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Site investigation for low-rise building: direct investigations

Digest 411

The main objective of a site investigation is to examine the ground conditions so that the most appropriate type of foundation can be selected. A typical site investigation begins with a desk study and a walk-over survey to establish the general geology of the site, and continues with an examination of the geotechnical properties of the ground.
This Digest discusses the various techniques for direct investigation of a site and provides guidance on how to select the appropriate method for a specific location.
This is one of a set of Digests dealing with site investigations. The other Digests in the set are listed on page 12.

The aims of direct site investigation

Site investigation is the gathering of all the information on ground conditions which might be relevant to design and construction on a particular site. On a site intended for low-rise development, a desk study is the first stage of investigation (see Digest 318). This involves checking existing records, such as geological maps of the site. The desk study, and a walk-over survey (see Digest 348), will indicate the probable ground and groundwater conditions and the problems they might pose.

Direct investigations are carried out:

- To check the information from the desk study
- To obtain any additional information required to ensure safe and economic construction.

Direct investigations are never routine. On each site, the process is tailored to the specific project and the specific ground conditions.

The type of information provided

The soil profile

Ground investigations identify the levels of the various soil or rock types on the site by identifying the boundaries between them. Boundaries between soil types are not always distinct, eg when one type changes gradually into another.

Soil classification

Ground investigations classify the soils beneath the site into broad groups: each group contains soils with similar engineering behaviour.

The simplest classification used by geotechnical engineers divides the ground into five categories:

- Rock
- Granular soil (eg sands or gravels)
- Cohesive soil (eg clays)
- Organic soil (eg peats)
- Fill or made ground.

Broad soil classifications, coupled with simple tests to determine soil parameters or to detect the presence of chemicals harmful to construction materials, are normally sufficient for low-rise building projects.

The natural variability of the soil in each classification can be assessed using index tests – see Table 1.

Soil parameters

Engineering design and calculation may require the determination of soil parameters. In many situations, soil parameters will not be required for

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the design of simple low-rise buildings, for example when ground conditions are clearly very good (eg in rock) or very bad (eg peat). Parameters need be determined only in difficult ground (eg clays). Such situations are, however, common in the UK.

Groundwater conditions

Groundwater conditions are significant because they can affect construction in a number of ways.

- A high groundwater table can lead to extra costs and make construction more difficult, eg because of the need for increased support and dewatering of foundation excavations.
- The presence of chemicals in groundwater (such as acids or sulfates) can lead to damage if foundation concrete is not of an appropriate quality (see BRE Digest 363).
- A high groundwater table implies that pore-water pressure in the soil is high, and this means that the soil will be correspondingly weaker. As well as influencing foundations, high pore-water pressures will adversely affect the stability of slopes and the pressures on retaining structures.

Planning direct investigations

BRE Digest 322 considers how site investigations for low-rise building may best be procured, and recommends that a geotechnical adviser be appointed to plan, supervise and interpret the results.

Direct methods of site investigation are generally more expensive than desk studies, walk-over surveys and other, indirect methods. It is therefore important that investigations are properly planned, not only to ensure value for money, but also to ensure that the objectives of the site investigation are met.

Stage 1: Carry out a detailed desk study and walk-over survey

Desk studies are discussed in detail in BRE Digest 318; walk-over surveys in Digest 348.

- Identify the probable ground and groundwater conditions
- Locate areas on the site likely to cause construction problems, eg areas of fill, old hedgerows and grubbed-up trees, mineshafts, low-lying ground, etc.

Stage 2: Make an initial design for the structures and the site

- Site the proposed structures so as to avoid as many problems as possible
- Design structural forms with special regard to anticipated ground hazards. For example, make the structure as flexible as possible if significant settlements are anticipated
- Make preliminary estimates of the types of foundation required, and determine the position of critical slopes and retaining walls
- Consider the parameters required for geotechnical design of the foundations.

Stage 3: Plan the direct methods required for the site investigation

- Identify the depths of investigation required at different locations around the site (see opposite page). Boreholes should always penetrate completely through made ground or infilling
- Identify suitable in-situ and laboratory testing methods for the expected soil conditions and the parameters required (see Table 1)
- Decide on the number of exploratory holes and the sampling and testing frequency, making allowances for the presence of unforeseen ground or groundwater conditions (see Table 2).

Stage 4: Keep a record of the investigation

Record the basis of the planned site investigation and the expected ground conditions. The specialist contractor who carries out the work will then know if the ground conditions he encounters are unforeseen (in which case it may be necessary to alter the scope of the field or testing work).

Table 1 Types of laboratory and in-situ tests

Purpose	Soil type	Suitable test	Frequency
Classification tests	Granular, cohesive	Particle size distribution	Every 1–1.5 m
	Cohesive	Atterberg limits	Every 1–1.5 m
Index tests	Granular	SPT[1]	Every 1–1.5 m
		Probing	Continuous
		CPT[2]	Continuous
	Cohesive	Moisture content	Every 1–1.5 m
		Undrained triaxial	Every 1–1.5 m
Parameter tests	Granular	CPT	Continuous
		SPT	Every 1–1.5 m
	Cohesive	Undrained triaxial	Every 1–1.5 m
		Oedometer	Every 1–1.5 m
		Sulfate content and pH	2–3 tests on each soil type
		Vane	every 1 m
		CPT	Continuous
		SPT	Every 1–1.5 m
Tests on groundwater	(Water)	Sulfate content and pH	On every water sample

[1] Standard penetration test
[2] Cone penetration test

Table 2 Number of exploratory holes

	Boreholes (use where depth required >4 m)	Trial pits
Suggested minimum	1 for every 3/4 dwellings	1 for every 2 dwellings
Suggested maximum	1 for every 2/3 dwellings	1 for every dwelling

Depths, numbers and locations of exploratory holes

Borehole depth depends on the stress distribution under the foundations (Fig 1).

