Chapter

4.5

NHBC

Vibratory ground improvement techniques

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

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Introduction

The vibratory process is generally applied 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 home.

4.5.1 Compliance

Also see: Chapter 2.1

Vibratory ground improvement techniques shall comply with the Technical Requirements and be designed by an engineer in accordance with established standards and codes of practice.

Vibratory ground improvement techniques that comply with the guidance in this chapter, and that are in accordance with the relevant British Standards, Building Regulations and statutory requirements, will generally be acceptable.

Design of vibratory ground improvement, including foundations, should be carried out by an engineer experienced in ground improvement techniques in accordance with Technical Requirement R5. In this chapter, the term 'engineer' refers to an appropriate engineer who is responsible for the foundation design and independent of the contractor responsible for the vibratory ground improvement techniques.

British Standards, codes of practice and authoritative documents relevant to vibratory ground improvement techniques and site investigations include:

BS 10175	Investigation of potentially contaminated sites. Code of practice
BS EN 1991	Actions on structures
BS EN 1997-1	Geotechnical design — General rules
BS EN 1997-2	Geotechnical design — Ground investigation and testing
BS EN 14731	Execution of special geotechnical works. Ground treatment by deep vibration
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

4.5.2 Provision of information

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

The vibratory improvement proposal and accompanying information including relevant drawings should be submitted to NHBC at least eight weeks prior to the commencement of the vibratory process or associated works.

All dimensions and levels should be indicated and relate to at least one benchmark and reference point on site. Design and specification information should be issued to site supervisors, relevant specialist subcontractors and/or suppliers, and include the following information:

- dimensions, type and depth of treatments
- detailing of ducts
- junctions
- steps
- movement and/or construction joints
- location of services
- critical sequences of construction.

Both designers and site operatives need to be aware of:

- ground conditions
- any features requiring special attention, such as existing sewers or other services
- water table levels
- the presence of any hazardous substances or unsuitable ground conditions.

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

4.5.3 Hazardous sites and ground hazards

Also see: Chapters 2.1, 4.1 and 4.2

Vibratory ground improvement techniques on hazardous sites shall be reported to NHBC before work on site commences, and be designed to take account of the characteristics of the site, including any ground hazards.

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

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

4.5.4 Desk study and site investigation

Also see: Chapters 2.1, 4.1 and 4.2

The engineer shall ensure a desk study and site investigation are undertaken and findings used to inform the design.

The engineer should establish the scope of, and supervise, the site investigation, taking account of the findings of the desk study, and relevant standards listed in Clause 4.5.1.

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 site investigation and desk study should be sent to NHBC prior to work starting and should, as a minimum, determine the items listed in Table 1.

Table 1: Results of the site investigation and desk study

Item to be determined	Guidance
Depths and properties of natural materials under the site	Includes the presence of caves, workings, or natural phenomena such as rocks or soils which dissolve or erode when exposed to the passage of water. Data for comparison with post-treatment properties should be established.
Extent and nature of any areas of filled ground on the site	Includes: • proportions and distribution of constituent materials • state of compaction of the fill material throughout its depth • grading and particle size distribution of fill materials • potential for gas generation from fill materials • potential for spontaneous combustion of fill and/or natural deposits.
Presence and extent of any existing or redundant services and drains	Includes information on the extent and nature of the backfill to the excavations.
The effect of sustainable drainage system (SuDS)	Includes the effect that any SuDS may have on the geotechnical parameters of the site.
Presence, level and nature of any groundwater	Includes the potential for groundwater to rise and cause heave or collapse by saturation.
Previous structures	Includes any potential underground obstructions or hard spots, eg basement walls, floor slabs, which remain.
Occurrence of contaminated substances	Includes the presence and extent of contaminated substances or gases present or suspected.

4.5.5 Confirmation of suitability for treatment

Also see: Chapters 2.1, 4.1 and 4.2

The builder shall obtain written confirmation from the engineer and specialist contractor that the site is suitable for the proposed ground improvement system.

NHBC should be notified prior to work starting, that the site is suitable for the proposed system. The engineer and specialist contractor should agree the following in writing before work commences on site:

- design objectives
- detailed schedule of work
- programme of work
- tests to be conducted on completion of the work
- responsibility for procedures and tests.

