CHAPTER 4: Site Investigation Reports, Geology and Contamination

CONTENTS

FUNCTIONAL REQUIREMENTS

SITE INVESTIGATION REPORTS, GEOLOGY AND CONTAMINATION

Workmanship

i. All work to be carried out by a qualified and technically competent person in a workmanlike manner.

Materials

i. All samples to be stored and kept in such a way that will not cause inaccuracy when soils are tested.

Design

i. The design and specifications shall provide a clear indication of the design intent and demonstrate a satisfactory level of performance.

ii. The site investigation should be completed at an appropriate level for the risk in accordance with the relevant British Standard.

iii. Site investigation and remedial measures must meet the relevant Building Regulations, British Standards, Eurocodes and other statutory requirements (refer to Appendix 2a for a list of standards referred to)

These Functional Requirements apply to the following sections of this Chapter:

4.1 Introduction and objectives

4.2 Roles and responsibilities

4.3 Flow chart of site investigation process

4.4 Phase 1: Geoenvironmental Assessment (Desk Study)

4.5 Phase 2: Geoenvironmental Assessment (Ground Investigation)

4.1 INTRODUCTION

This Chapter sets out the requirements for an acceptable site investigation. It is intended to be flexible and user-friendly, and includes simple checklists aimed at ensuring compliance. The aim is to raise standards in the interests of both the Warranty provider and the Builder or Developer. This will lead to a safe and economic design that will minimise the risk to all those involved in the project.

Where projects run over time and over budget, this is usually as a direct result of problems within the ground. It is therefore vitally important to reduce the risk of unforeseen conditions that can directly affect the overall cost of the project. It is believed that Builders and Developers will view this work as an important safeguard, rather than unnecessary expenditure.

To ensure a consistently high standard, all stages of the work should be carried out by a Chartered Engineer or Chartered Geologist with at least five years' experience of this type of work. Specifying properly qualified personnel will considerably increase the overall industry standard.

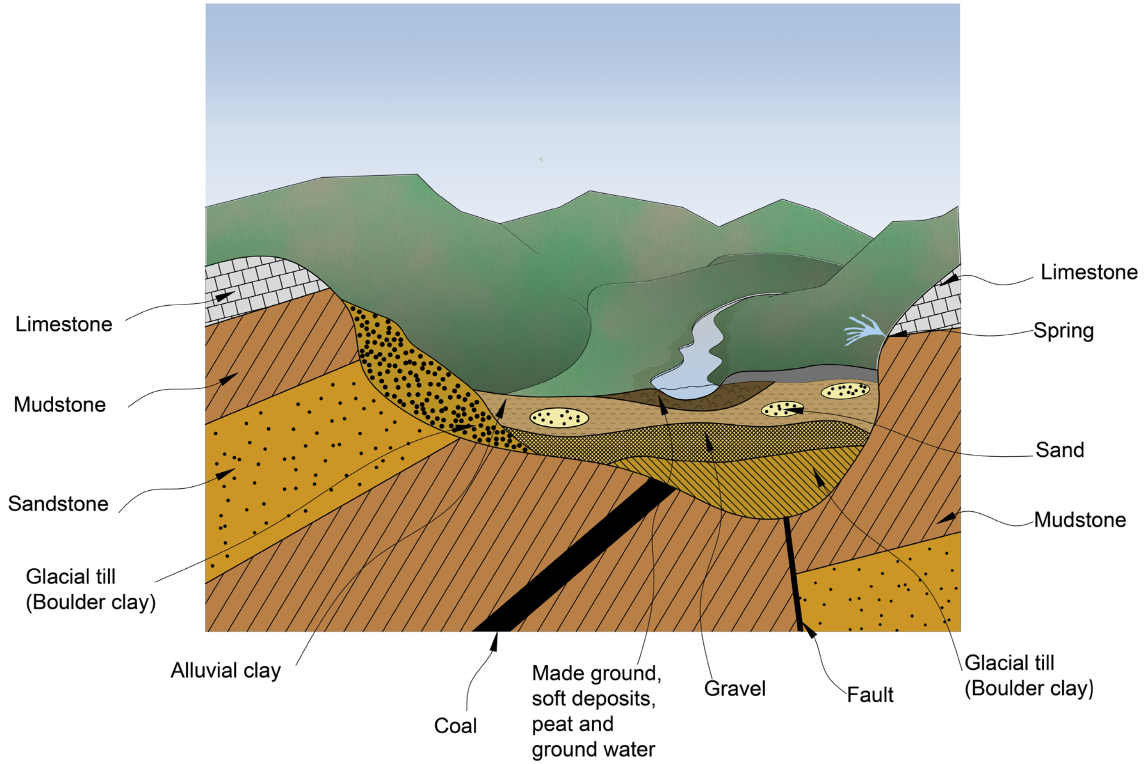


Figure 1: The geological environment: cross section of a river valley

4.2 ROLES AND RESPONSIBILITIES

The roles and responsibilities of those parties involved in the development are the Owner, Developer, Builder and Self Builder.

4.2.1 Owner/Developer/Builder/ Self Builder

The provision of clear development proposals for the site, and the implementation of a competent site investigation using appropriately qualified personnel, is now a priority for Regulators. These demonstrate that any geotechnical and contaminated land risks can be safely dealt with. Specific Health and Safety responsibilities, in particular the CDM Regulations, also require compliance.

4.2.2 Environmental Health/ Contaminated Land Officer

The provision of advice to the local Planning Department on technical matters and planning conditions requires a competent and comprehensive site investigation and associated Risk Assessment.

