

# CHAPTER 4: Site Investigation Reports, Geology and Contamination

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# FUNCTIONAL REQUIREMENTS

## 4 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. 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 and Euro-Codes 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 AND OBJECTIVES

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 both in the interests of the warranty provider and also of the Builder or Developer. This will lead to a safe and economic design which 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 which 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.

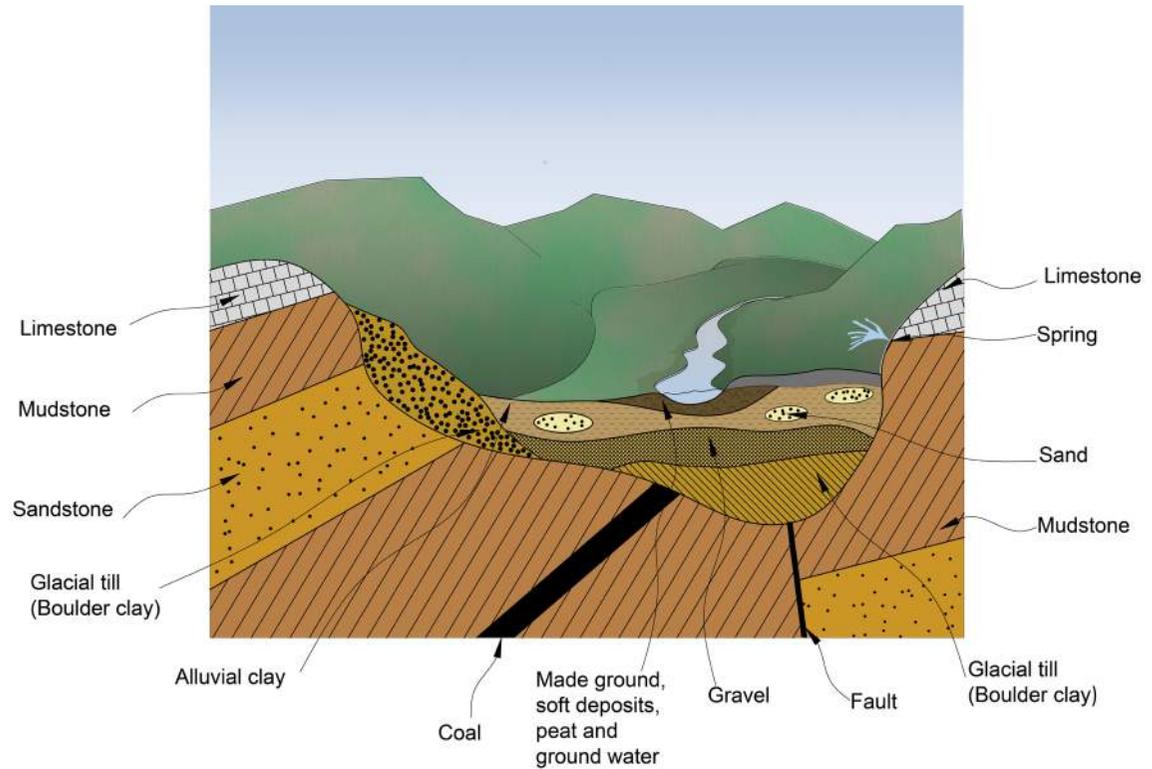


Figure 1: The geological environment, cross section of a river valley

**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 & 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.

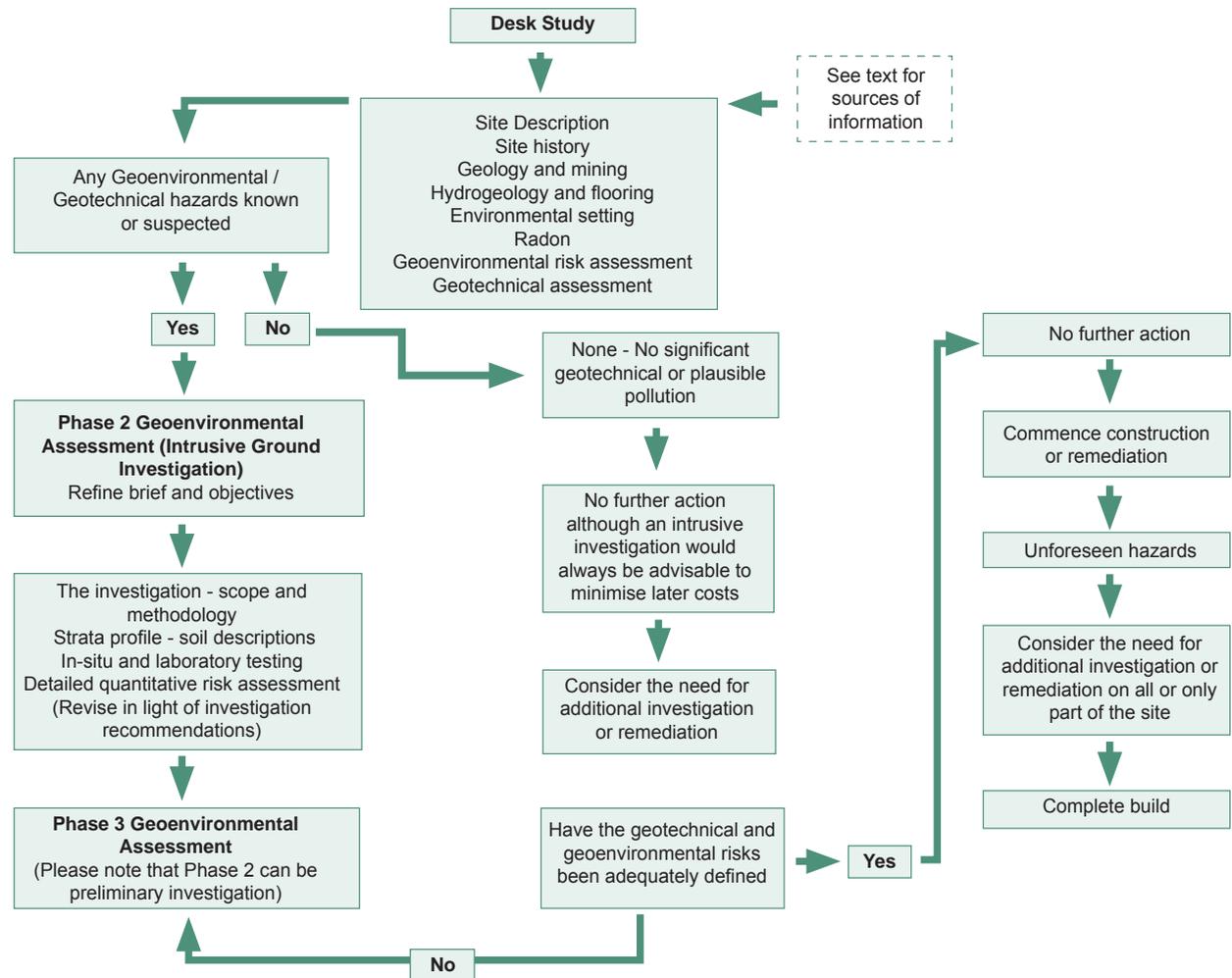
**4.2.3 Local Authority Building Control**

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

**4.2.4 Health & Safety Executive**

The HSE are responsible for Health & 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 and objectives

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. It 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 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 groundwater 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 be 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-19<sup>th</sup> Century and often specify the actual industrial use of particular sites or buildings.

They may show areas of quarrying or infilling as well as indicating 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), which have the potential to affect it.

Historical maps are available from libraries and also 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 and many military or sensitive uses may have been omitted. Other sources of information may include the ubiquitous internet search and historical aerial photographs. It may be necessary to additionally 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. These maps most commonly exist at 1:50,000 (1 inch to 1 mile) and 1:10,000 (or 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.

### 4.4.5 Hydrogeology and flooding

The assessment should include flood risk and the hydrogeology of the site; in particular whether the site lies on a Principle Aquifer and / or Source Protection Zone, which are both susceptible to pollution of groundwater. 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 groundwater or surface water abstraction points 'downstream' of the site; in particular 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 which 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 this 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. They 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

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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; the linkage 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.