The following considerations should be taken into account:

- layout and depth of the stone columns and the accuracy to be achieved
- safety issues to be incorporated into the design to allow for unforeseen circumstances
- criteria for non-acceptance of the vibrating poker work tests to be conducted on completion of the work
- responsibility for procedures and tests
- calculations and case histories 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.

4.5.6 Suitability of ground conditions

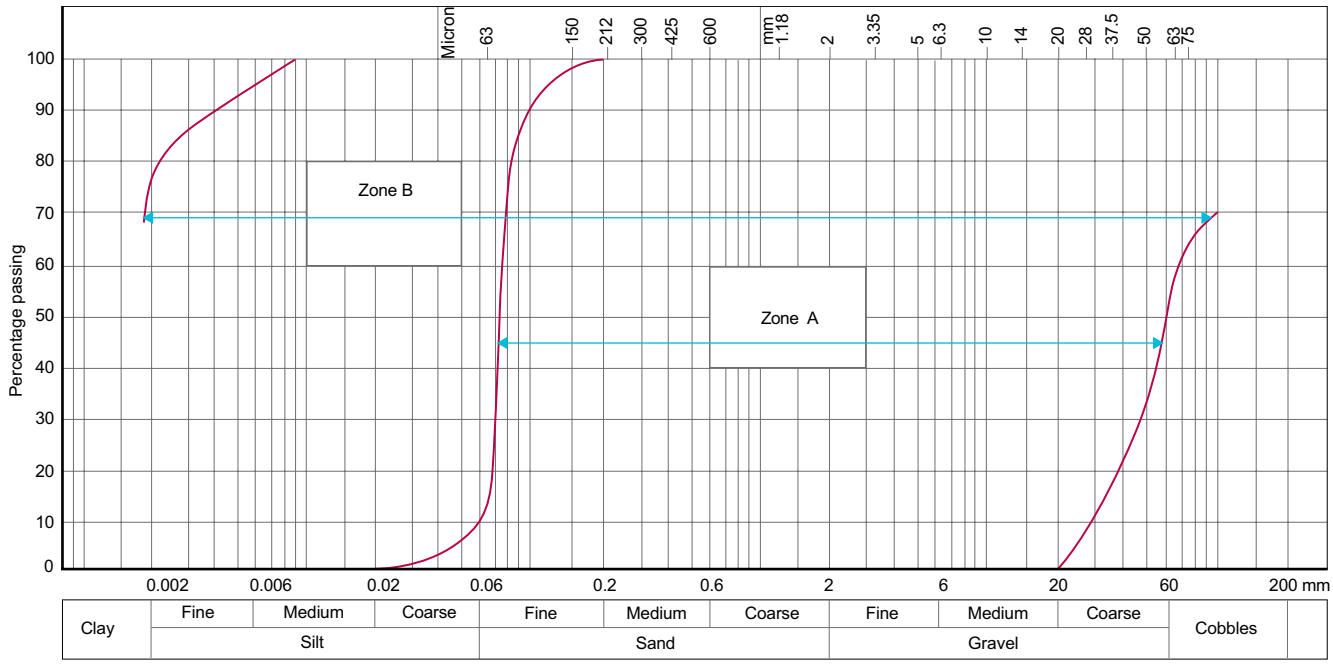
Also see: Chapters 2.1, 4.1 and 4.2

Vibratory ground improvement techniques shall only be conducted on suitable ground and be appropriate for the site conditions. Issues to be taken into account include:

1) **unsuitable ground conditions**
2) **detrimental factors**
3) **groundwater conditions.**

The engineer should assess the ground and be satisfied that it is suitable for treatment. Conditions acceptable for treatment are only those within zones A and B of Chart 1.

Chart 1: Conditions acceptable for treatment



Zone A – range of materials suitable for deep compaction (vibro-compaction) techniques.

Zone B – range of materials suitable for stone column (vibro-replacement) techniques.

