Chapter 3

The desk study and walk-over survey

INTRODUCTION

The desk study and walk-over survey are the two essential components of ground investigation. Other parts (for example, boring, drilling and testing) may sometimes be omitted, but these parts of the site investigation process must always be carried out.

The desk study should be carried out at the start of site investigation. Its purpose is to provide as much information on the probable ground conditions, and the likely problems that they will produce for the proposed type of construction, as is available without commissioning new ground investigation work (see Chapter 1). This information is also necessary for the design of ground investigation work.

The walk-over survey is carried out after the desk study has been substantially completed, and once preliminary plans have been made for any ground investigation site work, in order to glean extra information on the geology and on likely construction problems, and to assess access for investigation plant and equipment.

Both the desk study and walk-over survey provide large quantities of invaluable information at negligible cost. They are by far the most cost-effective parts of the site investigation process. They should be used not only to look at the site (which will often be in the ownership of the client), but also at its surrounds (which perhaps cannot be the subject of direct methods of ground investigation). Once these surveys are complete, the results should be formally presented in a report which brings together the details of:

- site topography;
- geology;
- geotechnical problems and parameters;
- groundwater conditions;
- existing construction and services;
- previous land use;
- expected construction risks; and
- proposed ground investigation methods.

A lack of knowledge of existing construction around or below a proposed development site can be disastrous, as the following example shows. In September 1991, piles were driven into the bed of the Chicago River to provide protection from riverborne traffic to the Kinzie Bridge (Fig. 3.1). It had previously been appreciated that the bridge pier lay close above a tunnel, because a contractual requirement was that existing piles were to be extracted, and the new ones were to be installed down the same pathway. This requirement was later relaxed, presumably because the proximity of the tunnel was by now forgotten. Unfortunately the piling fractured the wall of an underlying tunnel, part of the city's 61-mile long tunnel system. This system had been built at the turn of the century to carry heating and construction materials into the city centre. In April 1992 the crack opened, allowing 250 million gallons of water to flood the basements of downtown Chicago (the USA's third largest city), shutting down the power and bringing the city's business district to a halt for several days. The President of the United States signed a disaster declaration, making the city eligible for Federal disaster aid.

PLUGGING THE LOOP

Much of downtown Chicago remains without electricity as the city tries to recover from massive subterranean flooding.

Freight tunnels Run for more than 50 miles beneath downtown Chicago at a depth of about 40 feet. Tunnel system was used to deliver materials to various buildings from 1906 to 1950. They now carry optic cables for communications and electrical equipment.

Sub basements flooded through openings previously used to deliver mail, fuel and merchandise to buildings from freight tunnels.

Quick-drying concrete will be used to fill the hole.

How to drain Chicago Workers will attempt to drain water from one tunnel to a deep drainage tunnel by drilling a connection between the two

Water has flooded through freight tunnel into a utility tunnel

Workers will be lowered into a nearby drop shaft to drill a connection with the utility tunnel

This will allow water to flow into a deep drainage tunnel and out of the city

Rain hampers repair efforts

By DON TERRY
of The New York Times

CHICAGO — A heavy rain fell on this city Wednesday and lightning flashed across the sky, further frustrating efforts to stop the waters of the Chicago River from rushing into an abandoned underground freight tunnel system beneath the downtown Loop.

The breach that started out as a minor leak two months ago has caused massive flooding and a power blackout in the heart of downtown since Monday.

Wednesday afternoon President Bush signed a disaster declaration, making the city eligible for federal disaster aid.

Wednesday's storm delayed the city's two-pronged attack plan on the unusual flood, an alliance of man and machine to send divers into the river to repair the break and to use massive drills to help drain the flood water from the freight tunnels.

Along the river banks a fleet of dump trucks, pumps and cranes looming four and five stories

See RAIN, Page 9

Fig. 3.1 The Tampa Trbune, Thursday April 16, 1992
(sources: City of Chicago Mayor's office, Chicago Sun Times, Metropolitan Water Reclamation District of Greater Chicago, Associated press graphic)

The role of the desk study is therefore much wider than simply the determination of likely soil and rock conditions, although this is undoubtedly one of its most important functions. Not only should it aim to determine the position of adjacent services and structures, but it should also search for potential hazards to construction workers, for example from contaminated land.

Table 3.1 Types of information useful for desk studies

Aspect of investigation	**Type of information**
Site topography	Topographic maps Stereo air photographs
Geology	Geological maps Geological publications Regional guides Sheet memoirs Learned journals Air photographs Soil survey maps and records
Geotechnical problems and parameters	Geotechnical journals Engineering geology journals Civil engineering journals Newspapers Previous ground investigation reports
Groundwater conditions	Topographical maps Air photographs Well records Previous ground investigation reports
Meteorological conditions	Meteorological records
Existing construction and services	Construction (as-built) drawings Topographical maps Plans held by utilities Mining records Construction press
Previous land use	Out-of-print topographical maps Out-of-print geological maps Air photographs Airborne remote sensing Archaeological society records Mining records

SOURCES OF INFORMATION FOR DESK STUDIES

Available records come in many different forms. Some are readily available, whilst others are difficult to obtain. Examples are given in Table 3.1.

In the UK, geological and topographical maps, and air photographs are readily available from many sources. At the time of writing the main sources of information are given in Table 3.2. The main agent for Ordnance Survey Publications (topographical and geological maps) is currently: The London Map Centre, Cook, Hammond and Kell Ltd., 22-24 Caxton Street, Westminster, London SW1H OQU (tel: 0171-222-2466 fax: 0171-222-2619).

Table 3.2 Sources of maps and photographs

Type of information	**Source**
Current Ordnance Survey maps	Ordnance Survey distributors, Local authority engineer's department, Local library
Old Ordnance Survey maps	County archives or local muniment rooms, British Library (Reference Division) in: London, Aberystwyth, Edinburgh
Air photographs	Local authorities, Specialist air photography companies, Royal Commission on Ancient Monuments
Published geological maps	Ordnance Survey distributors, The Geological Museum, London
Handbooks on regional geology	Her Majesty's Stationery Office
Published sheet memoirs	Her Majesty's Stationery Office
Manuscript maps and out-of-print sheet memoirs	British Geological Survey Library, at the Geological Museum, London
General geological records	Refer to Geological Directory of the British Isles - A Guide to Reference Sources (Geological Society of London 1978)
Borehole records	Local authorities British Geological Survey
UK technical journals	Geotechnique, Quarterly Journal of Engineering Geology, Ground Engineering, Proceedings of the Institution of Civil Engineers, Geotechnical Engineering

Desk studies are carried out using existing air photographs, many of which are routinely taken (for example by the counties), for detailed topographical surveys. To obtain details of air photographs, a map showing the site, together with any preferred dates and scales of photography, should be sent to potential suppliers. The major sources of information on existing air photography in the UK are:

Air photography from 1971 onwards:
Air Photo Sales, The Ordnance Survey, Romsey Road, Maybush, Southampton SO16 4GU (tel: 01703-792584).
Old air photography:
Details of sources (including commercial air-photo organizations) can be obtained from: Air Photo Advisory Service, The Ordnance Survey (at the above address).
Air photographs for England are held by:
National Monuments Records Centre, Kemble Drive, Swindon SN2 2GZ (tel: 01793-414600/414700).
Air photographs for Scotland are held by:
Scottish Office, Air Photographs Unit, Room 121, New St. Andrew's House, St. James' Centre, Edinburgh EH1 3SZ (tel: 0131-244-4258 fax: 0131-244-4785).
Air photographs for Wales are held by:
Air Photograph Unit, Welsh Office, Cathay's Park, Cardiff CF1 3NQ (tel: 01222-823819 fax: 01222-825466).

Topographical maps

Topographical maps have been published in the UK for about 130 years. The most common scale available over recent years was the 1 in. to 1 mile (1 :63 360) map, but this has now been replaced by the 1:50 000 Second Series. Plate 3.1 shows examples of the same area as depicted at the two different scales, and shows that the 1 :50 000 plan is basically a photographic enlargement of the earlier map. These maps contain too little detail for many site investigations, where attention is devoted to a relatively small area of development, but they are very useful on extended sites such as highways, where existing road and footpath access is often complex.

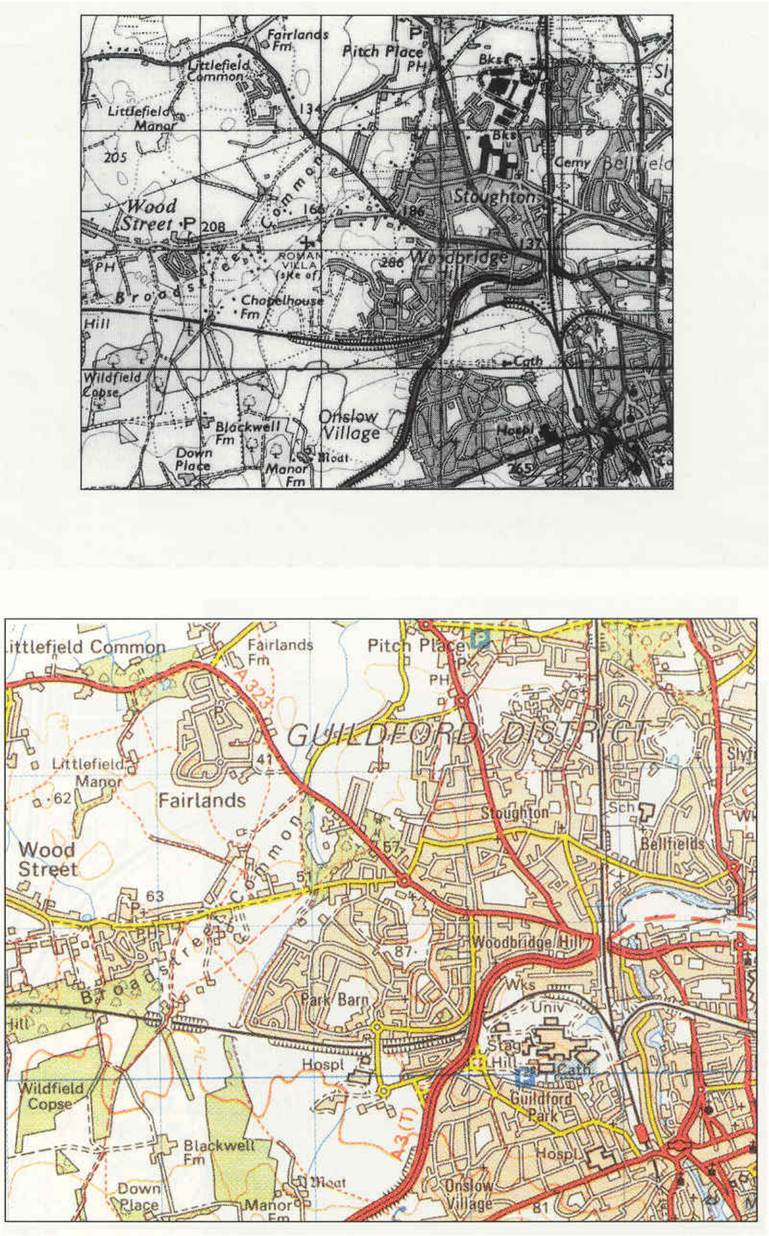


Plate 3.1 Two issues of small scale topographical maps: above 1:63 360 (1” to 1 mile); below 1:50 000. (© Crown copyright reserved)

The 1:25 000 map (approximately 2 inches to 1 mile) combines the advantages of the use of colour in the 1:50000 Second Series with a larger scale, and in common with the 1:50000 series is commonly available in good bookshops throughout the UK. The use of colour at this scale allows the sites of springs, streams and rivers to be easily detected and in addition regular parallel patterns of artificial drains are often marked, giving advanced warning of a high water table (Plate 3.2).

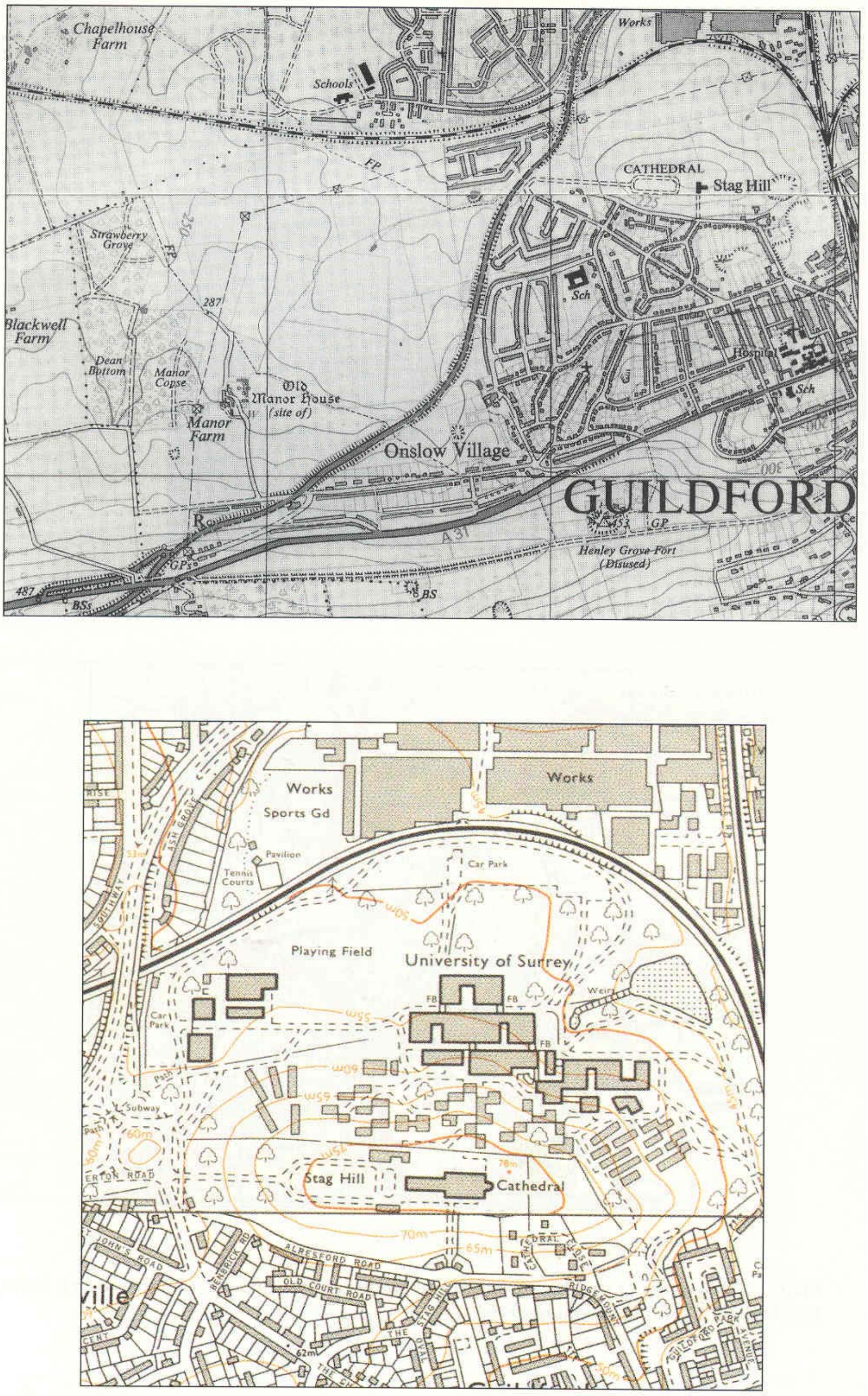


Plate 3.2 1:25 000 and 1: 10 000 maps of the Guildford area (© Crown copyright reserved)