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

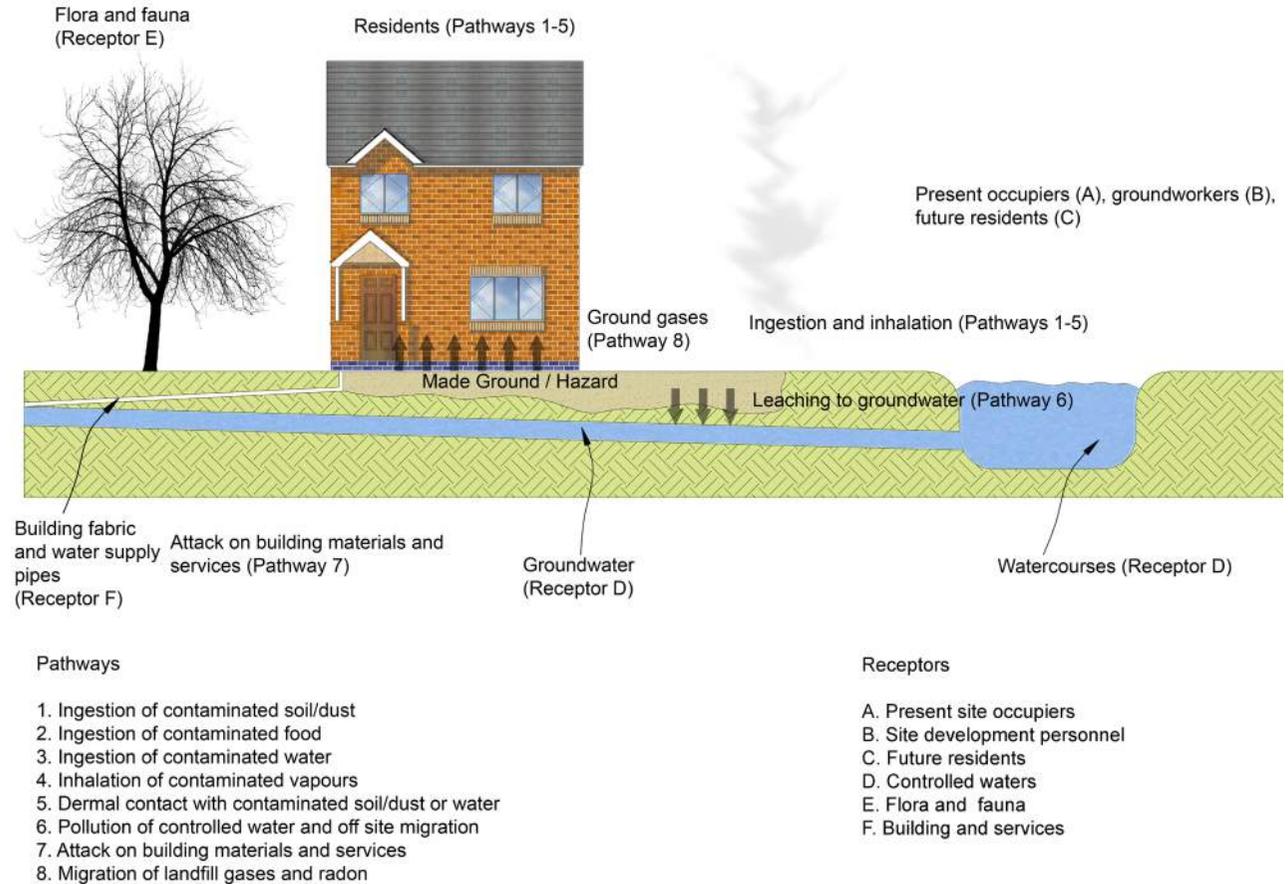


Figure 2: Pathways and potential contaminants

### 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, by eating plants which 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 cause ground subsidence and cause structural damage. Accumulations of flammable gases in confined space leads to a risk of explosion. Underground fires may damage services.

#### Chemical attack on building materials and services

Sulphates may attack concrete structures. Acids, oils and tarry substances may accelerate 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 into surface and ground waters.