4.5.6.1 Unsuitable ground conditions

Table 2: Ground conditions not generally acceptable for treatment

Soil composition	
Clays	Ground with a Plasticity Index of 40% or greater
Soft clays	Ground with soft clays with an undrained shear strength less than 30kN/m^2 For clay strength less than 30kN/m^2, additional consideration must be given to group effects, ground heave and settlement due to installation. Any proposals will be subject to NHBC agreement
Ground with peat layers	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
Highly sensitive soils	Ground liable to collapse or remoulding
Ground with fill	
Voided filled ground	Ground which includes, for example, old water tanks, pottery, glass bottles, concrete rubble or brick fill of unsuitable grading
Loose or non-engineered fill	Ground with any loose or non-engineered fill not previously subject to rising or fluctuating water levels or saturation
Filled ground which is still settling or expected to settle	Ground subject to settlement or settling: • 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	Ground where organic material forms more than 15% of fill by volume
Highly contaminated ground	
Ground which includes, for example toxic waste, or where inflammable, explosive or toxic gas generation may take place	Stone columns may act as vertical vents. Consideration will be given to proprietary systems which do not permit vertical venting such as vibro concrete plug technology.

Figure 1: Ground subject to settlement

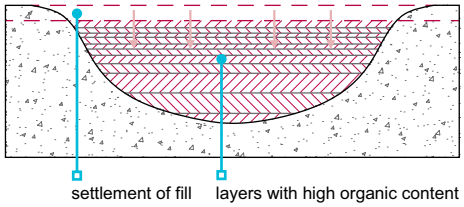
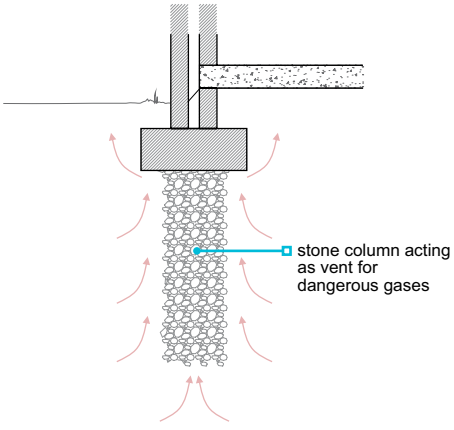


Figure 2: Stone column acting as vertical vent



4.5.6.2 Detrimental factors

When specifying vibratory ground improvement techniques, the following factors should be considered:

- partial depth treatment of filled ground. The engineer should be satisfied with the anticipated performance of both the treated and untreated zones
- the specialist contractor should take responsibility for the treated zone and the depth of treatment
- alterations to the oversite level before or after treatment, or the disturbance of ground by excavations after treatment
- soils with a Modified Plasticity Index of 10% or greater; foundations should be designed to accommodate volume changes (Figure 3)
- obstructions and variations in the density of fill and natural ground (hard spots) and 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
- the minimum depth of soil treated, which should allow for the interaction of adjacent foundations (Figure 4)
- stone columns that may form vertical drains, allowing the passage of water to a moisture-susceptible strata, or provide seepage paths for gases (Figure 5).

Figure 3: Vibro foundation depth in volume change potential soils

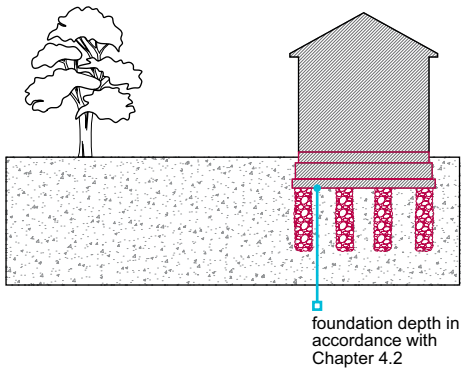


Figure 4: Interaction of foundations in close proximity

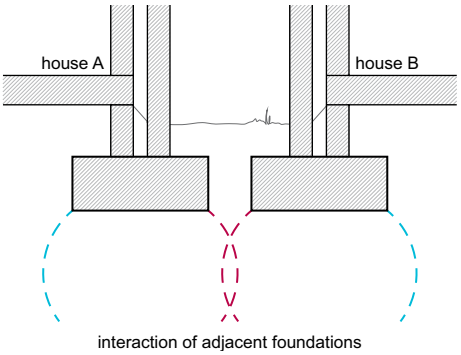
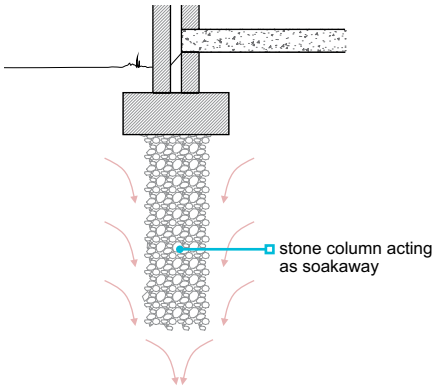


Figure 5: Stone column acting as vertical drains



4.5.6.3 Groundwater conditions

When specifying vibratory ground improvement techniques, the following factors should be considered:

- long-term lowering of the 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.