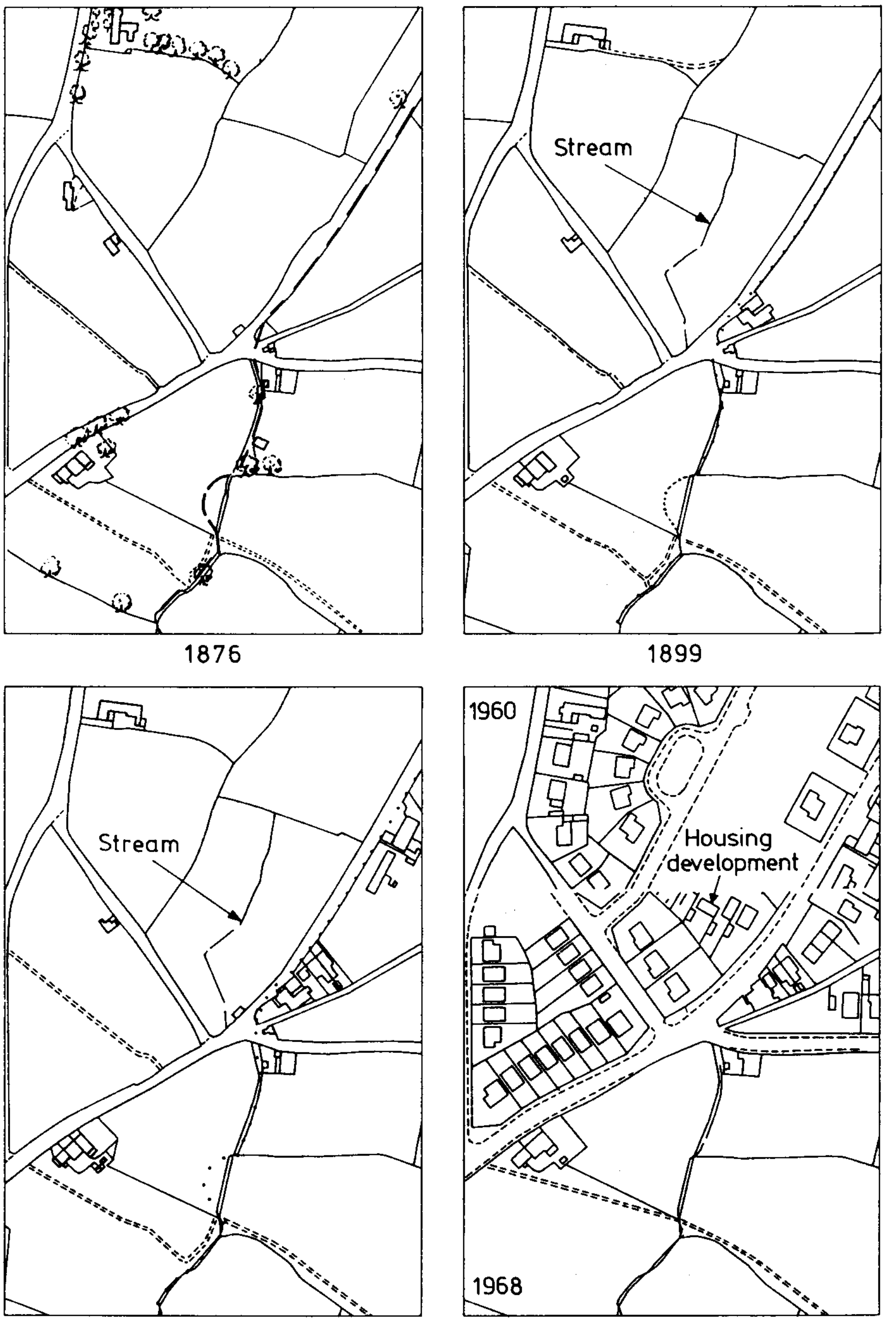
The 1 :25 000 map is the largest scale with close contouring, in this case at a 25 ft (7.6 m) interval. Steep slopes which may suffer from, or be liable to, instability can be marked out for further investigation.

Large-scale maps are available from the main Ordnance Survey distributor in London at scales of 1:10 000, 1:2500 and 1:1250. The 1:10 000 map replaces the old 6in. to 1 mile (1:10 560) map, while the 1:2500 map is at a scale of approximately 25in. to 1 mile. 1:10 000 scale maps are contoured at 5 or 10m intervals, or at 7 and 8m intervals where contours are derived from a 25ft interval. 1:10 560 maps are usually contoured, typically at 100 ft (30.48 m) intervals, which is too coarse for most purposes. 1:2500 and 1:1250 scale maps are uncontoured (Harley 1975). Whilst the 1:10560 and 1:2500 maps are available for most of the country, the 1:1250 is only available for urban areas. For site investigation purposes, the 1:2500 scale map (or, site investigation when the ground levels at boreholes must be determined.

Harley and Phillips (1964) have provided a useful guide to the early editions of the Ordnance Survey. Maps of 1 in. to 1 mile were issued from 1805, and by 1840 covered most of the south of the UK. In 1840, the 6in. to 1 mile (1:10 560) survey was started, and the first revision of this series and the 25 in. to 1 mile maps (1:2500) was carried out between 1891 and 1914. Where County Archives, libraries and engineers departments do not possess copies of the relevant maps, full sets can be found in the British Library Reference Division at the British Museum, London, in the National Library of Wales, Aberystwyth and the National Library of Scotland, Edinburgh.

Case Study - Use of old topographical maps to detect made ground

Figure 3.2 shows extracts from the 25 in. to 1 mile (1:2500) maps of the Biddulph Moor area in Staffordshire. Maps have been found from five different dates: 1876, 1899, 1925, 1960 and 1968; it is possible that further editions exist. The site remains fairly undeveloped until the 1960 map. By 1968, development is taking place in the centre of the area shown. Considerable structural damage occurred to these houses. Investigations revealed that they had been built on made ground and were subsiding. The maps should have given warning of this. The 1899 and 1925 maps show a broken line in the centre of the area; this marks the position of a stream which once ran south through the area, under the road, to emerge from a culvert and continue its course southwards. No such features exist on the 1960 and 1968 maps because the site had, by then, been infilled and levelled, but the stream continues to emerge on the south side of the road.
The 1876 map does not show the stream. This indicates how important it is to collect all archive material (and especially different editions of maps and air photographs) if there is to be a high probability of detecting problems.



1876

1899

1925

1960 (top) & 1968

Figure 3.2 Extracts from 25 in. to 1 mile (1:2500) maps of the Biddulph Moor area, Staffordshire. (Ordnance Survey materials was used in this map. © Crown Copyright reserved.) Courtesy of J.H.R. Haswell and Partners, London.)

Geological records

The first reaction of an experienced site investigation engineer to a new problem or site will almost certainly be to look at a geological map of the area. With experience, a great deal of valuable information can be obtained from a knowledge of the location and stratigraphy of the site.

Many types of geotechnical problems are similar over large parts of the same type of deposit. For example, the droughts occurring in the UK during the summers of 1947 and 1976 led to frequent observations of structural distress in houses founded on fatty clays such as the London clay and Gault clay. It has been observed by Ward (1953) that under open grassland significant soil movements will occur down to below depths of 1 m, while where trees exist desiccation by roots may penetrate to 4-5 m below ground level. Clearly, when small structures are to be placed on such soils, their foundations will almost certainly need to go to greater depths than are dictated solely by the strength of the soil.

This type of problem is not the only example of its kind; London clay frequently contains excessive quantities of soluble sulphates, requiring the use of sulphate resisting cement, and as a further example chalk and limestone outcrops frequently contain infilled dissolution features which may become unstable and collapse if built upon.

Another group of problems that may be detected from the geological map relates to the combination of geological and topographical features. Cambering, valley bulging, gulls and dip/fault movements are often associated with the sides of valleys where hard rock overlies clay. Gulls take the form of crevices, often running parallel to the valley bottom, which are typically infilled with loose or soft material. Site investigation by drilling will only rarely reveal the existence of these features and there is therefore the danger that a structure, supposedly founded on top of the rock, would undergo excessive differential settlement. Similar problems can occur when structures are placed on or near to partially infilled dissolution features, which may be reactivated by the change of surface drainage patterns as a result of construction. Whilst swallow holes can be found on most outcrops of water soluble rocks, they are particularly frequent where thin layers of impervious material overly them, such as in the Horndean area of Hampshire, and at Mimms in Hertfordshire. In both of these areas, the relatively impervious Eocene beds are very thin and close to the edge of their outcrop, and overlie chalk.

Finally, with experience it is possible to judge the amount of investigation required, partly on the basis of the stratigraphy of the site. All deposits vary, both in thickness and in geotechnical properties, and the degree of investigation should be related to the expected uniformity of ground conditions. For example, London clay has well documented properties and tends to be fairly uniform and of great thickness. In contrast, where a stratum is of limited vertical extent (for example, Cornbrash rock which has a maximum thickness of about 10 m) small variations of thickness are much more significant. CP 2004 (Foundations) gives presumed bearing pressures of up to 4000kN/m2 for this type of rock but if such foundation pressures are to be applied, then a detailed investigation of the thickness of the rock will be required to ensure that the Oxford clay beneath will not be overstressed. Similarly, all alluvium tends to have internally more variable lithology, and to be less compact than other sedimentary deposits.

Geological maps are published by the British Geological Survey and are available at the Geological Museum in London, or from the official Ordnance Survey distributor. The availability of maps is given in *Government Publications Sectional List No. 45* (HMSO) which can be obtained free of charge. Published and unpublished maps that are available fall into the following categories:-

1. 1 in. to 1 mile and 1 :50 000. As with the Ordnance Survey topographical maps, the 1in. to 1 mile (1:63 360) map is being replaced by the 1:50 000. In the case of geological maps, the majority of cover now existing remains at a scale of 1 in. to 1 mile. These maps are available in 'solid', 'drift', or 'solid and drift' versions. 'Drift' is a 'dustbin' term used by geologists for all Pleistocene and recent deposits, such as alluvium, glacial material (till) and peat, while 'solid' refers to the sedimentary, metamorphic or igneous rocks which lie beneath any such material. 'Solid' maps do

not show so clearly the extent of any drift that may exist at the ground surface, which is a serious disadvantage in site investigation. 'Solid and drift' maps give the fullest information since they not only give the boundaries of drift materials, but indicate the positions of boundaries between solid strata, where these occur below drift deposits. Whilst it is not usual to find more than one type of map for each location, where there is a choice 'solid and drift' is to be preferred.

2. 1:25 000 (2 in. to 1 mile) and 1:21 120 (3 in. to 1 mile). A few maps of this scale are available, some of which give engineering geology and geotechnical details. At present the cover is limited to Milton Keynes New Town (1:25000). Belfast (1:21 120) and Peterborough (1:25 000).
3. 6 in. to .1 mile (1:10560). Only limited maps of this series are available for purchase, for areas of Northern Ireland, London and for coalfield areas. The great value of this series, however, lies in the manuscript copies held in the Geological Museum Library and at the British Geological Survey's office, and known as the 'County Series'. These maps can be referred to and photo-copies may be purchased, and provide an excellent starting point for geological investigations.

In addition to geological maps, in the UK the British Geological Survey publishes various written sources of information, and will also give access to unpublished information. The most important published works are the 'regional guides' and the 'sheet memoirs'.

Seventeen regional guides are published (Fig. 3.3), covering England, Wales and Scotland. For the non-geologist, these Handbooks on the Regional Geology of Great Britain provide a simple guide to a large section of the country and are therefore a good starting point for the fact-finding survey. More specific and detailed information, including lists of exposures, can be obtained for a particular 1 in. to one mile geological map in the form of the sheet memoir. Sheet memoirs contain detailed information on the local nature of each of the strata, descriptions of the exposures in the area, borehole and well records and groundwater supply details. In addition, slope stability and mineral resources are sometimes discussed. Only part of the available 1 in. maps are covered by sheet memoirs available for purchase, but those which are at present out of print can be referred to at the British Geological Survey Library in Exhibition Road, London, or at local BGS offices.

'Economic and coalfield memoirs' are similar to sheet memoirs, but cover a wider area of specific interest. Two examples are: The Mesozoic Ironstones of England- The Liassic Ironstone and Geology of the S. Wales Coalfield, Part 1, Country around Newport, both of which are currently in print.

The BGS offices also hold various types of unpublished information which may be particularly useful during a desk study. These include out of print sheet memoirs, records made during mapping for the 6in. County Series (known as 'field slips') and the Field Unit Borehole Collection. The Field Unit Borehole Collection may be especially useful as it contains previous site investigation records. Well catalogues can also give valuable information on the depths of different soil types. Well catalogues are now being augmented by the new series of well inventories.

Fig. 3.3 Index map to the areas described in the *Handbooks on the Regional Geology of Great Britain.*

Case Study – Use of well records

For example, well records for two wells made at the British Sugar Corporation's Factory at Sproughton near Ipswich (Table 3.3) show one of the problems of boring in the Gipping Valley.

Despite the fact that these two wells are only approximately 200 m apart, the surface of the Upper Chalk descends from 15.2 m below ground level to over 58.2 m below ground level. This infilled glacial valley often contains materials which are loose and highly compressible. Because the floors of buried channels are irregular, and their sides are very steep, it is rather difficult to detect their presence without closely spaced borings.