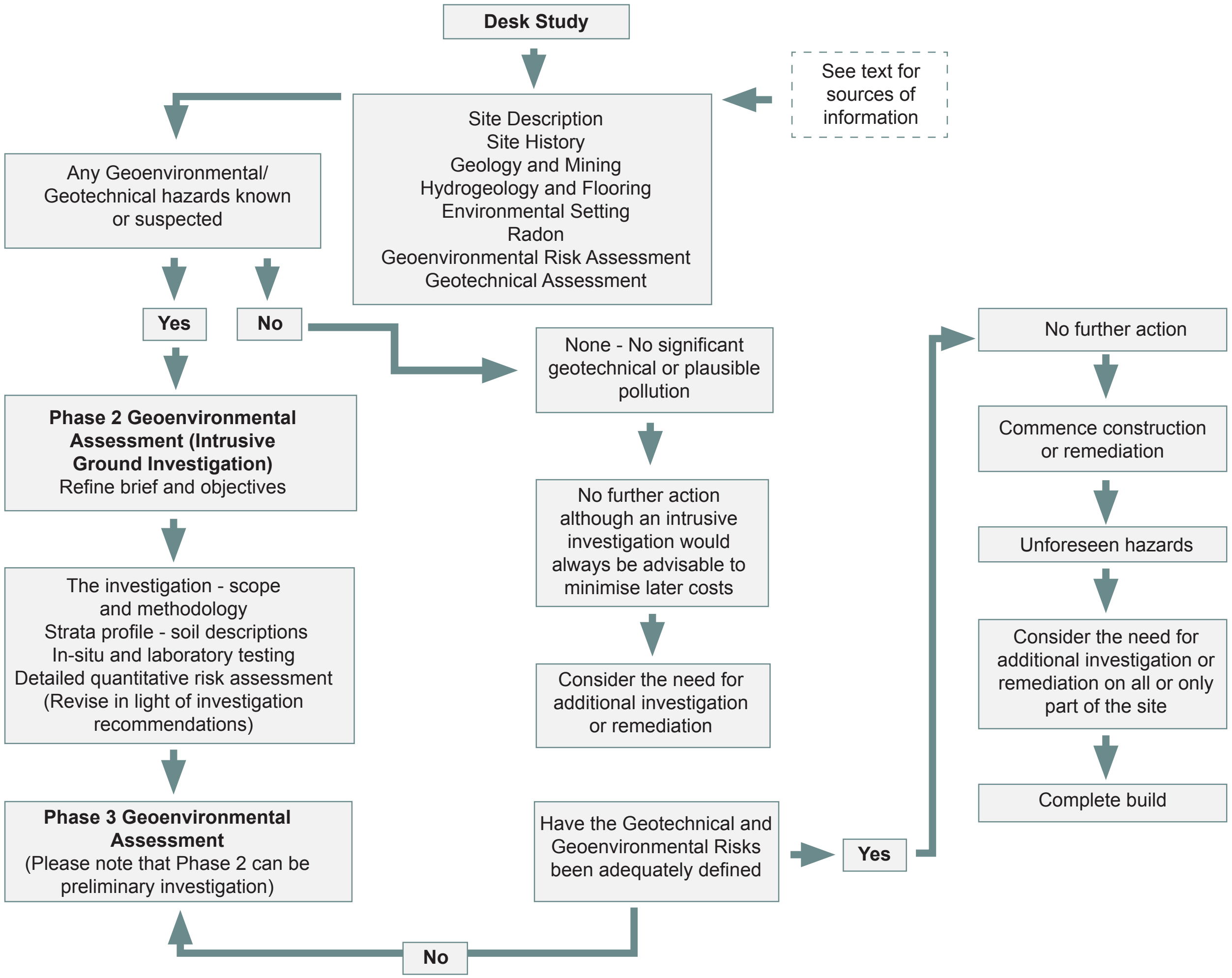
4.2.3 Local Authority Building Control

Building Control is responsible for enforcing the Building Regulations, which also requires a competent and comprehensive site investigation.

4.2.4 Health and Safety Executive

The HSE are responsible for Health and Safety at work, including the CDM Regulations

4.3 FLOW CHART OF SITE INVESTIGATION PROCEDURES



4.4 PHASE 1: GEOENVIRONMENTAL ASSESSMENT (DESK STUDY)

4.4.1 Introduction

The aim of the Phase 1 Geoenvironmental Assessment is to identify and assess the potential geotechnical and geoenvironmental (contamination) hazards on the site. Since all sites are different, it is important to identify the scope and purpose of the desk study. This will include who commissioned the work, the development proposals, the relevant procedures followed and the objectives. Any issues specifically excluded should also be noted if these might normally be expected as part of the desk study.

4.4.2 Site description

The site description should define the exact extent of the site, and should include a site address, grid reference and elevation. The boundaries and topography of the site should be defined.

A site inspection should always be carried out not only of the site itself, but also the immediate surrounding area. This should include any information not apparent from the maps and describe what currently occupies the site, such as buildings, hard standing, watercourses, vegetation, trees and any particular features.

The type and distribution of vegetation can indicate soil and ground water conditions, and note should be made of any invasive plants, such as Japanese Knotweed and Giant Hogweed.

Adjacent features and land use should be reported if there is likely to be an impact on the development. It is not uncommon for features such as tanks to be known about but unrecorded.

The walkover should note any potential sources of contamination and geotechnical hazards, such as slopes, excavations, land slipping, ground subsidence, soft ground or desiccated/shrinkable soils.

All structures on the site should be inspected both internally and externally for any evidence of structural damage, such as tilting, cracking or chemical attack. Any evidence of underground features should be noted. Where practical, the local residents can often give valuable information, although caution should be used in respect of their ‘memories’. Local place names can give useful indications of former uses, e.g. Gas Works Lane, Water Lane, Tannery Road, etc. Aerial photographs and their interpretation can also prove helpful.

A photographic record of the site, and any specific features of the site, should be included with the report.

4.4.3 Site history

The history of the site and the surrounding areas is extremely important when assessing the likelihood of contamination or geotechnical hazards. Historical Ordnance Survey maps date back to the mid-19th Century and often specify the actual industrial use of particular sites or buildings. They may show areas of quarrying or infilling, and indicate where buried obstructions, such as underground tanks or old foundations, can be expected.

The influence or impact of off-site past industrial use will depend upon the type of industry, the underlying geology and the topography. However, consideration should normally be given to any such features within a 250m radius of the site (or further where appropriate) with the potential to affect it.

Historical maps are available from libraries and commercial providers, such as GroundSure or Envirocheck. The latter provide a cost-effective method of obtaining maps, and include the ability to superimpose current site boundaries on older maps. Issues regarding possible breaches of copyright are also avoided by using licensed products.

It should be remembered that historical maps only provide a snapshot in time, and care must be taken when interpreting what may have occurred in the intervening years. For example, a quarry may be shown on one map and infilled on the next. However, in the intervening period, it could have expanded prior to infilling; similarly, industrial uses may not always be recorded, while many military or sensitive uses may have been omitted. Other sources of information may include the ubiquitous internet search and historical aerial photographs. Additionally, it may be necessary to search the libraries of Local Authorities and Local History departments.

4.4.4 Geology and mining

The geology of the site should be recorded by reference to published geological maps, which most commonly exist at 1:50,000 (1 inch to 1 mile) and 1:10,000 (6 inch to 1 mile). The British Geological Survey Geo-Index also provides existing ground investigation records, including logs and reports. It should be noted that these records can relate not only to the surrounding areas but may also include previous investigation of the site itself. The information on the geological maps can also be supplemented with British Geological Survey technical reports, flood risk appraisals and memoirs.