Boreholes should penetrate all deposits unsuitable for foundation purposes, such as unconsolidated fill, peat, organic silt and very soft compressible clay.

Depth requirements should be reconsidered when the results of first borings are available, and it is often possible to reduce the depth of subsequent borings or to confine detailed and special explorations to particular strata.

The maximum number of boreholes will depend on the complexity of the local geology and the planned construction project; it may change as information emerges from early investigations.

Although there will be financial constraints, between 0.5% and 1% of the capital cost of the construction is likely to be available for site investigation. Problem areas need investigation, and where the site is particularly problematic the number of boreholes must be increased to ensure adequate coverage.

Boreholes should be located in potential problem areas, eg slopes near proposed site of structures. Where practicable, they should be located along straight lines to facilitate section drawing (Fig 2).

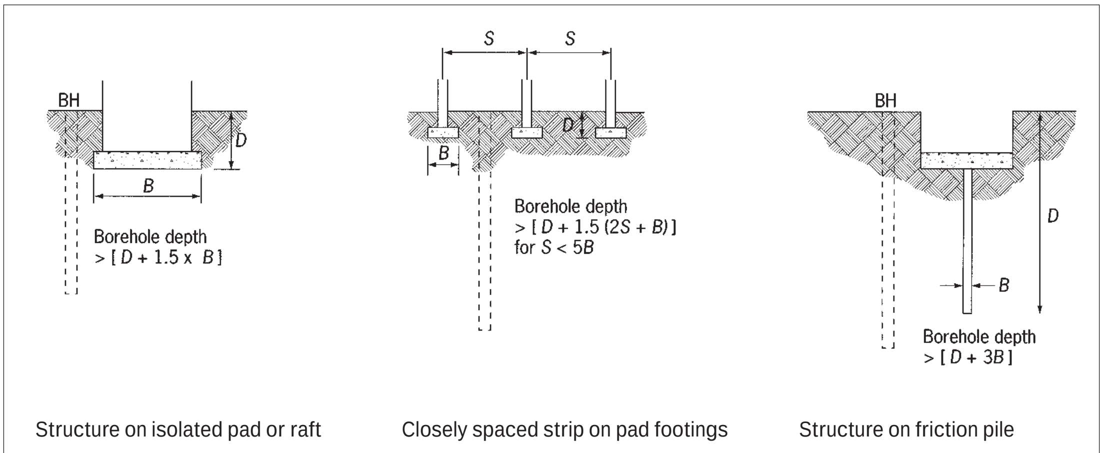


Figure 1 Borehole depth depends on the stress distribution under the foundations

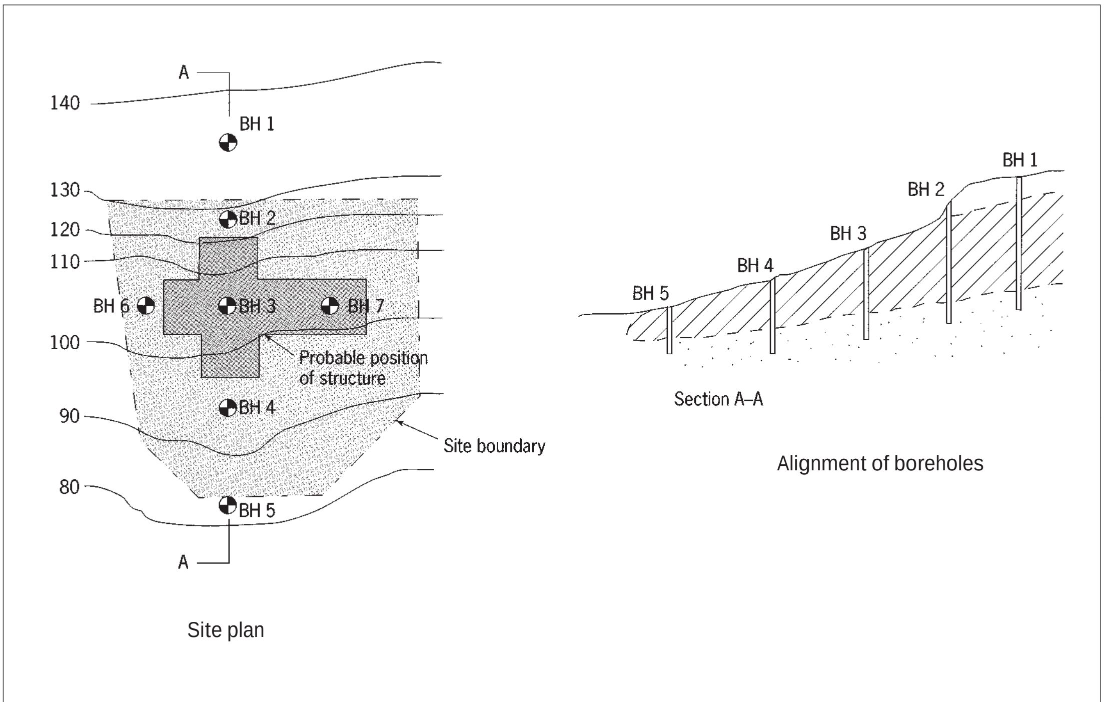


Figure 2 Boreholes should be drilled in straight lines to facilitate section drawing