Table 3.3 British Sugar Corporation, Sproughton - well records

Well no.	National Grid ref.	Surface Level ft. (m)	Strata	Depth to base ft. (m)
207/139(a)	TM136448	+20 (6.1)	Drift (buried channel) Sand and Gravel (buried channel) End of well	22 (6.7) 191 (58.2)
207/139(b)	TM135450	+20 (6.1)	Drift Sand and Gravel Upper Chalk End of well	34 ½ (10.5) 50 (15.2) 250 (76.2)

Case study - Use of geological maps to plan foundations

Plate 3.3 shows a section of the 1:25000 geological map (solid and drift) for Milton Keynes Sheet SP83 and Parts of SP73, 74, 84, 93, and 94). The area within the box was the site proposed for a low-rise school complex. The geological map shows a fault ('Willen Fault') running through the site, which the cross-section given on the map indicates downthrows to the south. Ground conditions in the area consist of Head, Oxford clay, Kellaways Beds, and Cornbrash. The nature of the Head cannot be deduced from the map, except that it is a drift deposit and may, therefore, be loose or soft. The Oxford clay is described on the generalized vertical section at the edge of the map as 'Bluish grey mudstones about 220ft (67m)' thick, but appears as a stiff or very stiff clay near the surface. The Kellaways Beds are described as 'Fine grey sands overlying bluish grey clay 16-17ft (4.9-5.2m)' thick. The Cornbrash is a limestone rock 3.5-7ft (1.0-2.1m) thick.

Extensive trial pitting and borehole excavation carried out on this site showed that the Head was often soft and loose and therefore unsuitable as a founding stratum. It extended further to the west than shown on the geological map. The trial pits confirmed that, under the proposed building area, the Cornbrash was at a suitably shallow and uniform depth to provide a foundation for spread footings, with the exception of a small area in the south-west of the site. In this area the Cornbrash was found to be 10 m below ground level, and it was deduced that this was as a result of the fault. In this area the foundations were piled.

It will be apparent that although geological maps will not always be precise they can give excellent guidance on the likely ground conditions, their disposition and the approximate thicknesses of each soil or rock type.

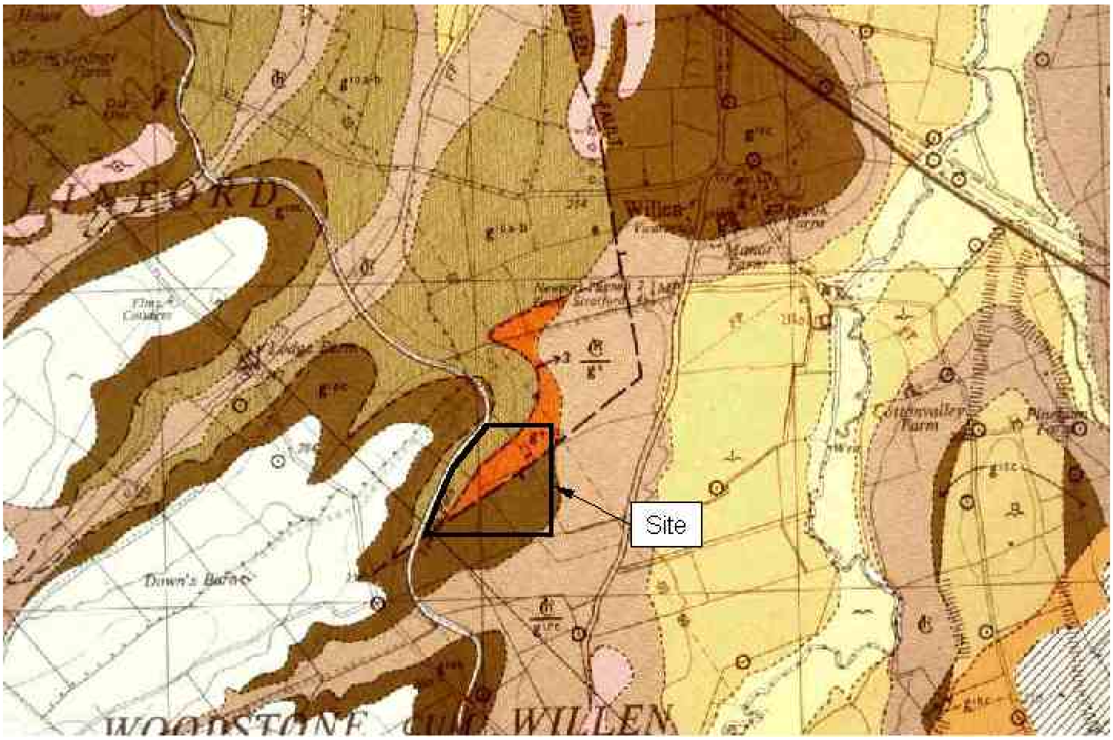


Plate 3.3 Part of the 1:25 000 geological map of Milton Keynes (Sheet SP83 and parts of SP73, 74, 84, 93 and 94). (Courtesy of the British Geological Survey)

Case study - Use of topographical maps and geological records to study housing subsidence

Figure 3.4 shows sections of topographic maps for an area in Dorset: Fig. 3.4a (1963) is the site before construction and Fig. 3.4b (1977) shows the development of detached houses in a cul-de-sac. The earlier map shows that the area of development was previously an excavation. The 1:50000 drift geological map of the area (Sheet 328) records that the site is underlain by Reading Beds, which in many parts of the UK consist of a highly shrinkable clay. This gives the clue that these excavations were formed to win clay for brickmaking. Enquiries at the Dorset County Records Office in Dorchester showed that brickmaking had been carried on at this site from at least 1811, when an Inclosure map showed what is now Watergates Lane as Brickyard Road.

Plate 3.4 shows a reproduction of the manuscript 6in. to 1 mile 'County Series' geological map of the area, held by the British Geological Survey library. The map, from 1895, contains notes on the nature of the materials seen in the area at the time of preparation of the map. These 'exposures' are no longer available. Further details of the materials in this area are given in the sheet memoir (Geology of the Country around Weymouth, Swanage, and Lulworth by W. J. Arkell (1947) and in Chapter XII there is specific reference to the particular brickpit in which the site now lies:-

> The Reading Beds are well exposed at Broadmayne, where for many years they have been made into the well-known speckled bricks. The last surviving brickyard of a line of six about 1/2 mile north-east of the village shows the following section. (see Table 3.4). According to the manager, who supplied the particulars of the lowest three beds, the Chalk lies 'a good way below'.

Table 3.4 Record of Webb, Major and Co's brickyard, Broadmayne (Arkell 1947)

Description	Thickness		Depth
	(ft.	in.)	(m)
Loamy soil full of subangular flints and locally becoming a flint gravel	3-4	0	0.0 – 1.1
Red clay, mottled white	6	0	1.1 – 2.9
Brown loam with manganese nodules	10	0	2.9 – 5.9
Manganese concretionary sandrock; white quartz grains cemented in small black nodules; holds up water	2	0	5.9 – 6.5
White sand, mottled red (seen to7ft.)	8	0	6.5 – 8.9
Black flints, sparsely distributed	0	6	8.9 – 9.0
White tough clay, from which bricks have been made	1	0	9.0 – 9.3
Rough sand, proved to about	5	0	9.3 – 10.8

It can be seen that although a layer of shrinkable clay once existed in these brickpits, it was relatively thin (perhaps 2 m) and will have been worked out over much of the area. Loam is a sandy clay and does not have much potential for shrinkage. Below it, the sand layers should provide good founding layers. It is interesting to make comparison between this record and that produced in 1985 from a borehole just outside the area of the brickpit, details of which are given in Table 3.5.

Table 3.5 Borehole record, Broadmayne, 1985

Soil description	Depth (m)
Topsoil and made ground	0.0 - 1.3
Stiff grey and red mottled silty clay becoming sandy at 2.0m	1.3 - 3.3
Very weak yellowish grey and brown sandstone	3.3 - 8.7
Very stiff light grey silty clay	8.7 - 9.7
Inter-layered sand and clay	9.7 - 10.2
Weathered chalk	10.2 - 15.0

The generally sandy nature of the Reading Beds at this locality is confirmed, and it can be seen that there is quite good general agreement between the borehole record and the desk study information. A number of structures in the area near the disused brickpit have suffered from desiccation and foundation movement problems, because a significant thickness of shrinkable clay exists just below ground level. Within the pit, there may well be areas where all the shrinkable clay has been removed.

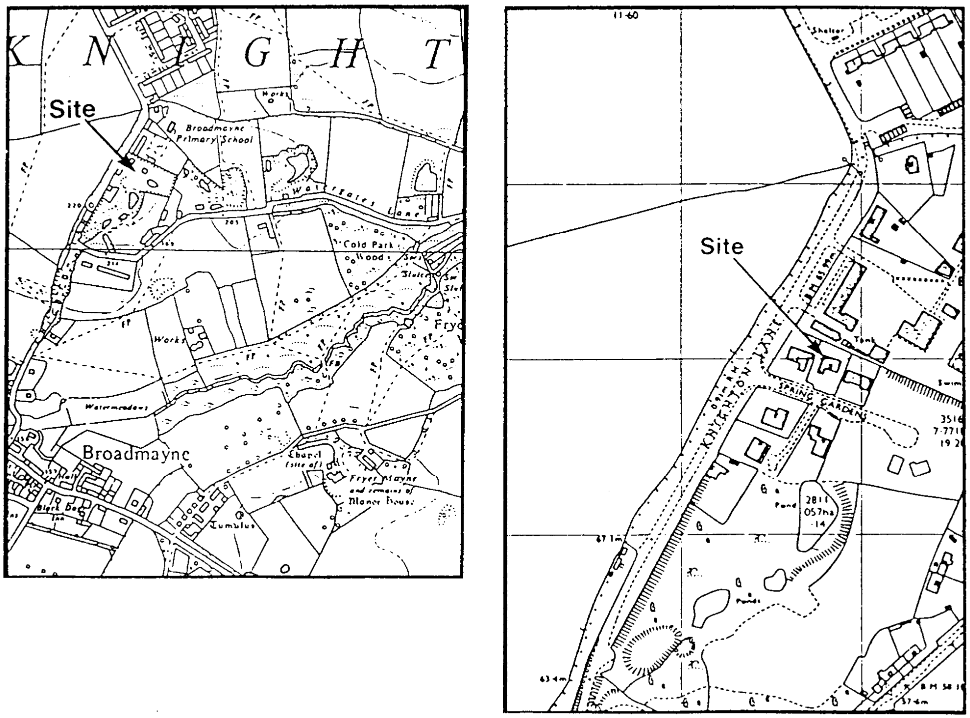


Fig. 3.4 Topographic maps of an area in Dorset showing developments in an old pit: (a) 1:10 560 scale map before construction (1963); (b) 1:25 000 scale map of site after construction (1977) (© Crown Copyright)

Mining records

Mining records are held by a wide variety of organizations, and may sometimes be very difficult to obtain. They are of obvious importance in assessing the effects of future mining activities on proposed structures, and in tracing the extent of past mineral workings which may collapse or settle below existing or proposed structures.

Mining in the UK is not restricted to deep coal mining; a wide variety of minerals has been extracted in the past, and is presently being obtained by both deep mining and quarrying. These minerals include stratified ironstone, shale, fireclay, limestone, chalk flint, sandstone, fluorspar, iron ore, gypsum, potash, galena, slate, gold, rocksalt, ball clay, Fuller's earth, tin and copper. In addition, considerable areas in the south-east of England have been quarried for sand and gravel.

A concise guide to the problems of construction over abandoned mine workings is given by Healy and Head (1984). They provide details of the many different types of mining that have been used over the centuries, and describe how a mining investigation should be carried out. Their methodology, shown in Fig. 3.5, relies on a thorough desk study and archival search both to assess the probability that mining has taken place, and to try to determine the extent of any mining activity. Appendix A of Healy and Head (1984) gives details of desk study sources of information useful during mining investigations.

The presence of mine workings can obviously be inferred from observations of spoil heaps, shafts and disturbed ground on standard records such as topographical maps and air photographs. More specific information can be obtained from geological maps and records, many of which show details of coal, iron deposits, limestone, sands and gravels, and other deposits of economic importance. Maps of the Second Land Utilisation Survey of Britain provide partial coverage of England and Wales, and show the locations of extractive industries and active tips. These are available from the Ordnance Survey agents.

- Abandonment plans for coal and oil shale mines in the UK are now held centrally by: Mining Records Office, Operations Department, British Coal Corporation, Bretby Business Park, Bretby, Burton-on- Trent, Staffs DE15 OQD (tel: 01283-550500).
- Records of coal mine shafts and boreholes are held centrally by the Mining Reports section of the Operations Department, at the same address. When records of operational mines are required, these must be obtained directly from the working pit.
- For quarries and tips, and mines other than for coal and oil shale, Her Majesty's Inspectorate of Mines has now passed all records back to local authorities. These are held by a variety of departments, but primarily by county archivists.
- For salt mining, information on areas which are subject to brine solution mining, and which have been affected by subsidence can be obtained from: Cheshire Brine Compensation Board, 41 Chester Way, Northwich, Cheshire (tel: 01606-2172).
- For iron ore, some help may be obtained from the Iron Ore Mining Division of British Steel Corporation at: Iron Ore Mining Division, British Steel Corporation, Scunthorpe, Humberside (tel: 01724-843411).

General information on mining may be obtained from The Institution of Mining and Metallurgy, in London.

Mining has been carried out since time immemorial. Therefore one of the major, and unexpected, hazards that can affect construction is the collapse of ancient mine-workings. Figure 3.6 shows the result of such a collapse, which occurred in the city of Norwich (UK) in March 1988, probably as the result of the collapse of an ancient chalk mine, triggered by a waterpipe burst. The double-decker bus had just pulled away from a bus stop when the rear wheels sank into the road up to their axle. Within minutes the bus had sunk into a hole about 10m across, and 4m deep. Although the driver and passengers escaped unhurt, it was necessary to evacuate some 30 local residents because of gas leakages. The road was not re-opened to two-way traffic for more than a year, and the repair, involving the placement of a large volume of concrete in a complex of holes with a maximum depth reported as 17 m, was estimated to cost about £70,000.

Because of the wide occurrence of abandoned mines, it will be wise to carry out a thorough desk study when working in a new area, giving particular priority to the identification (via geological maps, old topographical maps and local historical records) of strata that may have been mined in the past, and of the problems that these cause (by reference to old newspaper articles, and technical journals). Speleological societies may provide useful records of underground cavities. In the UK, the Chelsea Speleological Society (previously the London Speleological Society) has a computerized database of records of over 2000 caves and mines in the south-east of England, compiled largely from their own records, but also from the records of industrial societies, archaeological societies, and natural history societies (for example, bat groups) Chelsea Speleological Society 1990).

Large national organizations whose work is affected by mining subsidence may hold records of abandoned mines near to their properties. In the UK, these include:

- British Rail (Derby);
- British Waterways (Leeds); and
- local authority mining valuers, who may hold data.