The bedrock geology, any overlying superficial deposits and the effects of weathering should all be described, together with any geological faults that may affect the site. An explanation of the likely ground conditions should be given, together with reference to any other mapped geological features, particularly if there are likely to be any natural cavities or solution features.

4.4.4.1 Mining areas

In former coalfields, or other areas of mineral extraction, the maps may not always record the presence of old or active workings. The likelihood of shallow coal workings affecting surface stability should be established in conjunction with a Coal Authority report. Such reports also record areas that have been affected by the extraction of brine, which is particularly prevalent in the Cheshire area. Other forms of mineral extraction will require site-specific research.

The potential for mine workings and mine entries within an influencing distance of the proposed development should be addressed by a suitably qualified and experienced Engineer prior to commencement of works, and in accordance with CIRIA SP 32: Construction Over Abandoned Mine Workings, 2002.

Reference should be made to reports on geological hazards, such as Envirocheck or GroundSure reports, both on-site and locally.

4.4.4.2 Solution features in chalk

Solution features (such as pipes, swallow holes and solution cavities, sometimes loosely infilled with drift deposits) are commonly found in chalk, caused by water draining through the chalk and dissolving it. The risk of solution features should be addressed in the Site Investigation Report (commonly from an Envirocheck or GroundSure report on geological hazards, both on-site and locally).

Hazard maps are available with different coloured areas representing different levels of risk. Where the risk is moderate or high, special precautions should be taken, which for strip foundations would include careful inspection of the excavation, probing and use of reinforcement to span potential voids.

Where piled foundations are used, CIRIA PR 86 recommends “that a CPT (Cone Penetration Test) is undertaken at each pile location at sites identified during desk studies to be prone to dissolution”. Alternatively, in some instances it can be appropriate to design the pile for shaft friction alone, assuming that the pile has no end bearing due to a solution feature below it. In extreme circumstances where a site investigation borehole has encountered an extensive solution feature, the shaft friction may also be reduced to take account of this.

The potential effects of soakaways, leaking drains, run off, etc. on the chalk will need to be considered and addressed in the design.

CIRIA C574: Engineering in Chalk, 2002 gives the following recommendations:

Concentrated ingress of water into the chalk can initiate new dissolution features, particularly in low-density chalk, and destabilise the loose backfill of existing ones. For this reason, any soakaways should be sited well away from foundations for structures or roads, as indicated below:

- In areas where dissolution features are known to be prevalent, soakaways should be avoided if at all possible but, if unavoidable, should be sited at least 20m away from any foundations.
- Where the chalk is of low density, or its density is not known, soakaways should be sited at least 10m away from any foundations.
- For drainage systems, flexible jointed pipes should be used wherever possible; particular care should be taken for the avoidance of leaks in both water supply and drainage pipe work.
- As the chalk is a vitally important aquifer, the Environment Agency and Local Authority must be consulted when planning soakaway

installations where chalk lies below the site, even where it is mantled with superficial deposits.

4.4.5 Hydrogeology and flooding

The assessment should include the flood risk and hydrogeology of the site, particularly whether the site lies on a Principle Aquifer and/or Source Protection Zone, which are both susceptible to pollution of ground water. The presence of surface water features and drainage should be described, and the overall risks of flooding to the site should be determined, primarily with reference to the Environment Agency flood map data and Local Authority-commissioned Strategic Flood Risk Assessments. Flood risk data is continually being updated by the Environment Agency and Local Authority.

Any ground water or surface water abstraction points 'downstream' of the site, particularly any potable (drinking water) abstraction points, should be recorded, as this may have liability implications should the development cause any pollution.

4.4.6 Environmental setting

The question as to whether a site poses an actual or potential environmental risk, or is at some external risk from pollution, will be determined by its environmental setting. This will in turn depend upon the site's topography, geology, hydrogeology and hydrology, amongst other site-specific considerations.

It is necessary to consider other potential sources of contamination, such as pollution control licenses, discharge consents, hazardous sites (COMAH, NIHHIS), pollution incidents, landfills, waste treatment sites and past and current industrial sites.

Current industrial operations rarely provide a risk of pollution to a site. Pollution is most likely to have been caused by historical activities and processes that were often deemed normal practice in the past, but which are considered unacceptable today. In this regard, the past history is invariably highly significant in respect of possible ground pollution.

The site should be considered in relation to any designated environmentally sensitive sites, such as Special Areas of Conservation, Special Protection Areas, Nature Reserves and Sites of Special Scientific Interest. In particular, could contamination on the site be affecting such sensitive areas, whether these are on or adjacent to the study site?

Data relating to current industrial licensing, consents and the like, together with information relating to environmentally sensitive sites, is typically available through commercial data suppliers. As with the historical maps, this is usually a cost-effective method of obtaining data.

For both the historical maps and datasets, there is usually little or no interpretation of the information, and it is essential that this interpretation is carried out by an experienced and qualified individual. Automated Risk Assessments do not include appraisal by qualified staff, and should therefore be viewed with caution and are not usually acceptable to Regulators. An example of this was a contaminated former petrol filling station site recorded as having no past industrial use. The historical maps never recorded the site as a filling station, nor did the environmental data. However, the walkover quickly identified former bases for pumps and filling points for underground storage tanks (USTs).

4.4.7 Radon

The need to incorporate radon protection measures should be determined by reference to risk maps produced by the Health Protection Agency. Such information is also usually included within commercially available datasets.

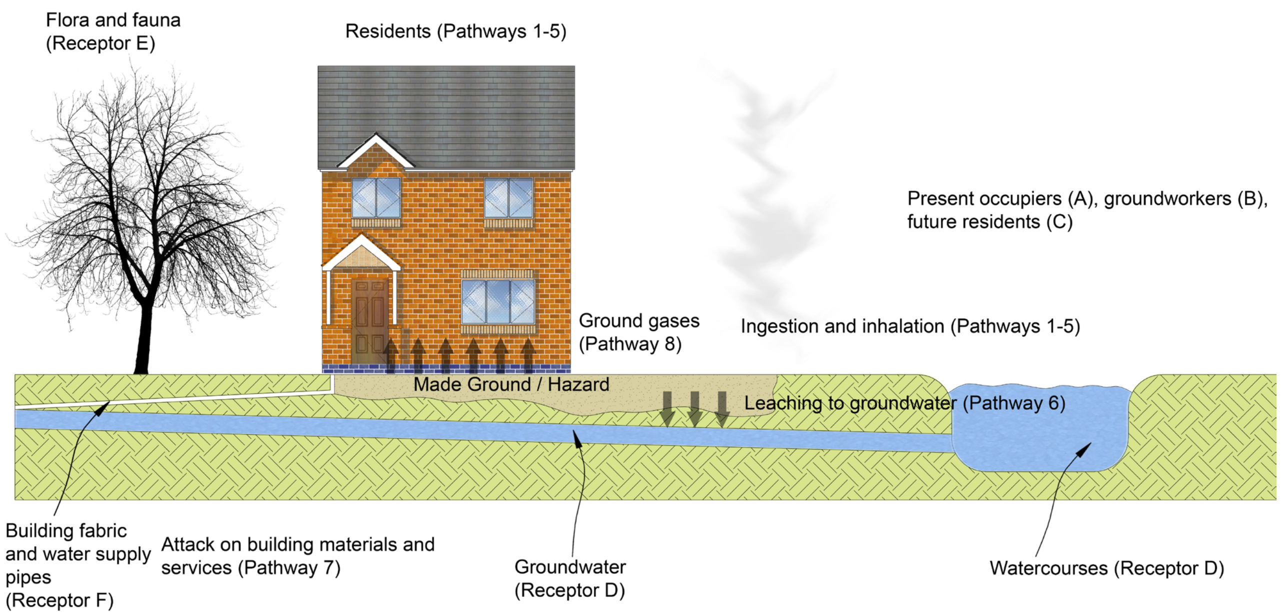
4.4.8 Geoenvironmental Risk Assessment and conceptual site model