Ground investigation techniques

Many different methods are now available for direct site investigations. The problem is to select methods which:

- Will work in the particular ground conditions expected at the site
- Give the information required to resolve the particular construction problems that are anticipated and to make the necessary design calculations
- Are sufficiently economical, given the restricted budget within which most low-rise building projects operate.

This Digest describes only those techniques that are currently in fairly common use in the UK. Other methods may also be appropriate in special circumstances: descriptions of these methods are in BS 1377 and 5930, and in ref [(1)].

Soil and rock description

The description of soil must be carried out to an agreed and accepted standard. Very detailed engineering soil descriptions require some expertise, but simple soil descriptions can be done by following the rules and guidelines laid down in BS 5930 and Digest 383.

The description of rock is more specialised, and requires the detailed identification of the rock-forming minerals[(1)]. However, detailed rock descriptions will not normally be necessary for the ground encountered during the investigation of low-rise building sites.

Soil description requires the identification of the material making up the soil — termed *material characteristics* in Digest 383 — and also the *in-situ soil characteristics*, including the strength or density of the soil and the presence or absence of fabric features, such as laminations, joints and fissures. A full sample description gives information on colour, consistency, moisture condition, fabric and structure, principal soil type and subsidiary soil types. Not all methods of investigation provide the opportunity to determine both sets of characteristics. Table 3 shows the ability of various methods of investigation to provide information for soil descriptions.

BRE Digest 381 considers the way that trial pit excavations should be recorded, and gives detailed safety recommendations on support and other important matters. Digest 383 discusses soil description.

Trial pitting is by far the most satisfactory method for describing the soil because it is generally quick and economical. However, although trial pitting is relatively cheap when carried out to shallow depths, it becomes rapidly more expensive as the depth increases. Where the depth to be investigated exceeds 3–4 m, the most common methods are boreholes with tube samples (in clay), and disturbed samples and SPT tests (in granular soils).

Table 3 Methods for soil and rock description

Method	Colour	Consistency / strength	Fabric	Soil type
Trial pits	✔	✔	✔	✔
Hand-auger holes	✔			✔[5]
Window samplers	✔			✔[5]
Boreholes	✔	✔[2]	✔[4]	✔[5]
SPT	✔[1]	✔[3]		✔[1]
Atterberg limit tests				✔
Triaxial tests		✔		
Field vane tests		✔		
CPT		✔[3]		✔[6]

Notes:

1 Using the disturbed sample obtained from the split spoon

2 Tube samples are required in clays, and SPT tests in non-cohesive soils

3 Using the penetration resistance

4 Large-diameter (minimum 100 mm) tube samples are required

5 Unsuitable for determining the particle size distribution of very coarse soils

6 Using the friction ratio

An accurate soil description is the most valuable outcome of a direct investigation. It must be carried out systematically, using appropriate investigation techniques, but once this is done a wealth of information on the likely behaviour of the soil can be obtained rapidly and at relatively little cost.

Exploratory holes

Trial pits

Trial pits are extremely valuable if the depth of investigation required is less than about 5 m (see Digest 381). This is the depth that can conveniently and easily be excavated in most soil types using a back-actor or 360° slew hydraulic excavator.

Trial pits are particularly useful in the investigation of sites intended for low-rise construction. This is because foundations for this type of structure are generally 0.4–0.45 m wide and 1–3 m deep, so the required depth of investigation is 3–5 m.

Safety warning!

There are very significant safety risks associated with working in narrow, deep excavations of this sort: do not enter unsupported trial pits deeper than 1.2 m.

Advantages of trial pits compared with auger holes

- Trial pits allow a detailed examination of the ground in situ
- They provide some indications of 'digability', trench stability and groundwater conditions.

Pros and cons of small-diameter augering

Advantages

- There is less disruption to the site than with either trial pits or boreholes
- The equipment is light, and can relatively easily be brought to the position of boreholes
- Under favourable circumstances, the depth of investigation is greater than with trial pits.

Disadvantages

- Auger holes of this type cannot be cased, and therefore will not stand open in many soils below the water table
- The equipment used is not robust enough to penetrate stiff, hard or stony ground
- Compared with other methods, progress is relatively slow and is often made slower by unfavourable ground conditions
- Tube sampling is difficult, and without borehole support it may not always be possible to assess the depth from which disturbed samples originate
- In-situ testing is not possible.