Also, in the UK, other sources of information on unstable ground include:

- the Ove Arup and Partners/Department of the Environment catalogue of areas of mining instability; and
- the Applied Geology Limited Natural Cavities Catalogue.

Case study - Use of geological maps to locate the presence of coal seams

Figure 3.7 shows part of the published 1:10 560 geological map of an area of south-east Bristol. The area, which had previously been the site of a jam factory (see later) was to be redeveloped as a large retailing facility, with provision for a petrol station, and parking for 700 cars. As part of the desk study for the project, the geological maps were examined. This map shows that the geological structure of the area is quite complex. The map"" gives considerable insight into the likely problems of redeveloping the site, showing alluvium in the valleys, and the presence of a fault and an unconformity. One obvious and important feature to be seen on the map is the existence of a number of thin coal seams, shown as thick black dashed lines. One of these (the 'Pot Seam') is likely to be at shallow depth beneath the proposed location of a large building, at the north end of the site. Thin coal seams (of the order of 300mm thick) are known to have been mined in some parts of the UK, and so the development of the site involved special and detailed drilling of this area, and subsequent grouting of the seams, which were found to lie at a depth of about 10 m below ground level.

Records to establish previous site use

Any plans for construction should take into account existing construction, and the impact that this may have on the proposed project. Nearby services, foundations and retaining structures may be adversely affected or, conversely, may cause difficulties for the new construction.

Case study - Use of construction records and technical journals to investigate the position and depth of old foundations

It is proposed to construct a service tunnel between St John's Wood (north London) and Clapham Common (south London). As part of the process of deciding on the precise route of the tunnel it was necessary to investigate the depths of foundations along the route, to ensure that the tunnel line would not pass through them. One of the largest structures along the route is in Victoria, and is currently occupied by the National Audit Office.

A desk study was carried out, to establish as far as possible the site history, and foundations used for the National Audit Office. The records used included:

- topographical maps;
- geological survey 'memoirs';
- geological maps;
- previous site investigation reports;
- articles in journals, including:
  - Railway Magazine (1960),
  - The Architect and Building News (1939),
  - Civil Engineering (1938),
  - Proceedings of the Institution of Civil Engineers (1946),
- British Rail drawings for Victoria Station; and
- approximately 70 engineering drawings, relating to the design of the building, many obtained from British Rail, and from the current occupiers of the building.

The site lies parallel to the tracks entering one of London's major railway termini, alongside what was once a small valley, containing a minor tributary to the River Thames. Available geological records indicate that the site is underlain by made ground, alluvium and London clay.

Records suggest that since the 17th century the site was adjacent to man-made waterways. In the 1830s these waterways were made navigable, and the site then became developed for wharfs and warehousing to serve what became known as the Grosvenor Canal, immediately to the north-east of the site. Initially, in the 19th century, the railway was constructed alongside the canal, but finally, around 1900, the canal basin was infilled to allow the development of the station terminus.

The building, as it stands today, was constructed in three phases. The records show that in 1937-38 the foundations for the first phase, including the large central tower, were planned. Articles in technical journals provided not only simplified borehole records, but also records of pile tests to establish bearing capacity. These records show the existence of an alluvial brown sand layer beneath the site, above the London clay. Current practice uses large-diameter bored piles to support heavy structures founded on the London clay, but in the 1930s the plant and technology were not available to construct them. It was therefore stated, on the basis of pile test results (Williams 1938) that 'the results of test piles definitely ruled out the use of piles…. to carry the very heavy loads of the main tower'. The tower was therefore founded on a shallow reinforced concrete raft, on the sand. Beneath the remaining areas of the building, developed over a period of almost 30 years, a wide variety of pile types and lengths was used. Either from records of pile length, or from a knowledge of ground conditions at the site, estimates of the maximum foundation depth were obtained, and compared with the proposed elevation of the tunnel.

As demand for land for development increases, there has been a rapid increase in the re-use of derelict industrial sites in the UK. The re-use of derelict land presents the following special problems to the geotechnical engineer.

1. Structural foundations must take into account the greater ground movements, and the possibility of attack of corrosive ground on foundations, which are often associated with made ground. Ground improvement may need to be carried out.
2. The special hazards to the health of construction workers, and to the occupiers of the site once construction has been completed, must be fully investigated. A preliminary estimate of the potential nature of these hazards can often be made on the basis of the precise nature of previous land use. Table 3.6 gives examples of the hazards associated with different types of land use.

The main stages to be carried out are an investigation of site history, using existing records, and a site visit (see later). The desk study must include a search of all available large-scale topographical maps (i.e. 1:10560 or larger), including maps that are now out of print.

Table 3.6 Contaminants associated with various industrial sites (from DD175: 1988)

Industry	Examples of sites	Likely contaminants
Chemicals	Acid/alkali works Dyeworks Fertilizers and pesticides	Acids; alkalis; metals; solvents, (e.g. toluene, benzene); phenols,

	Pharmaceuticals Paint works Wood treatment plants	specialized organic compounds
Petrochemicals	Oil refineries Tank farms Fuel storage depots Tar distilleries	Hydrocarbons; phenols; acids; alkalis and asbestos
Metals	Iron and steel works Foundries, smelters Electroplating, anodizing and galvanizing works Engineering works Shipbuilding/ shipbreaking Scrap reduction plants	Metals, especially Fe, Cu, Ni, Cr, Zn, Cd and Pb; asbestos
Energy	Gasworks Power stations	Combustible substances (e.g. coal and coke dust); phenols; cyanides; sulphur compounds; asbestos
Transport	Garages, vehicle builders and maintenance workshops Railway depots	Combustible substances; hydrocarbons; asbestos
Mineral extraction Land restoration (including waste disposal sites)	Mines and spoil heaps Pits and quarries Filled sites	Metals (e.g. Cu, Zn, Pb); gases (e.g. methane); leachates
Water supply and sewage treatment	Waterworks Sewage treatment plants	Metals (in sludges); microorganisms
Miscellaneous	Docks, wharfs and quays Tanneries Rubber works Military land	Metals; organic compounds; methane; toxic, flammable or explosive substances; micro-organisms

Note: Ubiquitous contaminants include hydrocarbons, polychlorinated biphenyls (PCBs), asbestos, sulphates and many metals used in paint pigments or coatings. These may be present on almost any site.

In the UK, the most useful maps are the 'County Series', produced from the mid-19th century up until the Second World War, and the Ordnance Survey National Grid mapping, which replaced the County Series. In addition to these plans, county libraries, muniment rooms, and archives will contain valuable historical information, for example:

- old mining records;
- trade directories (Kelly's - from about 1850);
- the Victoria County History;
- specialist archival materials on local industries;
- old newspaper files (also available from newspaper publishers);
- Public Health Act plans (c. 1850) which were prepared for the installation of the early Victorian sewer systems; and
- early maps, for example related to property ownership.

In addition, it will be useful to contact local waste disposal authorities (in the UK, the County Waste Disposal Authority), who may have information on old waste disposal sites.

Other records

Virtually any type of record may have practical significance to construction. Records which are less frequently used during desk studies include the following.

1. *Service records.* Service records are kept by utility companies, such as gas, electricity, telephone and water supply companies, as a record of their installations. These records have considerable significance when site investigations are planned in urban areas, where the presence and high density of services may put the safety of drilling operatives at risk.
2. *Soil Survey Records.* These are made primarily to give information on agricultural soil conditions. The results of pedalogical soil surveys are usually published as maps and accompanying soil survey records (in the UK, by the Soil Survey of England and Wales, who started this work in 1966). Soil surveys consider only shallow deposits, to a depth of about 1-1.5 m. The properties of these materials are related not only to vegetation and weathering, but also to the materials beneath them. Therefore soil survey maps reflect the underlying geology. In the UK, published soil survey maps exist at scales between 1:1 000 000 and 1:10 560, with the most useful cover being at 1:63 360 and 1:25 000 scales. Examples of the usefulness of this type of record are given by Aichison (1973), Allemeier (1973), McGown and Iley (1973) and Dumbleton and West (1976a).
3. *Meteorological records.* Meteorological records are of use in assessing future weather conditions, for example to provide an estimate of the time likely to be lost, during construction, as a result of bad weather conditions. They can also play an important role in the investigation of failures, or the investigation of lack of productivity of earthmoving plant. The Meteorological Office (Bracknell, UK) will provide certified statements of past weather (perhaps useful in preparing insurance claims), as well as the full range of specialist forecasting services for the construction industry.
4. *River authority records.* This form of record is of particular value in providing records of flooding, perhaps when construction is to take place close to a river.
5. *Earthquake records.* Although the UK occupies a relatively quiescent area of the world, this is not the case elsewhere. Large areas of Europe and the USA are subjected to frequent and intense earthquakes, but of varying magnitude. Earthquake records from around the world are available from the International Seismological Centre at Piper's Lane, Thatcham, Newbury, Berks RG13 4NF (tel. 01635-861022 fax. 01635-872351).Given a location (in terms of latitude and longitude) and a search radius, the date, time and magnitude of earthquakes, from approximately 1920 onwards, can be provided on payment of a fee. Local observatories will also generally be able to provide a similar service for their area.

AIR PHOTOGRAPHY AND REMOTE SENSING

Topographic and geological maps, although of great value in the preliminary desk study, give only a limited amount of data which is capable of geotechnical interpretation. The limitations of maps are a function of scale, subjectivity and frequency of revision. Features whose recognition is important for geotechnical purposes are often too small to be shown on conventional maps drawn at scales of 1:25000 or 1:50000. Such features may be shown on maps drawn at scales of 1:10000 or 1:2500, but in some cases the contour interval is too large for a minor topographic feature to be shown, or the subject of the map does not warrant the inclusion of certain features. It is not practical to indicate symbolically all surface features on a single map because the cost of surveying would be prohibitive and furthermore the map would be too complex to be read efficiently. Because of the time and cost involved in survey and map preparation, complete revision of maps is not carried out very frequently. The most frequent revision to existing maps is for major features such as roads and urban development. Minor revisions such as small changes in topography due to lands lip activity or changes in field boundaries are not always included. Geological maps undergo revision most infrequently. Of course the rocks are not expected to change over fifty or one hundred years, but the interpretation, particularly in questionable areas and for superficial geology (drift) may change as new data become available.

The limitations of topographic and geological maps are overcome to a certain extent by the use of aerial photographs, which provide a detailed and definitive picture of the topography, lines of communication (roads, railways and canals), surface drainage and urban development. Furthermore, additional information is provided on land use, vegetation, erosion, and instability, which may be interpreted in geotechnical and geological terms. No surface detail is omitted in an aerial photograph, but some features may be obscured or hidden by vegetation (usually trees). Some detail may also be hidden by buildings, or diminished by the scale of the photographs.

The uses of aerial photographs are two-fold:

1. photogrammetry; and
2. air-photo interpretation.

Photogrammetry refers to the technique of making accurate measurements from aerial photographs and is discussed in detail by Kilford (1973). This technique requires the use of a certain type of aerial photograph (the vertical aerial photograph) which is discussed later. Photogrammetry is used widely in topographic surveying for map preparation, because the use of aerial photography is much less expensive than ground surveys. Clearly such a technique can be of immense value in site investigation for revising existing maps and plans, surveying remote unmapped areas, and siting boreholes. Most small-site investigation contractors however will not have the necessary facilities to carry out photogrammetric work.

Air-photo interpretation refers to the use of aerial photographs in the qualitative or semi-quantitative study of the character of the ground, or of vegetation or structures on it. Its fields of application are numerous. Military reconnaissance was probably the first application of air-photo interpretation, and World War II gave rise to some major advances in aerial photography for interpretation purposes. Since World War II air-photo interpretation has been applied extensively in the fields of geology, terrain evaluation, land use, agriculture, forestry, archaeology, hydrology, pedology, vegetation and environmental studies.

Air photographs are as readily available in most parts of the world as topographic and geological maps, and are similar in price. Indeed, in some areas (for example, Italy) published topographical maps consist of contoured vertical black and white air photography, with the names of prominent features superimposed upon them. The information that may be obtained from air photographs includes the following.

1. *Topography of the site and surrounding area.* The inclinations of slopes as well as small changes in topography may be seen from a three-dimensional image produced by viewing overlapping pairs of aerial photographs (the viewing of air-photos is discussed later).
2. *Geology of the site.* The superficial geology and solid geology can often be interpreted from features such as landforms, drainage patterns, land use, and vegetation.
3. *Site drainage.* The location of springs, seepages, poorly drained ground, ponds and potential flood zones can usually be identified from aerial photographs.
4. *Instability.* Landslip activity, whether recent or not, can often be identified. Examination of photographs taken at different times can be used to define the most active zones in landslip areas.
5. *Site history.* Previous uses of the site can be seen from a series of aerial photographs taken over a period of time.
6. *Site accessibility.* Gates and breaks in hedges or fences together with an overview of the general terrain to be covered can be seen on air-photos. This can be of great

assistance in planning the movement of drilling rigs and other equipment over the site.

7. *Identification and location of features of special engineering interest.* In some cases, features such as gulls, sink holes and mine shafts can be identified from aerial photographs.

It should be pointed out that much detail can be hidden by trees, particularly if the tree cover is dense. In such cases, aerial photographs may be of little use. The amount of tree cover can often be assessed prior to obtaining the air-photos of a site from topographic maps. The geotechnical and engineering geological interpretation of sites in the UK is discussed by Burton (1969), Norman (1969, 1970), Dumbleton and West (1970) and Norman et al. (1975). The importance of air photographs as a source of desk study information is hard to over-emphasize, not only because of their versatility, but also because of the unique role that they can play in allowing the identification of certain types feature which can be difficult, if not impossible, to detect in other ways, for example:

- slope instability; and
- solution features in carbonate rocks

and in addition because of their increasingly important role in providing a complete record of site conditions.

Types of photographic image

Two types of image are available for use in site investigation desk studies:

1. photographic images, taken by camera, typically from an aircraft (generally termed 'air photography'); and
2. digital images, typically produced by a multi-spectral scanner, most usually operating from a satellite (termed 'satellite imagery').

Air photographs are of most use during desk studies in developed countries, because the images are cheap, readily available, and do not need computer processing. As the resolution of multi-spectral scanners improves (currently SPOT imagery has a pixel size of about 10 m) it can be expected that this form of remote sensing will become more popular.

Generally the amount and type of data which may be obtained from aerial photographs will depend upon the following:

1. orientation of the camera axis with respect to the vertical;
2. the type of film and filters used;
3. the amount of overlap between adjacent photographs;
4. the scale of the photographs;
5. time of photography; and
6. season of photography.

