in-cab monitoring is available.
- The site investigation is undertaken to a depth of at least 1.5 x the depth of the treatment.

Test	Description	Notes
Plate Tests	600mm diameter plates loaded to 3 x WL or 11 tonnes, whichever is greater. Minimum rate of 1 test per rig per day.	Plate tests alone may not provide a direct indication of the anticipated settlement of the completed structure. Usually they cannot be considered as the sole means of load testing.
Dummy Footing Test	1500 x 600mm plates loaded to at least 1.5 times Working Load (kPa) for a minimum period of 13 hours. Minimum rate of one per week.	The test should be applied to at least two stone columns and the area of foundation they support.
Penetration Test	Rate of one per (20 to 50) stone columns or one test for not more than 500sqm 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 recommended rate.
Trial Pits	Trial pits can be excavated around stone columns to prove they are fully formed to the required depth and diameter.	This is a destructive test and therefore allowance should be made accordingly.

Flexible and rigid retaining walls

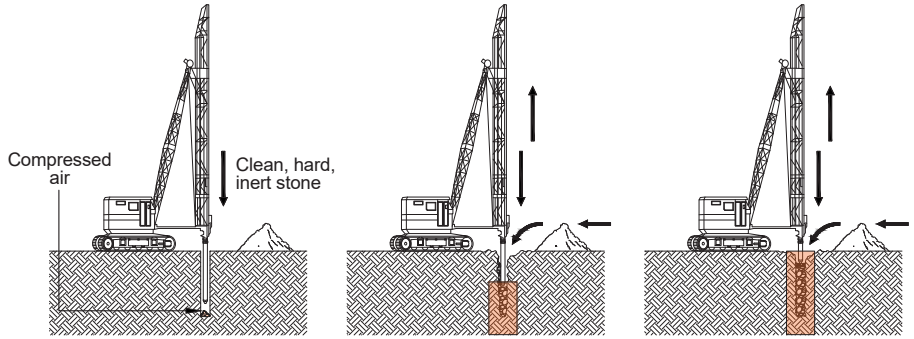
Flexible retaining walls
For the purposes of Warranty, flexible retaining walls may be defined as walls that support soil laterally whilst allowing deformations of the unsupported edge of the flexible retaining wall. Examples of flexible retaining walls include gabion, crib, block, timber or modular retaining wall systems.

Flexible retaining walls should not be used to support the structure of the property, garages, roads, drives, car parking areas or drainage systems.

Rigid retaining walls
Where rigid retaining walls are specified which support the foundations of a building, an Engineers design must be provided to confirm capable of maintaining stability for a period of at least 60 years and all works to the rigid retaining wall should be completed prior to works for the foundations of the property starting.

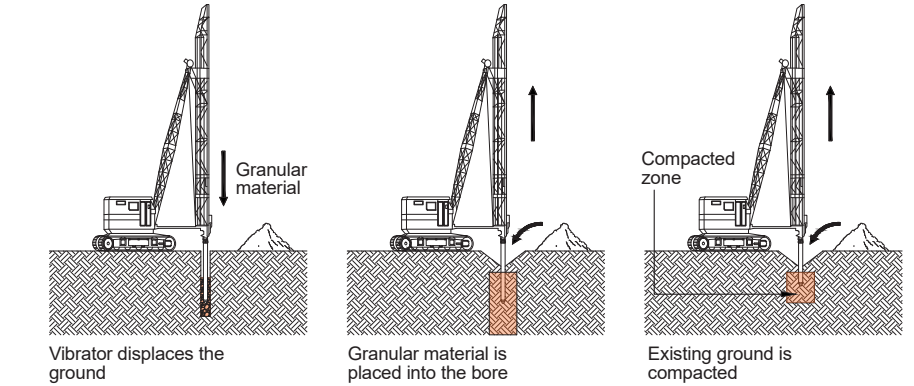
There are two vibratory techniques commonly used in the UK. These are known as the ‘dry bottom feed’ and ‘dry top feed’ methods; a third technique, less frequently used in the UK, is known as the ‘wet bottom feed’ method.

Vibratory techniques: dry bottom feed method



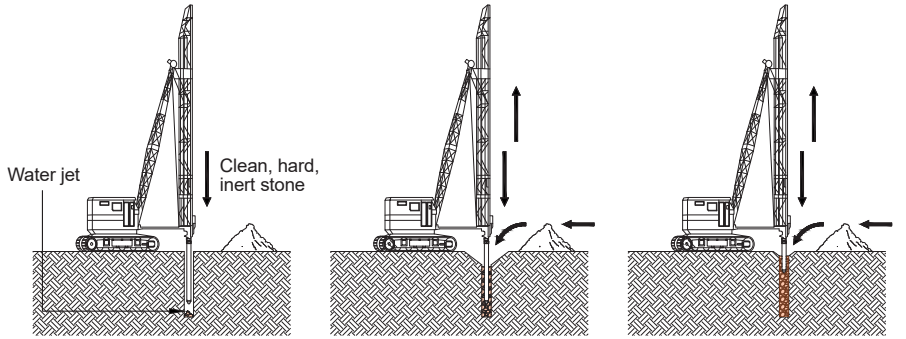
The dry bottom feed method is used in weaker soil conditions or where there is a high water table and the borehole is liable to collapse between vibroflot insertions. The vibroflot penetrates using its mass, air flush and vibration, but at design depth, the stone is introduced via a hopper into a pipe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



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

References

British Standards, codes of practice and good guidance relevant to vibratory ground improvement include the following:

- 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.
- 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 (BRE).
- BRE Information Paper 5/97 Collapse compression on inundation.
- BRE 424 Building on fill: Geotechnical aspects.
- CIRIA C572 Treated ground: Engineering properties and performance, 2002.
- CIRIA C573 A guide to ground treatment, 2002.
- ICE Specification for ground treatment: Notes for guidance, 1987.
- ICE Manual of geotechnical engineering: Volume II.