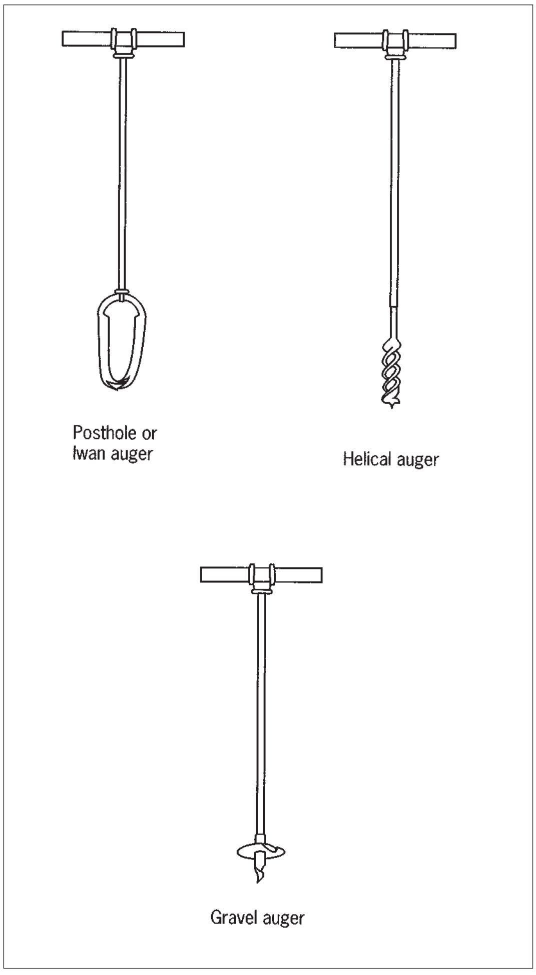


Figure 3 Hand augering equipment

Routine trial pit records — 'logs' — are normally taken by 'profile logging': the material is inspected as it is dug by the excavator, and the depth is determined by dipping the hole with a weighted tape. Lateral variability of the ground is not recorded, and in-situ fabric and special features (such as the presence of shear surfaces) may be difficult to detect. The advantage of this simple method is that, because people are not required to go down the hole, there is no need for side support.

'Detailed logging' is also common, and is preferable to profile logging because it allows close inspection of the ground. However, for safety reasons, hydraulic (or equivalent) trench shores must be used wherever the trench is more than 1.2 m deep.

Trial pitting is normally relatively fast. In good conditions, four to six 4 m-deep trial pits can typically be excavated and logged per 8-hour shift.

Auger holes

Auger holes are normally made by hand-turning a very light auger into the ground (Fig 3) or by using light power-auger equipment.

For two reasons, augering is not as widely used as trial pitting and boreholes:

- Auger holes — unlike trial pits — do not allow the ground to be examined in situ
- Auger holes do not allow the depth of investigation, or the range of sampling and in-situ testing, that conventional site investigation boreholes will give.

Typical auger holes are 75–150 mm in diameter. Short helical augers are generally used, and disturbed soil is collected from the auger flight as it is brought to the surface. Small continuous-flight auger drilling rigs are available which allow greater depths of investigation. Small diameter (38 mm) undisturbed tube samples may be taken, using the same equipment as is used in trial pits, but this is unusual (see section on *Soil sampling*).

The small disturbed samples typically obtained from an auger hole are described, and the descriptions collated to produce a borehole record, in the same way as for larger-diameter boreholes.

Window samplers

These are becoming a more readily available alternative to auger holes. A window sampler is a steel tube, usually about 1 m long, with a series of windows cut in the wall of the tube through which to view or take specimens of the soil sampled. It is driven into the ground by a lightweight percussion hammer, then extracted using jacks. Samplers come in a range of diameters. In practice, the largest is driven into the ground; then it is withdrawn and a smaller-diameter sampler is used to sample the soil at the bottom of the hole left by the first sampler. This sequence is repeated using progressively smaller-diameter samplers to obtain a profile of disturbed samples down to a maximum depth of 8 m.

Boreholes

In the UK, 150 mm or 200 mm diameter boreholes are normally made using light percussion (often incorrectly termed 'shell and auger') equipment (Fig 4). This is relatively light, and is normally towed to the borehole positions behind a light 4-wheel drive vehicle, and operated by a two-man crew.

In clays, the borehole is progressed by dropping a weighted hollow tube (the 'claycutter') into the hole, so that soil becomes lodged in its base. The claycutter and its contents are then lifted carefully to the surface (Fig 4). In granular soil, a hollow tube (the 'shell' or 'bailer') with a flap valve or 'clack' at its base, is surged in the bottom of the water-filled hole, creating a soil/water mixture. Soil drops out of this mixture and is collected. Typically, each drilling rig carries out 7–15 m of drilling per shift.

Material taken from the drilling tools is usually retained as small 'disturbed' samples. These are far less suitable for soil description than tube samples, since the drilling process will have:

- Changed the strength of the soil, by remoulding it
- Removed fine particles from granular soils
- Increased the moisture content of the soil, due to the presence of water in the hole.

In cohesive soils, tube samples — known as 'undisturbed samples' — are normally taken at intervals of 1.0–1.5 m by driving a 100 mm diameter tube into the soil at the bottom of the borehole (Fig 5). These samples are normally taken to a laboratory for engineering soil descriptions and laboratory testing to be carried out. In-situ tests, such as the Standard Penetration Test (SPT) or the vane test, can be carried out in the borehole as drilling proceeds.

In granular soils, large disturbed ('bulk') samples are taken from the soil, typically at intervals of 1.0–1.5 m.