The above parameters may be varied to suit the application for which the photographs are to be used. The interpretation of the photographic data will not only depend on the application but also on the type of aerial photograph which is a function of the first three parameters listed above.

Vertical / oblique photography

The types of aerial photographs available are normally defined by the orientation of the camera axis, the type of film and filters and the amount of overlap between adjacent photographs. Based on orientation of the camera axis, aerial photographs may be classified as either vertical or oblique. Vertical aerial photographs are those made with the camera axis orientated as near to vertical as possible. Truly vertical air-photos are rarely obtainable because of the aircraft tilting and thus causing the camera to tilt. A slight unintentional tilt of about 10 to 50 from the vertical is normally tolerated for vertical photographs. Thus, for photogrammetric work, vertical aerial photographs are necessary. Aerial photographs taken with an intentional inclination of the camera axis to the vertical are termed oblique aerial photographs. Such photographs are classified as high oblique if an image of the horizon is included and low oblique if it is not.

Both oblique and vertical aerial photographs are used in site investigations. Vertical aerial photographs, however, are used more extensively than oblique aerial photographs for interpretation purposes. This is due to three important factors. First, vertical photography covering most of the UK is readily available, whereas oblique coverage is very limited. Secondly, accurate measurements generally cannot be made from oblique aerial photographs except in areas of low relief where co-planar control points can be used (Matheson 1939). Thirdly, the qualitative data obtained from oblique photographs are generally less comprehensive than those obtained from vertical air photographs for the following reasons.

1. The change in scale across the photographs can be rapid in the case of high oblique photographs and complex in areas of high relief.
2. The distortion of shapes on oblique photographs can give the wrong impression of the importance of a ground feature.
3. A considerable amount of ground can be hidden from view by hills (dead ground).
4. The production of a print laydown using oblique photographs is difficult and in many cases impossible.

Despite the disadvantages of oblique aerial photographs, they can be very useful in supplementing data obtained from vertical aerial photography. Some of the disadvantages can be overcome by using low oblique photography. Topographic features, however (particularly subdued topography), are generally shown more clearly on high oblique aerial photographs.

Case study - The use of oblique air photography to investigate the morphology of a landslide at Stag Hill, near Guildford, Surrey

The north face of Stag Hill near Guildford, Surrey, was the site chosen for the University of Surrey. The reason why a site so close to the town centre of Guildford had not been previously developed was because of a large landslip which occupies the north face of Stag Hill. This landslip occurred on a 9° slope in brown London clay (Fig. 3.8) and its extent is clearly visible on vertical aerial photographs taken before construction of the university began in 1967. An example of such a photograph (taken during 1961) is shown in Fig. 3.9.

The landslip is identified on Fig. 3.9 mainly by shadow and relief. The rear scarp and toe of the landslip form a small step in the slope which can be seen when the vertical air photographs are viewed stereoscopically (Fig. 3.10). These topographic features are enhanced by shadow allowing the limits of the slip to be estimated readily from a single photograph (Fig. 3.9). It will be seen from Fig. 3.9 that a line of trees and bushes marks the position of part of the rear scarp and toe. The topographic expression of these features appears to be more pronounced here than elsewhere, making cultivation across them very difficult. Thus natural vegetation has been allowed to become established on these parts of the rear scarp and toe. If early photographs of the site before development (1949 or before) are compared with that shown in Fig. 3.9 the increase in the amount of vegetation in these regions of the rear scarp and toe is most noticeable, and may indicate relatively recent movement.

Several coalescing landslips of different ages give rise to the overall feature seen in Fig. 3.9. Although the contact scale of the photograph in Fig. 3.9 is 1:4000, many of the minor features associated with the individual landslips are difficult to identify. The photographs were taken nearly two hours from noon, but the inclination of the sun's rays was clearly not low enough for shadow to be used to enhance the subdued topography of these features. The minimal shadow normally required for vertical air photography can severely limit the detection of minor landslip features. As mentioned earlier, however, oblique photographs (when available) can often overcome this problem. It is fortuitous that the Stag Hill site is immediately adjacent to the site of Guildford Cathedral; numerous oblique aerial photographs have been taken of the Cathedral and most of these include the north face of Stag Hill. This allows the landslip features to be examined using oblique air photographs over a period of about 35 years (from the start of construction of the Cathedral to the start of construction of the university). The oblique air photograph shown in Fig. 3.11 was taken with a low sun angle. Minor topographic features associated with the landslip are clearly visible because of the long shadows. A feature indicative of a toe of an old landslip may be seen in the field to the north-east of the cathedral (marked A on Fig. 3.11). This feature cannot be identified on the vertical photographs. Both oblique and vertical aerial photographs have been used to produce a map of the Stag Hill site showing the probable sequence of landslips. This map is shown in Fig. 3.8.

Figure 3.12 shows the Stag Hill site in 1971 when the main phase of construction of the university was completed. The toe of the landslip is still visible at A. The contact scale of the photograph is 1:12000. At this scale, only the major features such as the toe of the landslip and some tonal contrast within the slipped area are identifiable. A comparison of Figs 3.9 and 3.12 illustrates the loss of detail with decreasing photo scale.

Aerial photographs can be of value in locating areas of landfill. Figure 3.9 clearly shows the location and extent of a brick pit in London clay to the east of the cathedral. Comparing this photograph with that shown in Figure 3.12, it will be seen that the brick pit has been backfilled and the university buildings sited to avoid the fill. It is always advisable to examine early aerial photography as well as recent aerial photographs in order to detect old as well as recent landfill sites. An example of the detection of a wartime military trench illustrates this point well, and is given later.

Film type

The type of film used in the camera gives rise to the following general types of aerial photograph:

1. black and white;
2. colour; and
3. infra-red (in colour or black and white).

The most common type of film used in aerial photography is black and white panchromatic film. The data obtained from black and white photography are normally sufficient for interpretation in most site investigation applications. The use of colour photographs, however, can provide additional information. This is because the human eye is capable of separating at least one hundred times more colour combinations than grey scale values (Beaumont 1979). Colour photography has proved most effective for geological interpretation (Fischer 1958; Chaves and Schuster 1964), but it is more expensive and less readily available than black and white photography and hence its use tends to be limited in site investigations.

Infra-red films record reflected radiation in the visible part of the spectrum, but are also sensitive to reflected infra-red radiation (to wavelengths of about 0.9ftm), which is invisible to the naked eye. The dyes used in colour infra-red film produce false colours. Blue images result from objects reflecting primarily green energy; green images result from objects reflecting primarily red energy, and red images result from objects reflecting primarily in the photographic infra-red portion of the spectrum (0.7-0.9 μm). Reflected energy of different wavelengths appears as different tones of grey in black and white infra-red photographs. The advantage of colour infra-red photography over black and white infra-red photography is basically the same as that mentioned earlier for normal colour photography compared with normal black and white photography. Colour infra-red photography (or false colour photography) is used extensively in forestry, agriculture and vegetation studies. This is because differences in reflectivity between different flora and between healthy and unhealthy flora are most pronounced in the infra-red part of the spectrum.

Water totally absorbs infra-red radiation, making colour infra-red photography most useful for studying drainage. Springs and seepages can be easily located using this film. Objects which reflect primarily blue energy appear as black images on both colour and black and white infra-red photographs since blue energy is normally filtered out. Free standing unpolluted water therefore appears as a black image on an infra-red photograph. Polluted water is highlighted by colour infra-red photography.

Despite the additional data provided by infra-red photography, it is little used in site investigation. This is because the cost of infra-red photography is greater than normal colour photography, and the interpretation of such photographs is a highly specialized field requiring a knowledge of film processing technology. It should be pointed out that an understanding of how films are processed is also helpful for the interpretation of normal colour photographs.

The identification of ground features is greatly aided by the use of multi-band photography. This technique allows small wavelength bands or spectral regions of the visible and invisible parts of the spectrum to be sampled. This is achieved using different filters and film types. Multi-band photography is carried out using a special multi-lens camera (generally four lenses are used) which allows different bands to be sampled at the same point in space and time. Within a single band, certain ground features will be enhanced while others are suppressed. Thus an examination and comparison of the images produced within each band enables ground features which are normally subdued in conventional photographs to be identified easily. Multi-band photographic systems are limited to the 0.3-0.9 μm spectral range because of the spectral sensitivity of photographic film. Multi-spectral scanners described by Lillesand and Kiefer (1979) are capable of sampling a far greater range of wavelengths (0.3-14 μm) and should not be confused with multi-band photography. Multi-band photography has been used with success in the fields of photogeology (Ray and Fischer 1960; Fischer 1962), soil mapping (Tanguay and Miles 1970) and archaeology (Hampton 1974). Some of the applications of multi-band photography in site investigation would include detection of sink holes, abandoned mine shafts, areas of fill, and unstable ground. However, multi-band photographs of the UK are not readily available and hence have to be specially flown. This severely restricts their use in site investigation on the grounds of cost.

Amount of overlap

The interpretation of aerial photographs and photogrammetric measurements involves the utilization of stereoscopic viewing to provide a three-dimensional image of topographic relief. This effect is possible because our eyes are separated by a small distance (eye base) allowing objects to be viewed simultaneously from two different positions. The eye base is such that the brain is able to merge the two images resulting in a three-dimensional image. This phenomenon is termed depth perception. If two aerial photographs overlap, the objects within the area of overlap will be seen from two viewpoints as a finite distance exists between the centres of the photographs (the distance between camera positions is termed the air base). Thus if the left photograph of the pair is viewed with the left eye and the right photograph with the right eye, a three-dimensional image (stereomodel) of the area within the overlap can be produced. A pair of photographs which can be viewed in this way is termed a stereopair. The stereo viewing of aerial photographs is aided by the use of a stereoscope. The simplest stereoscope (pocket stereoscope Fig. 3.13a) merely consists of a pair of lenses mounted on a frame. The photographs have to be placed close together when using this device which makes stereoviewing of stereopairs with a large overlap difficult without bending the photograph.

The mirror stereoscope optically extends the eye base allowing a stereomodel to be formed with the photographs separated by several centimetres as shown in Fig. 3.13b.

Clearly, the amount of overlap between adjacent aerial photographs will affect the area which can be viewed stereoscopically. An overlap of 60% ensures that the whole area covered by each photograph in a traverse line (run) can be viewed stereoscopically with the exception of the first and last photographs in the traverse. This amount of overlap is normally used for air-photo interpretation and photogrammetric work. The minimum overlap generally accepted for stereoscopic viewing is 20%. This amount of overlap allows only a small area to be viewed stereoscopically. In a sequence of photographs taken along a traverse line, 60% of each photograph cannot be viewed stereoscopically. The use of such a small overlap is thus limited.

The effect of viewing stereopairs with an eye base far less than the air base of the photographs and a viewing height considerably less than the distance between the camera and the ground (flying height) is the exaggeration of vertical scales. This is referred to as the vertical exaggeration. The amount of vertical exaggeration is dependent upon the ratio of air base to flying height. The larger the air base/flying height ratio, the greater the vertical exaggeration. Clearly if the flying height remains constant, then the vertical exaggeration will increase with decreasing amount of overlap between adjacent photographs. For 60% overlap, the terrain is normally seen exaggerated in height by about three or four times. The vertical exaggeration will also cause slopes to appear steeper than they are in reality. Figure 3.14 shows the relationship between actual slope angle and apparent slope angle.

Scale

The amount of detail that can be seen on an aerial photograph will depend to a large extent on the scale of the photograph. Unlike a topographic map, the scale of vertical aerial photographs varies in relation to the terrain elevation. Thus if the differences in elevation are small, the variation in scale is small, but large differences will result in significant variations of scale. For this reason an average scale (contact scale) is given which is a function of the focal length of the camera and the average flying height above ground level:

$$S_{av} = \frac{f}{H - h_{av}} \tag{3.1}$$

where S_{av} = contact scale, f = focal length of camera, H = flying height above sea level and h_{av} = average terrain elevation.

The scale of aerial photographs can vary from about 1:4 000 000 (for photographic images produced by satellites) to about 1:2000. Plate 3.5 shows the area of ground covered by air photographs (conventional 230 x 230 mm contact prints) taken at different scales. Clearly as the scale increases the area covered by the photograph decreases making it difficult to place large features such as major landforms into an environmental setting.

The optimum range of photo-scales for more local geological surveys is between 1:10 000 and 1:20 000 (Norman 1968b). Webster (1968) points out that at photo-scales less than 1:40000 meaningful interpretation becomes very difficult since much of the topographic detail used as landmarks in walk-over surveys is lost and the attributes of the land used to detect soil differences become indistinct. This scale marks the lower limit for most air-photo interpretation purposes, particularly in the UK. Much larger photo scales are required for geotechnical interpretation. There are two reasons for this. First, the geotechnical maps produced during site investigations are normally drawn at scales larger than 1:10 000, and the air photographs used in the preparation of these maps should be at the same scale or larger.

Secondly, many ground features that are used to aid geotechnical interpretation become indistinct at small photo-scales. The optimum range of photo-scales from which meaningful geotechnical interpretation can be carried out is between 1:2500 and 1:10 000. Most of the available SI aerial photography of the UK is at a photo-scale of between 1:10 000 and 1:30 000. The most popular photo-scale appears to be about 1:10 000 and hence much of the geotechnical interpretation must be carried out at the minimum scale in the range mentioned earlier on the grounds of general availability.

Time and season of photography

The time of day at which aerial photographs are taken can have a great. influence on the appearance of ground features. The controlling factor is the sun's elevation. At low elevations (i.e. during early morning or late evening) long shadows are cast by objects on the ground. The shadow will enhance subdued topography which may be associated with features of geotechnical interest, such as areas of slope instability (Fig. 3.11). Hackman (1967) has shown in model tests that subdued morphology becomes more distinct when the sun is very low and the inclination of its rays are 100 or less with respect to the horizontal. The subdued pattern of relief associated with many archaeological features makes low sun angle photography extremely useful in aerial archaeological surveys. Examples of archaeological features enhanced by shadow are shown in Figs 3.28 and 3.29.

While shadow can be an aid to interpretation, it can also be a hindrance, particularly in areas of high relief, since important detail may be hidden. It is for this reason that most vertical air photography is taken during late morning or early afternoon when the sun's elevation is at or near maximum, and hence the amount of shadow is minimal. Low sun angle vertical aerial photography is therefore not readily available for most of the UK. Oblique air photography taken during early morning or late afternoon tends to be more common, but existing oblique photography is very limited in terms of the areas covered.