A quantitative health and environmental Risk Assessment should be carried out as part of the assessment. The process of Risk Assessment is set out in Part IIA of the Environment Protection Act 1990, and amended in subsequent legislation.

This Act introduces the concept of a pollution linkage, which consists of a pollution (contaminative) source or hazard and a receptor, together with an established pathway between the two. For land to be contaminated, a pollution linkage (hazard-pathway-receptor) must exist; this forms a so-called 'conceptual model' of the site.

Source → Pathway → Receptor

Examples of pathways and the effects of land contamination (after PPS 23) are shown on Figure 2: Pathways of potential contaminants.



Pathways

1. Ingestion of contaminated soil/dust
2. Ingestion of contaminated food
3. Ingestion of contaminated water
4. Inhalation of contaminated vapours
5. Dermal contact with contaminated soil/dust or water
6. Pollution of controlled water and off site migration
7. Attack on building materials and services
8. Migration of landfill gases and radon

Receptors

A. Present site occupiers
B. Site development personnel
C. Future residents
D. Controlled waters
E. Flora and fauna
F. Building and services

Figure 2: Pathways of potential contaminants

4.4.8.1 Human health (pathways 1–5, receptors A–C)

There is an uptake of contaminants by food plants grown in contaminated soil. The uptake will depend on their concentration in the soil, their chemical form, soil pH, plant species and prominence in diet.

Ingestion and inhalation

Substances may be ingested directly by young children playing on contaminated soil if they eat plants that have absorbed metals or are contaminated with soil or dust. Ingestion may also occur via contaminated water supplies. Metals, some organic materials and radioactive substances may be inhaled from dusts and soils.

Skin contact

Soil containing tars, oils and corrosive substances may cause irritation to the skin through direct contact. Some substances, e.g. phenols, may be absorbed into the body through the skin or through cuts and abrasions.

Irradiation

As well as being inhaled and absorbed through the skin, radioactive materials emitting gamma rays can cause a radiation response.

Fire and explosion

Materials such as coal, coke particles, oil, tar, pitch, rubber, plastic and domestic waste are all combustible. Both underground fires and biodegradation of organic materials may produce toxic or flammable gases. Methane and other gases may explode if allowed to accumulate in confined spaces.

4.4.8.2 Buildings (pathways 7 and 8)

Fire and explosion

Underground fires may damage services and cause ground subsidence and structural damage. Accumulations of flammable gases in confined spaces leads to a risk of explosion.

Chemical attack on building materials and services

Sulphates may attack concrete structures. Acids, oils and tarry substances may accelerate the corrosion of metals or attack plastics, rubber and other polymeric materials used in pipework and service conduits or as jointing seals and protective coatings to concrete and metals.

Physical

Blast-furnace and steel-making slag (and some natural materials) may expand. Degradation of fills may cause settlement and voids in buried tanks, and drums may collapse as corrosion occurs or under loading.

4.4.8.3 Natural environment (pathway 6, receptors D–E)

Phytotoxicity
(prevention/inhibition of plant growth)

Some metals essential for plant growth at low levels are phytotoxic at higher concentrations. Methane and other gases may give rise to phytotoxic effects.

Contamination of water resources

Soil has a limited capacity to absorb, degrade or attenuate the effects of pollutants. If this is exceeded, polluting substances may enter surface and ground waters.

Ecotoxological effects

Contaminants in soil may affect microbial, animal and plant populations. Ecosystems or individual species on the site, in surface waters or areas affected by migration from the site may be affected.

For any contaminant source identified, judgement is required to assess the probability of a pollution linkage occurring and the potential consequences of that linkage. Based on the probability and likely consequences, the overall risk (significance) can be established. The definitions that are used for this purpose should be clearly stated.

The probability of a hazard, combined with its consequences, can be used to assess risk, and this forms the so-called Conceptual Site Model.

This is in accordance with the Statutory Guidance for Contaminated Land (Defra 2006).

The following tables may be used to explain the decision-making process:

Severe	Damage to human health Substantial pollution of controlled waters Significant change in ecosystem population Irreparable damage to property
Moderate	Non-permanent damage to human health Minor pollution of controlled waters Change in ecosystem Damage to property
Mild	Short term health effects Slight pollution of controlled waters Slight effect on ecosystem Minor repairable damage to property
Near zero	No noticeable effect on human health No significant pollution to controlled waters No measurable effect on ecosystem densities Non-structural cosmetic damage to property

Table 1: Consequences of pollution linkage

Probability of a hazard and an associated linkage	**Consequences of a pollution linkage (hazard-pathway-target)**			
	Severe	**Moderate**	**Mild**	**Near zero**
High	Very High	High	Medium/Low	Low/Negligible
Medium	High	Medium	Low	Low/Negligible
Low	High/Medium	Medium/Low	Low	Negligible
Unlikely	High/Medium/Low	Medium/Low	Low	Negligible

Table 2: Decision making

Final overall risk is based on an assessment of the probability of a hazard and its consequences. Risk categories are shown shaded in the table above and are defined below.

Risk	**Description of risk levels**
High	Site probably or certainly unsuitable for present use or environmental setting. Contamination probably or certainly present and likely to have an unacceptable impact on key targets. Urgent action needed.
Medium/ Moderate	Site may not be suitable for present use or environmental setting. Contamination may be present, and likely to have unacceptable impact on key targets. Action may be needed in the medium term.
Low	Site considered suitable for present use and environmental setting. Contamination may be present but unlikely to have unacceptable impact on key targets. Action unlikely to be needed in present use.
Negligible	Site considered suitable for present use and environmental setting. Contamination may be present but unlikely to have unacceptable impact on key targets. No action needed while site remains in present use.