The foreman driller prepares a daily record of the ground and groundwater conditions encountered during drilling. This record is given to a geotechnical engineer or engineering geologist who then carries out an engineering soil description on all the samples, and compiles an engineering borehole record by bringing together the driller's daily records, the descriptions of soil samples, and the results of in-situ tests. This borehole record will contain detailed engineering information on the types of soil beneath the site and the depths at which the soils and the groundwater are found. Further information may then be obtained by carrying out laboratory tests on disturbed or tube samples.

Pros and cons of light percussion drilling

Advantages

- Light percussion drilling can be used to make deeper holes in a wide range of ground conditions. This is the normal method of investigation for civil engineering projects and for medium-rise construction
- This technique is also frequently used for the investigation of low-rise building sites when greater than normal depths of investigation are required (perhaps due to the presence of pre-existing slope instability, or fill, or in cases where deep clay desiccation is suspected).

Disadvantages

- Light percussion drilling is considerably more expensive than shallow trial pitting and shallow augering.

Backfilling

Once boreholes and trial pits have been completed, it is important that they are properly backfilled. If the soil excavated from trial pits is simply tipped loosely back into the hole from which it has been excavated, it will be in a much weaker and more compressible state than before excavation took place. Foundations placed over old pits may suffer excessive differential settlement, and the sides of temporary excavations may collapse. Poorly backfilled boreholes are less of a hazard to spread or strip foundations, but may affect small-diameter piles, and may allow unwanted ingress of surface water or mixing of ground and surface water.

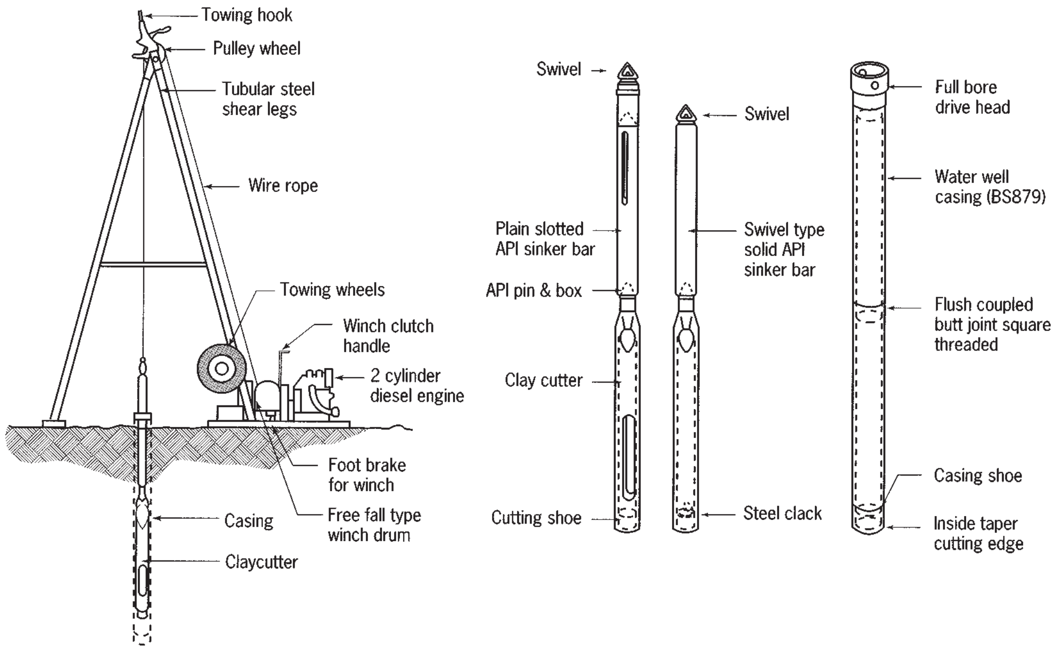
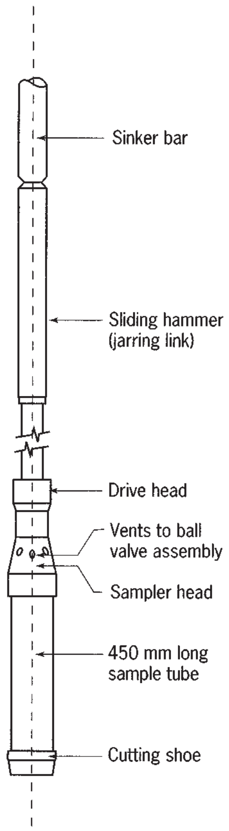


Figure 4 Light percussion drilling rig and tools



Courtesy of Wykeham Farrance Engineering

Sample tubes and accessories

Figure 5 Tube sampling equipment

Soil sampling

Soil samples are classified as *undisturbed* or *disturbed*. When sampling is carried out badly, it is also possible to obtain *unrepresentative* samples, eg samples which do not contain representative fractions of all the particle sizes that are found in the ground. Obviously, such samples should not knowingly be taken.

When water is encountered, water samples are often taken for laboratory chemical analyses.

Undisturbed sampling is normally confined to cohesive soils (like clays), and is carried out by pushing or hammering tubes into the ground. These samples are required for strength and compressibility testing in the laboratory. Disturbed samples are easier and cheaper to obtain, and are used in all soil types. However, the testing that can be carried out on them will be more restricted.