The season in which aerial photographs are taken is often a critical factor in detecting features of geotechnical interest, such as soil patterns, areas of instability and springs and seepages. Soil patterns may be used to locate old stream channels (Fig. 3.18), areas of peat, and to obtain an overall idea of soil types and their variability over the site. Webster (1968) points out that most surface differences in soil depth and type are most apparent on aerial photographs when there is a large range of soil suction. The larger the soil water deficit, the larger the total range and the greater the tonal contrasts produced on the photograph. On these grounds, Webster has found photography taken in later summer (August and September) to be best. Evans (1972) suggests that most soil patterns are clearly shown on photographs taken during March and April (Fig. 3.15). For the photogeological interpretation of faults, rock contacts and soil contacts, Norman (1968b) recommends photographs taken during the autumn. However; it should be pointed out that of the photographs examined by Norman, less than 5% were taken during autumn. In some cases, features of geotechnical interest may be hidden by crops in cultivated areas. In such cases photographs taken during the months when the ground is bare of crops will be necessary. Springs and seepages may not be visible on photographs taken during summer when the groundwater table is low. In general, photographs taken during spring or autumn will normally provide sufficient data for the interpretation of most geotechnical features. Of course the choice of season is limited to a large extent by the availability of existing photography.

In the UK, periods of good weather favourable for air photography (i.e. minimum cloud and good visibility) amount to less than 500h in a year. The summer offers the most settled conditions, but spring and autumn have the highest proportion of days with good visibility (St Joseph 1977) and hence photographs taken during these seasons should be readily available.

The interpretation of aerial photographs

The ability to interpret aerial Photographs for site investigations depends primarily on having a knowledge of geology, geomorphology and geotechnics, and acquiring experience in recognizing features of interest from the air. Keen powers of observation together with imagination and patience are clearly necessary prerequisites for this exercise. The detailed analysis of ground features which appear on aerial photographs not only requires a great deal of experience, but also a knowledge of the science of photography. This can be a critical factor when interpreting colour, infra-red and multi-band photography. Interpretation of air photographs without studying all the available information concerning the site is of little value even if the interpreter has satisfied the above requirements.

Good use can generally be made of black and white panchromatic and colour aerial photographs without special experience or an extensive knowledge of geology, geomorphology and photography. However, the specialist interpreter will be capable of making a much more detailed analysis of the photographs. Large organizations involved in site investigation are likely to employ a geologist, engineering geologist, or geotechnical engineer who is able to make such detailed interpretations. Smaller organizations lacking such expertise can make use of companies which offer an air photograph interpretation service. Examples of such UK based companies are given by Burton (1969).

The limited availability (of existing photographs) and the high cost of colour and infra-red aerial photography compared with that of (black-and-white) panchromatic film result in the latter being used extensively for interpretation purposes in site investigations. The following discussion is essentially devoted to the interpretation of black and white vertical aerial photographs although much of it will apply equally to the interpretation of oblique photographs.

Air-photo interpretation involves a systematic examination of each stereopair covering the area under consideration. Anyone looking at a photograph for whatever purpose is performing interpretation. However, an aerial photograph of the area which includes one's house is more meaningful than an aerial photograph of another part of the country. This is because one's knowledge of the area in which one lives is generally greater than one's knowledge of other areas. This fundamental difference in capacity for interpretation is clearly a function of the amount of knowledge stored in the mind of the interpreter and is termed the reference level of the interpreter (Tait 1970). In practice, the successful interpretation of aerial photographs depends upon the basic reference level of the interpreter, the degree to which this basic reference level can be extended for each site, and the ability of the interpreter to make full use of interpretative aids, such as image and physical characteristics.

For site investigations the basic reference level required by the interpreter is a knowledge of physical and cultural features and their relationships with geology, geomorphology and land use. A study of these features should enable points of geotechnical interest to be identified. Ideally the interpreter should be familiar with the site and surrounding area. The necessary extension of the basic reference level is achieved to some extent by studying all the data collected during the preliminary desk study. At the very least this should include topographic and geological maps together with soil survey maps when available. Further familiarization is provided by a walk-over survey of the site.

Aids used in interpretation

Every photograph must be treated on its own merits, and hence there are no rules which define how a photograph should be interpreted. This makes teaching photo-interpretation for any purpose difficult without practical examples. The interpreter will only improve with practical experience. However there are several aids which are recognized as necessary for successful interpretation. These aids may be termed collectively as image characteristics and physical characteristics as in Table 3.7.

Table 3.7 Aids to interpreting a photograph

Image characteristics	**Physical characteristics**
Shape	Landforms
Size	Vegetation
Pattern	Land use
Shadow	Drainage and erosion
Tone	Lineations (natural and man-made)
Texture	
Site	

IMAGE CHARACTERISTICS

1. *Shape*. Shape refers to the shape of features seen from the air. Man-made features are normally characterized by straight lines or regular curves, and hence are often recognizable by shape alone. Many natural features have distinctive shapes. For example, mudflows are generally lobate and sink holes are commonly circular. However, in general, natural features may be difficult to identify on the basis of shape alone, and require other image or physical characteristics to be taken into consideration.

2. *Size*. The size of objects can often aid identification. It should be pointed out that the size of objects on the photograph must be considered in relation to the scale of the photograph, or in relation to objects of known size to avoid misinterpretation. Vertical exaggeration will make objects look much higher than in reality.

3. *Pattern*. The spatial arrangement of features on the ground often gives rise to patterns. The most noticeable pattern seen on most aerial photographs of the UK is a 'patchwork' of fields. Land use patterns are essentially a physical characteristic and are discussed later. Variation in near-surface soil types may give rise to distinctive patterns such as polygons and stripes (Fig. 3.16). Drainage patterns can generally be related to soil or rock type together with geological structure. The use of drainage patterns in interpretation is discussed later. A regular pattern of lines (lineations) is often present on exposed rock surfaces as a result of bedrock jointing. If there is a single dominant joint direction and the joints are closely spaced, the resulting texture is similar to that of wood grain. Bedding in rock can also produce distinctive patterns.

4. *Shadow*. The shape of objects and relief shown on aerial photographs are enhanced by shadow. As mentioned earlier, the amount of shadow can be varied by the choice of the time of day at which the photographs are taken. Shadow affords a profile view of objects and can aid interpretation considerably. However, shadow can hinder interpretation by obscuring important detail.

5. *Tone*. Tone refers to the colour or reflective brightness of features shown on the photographs. Thus differences in reflectivity of surfaces give rise to tonal variations which may be associated with differences in composition, colour, or moisture content of the materials forming the surface. Most of the features which appear on aerial photographs are identified on the basis of tone or tonal variations. The patterns discussed earlier appear as repeated tonal variations on the photographs. Fine tonal variations give rise to textures which are discussed later. In general, dark tones are indicative of wet conditions or dark-coloured materials such as basalt, or peat, while

light tones indicate dry conditions or light-coloured materials, such as chalk. The relationship between tone and moisture content is clearly useful in the recognition of seepages, springs, and water-logged or marshy ground from aerial photographs.

6. *Texture*. The frequency of tonal change on a photograph can give rise to distinctive textures which can aid interpretation. Generally, texture (as seen on the photograph) is produced by an aggregation of features which individually are too small to be identified. Thus texture is not a function of photographic tone alone, but also the shape and size of the individual features, together with the pattern of shadows produced by them. Trees are easily recognized on aerial photographs owing to the characteristic texture produced by tree leaves. The tonal variations produced by crop or cultivation patterns could be considered in terms of texture. Texture is most useful in the identification of slope instability. The hummocky ground (often enhanced by shadows), and the impedance of drainage give rise to variations in tone which often result in characteristic textures.' A 'turbulent' texture is commonly associated with landslips that have involved the flow of material down slope (e.g., solifluction lobes and mudflows). An example of this texture is given in Fig. 3.36.

7. *Site.* The location of objects or features in relation to other objects or features can be an important aid to interpretation and reduce the possibility of misinterpretation. For example, dark-toned arcuate features observed in river valleys may be interpreted as infilled ox-bow lakes but the interpretation of similar features which are not associated with river valleys would be different.

PHYSICAL CHARACTERISTICS

1. *Landforms.* When aerial photographs are viewed stereoscopically, the first feature that is noticed is relief. Using the stereo image, various distinctive landforms may be identified and hence the area covered by the photographs can be broken down into major landforms. Such landforms are often related to different soil and rock types. For example, areas underlain by soft rocks such as clay will tend to form relatively flat ground whereas hard rocks such as limestone are usually characterized by steep slopes. The type of landform is not only a function of resistance to erosion but also geological structure. For example, dipping strata with alternating resistance to erosion give rise to the distinctive landform of dip and scarp slopes which trend parallel to the strike. Such landforms may be modified by the presence of boulder clay. In order to understand fully the significance of landforms in relation to the underlying geology, a knowledge of geomorphology is required.

2. *Vegetation.* Vegetation in cultivated areas is controlled by various environmental factors, the most important of which are soil type and the availability of water. Moisture conditions and the general groundwater regime can be surveyed by observing hydrophilic vegetation (Svensson 1972). Other assemblages of flora may be indicative of different soil types, but it is very difficult to identify plant species from aerial photographs without experience and a knowledge of botany. Different types of vegetation can be identified by interpreters without specialized knowledge on the grounds of tonal differences. Thus, the area covered by the photographs can be broken down into sub-areas based on vegetation. These data may be used in conjunction with other physical characteristics in interpreting soil and rock boundaries together with other features of geotechnical interest. Clearly the season of photography is important in making the best use of vegetation as an aid to interpretation. Svensson (1972) shows that for areas in the temperate zone an extreme situation during the period preceding the photography is required to give the most informative picture of cultivated areas. Such an extreme situation would be a period of little rainfall.

3. *Land use.* Land use may be divided into four broad categories: (i) agriculture; (ii) urban development; (iii) moorland; and (iv) materials extraction (quarrying and mining). In general the most useful category for interpreting ground conditions is agriculture. Farming in the UK is intensive, particularly in the lowland areas of the country. During the long history of farming in Britain, farmers have adjusted their farm management to take account of the differences in soil type (Webster 1968). This is often reflected in the size and pattern of fields. Webster (1965c) discusses the significance of land use in relation to different soil types in the Upper Thames Valley. The well established boundaries between cultivation and moorland usually mark changes in both soil and rock type. Where superficial deposits are relatively thin, the type of cultivation may be indicative of underlying rock types.

4. *Drainage and erosion.* Drainage patterns are easily identified from aerial photographs. The type of drainage pattern and the density of the drainage network (texture) of the pattern, are often indicative of the types of soil/rock beneath the site. In some cases the area covered by the photographs will not be sufficient to show the complete drainage pattern. However a more complete picture may be obtained from topographic maps. 1.

   Dendritic patterns indicate generally homogeneous materials. The texture of such patterns is related to the permeability of the underlying materials. Coarse-textured patterns (Fig. 3.17a) develop on materials with good internal drainage with little surface run-off. Fine-textured patterns (Fig. 3.17b) develop on materials with poor internal drainage and high surface run-off. The texture is also a function of resistance to erosion of the underlying materials. Coarse textures tend to be associated with resistant materials such as granite, and fine textures with easily erodable materials, such as clay and shales. A good example of a dendritic pattern is seen in the infilled channels shown in Fig. 3.18.

Case study - Polygons and stripes shown by differential ripening

The aerial photograph shown in Fig. 3.16 is of an area east of Narborough, Norfolk (TF 765113) which is in the chalkland north of the Breckland District. The geology of this area is essentially chalk overlain by superficial deposits. These superficial deposits comprise dark brown sandy drift over a very pale brown sand chalk drift (Evans 1972). The patterned ground is shown clearly on the aerial photograph by the tonal contrast produced by differential ripening of crops. Such vegetational patterns (crop marks) are not usually so clear unless photographed under extreme weather situations. The photograph in Fig. 3.16 was taken during the summer of 1976 which was a period of severe drought in Britain. Thus the differential ripening of crops strongly reflects variation in the underlying soil types. The distinctive pattern produced is related to undulations of the chalk (Fig. 3.19). The dark tones indicate where the chalk is nearest to the surface and the light tones indicate the infilling of ice wedges, formed during the Pleistocene. On sloping ground solifluction has drawn out the polygonal pattern to form stripes. Two sets of stripes are seen on Fig. 3.16 marking a slight linear depression running WSW - ENE across the eastern part of the area shown.

In general, polygons and stripes may show up on air photographs as a contrast of light coloured (calcareous) and dark coloured (non-calcareous) soils in fallow fields, or as crop marks resulting from differential ripening, differential growth, disease or patterns created by different assemblages of natural vegetation. Clearly the season of photography and the conditions (physical and meteorological) preceding the photography effect the way in which these features appear on the photographs. Most of the patterns observed by Evans (1972) were on photographs taken when the fields were without crops (during March and April). The use of air photographs in studying patterned ground is discussed by Perrin (1963).

Well-developed polygons and stripes tend only to occur in the presence of a thin layer of sandy drift overlying chalk. The patterning appears to be particularly sensitive to the thickness of the superficial deposits, and will not occur when it exceeds about 2.5 m (Watt et al. 1966). The patterns cease abruptly on the eastern and southern margins of the Breckland area where the sandy drift is underlain by boulder clay instead of chalk. Small polygonal patterns have been observed on loamy sands overlying Triassic derived boulder clay and on sandy clay overlying Corallian limestone (Evans 1972).

Patterned ground is commonly produced in permafrost areas by frost action. Such features were produced in the periglacial zone of the UK during the Pleistocene, and have been preserved as fossil patterned ground. These fossil patterns are most common in the Breckland District of East Anglia and were first described in this country by Watt (1955). In plan the patterns are reticulate or polygonal on level ground and on slopes of less than 1° (Evans 1972), but with increasing slope they become first vermicular and then lengthen into stripes which may be simple or anastomosing (Watt et al. 1966). Stripes occur on slopes of 1°-5° but rarely on 6° slopes (Evans 1972). The polygons or near-circular features are generally between 5 m and 10 m in diameter and the interval between the stripes is commonly about 7 m.

The drainage and erosional features used in identifying the three commonest glacial soil types are shown in Fig. 3.20. These features may be used to identify soils of similar composition but of non-glacial origin.

5. Lineations. Many features, both natural and man-made, appear on aerial photographs as lineations. Such features are commonly the linear expression of characteristics such as tone, texture, landforms, drainage and vegetation. In some cases, these characteristics may be disrupted in a linear fashion, thus giving rise to linear features. Natural lineations can be used to interpret soil and rock boundaries, together with structural features such as faults and bedrock jointing. Norman (1968a) has made an extensive study of the significance of natural lineations in photogeology. Some lineations represent buried features of man-made origin, such as services and infilled trenches. An example of such a linear feature is shown in Fig. 3.33.

Use of air photography

In general the interpretation of aerial photographs involves four stages:

1. preliminary examination;
2. detailed examination;
3. interpretation; and
4. compilation.