Table 3: Overall risk

4.4.9 Geotechnical assessment

Although no intrusive investigation may have been carried out on the site at the desk study stage, it should be possible to give preliminary indications in respect of the geotechnical matters set out below:

Foundations	Are normal to deep strip footings likely to be suitable or may piling or ground improvement be necessary? Will made ground, old foundations, cellars or services be encountered?
Mining and quarrying	Will the possibility of shallow mine workings or quarrying on the site need to be addressed?
Soakaways	Are soakaways likely to be suitable based on the mapped geology? (Actual on-site permeability tests would need to be carried out to determine suitability or not).
Roads	What is the sub-grade strength (CBR) likely to be? (The actual design will be dependent on the CBR measured on-site).
Excavations	Will soft ground plant be suitable or will rock breakers be needed for deeper excavation?
Ground water	Is shallow ground water expected?
Earthworks	Are any significant earthworks anticipated?
Gas protection	Will gas protection measures be required or would they be prudent in accordance with good practice?

Table 4: Geotechnical assessment: preliminary indicators

The above can only be provided on the basis of limited site data, and it is recommended that the scope of any intrusive ground investigation is set out here if the desk study is to be presented as a stand-alone document.

4.5 PHASE 2: GEOENVIRONMENTAL ASSESSMENT (GROUND INVESTIGATION)

4.5.1 Pre-ground investigation

The initial investigation should comprise a desk study as described in Section 4.3 of this Chapter.

4.5.2 The investigation

After the desk study has been carried out, the objective of the intrusive investigation is to provide detailed information for the safe and economic development of the site at minimum cost. Clearly, no guarantee can be given that all relevant conditions will necessarily be identified, but the work carried out should be aimed at reducing risk to acceptable levels.

Increasing expenditure on the site investigation will reduce the risk of unforeseen conditions, but professional judgement and experience is also required. Not all forms of investigation will be needed, and that which is necessary in the best interests of the client should be carefully assessed for each individual project.

The investigation must be designed to provide the appropriate level of information on ground and ground water conditions on the site, together with identifying potential areas of contamination. The investigation should be undertaken in accordance with the principles of:

- BS EN 1997-1: 2004 Eurocode 7 – Geotechnical design – Part 1: General rules
- BS EN 1997-2: 2007 Eurocode 7 – Geotechnical design – Part 2: Ground investigation and testing
- BS 5930: 1999 and BS 10175: 2001

It will also require the full-time supervision of a Chartered Geologist or Chartered Engineer.

The dates of the investigation and the methods used should be stated, with the exploratory hole positions being shown on a drawing.

An intrusive investigation may comprise the following:

4.5.2.1 Trial pitting

Normally, these should be at least three times the foundation depth where possible, or sufficient to prove competent bedrock. They should be excavated outside proposed foundation positions where possible. On completion, the excavations are normally backfilled with the arisings.

This method enables soil conditions to be closely examined at any specific point and samples to be taken. It also gives useful information on the stability of excavations and water ingress. In-situ gas, strength and California Bearing Ratio (CBR) tests can also be carried out.

4.5.2.2 Window sampling

Window sampling consists of driving a series of 1m and 2m long tubes into the ground using a dropping weight. On completion of each run, the tube is withdrawn. The next tube is then inserted and the process repeated to provide a continuous profile of the ground. On each run, the tube diameter is reduced in order to assist in its recovery. When complete, the borehole is normally backfilled with arisings. It is also possible to carry out Standard Penetration Tests (SPT) using the window sampling equipment.

4.5.2.3 Shell and auger boring

This technique uses a tripod winch and a percussive effect with a variety of boring tools, where disturbed and undisturbed samples can be taken. This is the most suitable method for soft ground investigation as it enables the maximum amount of information to be obtained. However, minor changes in lithology may be overlooked unless continuous undisturbed sampling is used.

Disturbed samples of soils can be taken for identification and classification purposes. In cohesive soils, ‘undisturbed’ samples 100mm in diameter can be taken by an open drive sampler for laboratory testing of strength, permeability and consolidation characteristics.

SPT are used in granular and cohesive materials and in soft or weathered rocks. The resulting ‘N’ value can be compared to empirical data on strength and relative density. Difficulties in obtaining true ‘N’ values mean they should only be used as a guide, and not as an absolute value in foundation design.

4.5.2.4 Rotary drilling

Two main types of rotary drilling can be carried out in rock. Rock coring using a diamond or tungsten carbide-tipped core bit provides samples and information on rock types, fissuring and weathering. Open-hole drilling only produces small particles for identification purposes, and the information gained is therefore limited. The latter is, however, useful as a quick method of detecting major strata changes and the location of coal seams and old workings. Water, air, foam or drilling muds may be used as the flushing medium in either case.

Rotary open-hole drilling is carried out to determine the existence of any voids or broken ground that could affect surface stability. Due to the risk of combustion, the drilling is normally done using a water flush. On completion, the boreholes are backfilled with bentonite cement. A Coal Authority Licence is required in advance of any exploratory work intended to investigate possible coal workings.

4.5.2.5 Geophysics

Geophysics can be used in certain situations and is useful where significant anomalies exist in the ground. Ground-penetrating radar is probably the most common for defining near-surface features. The results from geophysics can be variable and, combined with the relative high cost, should be used advisedly.

4.5.3 Strata profile

Full strata descriptions should be given based on visual identification and in accordance with the requirements of:

- BS EN ISO 14688-1: 2002 Geotechnical investigation and testing – Identification and classification of soil – Part 1
- BS EN ISO 14688-2: 2004 Geotechnical investigation and testing – Identification and classification of soil – Part 2
- BS EN ISO 14689-1: 2003 Geotechnical investigation and testing – Identification and classification of rock – Part 1

4.5.4 Soil description

Samples from boreholes or trial pits should be fully described in accordance with the latest guidance from the British Standards and Eurocodes. They should include colour, consistency, structure, weathering, lithological type, inclusions and origin. All descriptions should be based on visual and manual identification as per recognised descriptive methods. The methodology for soil and rock description is given in more detail in Appendix B.

4.5.5 In-situ and laboratory testing

4.5.5.1 In-situ gas monitoring

Methane is the dominant constituent of landfill gas, and can form an explosive mixture in air at concentrations of between 5% and 15%. Thus, 5% methane in air is known as the Lower Explosive Limit (LEL). Concentrations less than this do not normally ignite. Carbon dioxide can also be a potential problem, especially where it occurs in concentrations greater than 1.5%.