All sample types must be sealed as soon as practical after they are taken from the ground, in order to minimise the loss of moisture during storage and before testing.

Methods for soil sampling in trial pits

- Obtain disturbed material from the face with the excavator bucket during excavation
- Hammer 38 mm diameter tubes into the sides or base of the excavation, using a hand-held hammer with a 'jarring link' (Fig 5)
- Push standard 100 mm diameter tubes (U100's) into the ground with the excavator bucket
- Hand-cut 'block samples'(when time and money permit).

Methods for soil sampling when carrying out light percussion boring

- Obtain disturbed material from the drilling tools as drilling proceeds. Small disturbed samples (sometimes termed 'jars', weighing about 2 kg) are normally taken from fine-grained soils, such as clays, silts and peats. Large disturbed samples (termed 'bulk bags', weighing 25–50 kg) are required from coarse granular soils, such as gravels. Representative samples cannot normally be obtained from soils containing cobbles or boulders.
- Hammer — or, in special circumstances, jack — standard 100 mm diameter tubes (U100's) into the base of a borehole.

Basic laboratory testing

Laboratory tests are carried out in order to:

- Examine the natural variability of the soil (*index tests*)
- Classify the soils that have been sampled into groups with broadly similar engineering behaviour (*classification tests*)
- Determine parameters and values for engineering design and calculation (*parameter tests*).

The tests most commonly used during low-rise building site investigations are shown in Table 4. Moisture content, Atterberg limit, particle size distribution, pH and sulfate tests can be carried out on either tube (undisturbed) or disturbed samples, but good-quality tube or block samples are required for filter paper suction tests and triaxial and oedometer tests.

In-situ testing

Many different types of in-situ test are available[(1)], but only a few are used in the routine investigation of low-rise building sites.

Common types of test

- Probing, using either lightweight dynamic penetrometers or the Cone Penetration Test (CPT) is generally carried out from the surface, without the need for boreholes
- The Standard Penetration Test (SPT), in light percussion boreholes
- The field vane test, carried out from the surface, in trial pits or light percussion boreholes.

Because it is carried out from ground surface, without the need for a borehole, probing is very fast and economical. It can provide good information on the variability of soil conditions across a site, but does not allow visual examination and description of the soil.

The SPT is routinely used in conjunction with light percussion boring, to obtain information on the density of granular soils. It can also be used to obtain data on the undrained shear strength of heavily-overconsolidated cohesive soils.

The vane test is used solely to obtain data on the undrained shear strength of relatively weak and compressible clays. It cannot be used in stiff, very stiff or hard clays, because the equipment is likely to be damaged.

The advantages and disadvantages of these different test methods are summarised in Table 5 opposite.

Table 4 Laboratory tests commonly used during site investigations for low-rise building

Class of test	Parameter (and example of use)	Type of test	Type of sample
i	Moisture content (soil variability)	Moisture content	u, d
i, c	Atterberg limits (identification of shrinkable clays)	Liquid limit, plastic limit	u, d
i, c	Particle size distribution (identification of soil type)	Particle size distribution	u,d
i, p	Soil suction (identification of desiccated clays)	Filter paper suction test	u
p	Undrained shear strength (bearing capacity of foundations)	Undrained triaxial test	u
c, p	Coefficient of compressibility (settlement of foundations)	Oedometer consolidation test	u
c, p	pH of soil or groundwater (specification of foundation concrete)	pH test	u, d, w
c, p	Sulfate content of soil or groundwater (specification of foundation concrete)	Sulfate tests	u, d, w

i = Index
c = Classification
p = Parameter

u = Undisturbed
d = Disturbed
w = Water

Table 5 In-situ tests commonly used during site investigations for low-rise buildings

Test method	Applications	Advantages	Disadvantages
Dynamic probing	● Soil profiling ● Identifying soft spots ● Assessing ground variability	● Very fast, ● Inexpensive ● Able to cover large areas in detail	● Unable to determine soil type ● Cannot penetrate coarse soils (cobbles) or hard layers
CPT	● Soil profiling ● Identifying soft spots or cavities ● Assessing ground variability ● Assessing soil type, undrained strength and compressibility	● Very fast, ● Relatively inexpensive ● Able to cover large areas in detail	● Cannot penetrate dense or coarse granular soils, hard layers or rocks
SPT	● Density and effective angle of friction in sands and gravels ● Assessment of undrained shear strength in clay	● Simple, rugged equipment which works in all ground	● Test affected by boring disturbance
Field vane	● Determination of undrained shear strength of clays	● Allows in-situ strength determination	● Useful only in soft–firm clays

Probing is carried out by dynamic or quasi-static methods. Both may be useful during the direct investigation of low-rise building sites. For most types of probing it is not necessary to make boreholes, and the rate at which ground can be investigated is therefore extremely rapid. However, soil samples are not generally available, so visual soil description is not possible.

Quasi-static cone penetration testing

The quasi-static cone penetration test (CPT) [2] is sometimes considered to be probing, and sometimes to be in-situ testing.

This technique involves hydraulically pushing a 10 or 15 cm^2 cone into the ground, at a standard rate of penetration (2 cm/sec), and measuring its penetration resistance (Fig 6). Modern electric cones are also equipped with a 'friction sleeve', which measures the shear stress applied by the soil as the sleeve passes through it. The ratio between cone resistance (expressed in units of stress) and side shear is termed 'friction ratio', and is used to estimate the type of soil through which the cone is being driven – see BS 1377 and BS 5930.