The preliminary examination stage involves obtaining a general overview of the site and surrounding area, allowing the interpreter to become familiar with the area. The basic reference level of the interpreter is extended during this stage by the examination of maps and reports concerning the site or nearby sites together with the aerial photographs. In order to obtain an overview of the site, it is often necessary to work from the whole to the part. This is best achieved either by laying the photographs side by side or by cutting the photographs to make a print laydown. An example of a print laydown made from six individual photographs is shown in Fig. 3.36. The preparation of a print laydown requires an extra set of photographs since there must be an undamaged set retained for stereoscopic examination. The photographs should be examined stereoscopically during this stage to observe the topography of the site.

Little distinction is made between the detailed examination stage and the interpretation stage, as in practice they are normally carried out simultaneously. The detailed examination stage involves a systematic stereoscopic examination of each stereopair. Full use is made of image and physical characteristics. It is often useful to separate each physical characteristic by making a series of overlays. Overlays may also be used to separate some image characteristics such as tone and texture. These overlays may be combined or examined individually when attempting to interpret certain features. In many cases, small features of geotechnical interest are easily missed because they are overshadowed by larger features of lesser relevance. The most efficient method of searching for such features is that of logical search (Tait 1970) which involves the use of probabilities and some systematic scanning. The areas of the image in which the features are most likely to occur are singled out and examined first. The remaining area can be systematically scanned. An overlay showing roads, tracks, paths and breaks in field boundaries can be made during this stage, for use in planning access of drilling rigs and site vehicles. Estimates can also be made from the photographs of widths of entrances and tracks since these are critical to the access of drilling rigs.

The interpretation of data collected during the previous stages should be carried out in terms of:

- geology;
- geotechnical hazards;
- site drainage;
- archaeology; and
- access for plant.
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Geology

The interpretation of underlying geology from air photographs (termed photogeology) is a specialist skill which uses information contained on the photographs relating to geomorphology, drainage patterns, erosion features, slope instability, land use, vegetation, and lineations, together with image characteristics, to determine the soil and rock types, and the structure (i.e. dip, folding and faulting, etc.) of the beds beneath a site. Even in areas of minimal vegetation, where there is maximum exposure of the bedrock, this requires very considerable training, and is beyond the skills of most geotechnical engineers and engineering geologists. In temperate regions, such as the UK, where superficial deposits may be relatively thick, and vegetation is often controlled by agriculture, photogeology is made even more difficult.

The use of photogeology in engineering geology is discussed by Belcher (1946), Ray (1960), Miller (1961), Mollard (1962), Allum (1966), Norman (1968a,b,1969), and Lillesand and Kiefer (1979). The use of airphotography in soil science is discussed by Webster (1965a,b,c), Webster and Wong (1969), Evans (1972) and Perrin (1977). In most developed countries it will not be necessary to use air photographs to deduce the general geology of a site area, because good quality geological maps will normally be readily available. Photogeology may, however, be of use in determining the detailed ground conditions in the area of proposed construction, as the following example shows.

Case study - Use of large-scale aerial photography for the interpretation in detail of ground conditions at a proposed earth-dam site in North Wales

THE BRENIG DAM SITE, NEAR DENBIGH, CLWYD, NORTH WALES

The Brenig reservoir is situated south-west of Denbigh, Clwyd, North Wales, as shown in Fig. 3.21. This reservoir together with the adjacent Alwen reservoir (Fig. 3.21) provide water for Birkenhead. Investigations for a dam in the Brenig Valley were initiated at the end of the nineteenth century. The site chosen for the dam is shown in Fig. 3.22. The main Brenig Valley here is wide, relatively flat-bottomed and generally shallow with a small valley incised on the eastern side. The preliminary subsurface investigations carried out in 1948 indicated the main valley to be a pre-glacial till-filled valley underlain by shales and gritstones of Silurian age. Subsequent design investigations were carried out during 1969, 1972, and 1973 (Carter 1983). The main objectives of these investigations were:

1. to determine the nature of the bedrock and the depth to bedrock across the main valley;
2. to determine the geology of the drift deposits at the dam site and locate any weak clay or highly permeable sands and gravels;
3. to take undisturbed samples of till and any weaker layers in order to measure their strength and compressibility in the laboratory;
4. to measure the permeability of any sand or gravel layers within the foundations;
5. to locate suitable construction materials and determine whether there were sufficient quantities to build the dam;
6. to determine whether the reservoir basin was sufficiently permeable to allow reservoir impounding to the full height of the proposed top water level.

Clearly, air photography can provide valuable information which could aid in fulfilling objectives (2), (5), and (6). The basic interpretation of the black-and-white aerial photographs taken of the dam site is described below. The contact scales of the original photographs were 1:12000 and 1:3000. (The illustrations shown here have been reduced.) It is unusual find photography taken at contact scales as large as 1:3000 in areas of high relief such as this due to the obvious difficulties of maintaining a constant altitude. Such large-scale photography was necessary in this case to identify soil boundaries due to the complex heterogeneous nature of glacial deposits.

The main topographic features associated with the project area are best identified by examining the small-scale photography (Fig. 3.23) stereoscopically. These features include three drumlins (A, B, and C in Fig. 3.22) and a minor steep sided V-shaped valley (D in Fig. 3.22). Drumlins are glacial features composed of till moulded into smooth elongate hills resembling inverted spoons. Normally drumlins have a length to breadth ratio of about 2.5:1 with the long axis more or less parallel to the direction of ice movement at the time of formation (Boulton 1972; McGown et at. 1974; McGown and Derbyshire 1977). Another characteristic feature of drumlins is that the end which faced the oncoming ice is generally steeper than the down-ice end. Drumlins A and B in Fig. 3.23 are clearly defined on the grounds of topographic relief, shape and association. Association is probably the most important element in recognizing these hills as drumlins since such features are associated only with areas which have been subject to glaciation. The Brenig area is known to have been subject to these conditions during the Pleistocene period. A significant area of seepage is clearly visible on the north-west. side of drumlin A and around the southern end of drumlin B (springs and seepages are marked S in Fig. 3.22) indicating the presence of permeable material, possibly glacial sands and gravels. Drumlin C is smaller and less well developed than the others.

Thirty-five drumlins have been identified from the 1: 12 000 scale aerial photographs within the immediate vicinity of the dam site (Carter 1983). The long axes of these drumlins are shown in Fig. 3.24a. The rosette (Fig. 3.24b) indicates a general NE to SW trend. The form of these, drumlin A and around the southern end of drumlin B (springs and seepages of soil fabric and the pattern of discontinuities within some glacial deposits (e.g. lodgement till», are closely related to the direction of ice movement. Soil fabric and discontinuities have a strong influence on the geotechnical behaviour of engineering soils (Rowe 1972), hence the determination of the direction of ice movement is of importance. The scale of photography is important in the identification of these drumlins. At 1:12000 these features can be easily viewed in context with their surroundings. At large scales, the task is made more difficult. For example, at 1:3000 drumlin A almost fills the area covered by a 230 x 230mm contact print. At the other extreme, a contact scale of 1:80000 may result in these features becoming too small to be readily identified, particularly by the inexperienced interpreter.

The eastern side of drumlin A has been oversteepened by the erosive action of the Afon Brenig. Much of this erosion probably occurred during the downwasting of the last glaciers which occupied the Brenig and adjoining valleys. The steep-sided channel thus formed was clearly a critical factor in the choice of the final dam site. Stereoscopic examination of D reveals the east side of the channel to be steeper and less rounded than the western side. Furthermore at E (Figs 3.22 and 3.25) there is a feature which probably represents an old landslip scar, since it occurs in a place where the river is most likely to undercut the slopes of the drumlin. A similar but smaller feature is seen to the north of E in Fig. 3.22. No similar landslip features exist on the eastern side of the channel. In fact, where landslipping is most likely (at F in Fig. 3.22) the slopes appear to be very steep and stable. This suggests that whilst the western side of the channel is clearly formed of till (part of the drumlin) the eastern side is composed of a much stronger material, possibly bedrock. An outcrop of bedrock can be seen at G (Fig. 3.22). This outcrop was quarried for construction materials. The existence of bedrock in the east side of the minor valley was confirmed by site inspection (Carter 1983).

The ground between the drumlins A and C (Fig. 3.22) is traversed by a series of drainage ditches. These are clearly identified by pattern and the fact that the spoil has been placed along one side of each ditch in most cases. These ditches and the dark tones suggest poorly drained ground. Peat probably covers most of the area between the drumlins giving rise to the dark tones. In places small ridges of till rise above the peat and are indicated by lighter tones. The stream on the west side of drumlin C is fed by a series of springs and seepages identified by a marked tonal contrast. These springs and seepages indicate an extensive horizon of permeable material in the west side of the main Brenig Valley. The dark tones associated with the stream probably result from the presence of peat.

In order to carry out a more detailed examination of ground conditions, photography taken at a larger scale is necessary. Figure 3.25 shows the minor valley at a suitable scale for mapping complex soil boundaries and locating small features which may prove significant. Wet areas probably associated with peat are clearly seen on the photographs. Careful examination reveals deep rutting of vehicle tracks at R indicating areas of soft ground. The small patch of peat at P, and the evidence of minor landslipping at L, cannot be seen clearly on the smaller-scale photography. The large-scale photography facilitates a closer examination of the morphology of the sides of the minor valley and hence allows a more accurate delineation of areas of bedrock, till and alluvium.

The interpretation described above is typical of what may be achieved from an examination of the photography with little background knowledge of the project area. Carter (1983) carried out a detailed air-photo interpretation of the dam site using the 1:12000 and 1:3000 black-and-white vertical photography together with coloured oblique photography. Carter's reference level had been considerably extended through studying all the available information about the project area and site inspection. Examples of Carter's interpretation are shown in Figs 3.26 and 3.27. The object of this detailed study was to find the best layout for a subsurface investigation which would establish more thoroughly than earlier investigations the stratigraphy and nature of the materials comprising the foundations of the dam and in particular to locate areas in which permeable materials might exist. The layout of earlier subsurface investigations which had concentrated on the centre lines of the envisaged engineering structures failed to reveal the complex heterogeneous nature of the glacial deposits. In the later investigations, more emphasis was placed on the geology rather than the position of engineering structures, hence the need for a detailed air-photo interpretation. Individual drillholes were laid out on a framework inferred from the geological characteristics of the materials that were expected to be associated with the glacial landform features identified from the air-photo interpretation. The drillholes and test trenches therefore served not only to examine areas considered to be of direct engineering significance, but also to ensure that all the various landform features identified from the aerial photography were investigated in sufficient detail to attempt a reconstruction of the three-dimensional glacial stratigraphy of the dam foundations. Carter found this approach most useful in unravelling the complex nature of the glacial deposits which greatly aided the design of the dam foundations.

Geotechnical hazards

Despite the skill and experience required to make satisfactory interpretations of the geology of a site, geotechnical engineers and engineering geologists should still find the examination of air photographs a rewarding experience. The authors received little formal training in air-photo interpretation, yet have found them to be one of the most useful sources of information available during desk studies. In the following section we give details of our approach. The fundamental point to be made is, however, that almost anyone, however inexperienced, can gain useful information from air photographs.

Air photographs can provide very good quality information on:

- the presence of archaeological sites;
- site history;
- pre-existing vegetation;
- made ground;
- slope instability;dissolution features; and
- cambering and valley bulging.

Some of these features (for example, pre-existing vegetation, and the presence of made ground, slope instability and solution features) may be extremely difficult, if not impossible, to detect in any other way.

Archaeological features

The most efficient method of recognizing sites of archaeological interest is by the use of aerial photographs. The value of air photographs in archaeological research was first recognized during the period between World War I and World War II by Major Allen, who formed a pioneer collection of air photographs of the Oxford region, and Dr Crawford, who was made the first Archaeology Officer of the Ordnance Survey (St Joseph 1977). A brief account of the early history of application of air photography to archaeology is given by Crawford and Keiller (1928) and St Joseph (1957).

Archaeological features show up on aerial photographs as crop marks, subdued topography and tonal contrasts. For these reasons, the air photograph requirements of the archaeologist are quite specialized. The time and season of photography together with crop types are critical in many cases if archaeological features are to be identified. Ancient trenches, pits, post holes and foundations produce localized variations in the surface layers of soil. Such variations are often reflected in the differential growth or ripening of crops which are only visible during certain seasons.

As mentioned earlier, crop marks are best seen if extreme conditions, such as a period of drought, precede the photography of the crops. The period between May and July generally yields the best results. The crops most sensitive to local variations in soil type are cereals such as wheat and barley (St Joseph 1977). Hay and meadow grass are frequently unresponsive to such variations.

In order to enhance crop marks and subdued topography associated with foundations and ancient agricultural patterns, conditions of clear sunlight and long shadows are required. Such conditions occur only during early morning and late afternoon. Since minimum shadow is normally a fundamental requirement for conventional vertical air photography, photography for archaeological purposes is often specially commissioned. In many cases the best results are produced using oblique aerial photography. Figures 3.28 and 3.29 illustrate the use of shadow in detecting archaeological features.

Figure 3.28 shows an example of an ancient enclosure on Marlborough Down. The rectangular or trapezoidal areas are separated by small ditches. It is these ditches that give rise to the shadows which help define the pattern of this enclosure. Such features are also characteristic of deserted medieval villages. A later development is seen in the centre of the photograph in the form of an irregular circle made by a ditch superimposed on the older system of ditches.

Figure 3.29 shows an excellent example of ridge and furrow. The low sun angle allows each ridge and furrow to be picked out clearly. When seen at ground level, these features are often mistaken for some form of land drainage system, whereas an aerial view shows clearly that this is not the case. Ridge and furrow is the characteristic pattern associated with the medieval 'open field' system of farming (Beresford and St Joseph 1979). The photograph illustrates how the modem field system is superimposed on the medieval 'open fields'. The presence of ridge and furrow indicates the close proximity of a medieval settlement. Many towns and villages in Britain have grown from such settlements. There are however numerous deserted medieval villages in this country (Beresford and Hurst 1971).

Figure 3.30 shows an example of an early Iron Age fort (Maiden Bower, Hertfordshire). The characteristic shape of such a fortress is circular. A ditch bounded by a ridge made with the material taken from the ditch forms the perimeter of this circle. In the photograph, the ridge is marked by trees and bushes. It will be seen from the photograph that this fort has been in danger of being destroyed by the adjacent chalk quarry. Modern chalk and gravel workings are responsible for the total destruction of a great number of ancient sites such as this. The road in the foreground of the photograph is part of the A5 from London to Holyhead. It follows the line of the Roman Watling Street, but the cutting and embankment at the top of this photograph were made by Thomas Telford.