Figure 6: Effect of depressed water level on adjacent building

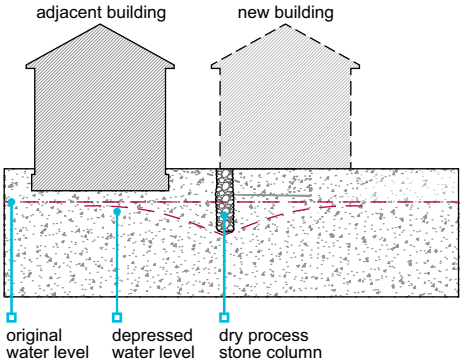
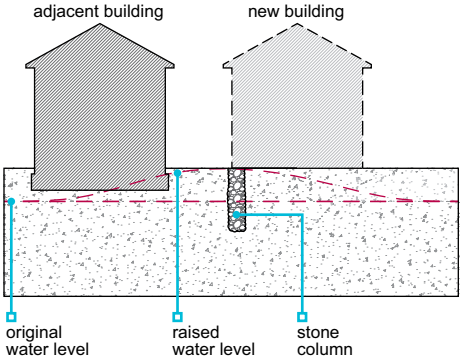


Figure 7: Effect of raised water level on adjacent building



Surface water sewers should be used for rainwater disposal where possible, but where soakaways are necessary, they 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 compaction improvement techniques are proposed.

4.5.7 Compatibility of the ground, design and treatment

Vibratory ground improvement techniques shall be compatible with the treated ground, site layout and the home design. Issues to be taken into account include:

1) **limitations of the treated ground**
2) **limitations of ground support**
3) **suitable foundation types**
4) **use of suspended ground floors**
5) **notice to NHBC.**

4.5.7.1 Limitations of the treated ground

The engineer should:

- avoid siting homes in locations where major changes in ground conditions can be expected
- consider limitations of the configuration of the homes, including the vulnerability at junctions and of long blocks
- determine the loads to be imposed by the homes, and assess them against the results of the site investigation
- discuss the feasibility of proposals with the specialist contractor
- confirm the required load and settlement performance of the treated ground
- advise and discuss design criteria with NHBC at the design stage.

Figure 8: Building located over changing ground conditions

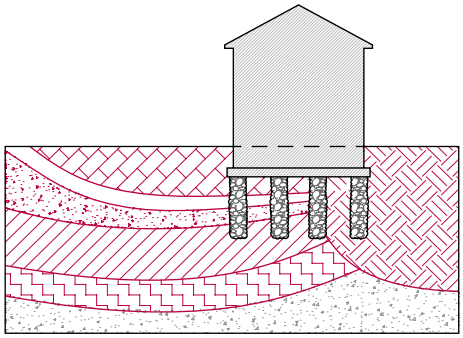
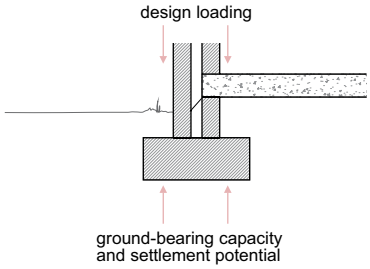


Figure 9: Assessing the effect of load distribution on foundations with corresponding settlement characteristics

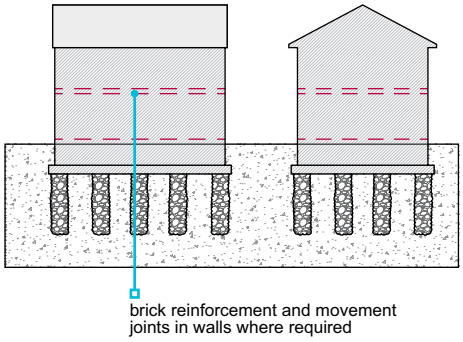


4.5.7.2 Limitations of ground support

The engineer should establish the likely limits of ground movement and account for this in the design, including:

- the position and spacing of movement joints
- the flexibility of masonry mortars
- masonry reinforcement.