The special electronic and hydraulic equipment necessary for the test is housed in a large truck so access may be restricted on difficult sites. Light-weight tracked or tractor-mounted equipment is also available for use in soft or difficult ground conditions. There are also limitations on the hydraulic thrust available to push the cone into the ground, so that penetration of dense coarse soils may be impossible. However, progress is normally extremely rapid and a great deal of information can be obtained, not only concerning the soil profile, but also its type and its strength or density.

Figure 7 shows the results from an electric CPT. These are best interpreted by specialists, experienced in this type of work. The information which can be obtained includes:

- The soil profile
- Estimates of the soil types encountered, including consistency (in cohesive soils) and density (in granular soils)
- Preliminary estimates of the properties of the soil, including the undrained shear strengths of clays, the effective angle of friction of granular soils and their compressibilities
- Evidence of the presence of voids beneath the site.

Additional sensors can also be incorporated into the CPT to assess other ground properties, including contamination, but generally at considerable extra cost.

The equipment is housed in a large truck

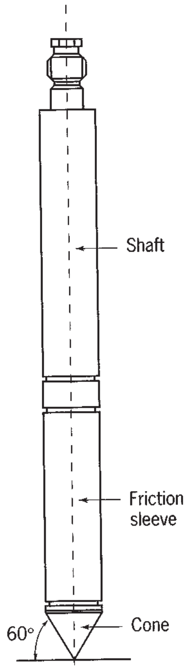


Figure 6 Electric cone penetration test equipment

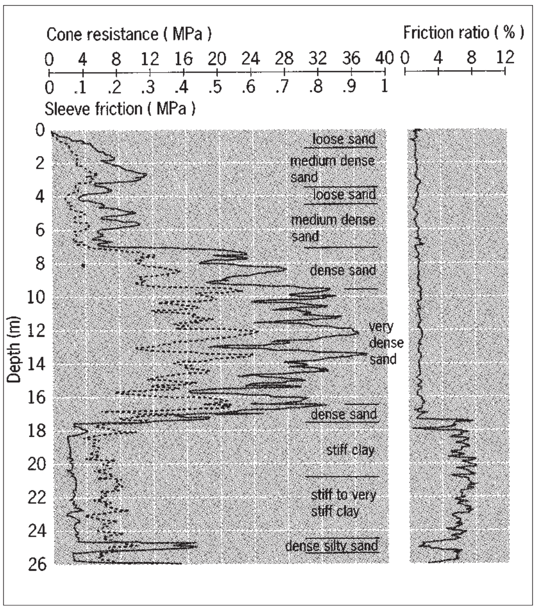


Figure 7 Results from a typical cone penetration test

Dynamic probing

Dynamic probing is much less sophisticated than CPT. It involves driving a steel rod (often with a specially shaped and hardened tip) into the ground, by using repeated blows of a hammer of a specified mass falling through a fixed distance. The number of blows required for each increment of penetration (eg 100 mm) is recorded, and plotted as a depth v blow-count log (Fig 8).

Different types of dynamic penetrometer are used around the world. Several types are in common use in the UK. Table 6 gives details of common dynamic penetrometers, showing the variations in the energy that they deliver. In general, higher energies per blow are required to achieve greater depths, to penetrate stronger and denser soils, and to penetrate coarser granular soils.

A detailed account of the SPT test and its use is available from the Construction Industry Research and Information Association (CIRIA) [3].

The apparatus is very light, and can be taken to site in a conventional van and quickly manhandled into position by one or two people. In terms of metres probed per day, rates of output are high, so that the cost per metre for probing is much lower than that for boring or trial pitting. The information given by probing is, however, very restricted, and is difficult to interpret in the absence of results obtained with more definitive techniques, such as boring or trial pitting.

The most useful application of probing is in determining the variability of a site, by making probe holes on grid lines at regular intervals across a site. Areas where unusually low or high penetration resistances are encountered can then be the subject of further investigation by trial pitting or boreholes. Another application of this technique is to determine the thickness of soft or loose material overlying more competent ground, perhaps where this is the proposed level for foundations. Probing will rapidly determine the depth of a thin layer of poor ground across a wide area, with little disruption and at low cost.

Lightweight dynamic probes cannot penetrate hard layers or very coarse soils, such as cobbles and boulders. In such circumstances their use will be restricted, since the aim of any investigation should be to investigate the depth of all soft, loose and unconsolidated materials, even when they are overlaid by stronger soils.

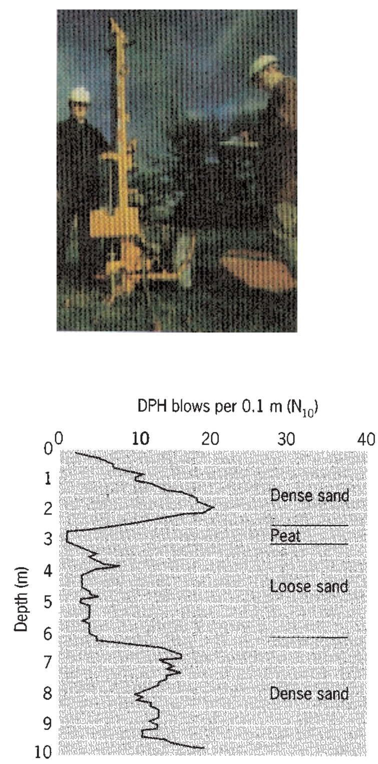
The Standard Penetration Test

The Standard Penetration Test [3] involves driving a 52 mm outside diameter 'split spoon' open-drive sampler (Fig 9) into the bottom of a borehole, with repeated blows of a hammer of 62.5 kg mass falling 760 mm. In the UK an automatic trip hammer ensures a correct height of fall for the hammer weight.