#### Ecotoxicological 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).

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

<b>Severe</b>	Damage to human health Substantial pollution of controlled waters Significant change in ecosystem population Irreparable damage to property
<b>Moderate</b>	Non-permanent damage to human health Minor pollution of controlled waters Change in ecosystem Damage to property
<b>Mild</b>	Short term health effects Slight pollution of controlled waters Slight effect on ecosystem Minor repairable damage to property
<b>Near zero</b>	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
<b>High</b>	Very High	High	Medium / Low	Low / Negligible
<b>Medium</b>	High	Medium	Low	Low / Negligible
<b>Low</b>	High / Medium	Medium / Low	Low	Negligible
<b>Unlikely</b>	High / Medium / Low	Medium / Low	Low	Negligible

**Table 2: Decision making**

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

Risk	Description of risk levels
<b>High</b>	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.
<b>Medium / Moderate</b>	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.
<b>Low</b>	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.
<b>Negligible</b>	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:

<b>Foundations</b>	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?
<b>Mining and quarrying</b>	Will the possibility of shallow mine workings or quarrying on the site need to be addressed?
<b>Soakaways</b>	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.)
<b>Roads</b>	What is the sub-grade strength (CBR) likely to be? (The actual design will be dependent on the CBR measured on site.)
<b>Excavations</b>	Will soft ground plant be suitable or will rock breakers be needed for deeper excavation?
<b>Ground water</b>	Is shallow ground water expected?
<b>Earthworks</b>	Are any significant earthworks anticipated?
<b>Gas protection</b>	Will gas protection measures be required or would they be prudent in accordance with good practice?

**Table 4: Geotechnical assessment – preliminary indicators**

This can only be given 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 Chapter 4.3 of this Manual.

**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 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 groundwater 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 ‘Euro-Code 7 - Geotechnical Design - Part 1: General Rules’
- BS EN 1997-2:2007 ‘Euro-Code 7 - Geotechnical Design - Part 2: Ground Investigation and Testing’
- BS 5930:1999 and BS 10175:2001

and under the full-time supervision of a Chartered Geologist or Chartered Engineer.

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 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 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, enabling 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.

Standard Penetration Tests (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 bits 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 for detecting major strata changes and for 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 if any voids or broken ground exist which 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 Standard and Euro-Codes. 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 of 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 which 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 rapid mixing and dilution of any gases with 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 -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 and 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:

- The British Standard 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 here 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 California Bearing Ratio (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 immediately 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 are 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 on the basis of those which are most likely to be contaminated and those which 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 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, groundwater 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. Groundworkers	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

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### 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 only 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 groundwater
- Re-use of materials
- Contamination

- Capping mine shafts
- Site soil re-use
- 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

- BS 1377:Methods of Test for Soils for Civil Engineering Purposes 1990 (Parts 1 to 8)
- BS 3882:British Standard Specification for Topsoil
- BS 5930:British Standard Code of Practice for Site Investigations, 1999
- BS 8485:British Standard Code of Practice for the characterisation and remediation from ground gas in affected developments, 2007
- BS 10175:British Standard Code of Practice for the Investigation of Potentially Contaminated Sites, 2001
- BS EN 1997-1:2004 'Euro-Code 7 – Geotechnical Design – Part 1: General Rules'
- BS EN 1997-2:2007 'Euro-Code 7 – Geotechnical Design – Part 2: Ground Investigation and Testing'
- BS ISO 14688-1:2002 'Geotechnical Investigation and Testing – Identification and Classification of Soil – Part 1'
- BS ISO 14688-2:2004 'Geotechnical Investigation and Testing – Identification and Classification of Soil – Part 2'

- BS ISO 14689-1:2003 'Geotechnical Investigation and Testing – Identification and Classification of Rock – Part 1'

### BRE

- Radon: Guidance on protective measures for new dwellings, BR 211
- Protective measures for housing on gas-contaminated land, BR 414, 2001
- Cover systems for land regeneration, 2004
- Concrete in aggressive ground. Special Digest SD1, 3<sup>rd</sup> Edition, 2005

### CIEH

- The LQM / CIEH Generic Assessment Criteria for Human Health Risk Assessment (2<sup>nd</sup> Edition)