In-situ gas tests should be carried out in the boreholes on completion, and in probe holes made in the sides of the trial pits. Testing is with a portable meter that measures the methane content as its percentage volume in air. The corresponding oxygen and carbon dioxide concentrations are also measured. Care is needed with this, since the rapid mixing and dilution of any gases within the atmosphere can occur very quickly.

A more accurate method used to monitor over the longer term consists of gas monitoring standpipes installed in boreholes. These typically comprise slotted UPVC pipework surrounded by single sized gravel. The top 0.5m to 1m of pipework is usually not slotted and is surrounded by bentonite pellets to seal the borehole. Valves are fitted and the installations protected by lockable stopcock covers normally fitted flush with the ground. Monitoring is again with a portable meter and is usually done on a fortnightly or monthly basis, with at least six visits being appropriate for most sites.

The risks associated with the gases should be considered in accordance with documents such as:

- BS 8485: 2007 Code of Practice for the characterisation and remediation from ground gas in affected developments
- CIRIA Report C665 Assessing risks posed by hazardous ground gases to buildings
- NHBC Report No. 4 Guidance on evaluation of development proposals on-sites where methane and carbon dioxide are present

4.5.5.2 In-situ strength testing

Hand vane and MEXE cone penetrometer tests can be carried out in trial pits in order to assess the strengths and CBR values of made ground, soils and heavily weathered bedrock materials.

4.5.5.3 Soakaway testing

If sustainable drainage is being considered, soakaway testing should be carried out. This is preferably done in trial pits, with the aim of intersecting permeable soils or naturally occurring fissures within bedrock.

Soakaway testing involves filling the trial pits with water from a bowser or such like, and measuring the fall in water over time. Where possible, two tests should be carried out to allow the immediate surrounding ground to become saturated. By knowing the dimensions of the trial pit, the permeability and/or rate of dissipation can be calculated.

Soakaway test results obtained from small hand-dug pits or shallow boreholes should be treated with caution.

4.5.5.4 Geotechnical laboratory testing

Soil testing should be carried out to BS 1377: 1990 Methods of test for soils for civil engineering purposes, and the laboratory used should be recorded and conducted by an approved UKAS laboratory. Normally, the results are summarised and the full results appended; a summary of the main types of test is presented in Appendix C.

4.5.5.5 Contamination laboratory testing

As with the investigation, the sampling should be under the full-time direction of either a Chartered Engineer or Chartered Geologist. All the recovered soil samples should be screened on-site for any visual or olfactory evidence of contamination, including the presence of Volatile Organic Compounds (VOCs). Samples should be selected from the trial pits and boreholes based on those most likely to be contaminated, and those that will give the most appropriate indication of the spread of any contaminants. The samples should be stored in either glass or plastic containers and where necessary kept in cooled conditions. Testing should be carried out by a UKAS accredited laboratory, in accordance with the Environment Agency's Monitoring Certification Scheme; MCERTS performance standards.

The aim of this is to make a preliminary assessment of the level of any contamination on the site, in order to determine if there are any significant risks associated with contaminants in respect of both human health and the environment, including controlled waters. In addition to the soil, ground water samples should be tested where appropriate.

4.5.6 Geoenvironmental Risk Assessment (conceptual site model)

The qualitative health and environmental Risk Assessment carried out as part of the desk study should be revised, based on the findings of the ground investigation and the results of the contamination testing, to produce a Detailed Quantitative Risk Assessment (DQRA).

The DQRA is again based on the conceptual site model, and might look similar to the following example summary of hazards, pathways and receptors. On-sites with known contamination, further investigation and testing may be necessary, together with recommendations for remediation and its validation.

Source	Potential pollutant	Pathways	Receptor	Risk
Potentially contaminated made ground Possible past minor spillages and metals	Oils, fuels, grease, hydraulic fluid, metals, asbestos	1-5	A. Present occupants	Site unoccupied
			B. Ground workers	Low risk involved with excavation work, provided personnel adopt suitable precautions, together with washing facilities
			C. Future residents/occupants	Low risk for residential use, provided made ground is capped by clean sub-soil and topsoil
		6	D. Controlled waters	Low to moderate risk at present. Provided on-site monitoring undertaken throughout the piling and ground work phases of development show no adverse effects, the risk will be low
			E. Ecosystems	Low risk as leaching is not a problem
		7	F. Building materials and services	Low to moderate. Install pipes in clean bedding materials. Adequate precautions to be taken in respect of buried concrete
Organic material	Landfill gases, Radon, VOCs, SVOCs	8	A-F	Low to moderate. Low values of ground gases present during the investigation, although basic gas protection measures are recommended
Waste materials	Fly-tipping			All waste materials to be removed from site

Table 5: Example detailed quantitative Risk Assessment

4.5.7 Construction

During construction, if unforeseen conditions are encountered then the Builder/Developer should seek additional advice from the consultant as to whether the new conditions will affect the continued development of the site, and whether any additional investigation or testing is necessary.

4.5.8 Recommendations

The report must include a site location plan and a plan showing any special features plus borehole and trial pit locations (factual reports will describe the work carried out, and will include borehole/trial pit logs and the results of all in-situ and laboratory testing, but there will be no interpretation of the data and no recommendations).

The interpretative report should make recommendations in respect of the main points or issues related to design and construction:

- Normal strip or deep trench footings
- Piling
- Vibro replacement
- Raft foundation
- Building near trees
- Landfill and radon gas
- Existing drains and services
- Road construction
- Sustainable surface water drainage (soakaways)
- Excavations and ground water
- Reuse of materials
- Contamination
- Capping mine shafts
- Site soil reuse
- Slope stability and retaining walls
- Further geotechnical considerations
- Change of use

Advice in respect of specific recommendations is given in Appendix A.

4.6 MAIN REFERENCES

British Standards Institution

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Appendix A

Checklist for Phase 1 Geoenvironmental Assessment (Desk Studies)

Site Description (and surrounding area of relevance)

- Location, O.S. grid reference and plans
- Topography, levels
- Site layout and main features
- Site infrastructure
- Site description and topography
- Made ground, erosion, cuttings or quarries
- Slope stability
- Evidence of faulting or mining
- Watercourses, seepages or sinks
- Marshy or waterlogged ground
- Type and health of vegetation
- Existing structures and condition
- Existing on-site processes
- Demolished structures/old foundations
- Visual evidence of contamination
- Existing site operations
- Underground and overhead services
- Trees

Mining

- Past, present and future mining
- Reference to geological sources
- Coal Authority Mining Report
- Register of abandoned mine plans and opencasts
- Shaft register
- Other mining, e.g. sand, sandstone, limestone, brine, etc.