Figure 10: Potential location of bed-joint reinforcement in masonry walls



4.5.7.3 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.

Figure 11: Reinforced concrete strip foundation detail

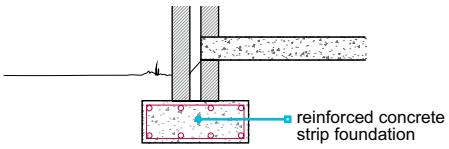
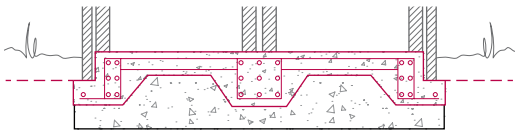


Figure 12: Raft or semi-raft foundation detail



- 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, 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.

4.5.7.4 Use of suspended ground floors

Suspended ground floors should be provided for all homes where vibratory ground improvement has been conducted, unless the engineer can substantiate an alternative solution that is acceptable to NHBC.

4.5.7.5 Notice to NHBC

Where vibratory ground improvement is proposed, NHBC should be informed of:

- proposed development
- appointment of the specialist contractor
- proposed start date of treatment.

4.5.8 Acceptable methods

Vibratory ground improvement techniques shall only be conducted using methods that are appropriate to the ground conditions and acceptable to NHBC.

There are two main vibratory methods commonly used in the UK. These are known as the 'dry bottom feed' and 'dry top feed' methods. A third method, infrequently used in the UK and known as the 'wet bottom feed' is also acceptable to NHBC.

Dry bottom feed method

The dry bottom feed method is adopted in weaker soils or situations where there is a high water table and the borehole is liable to collapse between vibrator insertions.

The vibrator penetrates by its mass, air flush and vibration. At design depth, the stone is introduced via a hopper into a pipe fixed to the side of a vibrator. The stone, generally of 40mm size, exits the pipe at the tip of the vibrator and discharges in to the bottom of the borehole. The stone is then compacted into the surrounding soil by repeated withdrawal and insertion of the vibrator.

Dry top feed method

The dry top feed method is only used on cohesive soils where the borehole can remain open. The vibrator penetrates the weak soil, or fill, by its mass, air flush and vibration to form a borehole.

Once refusal or design depth is reached, the vibrator is removed and stone fill introduced into the borehole, the 'charge' is generally 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. The stone grading is generally 40-75mm.

Figure 13: Vibratory dry bottom feed method

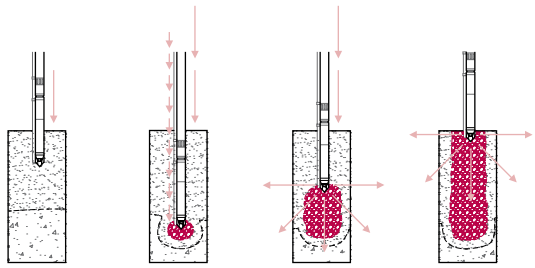
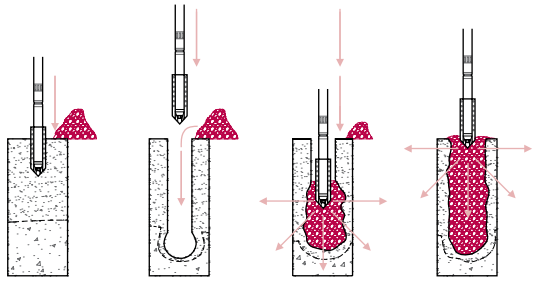


Figure 14: Vibratory dry top feed method



4.5.9 Materials for use as fill

Also see: BRE Special Digest 1 Part 1, BRE Digest 433 and BS EN 771

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 a clean, hard, inert material. Limestone fill may not be acceptable in acidic ground conditions.

Suitable sources for fill material

All material used for fill should be suitable.

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

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

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 for fill material

Tests should be carried out by a suitably qualified person with a detailed knowledge of the:

- material to be tested
- proposed conditions of use.

The samples which are 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.

Fill material requiring NHBC acceptance

The following types of fill should not be used unless written agreement 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)
- manufactured aggregates using materials from waste treatment plants.