The number of blows necessary to drive the split spoon six increments of 75 mm are counted and recorded. The blows for the first two increments of 75 mm are discounted, because they are considered to be affected by boring disturbance. The final four blow counts, for the last 300 mm of the test, are added together to give the penetration resistance, *N* (reported as blows/300 mm). In granular soil the *N* value is corrected for overburden pressure.

Field vane test

The field vane test uses a cruciform rectangular 4-bladed vane, which is pushed on thin rods ahead of the borehole in order to reach clay which is relatively unaffected by drilling disturbance. Equipment at the ground surface (Fig 10) allows the vane to be rotated via the rods whilst the torque being applied to it is measured. The maximum torque is recorded, and can be interpreted in terms of the undrained shear strength of the clay (ref [1] and BS 1377).



DPH: see BS 1377:1990

Figure 8 Dynamic probing apparatus and results

Table 6 Details of common dynamic penetrometers

Factor	Test specification				
	DPL	DPM15	DPM	DPH	DPSH
Hammer mass (kg)	10±0.1	30±0.3	30±0.3	50±0.5	63.5±0.5
Height of fall (m)	0.5±0.01	0.5±0.01	0.5±0.01	0.5±0.01	0.75±0.02
Mass of anvil + guide rod (max), (kg)	6	18	18	18	30
Rod length (m)	1±0.001	1±0.001	1±0.001	1±0.001	1±0.001
Mass of rod (max), (kg)	3	6	6	6	8
Rod eccentricity (max), (mm)	0.2	0.2	0.2	0.2	0.2
Rod OD (mm)	22±0.2	32±0.2	32±0.2	32±0.2	32±0.3
Cone apex angle (degrees)	90	90	90	90	90
Cone area (nominal), (cm^2)	10	15	10	15	20
Cone diameter (mm)	35.7±0.3	43.7±0.3	35.7±0.3	43.7±0.3	50.5±0.5
Mantle length (mm)	35.7±1	43.7±1	35.7±1	43.7±1	50.5±2
Number of blows:per *x* cm penetration	N_{10}:10	N_{10}:10	N_{10}:10	N_{10}:10	N_{20}:20
Standard range of blows	3–50	3–50	3–50	3–50	5–100
Specific work/blow (kJ/m^2)	50	98	150	167	238
References					
BS 1377:1990	—	—	—	✔	✔
International Reference Test Procedure (4)	✔	—	✔	✔	✔

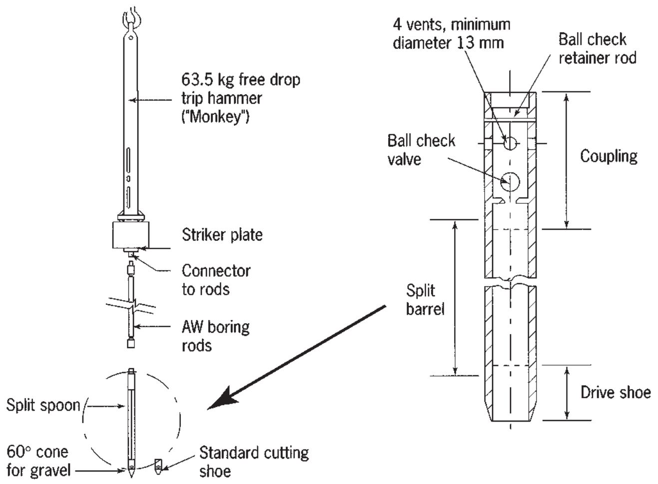


Figure 9 Standard penetration test equipment

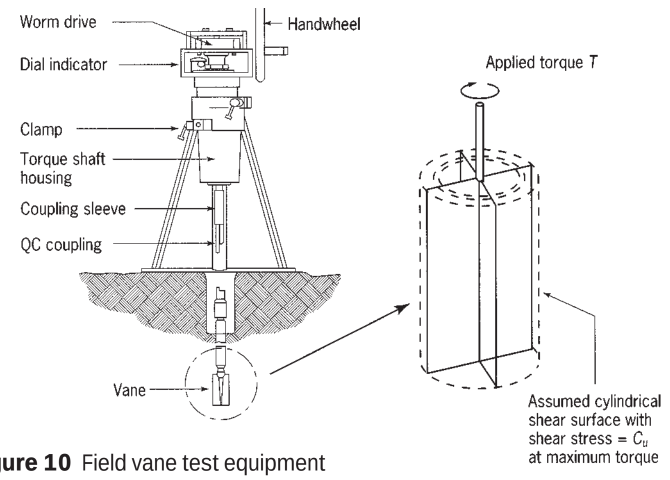


Figure 10 Field vane test equipment

References and further reading

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