Geology

- Geological maps (1:50,000 and 1:10,000 scale)
- Memoirs
- Technical reports
- Engineering geological maps
- Existing trial pit or borehole logs and reports
- Subsidence features

Hydrogeology and hydrology

- Ground water vulnerability
- Aquifer status
- Abstraction licences (within 1km)
- Flood risk, drainage and watercourses (within 1km)

Local Authority consultation

- Building Control, Planning and Environmental Health/Contaminated Land Officer
- Petroleum Officer

Archival research

- Past O.S. mapping and previous on-site and off-site usage
- possible contaminants associated with former use(s)
- town plans
- local history records, books and photographs (where relevant and practicable)
- Aerial photographs (where relevant)
- Archaeological register (where relevant)

Contamination

- Likely contaminants based on past history
- Hazard-Pathway-Receptor scenario
- Preliminary Conceptual Site Model

Environmental database

- Operational and former landfill sites, scrapyards and waste processing sites
- Radon protection measures

Checklist for Phase 2 Geoenvironmental Assessment (Ground Investigations)

Trial pits

- Strata profile and description
- In-situ gas testing for methane, carbon dioxide and oxygen
- Landfill gas, marsh gas and mine gas
- In-situ shear strength testing
- In-situ mexe cone penetrometer for cbr/in-situ shear strength
- Full description of ground and ground water conditions
- Soakaway testing
- Geotechnical contamination laboratory testing

Boreholes

- Cable percussive, window sampling, dynamic probing or rotary drilling to BS 5930
- Use of british drilling association accredited drillers
- Full description of ground and ground water to BS 5930
- Installations for long-term gas and water monitoring (if required)
- Geotechnical laboratory testing (BS 1377) and contamination testing if suspected by accredited laboratories

Other methods of investigation

- Geophysics
- Cone penetrometer

Recommendations for reports

Foundations and retaining walls

- Foundation type, depth, bearing capacity And settlement
- Ease of excavation
- Sulphate/acidity/concrete class
- Shrinkage/heave
- Effect of vegetation, including building Near trees
- Buoyancy or flotation effects
- Ground improvement options, e.g. Piling, Vibro, compaction, etc.

Mining

- Precautions for foundations in respect of past or future mining
- Treatment of shallow mineworkings
- Capping of shafts and adits

Landfill/mine gas/radon

- Requirements for long term monitoring
- Protection measures for structure
- Venting measures

Road construction

- CBR of subgrade and its preparation
- Sub-base type and thickness
- Excavation of unsuitable material
- Soil stabilisation
- Frost susceptibility

Drainage and excavations

- Ground water regime including dewatering
- Use of soakaways
- Support and ease of excavation
- Rock levels
- Use of sheet piling, diaphragm, bored piles and ground anchors

Earthworks

- Compaction characteristics
- Surcharging and self-settlement
- CBR at formation level
- Slope stability and slope stabilisation
- Suitability of excavated material for re-use

Contamination

- Full assessment of contamination testing
- Hazard–Pathway–Target scenarios/ Conceptual model
- Risk Assessment and liability
- Precautions or remediation of contamination

Further investigation

- Is further investigation needed?
- Nature of further investigation

Appendix B

Soil and rock descriptions

Fine soils (cohesive soils)

The following field terms are used:

Soil type	Description
Very soft	Exudes between fingers
Soft	Moulded by light finger pressure
Firm	Cannot be moulded by the fingers but can be rolled in hand to 3mm threads
Stiff	Crumbles and breaks when rolled to 3mm threads but can be remoulded to a lump
Very stiff	No longer moulded but crumbles under pressure. Can be indented with thumbs

The following terms may be used in accordance with the results of laboratory and field tests:

Description	Undrained shear strength Cu (kPa)
Extremely low	<10
Very low	10-20
Low	20-40
Medium	40-75
High	75-150
Very high	150-300
Extremely high	>300

Fine soils can also be classified according to their sensitivity, which is the ratio between undisturbed and remoulded undrained shear strength:

Sensitivity	Ratio
Low	8
Medium	8-30
High	>30
Quick	>50

Granular soils (non-cohesive)

The following descriptions are used for granular soils:

Description	Normalised blow count (N) 60
Very loose	0-3
Loose	4-8
Medium	9-25
Dense	26-42
Very dense	43-58

Rock description

This is based on:
i. Colour (minor then principal colour)
ii. Grain size

Description	Predominant grain size (mm)
Very coarse grained	>63
Coarse grained	63-2
Medium grained	2-0.063
Fine grained	0.063-0.002
Very fine grained	<0.002

iii. Matrix
iv. Weathering

Term	Description
Fresh	No visible sign of weathering/alteration of the rock material.
Discoloured	The colour of the original fresh rock material is changed with evidence of weathering/alteration. The degree of change from the original colour should be indicated. If the colour change is confined to particular mineral constituents, this should be mentioned.
Disintegrated	The rock material is broken up by physical weathering, so that bonding between grains is lost and the rock is weathered/altered towards the condition of a soil in which the original material fabric is still intact. The rock material is friable but the grains are not decomposed.
Decomposed	The rock material is weathered by the chemical alteration of the mineral grains to the condition of a soil in which the original material fabric is still intact; some or all of the grains are decomposed.

v. Carbonate content
vi. Stability of rock material

Stable indicates no changes when sample left in water for 24 hours. Fairly stable indicates fissuring and crumbling of surfaces. Unstable indicates complete disintegration of the sample.

vii. Unconfined compressive strength

Term	Field identification	Unconfined compressive strength (MPa)
Extremely weak [(a)]	Indented by thumbnail.	Less than 1
Very weak	Crumbles under firm blows with point of geological hammer, can be peeled by a pocket knife.	2 - 5
Weak	Can be peeled by a pocket knife with difficulty, shallow indentations made by firm blow with point of geological hammer.	6 - 25
Medium strong	Cannot be scraped or peeled with a pocket knife, specimen can be fractured with single firm blow of geological hammer.	26 - 50
Strong	Specimen required more than one blow of geological hammer to fracture it.	51 - 100
Very strong	Specimen requires many blows of geological hammer to fracture it.	101 - 250
Extremely strong	Specimen can only be chipped with geological hammer.	Greater than 250

Notes: [(a)] Some extremely weak rocks will behave as soils and should be described as soils.

viii. Structure

Sedimentary	Metamorphic	Igneous
Bedded	Cleaved	Massive
Interbedded	Foliated	Flowbanded
Laminated	Schistose	Folded
Folded	Banded	Lineated
Massive	Lineated	
Graded	Gneissose	
	Folded	

ix. Discontinuities
x. Discontinuity spacing, persistence and roughness, infilling and seepage
xi. Weathering of the rock mass