Expansive fill materials

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

4.5.10 Granular material

Granular material for raising site levels before treatment, or adding during deep compaction, shall be suitable for compaction and, unless appropriate precautions are taken, be free from hazardous materials.

The grading of material for adding during deep compaction should be within Zone A of Chart 1. 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 generally be acceptable for raising site levels.

Precautions, including testing where appropriate, should be taken where hazardous materials are present in fill.

4.5.11 Sitework

When using vibratory ground improvement techniques, the builder shall ensure that the engineer visits the site and provides competent supervision throughout the ground treatment process. Issues to be taken into account include:

1) **engineer checks**
2) **location, depth and alignment of columns**
3) **managing unforeseen circumstances.**

4.5.11.1 Engineer checks

The engineer should provide competent site supervision throughout the ground treatment process and at critical stages, including:

- the inspection of foundation setting out
- the installation of columns during the early stage of the work
- checking of materials
- where installation data differs from design assumptions
- where changes in treatment layout are required.

Some aspects of sitework may be the responsibility of the engineer or their representative, or of the specialist contractor, rather than of the builder.

4.5.11.2 Location, depth and alignment of columns

Supervision should ensure that:

- the minimum required depth of the stone columns is achieved and each one 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 are in the predetermined staggered arrangement, at a maximum of 2m centres 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
- the location of all stone columns is checked by the engineer's representative prior to the specialist plant leaving the site.

Figure 15: Ideal setting out of vibro columns

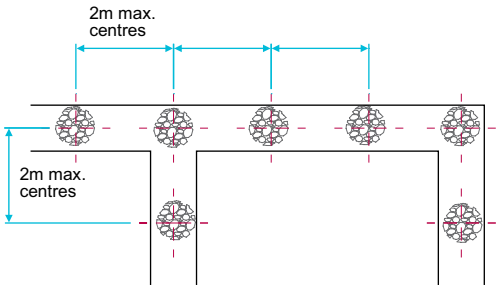
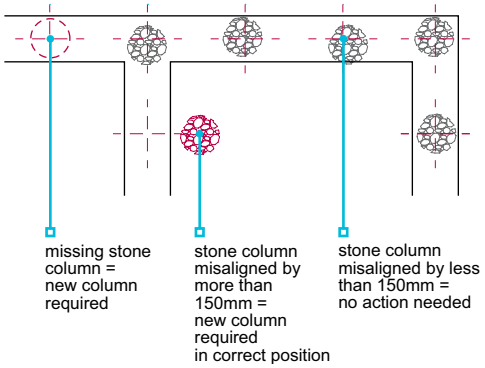


Figure 16: Setting out of vibro columns requiring corrective action

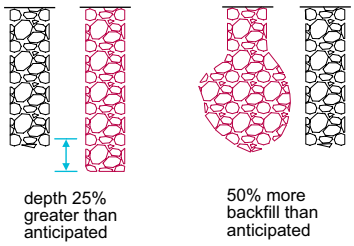


4.5.11.3 Managing unforeseen circumstances

Table 3: Actions for managing unforeseen circumstances

Circumstance	Action	In all cases
Unforeseen changes or trends which affect the site conditions	Recorded and reported to the engineer immediately	Where there is an effect on the final efficiency of the treatment, this should be fully considered by the engineer and the specialist contractor. The builder and NHBC are to be advised immediately regarding proposed remedial measures.
Change in the anticipated depth of the compaction point in excess of 25%	Recorded and reported to the engineer and specialist contractor as soon as possible but no later than the end of the working day of occurrence	
Variation of over 50% in the quantity of backfill used in compaction points of the same length		

Figure 17: Examples of unforeseen changes or trends during execution of vibro treatment



Allowance should be made for unforeseen obstructions that require either local removal and backfilling prior to treatment, realignment or additional columns, coupled with local amendment of foundation design.