### CIRIA

- Assessing risks posed by hazardous ground gases to buildings, CIRIA C665

### DoE

- CLR reports 1-4
- Waste Management Paper No. 26A 'Landfill completion: A technical memorandum...'
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### DEFRA

- Contaminated Land Report CLR 11, 2002 (7-10 withdrawn)
- R&D Publications TOX 1 – 12, 14, 16 – 25
- R&D Publications SGV 1, 3, 4, 5, 7, 8, 9, 10, 15 and 16 (withdrawn)
- Improvements to Contaminated Land Guidance - 'Outcome of the Way Forward', 2008
- Exercise on Soil Guideline Values. July 2008
- Guidance on the Legal Definition of Contaminated Land. July 2008

### DETR

- Circular 02/2000. Contaminated Land, 2000
- Guidelines for Environmental Risk Assessment and Management, 2000

### Environment Agency

- Guidance for the Safe Development of Housing on Land Affected by Contamination, 2000
- Guidance for waste destined for disposal in landfills, Version 2, June 2006
- Protective measures for housing on gas-contaminated land Remediation Position Statements, May 2006
- Guidance and monitoring of landfill leachate, groundwater and surface water
- Human health toxicological assessment of contaminants in soil (Science Report SC050021/SR2), 2008

- Updated technical background in the CLEA model (Science Report SC0520021/SR3)
- Using Soil Guideline Values, 2009

### HMSO

- Environmental Protection Act 1990
- Environment Act 1995
- UK Water Supply (Water Quality) Regulations 2000
- The Water Act 2003

### Institution of Civil Engineers

Contaminated Land: Investigation, Assessment and Remediation, 2<sup>nd</sup> Edition

### Joyce M D

Site Investigation Practice, 1982

### OPDM

- Planning Policy Statement 23: Planning and Pollution Control Annex 2: Development on Land Affected by Contamination

### 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

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- 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 California Bearing Ratio / 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 groundwater 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 <sub>60</sub> )
Very loose	0-3
Loose	4-8
Medium	9-25
Dense	26-42
Very dense	43-58

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### 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.

Term	Description
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 <sup>(a)</sup>	Indented by thumbnail.	>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

Term	Field identification	Unconfined compressive strength (MPa)
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.	<250

**Note:**  
<sup>(a)</sup> 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	

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- 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, groundwater should be noted both in terms of where it was struck and changes over time. Any unusual colouration or odours to 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 very 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 to give 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 high contents of colloidal particles, have high liquid limits; 'lean'

clays, having low colloidal particle contents 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 it becomes friable. The moisture content of the soil at this point is known as the 'plastic limit' of the soil.

The range of water content over which a cohesive soil behaves plastically, i.e. the range lying 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 to indicate likely engineering behaviour.

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

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Boulders - >200mm	Coarse sand - 2.0mm - 0.63mm
Cobbles - 200mm - 63mm	Medium sand - 0.63mm - 0.2mm
	Fine sand - 0.2mm - 0.063mm
Coarse gravel - 63mm - 20mm	Coarse silt - 0.063mm - 0.02mm
Medium gravel - 20mm - 6.3mm	Medium silt - 0.02mm - 0.0063mm
Fine gravel - 6.3mm - 2mm	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 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 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 denser state of packing. 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  $M_v$  and  $C_v$  are determined in the consolidation test and the results are 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 at present in use 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 secondly 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)  $\phi_u$ . In dry sands,  $C_u = 0$  and  $\phi_u$  is equal to the angle of internal friction, whereas with saturated non-fissured clays  $\phi_u$  tends to 0 and the apparent cohesion  $C_u$  is equal to one-half the unconfined compression strength  $q_u$ . 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 a fully drained test may be carried out. In either case, the effective shear strength parameters  $C'$  and  $\phi'$  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 which is 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 test**

In flexible pavement design, knowledge of the bearing capacity of the subgrade is necessary to enable the thickness of pavement for any particular combination of traffic and site conditions to be determined. The quality of the subgrade can be assessed by means of the 'California Bearing Ratio Test' or approximately by the MEXE cone penetrometer.

### **Chemical tests**

Knowledge of total soluble sulphate content and pH of soils and groundwater 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 (see standard appendix B).