Term	Description	Grades
Fresh	No visible sign of rock material weathering; perhaps slight discolouration on major discontinuity surfaces.	0
Slightly weathered	Discolouration indicates weathering of rock material and discontinuity surfaces.	1
Moderately weathered	Less than half of the rock material is decomposed or disintegrated. Fresh or discoloured rock is present either as a continuous framework or as core stones.	2
Highly weathered	More than half of the rock material is decomposed or disintegrated. Fresh or discoloured rock is present either as a continuous framework or as core stones.	3
Completely weathered	All rock material is decomposed and/or disintegrated to soil. The original mass structure is still largely intact.	4
Residual soil	All rock material is converted to soil. The mass structure and material fabric are destroyed. There is a large change in volume, but the soils have not been significantly transported.	5

xii. Rock mass permeability

In addition to the description of the soils and rocks and their associated depth, ground water should be noted in terms of both where it was struck and changes over time. Any unusual colouration or odours of any of the soils encountered during the investigation should be recorded.

It should be noted that lateral and vertical changes can occur between exploratory points, and care is needed when extrapolation is used. This is particularly true of the 'made ground', which, by its nature, can be highly variable in its physical and chemical composition.

Appendix C

Laboratory testing

Natural or in-situ moisture content

The natural or in-situ moisture content of a soil is defined as the weight of water contained in the pore space, expressed as a percentage of the dry weight of solid matter present in the soil. Soil properties are greatly affected by the moisture content, and the test can help provide an indication of likely engineering behaviour.

Liquid and plastic limits

Two simple classification tests are known as the liquid and plastic limits. If a cohesive soil is remoulded with increasing amounts of water, a point will be reached at which it ceases to behave as a plastic material and becomes essentially a viscous fluid. The moisture content corresponding to this change is arbitrarily determined by the liquid limit test. 'Fat' clays, which have a high content of colloidal particles, have high liquid limits; 'lean' clays, having a low colloidal particle content, have correspondingly low liquid limits. An increase in the organic content of clay is reflected by an increase in the liquid and plastic limits.

If a cohesive soil is allowed to dry progressively, a point is reached at which it ceases to behave as a plastic material, which can be moulded in the fingers, and becomes friable. The moisture content of the soil at this point is known as the 'plastic limit' of the soil.

The water content range over which a cohesive soil behaves plastically, i.e. the range between the liquid and plastic limits, is defined as the plasticity index.

A cohesive soil with natural water content towards its liquid limit will, in general, be an extremely soft material, whereas a cohesive soil with natural water content below its plastic limit will tend to be a firm or stiff material.

Particle size distribution

Knowledge of particle size distribution is used to classify soils and indicate likely engineering behaviour.

British Standards define soils in relation to their particle size, as shown below:

Boulders - >200mm Cobbles - 200mm - 63mm	Coarse sand - 2.0mm - 0.63mm Medium sand - 0.63mm - 0.2mm Fine sand - 0.2mm - 0.063mm
Coarse gravel - 63mm - 20mm Medium gravel - 20mm - 6.3mm Fine gravel - 6.3mm - 2mm	Coarse silt - 0.063mm - 0.02mm Medium silt - 0.02mm - 0.0063mm Fine silt - 0.0063mm - 0.002mm
	Clay <0.002mm

Bulk density

The bulk density of a material is the weight of that material per unit volume, and includes the effects of voids whether filled with air or water. The 'dry density' of a soil is defined as the weight of the solids contained in a unit volume of the soil.

Permeability

The permeability of a material is defined as the rate at which water flows through it per unit area of soil under a unit hydraulic gradient.

Consolidation characteristics

When subjected to pressure, a soil tends to consolidate as the air or water in the pore space is forced out and the grains assume a more densely packed state. The decrease in volume per unit of pressure is defined as the 'compressibility' of the soil, and a measure of the rate at which consolidation proceeds is given by the 'coefficient of consolidation' of the soil. These two characteristics, Mv and Cv, are determined in the consolidation test, and the results used to calculate settlement of structures or earthworks by a qualified person.

Strength characteristics

The strength of geological materials is generally expressed as the maximum resistance that they offer to deformation or fracture by applied shear or compressive stress. The strength characteristics of geological materials depend to an important degree on their previous history and on the conditions under which they will be stressed in practice. Consequently, it is necessary to simulate in the laboratory tests the conditions under which the material will be stressed in the field.

In general, the only test carried out on hard rocks is the determination of their compressive strength, but consideration must also be given to fissuring, jointing and bedding planes.

The tests currently used for soils and soft rocks fall into two main categories. First, those in which the material is stressed under conditions of no moisture content change, and second, those in which full opportunity is permitted for moisture content changes under the applied stresses.

Tests in the first category are known as undrained (immediate or quick) tests, while those in the second category are known as drained (slow or equilibrium) tests. The tests are normally carried out in the triaxial compression apparatus, but granular materials may be tested in the shear box apparatus.

The undrained triaxial test gives the apparent (cohesion) C_u and the angle of shearing (resistance) $Ø_u$. In dry sands, $C_u = 0$ and $Ø_u$ is equal to the angle of internal friction, whereas with saturated non-fissured clays $Ø_u$ tends to 0 and the apparent cohesion C_u is equal to one-half the unconfined compression strength qu. On-site, the vane test gives an approximate measure of shear strength.

For some stability problems, use is made of a variant of the undrained triaxial test in which the specimen is allowed to consolidate fully under the hydrostatic pressure, and is then tested to failure under conditions of no moisture content change. This is known as the consolidated undrained triaxial test. Pore water pressures may be measured during this test, or alternatively a fully drained test may be carried out. In either case, the effective shear strength parameters C' and Ø' can be obtained, which can be used to calculate shear strength at any given pore water pressure.

Compaction

The density at which any soil can be placed in an earth dam, embankment or road depends on its moisture content and on the amount of work used in compaction. The influence of these two factors can be studied in compaction tests, which can determine the maximum dry density (MDD) achievable at a certain optimum moisture content (OMC).

California Bearing Ratio (CBR) test

In flexible pavement design, knowledge of the bearing capacity of the sub-grade is necessary to determine the thickness of pavement for any particular combination of traffic and site conditions. The quality of the subgrade can be assessed by means of the CBR test, or approximately by the MEXE cone penetrometer.

Chemical tests

Knowledge of the total soluble sulphate content and pH of soils and ground water is important in determining the protection required for concrete or steel in contact with the ground. Other specialist tests may be carried out on sites suspected of being contaminated by toxic materials.