4.5.12 Adjacent excavations

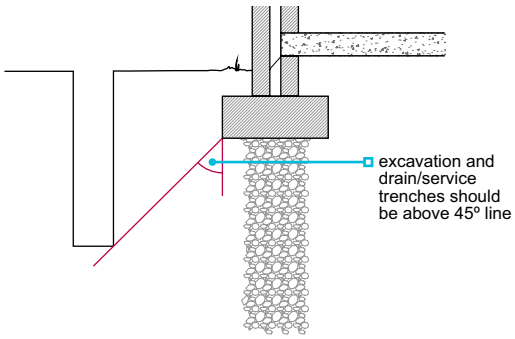
Also see: BR 391

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

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

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

Figure 18: Placement of excavation adjacent foundation on vibro treatment



4.5.13 Verification of completed treatment

The engineer shall require the specialist contractor to verify that the ground treatment is satisfactory, including:

1) **suitable testing**
2) **written confirmation of completed treatment**
3) **recording of work.**

4.5.13.1 Suitable testing

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

The specialist contractor should:

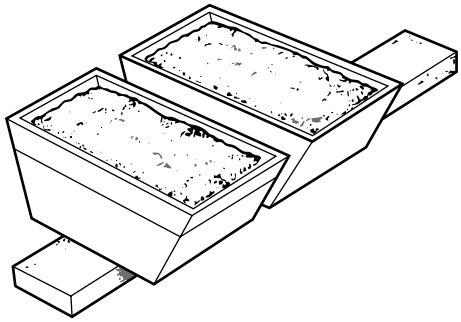
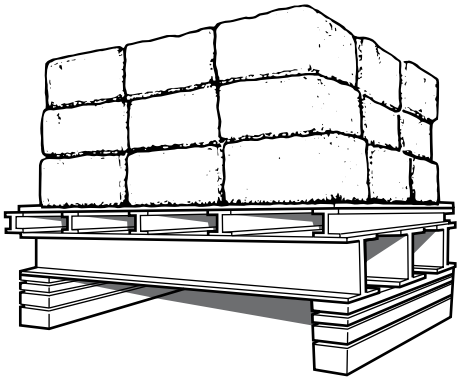
- predict the results from their experience of work on the type of ground prior to the test taking place
- agree acceptable results and degree of tolerance with the engineer prior to testing
- confirm that the final results are acceptable with the engineer on receipt and review of actual results.

Where the results are vastly different, a further investigation may be necessary.

Where a threefold improvement was predicted and only a twofold improvement achieved, this could indicate that the ground was different from that identified in the investigation, or that the treatment carried out differed from the specified treatment.

Tests on ground containing clay soils may need to be conducted several days after completion to allow excess pore pressures to dissipate. The engineer may choose any appropriate combination of the tests detailed in Table 4, with the agreement of NHBC.

Table 4: Test methods

Test	Comments
600mm diameter plate tests	Plate tests will not determine the design but will allow for an assessment to be made of the workmanship on the stone columns. The 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. Testing frequency should be at least one test per week per rig on normal sites. Where the site is of a geotechnically challenging nature, such as lengthy columns of over 6m or treatment of variable fill or soft/weak natural soils, then additional tests per week per rig will be required. Figure 19: Mini zone testing using skip  Mini zone tests should be continued for a sufficient time to allow creep behaviour to be quantified. Allowances for this time should be made in the overall project programme.
Zone test	An isolated pad or strip footing is used to test up to eight stone columns and the intervening ground. Loadings which should simulate the dwelling loads are held for 24 hours at predetermined stages to examine creep behaviour. Figure 20: Full zone testing simulating actual foundation load 
In-situ test	Where vibration will improve the ground itself, eg granular materials, then in-situ testing is appropriate. Improvement can be assessed when the in-situ test results are compared with the pretreatment 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.

4.5.13.2 Written confirmation of completed treatment

On completion of the treatment, the engineer should:

- use the test results to verify that the treated ground has achieved the anticipated condition assumed in the design
- advise the builder and NHBC in writing of the verified effectiveness of treatment in relation to the design
- advise the builder of any special precautions which should be taken for the positioning of services both beneath the home and adjacent to it.

4.5.13.3 Recording of work

A comprehensive record of all works should be made available to NHBC, including:

- information concerning the treatment
- depth of fill
- volume of stone used
- on-site changes
- any other relevant information.

4.5.14 Further information

- *BRE Special Digest 1 — Concrete in aggressive ground. 3rd Edition*
- *BRE Digest 391 — Specifying vibro stone columns*
- *BRE Digest 433 — Recycled aggregates*
- *BS EN 771-1 — Specification for masonry units. Clay masonry units*

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