Pre-existing vegetation

The rapid increase in insurance claims for 'subsidence damage' to low-rise buildings, principally housing, in the UK has emphasized the need for a careful appraisal of vegetation that may have existed prior to development, where construction is to take place on shrinkable clay. The removal of trees or large shrubs leads to swelling of the clay, and observations have shown that this swelling can go on for several decades. This means that even though a construction site may be clear of vegetation at the time of purchase, the removal of trees or hedges some time before may still present a threat. Air photographs can provide a valuable source of information on the vegetation existing on a site over a long period before construction.

Case study - Houses damaged by heave, following the removal of trees

Figure 3.31 shows sections of three air photographs, taken over a period of years, of an area of Basildon in Essex. They show clearly the development of housing in the area. In Fig. 3.31a, the site is undeveloped and can be seen to be partially wooded. Figure 3.31b shows the construction of houses in progress. Figure 3.31c shows the houses complete. The geological map of the area shows that the site is underlain by London clay, which is known to be a shrinkable clay. Following construction, some of the houses in these terraces began to crack, and investigations showed that parts of the structure were heaving. The air photographs provide not only a permanent record of construction but, more importantly in this case, permanent records of the size and position of trees and other vegetation which may have been removed some years before development was envisaged. In this case, it can be seen that one part of the site was densely wooded whilst another appears to have been grassland. It would be reasonable to expect large differential movements and damage to occur where long structures cross from one area to the other, as a result of differential heave due to tree removal. This did, in fact, occur on this site.

Made ground

It is important to locate any areas of made ground during the site investigation. Made ground may be the result of backfilling trenches used for buried services, backfilling old quarries, brick pits or gravel pits, or the disposal of waste materials. Any disturbed ground can usually be recognized on aerial photographs by variations in tone with the surrounding undisturbed ground. Buried services, such as gas mains, appear as linear features which generally"have a light tone. Backfilled quarries and pits can be difficult to detect unless the existence of the quarry or pit is known beforehand. This clearly illustrates the importance of examining topographic maps and other data in conjunction with the photographs.

Case study - Infilled World War II anti-tank ditch

Figures 3.32 and 3.33 show two air photographs of an area to the south of Basingstoke. Figure 3.32 was taken in 1963. The 1 in. to 1 mile geological map of the area indicates that the site is probably underlain by a thin layer of 'clay with flints', a Head material, below which lies chalk to great depth. The site (marked' A') was developed in the late 1960s as a small housing estate. Subsequently, brickwork in one house cracked in such a pattern that it was obviously caused by downward foundation movement of part of the house. In order to undertake remedial works (underpinning was proposed), the precise cause of the damage had to be established: air photograph cover was sought. In particular, there was concern that the house might have been positioned over a solution feature in the chalk, which might have been infilled with loose or soft soil, or perhaps might contain a void.

The 1963 air photograph shows that solution features are present in the area: see the feature marked 'S' as a typical example of the expression of an infilled 'pipe' in the chalk. None of these features are to be seen, however, at the position of the house. A light-toned linear feature was also seen (indicated by arrows) and measurements from the photograph indicated that the house lay partly over this feature. This feature is clearly quite recent because there is evidence on the photograph that trees and hedgerows have been removed along its line - marked B. Initially it was feared that it might have been the trace of a large service pipe, but investigations of local Electricity Board service plans gave the clue that this was, in fact, an infilled World War II anti-tank trench. It was probably excavated in the summer of 1940 and backfilled in 1945 or 1946. Subsequent searches produced Fig. 3.33, which was taken by the Royal Air Force in 1947, and shows the trace of the trench to be quite fresh (Fig. 3.33).

Further investigations, and discussions with military historians and retired army personnel, produced an estimate of the probable shape of this defensive work, as built. Figure 3.34a shows this estimated cross-section. Subsequently it became possible to excavate an exploratory trench across the position shown on the air photographs. Figure 3.34b shows the profile of the anti-tank trench, which, as expected, contained uncompacted fill. There are virtually no records to indicate the position of these infilled trenches. Yet, had the air photographs been examined at the time that the layout of the estate was being planned, it seems likely that the problem could have been avoided.

Slope instability

In the UK, any site in clay with a slope of more than about 5° may be potentially unstable, and contain pre-existing shear surfaces as a result of slope movements that occurred under periglacial conditions, at the end of the last ice age. Excavation at the toe, or loading at the top of such slopes will lead to large-scale instability, often involving hundreds of thousands of cubic metres of ground. Cases where construction projects have been seriously disrupted by the reactivation of pre-existing slope instability are relatively commonplace, and therefore the examination of air photographs for signs of instability must be a major activity in many site investigations.

In many other geologically younger and tectonically more active areas of the world pre-existing instability occurs in a much wider range of materials, including granular soils and rocks.

Whilst the presence and extent of instability will not always be determinable from air photographs, experience has shown that they provide one of the best sources of information available to the geotechnical engineer. It is unlikely that boreholes can be used to find the very thin shear surfaces which typically lie at the base of a landslip mass, and geophysical methods are not normally of practical use. Where, as is often the case, the shear surface lies within a few metres of ground surface, trial pitting (see Chapter 5) provides the only other satisfactory method, in most instances.

The use of oblique air photographs to map the extent and detail of the Stag Hill landslip (Guildford, Surrey) has already been described above. In the case records below we discuss the use of vertical air photography.

Case study - Solifluction lobes near Sevenoaks, Kent

The construction of the Sevenoaks bypass faced problems with earthwork failures. Subsequent investigation (Weeks 1970) revealed that the route crossed several solifluction lobes which are in a state of limiting equilibrium. These solifluction lobes are underlain by an extensive solifluction sheet which contains several principal slip surfaces located at the base of the sheet (Weeks 1969, 1970). The lobes appear to be more unstable than the underlying sheet.

The geology of the area is shown in Fig. 3.35. The Hythe beds which comprise ragstone (sandy limestone), hassock (calcareous limestone) and sandy silty clay layers form a steep escarpment. The Hythe beds are underlain by the Atherfield clay and the Weald clay, both of which outcrop at the base of the escarpment. The slope below the escarpment is between 3° and 10° which is characteristic of the underlying weak rocks. The lobes consist of blocks of sandstone and limestone from the Hythe beds in a matrix of sandy silty clay, and have moved down a7° slope for about 400m. Intermittent movement of the front ('nose' or 'toe') of these lobes still occurs during periods of high water table.

The print laydown (Fig. 3.36) shows the area where the instability occurred during the construction of the bypass. Most of the lobes are clearly visible, having a typically lobate shape, and 'turbulent' texture. The 'turbulent' texture is produced by the hummocky ground and poor drainage which is characteristic of such landslip features. The sides and 'nose' of each lobe are characterized by steep slopes (Fig. 3.37) which are clearly seen when the photographs are viewed stereoscopically. Within the area covered by the print laydown there is a total of five lobes. The position and extent of each lobe are shown in Fig. 3.35. Lobes E, F, G and H are easily identified. The 'noses' of lobes F and G are marked by a line of small scars and bushes which allow their extent to be defined.

Lobe H is most noticeable since the field in which it is situated is covered by a series of light toned lineations which are disrupted by the lobe and help enhance its characteristic 'turbulent' texture. Lobe 0 is not easily identified because the field boundaries follow the edges of the lobe to a large extent. The upper part of the eastern edge of the lobe occurs downslope of the field boundary and is easily identified by a change in slope and characteristic texture. Recent movement of lobe E is evidenced by the displacement of the field boundary on the western edge of the lobe. The road which runs North - South across the eastern edge of the print laydown crosses the top of lobe H, but there appears to be no evidence of movement.

From ground level the lobes appear as areas of hummocky ground (Fig. 3.37). The change in slope which marks the edge of the lobes (particularly the 'nose' of each lobe) is a most noticeable feature at ground level. However, it would be impossible to appreciate fully the extent and shape of these features simply from a walk-over survey.

Aerial photography has the advantage of providing the necessary overview which allows the rapid assessment of ground features such as these.

The photographs which were used to make the print laydown in Fig. 3.36 were taken during August 1961 at mid-day and at a contact scale of about 1:2500. The contact scale ,of the print laydown is about 1:7000 as it has been photographically reduced. Norman et at. (1975) is an extensive study of the use of air photographs in the detection of landslip features in the Sevenoaks area found that detection is improved when the sun is low (Table 3.8). The scale of the photographs is an important factor in the detection of these and other landslip features. The solifluction lobes were clearly visible on the original aerial photographs and still clear on the photographically reduced print laydown, despite the unavoidable loss of quality.

Figure 3.38 shows, however, that the number of features which can be detected is proportional to the scale of photography. Norman et al. (1975) examined a range of film types and found that excluding economic considerations, the best photographs for studying these landslip features were those produced from infra-red colour film, using infra-red colour prints and black-and-white prints from the red and infra-red part of the spectrum from this film.

More information on the form and extent of the solifluction lobes could be obtained from a series of high oblique aerial photographs taken looking towards the escarpment. These photographs would only provide qualitative data, but would nevertheless be valuable.

Table 3.8 Influence of time of photography on the detectability of landslips (after Norman et al. (1975))

Time of day	Hours from noon	Percentage detection of landslip features	Number of features covered by sortie
10:00	2	41	65
14:00	2	55	109

15:00	3	68	25
15:00	3	80	10
8:00	4	83	119

The photo scale was 1:10 000 in each case.

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Dissolution features

Cylindrical pipes or inverted cone-shaped sink holes are common features in soluble rocks such as limestone and chalk. These features are produced by localized solution weathering of the rock surface by acidic (CO2 rich) water. Sink holes associated with the chalk are particularly common in the south of England. They tend, however, to be particularly common in areas where chalk is present beneath a thin cover of younger Tertiary sediments or superficial deposits. The formation of these features is possibly related in part to periglacial conditions (Higginbottom and Fookes 1970). Higginbottom (1971) has pointed out that a concentrated inflow of near freezing water is a much more effective carbonate solvent than water at normal temperature. The pipes and sink holes in chalk are usually filled with material derived from the over-lying deposits. This infilling is often loose and may contain weakly bridged cavities (Higginbottom 1965), and hence it is generally weaker and more compressible than the chalk host rock. Clearly if such features are not detected they can present a potential hazard to any structure founded over them. Thus the detection of sink holes and pipes is an important part of site investigations on chalk or limestone. Detection by direct method of sub-surface exploration alone is difficult and in most cases not cost effective. In some cases, ground-based geophysical methods are used, but by far the most cost effective indirect method is the use of aerial photography at the preliminary desk study stage. Potential targets may be identified on air photographs and proved by drilling. Air photography may also be used to plan ground-based geophysical surveys if drilling each feature does not appear to be cost effective.

In some cases sink holes and pipes are associated with ground surface depressions which are easily identified on air photographs. Figure 3.39 shows an example of these surface features. The area shown in the photograph is south of Stokenchurch. Buckinghamshire. The geology of this area is Upper Chalk overlain by clay-with-flints. The light tones at A and B are indicative of chalk close to the ground surface. When viewed stereoscopically, it is found that these features are associated with two large depressions in the ground surface. Such depressions typically mark the location of sink holes. The chalk on the eastern side of these features is covered by clay-with-flints, hence the absence of light tones. A smaller depression is seen at C within the clay-with-flints.

The circular feature, A, in Fig. 3.16 appears as a large depression when viewed stereoscopically. The centre of the depression is hidden by trees. The fact that natural vegetation has been allowed to flourish in the middle of a field is highly suspicious. Features such as this occurring over chalk suggest the presence of sink holes.

The light-toned circular feature at S in Fig. 3.33 marks the position of a slight surface depression. Such features are produced by the subsidence of material into sink holes caused by solution of the underlying chalk. These features can cause serious foundation problems if undetected during site investigation. The M3 motorway now passes over the feature shown on the photograph. A comparison of Fig. 3.33 with Fig. 3.32 shows how the season of photography can affect the detection of these features. The feature is most clearly visible on the photograph taken during spring (Fig. 3.33). Although still visible it is less clear on the photograph taken during summer (Fig. 3.32).

Figure 3.40 shows the structure of a typical sink hole in chalk. It will be seen from this diagram that these features can extend to some depth. Tonal patterns produced by variations in soil type or vegetation are often useful in locating sink holes and pipes which are not associated with ground surface depressions. This type of feature is often difficult to locate and detectability is dependent to a large extent on the season of photography. The use of multi-band photography or remote sensing techniques such as aerial thermography or multi-spectral scanning (described by Beaumont (1979) and Lillesand and Kiefer (1979» or ground-based geophysics may be employed if conventional panchromatic or colour air photography fails to provide any useful data.

Sink holes and pipes are common features in the karst regions of the UK. Figure 3.41 shows a typical example of sink holes in Carboniferous limestone. It will be seen on this photograph that there is an abundance of these features over most of the area covered but their presence ceases abruptly along the line A-A. This marks the boundary of the limestone and a stratum of shale. The presence of sink holes is a useful aid to the field geologist and photogeologist in mapping limestone units. A well-developed surface drainage system is seen over the shale in contrast with that over the limestone, where most of the surface water finds its way underground via the sink holes. Streams can be seen disappearing underground in the bottom of the photograph. Most of the sink holes in the photograph appear as circular depressions in the boulder clay which covers the limestone.

SATELLITE REMOTE SENSING

Photographic remote sensing (described above, and conventionally termed 'air photography') is by far the most common form of imagery used during site investigations. But for large and remote sites satellite imagery can be of considerable use.

Whereas photographic systems typically are used to produced images from a limited number of wavelengths of electro-magnetic radiation, multi-spectral scanners (MSS) allow the detection simultaneously of both reflected and emitted radiation in several spectral bands. The operation of a typical MSS system is illustrated in Fig. 3.42.

Points on the Earth's surface are scanned in a raster fashion, normally by means of a spinning prism or oscillating mirror, in the case of optical/mechanical systems (in some landsat satellites), or by means of a fixed linear array of sensors (in Spot satellites) (Fig. 3.43). The Earth's surface is therefore sequentially sampled for radiation in discrete areas, and these later appear on MSS images as pixels (picture elements). The size of the pixels on the Earth's surface are an obvious limit to the resolution of such systems. The Landsat Satellite System was initiated by NASA in conjunction with the US Department of the Interior in 1967. Present generation Landsat systems offer spatial resolutions of about 30 m. The SPOT system (Systeme Probatoire d'Observation de la Terre) was initiated by the launch of the first Spot satellite in 1985, becoming operational in May 1986. Spot was originated by France's National Space Studies Centre (CNES), acting as an agency for its Ministry for Research and Space. Spot-3 is under assembly at the time of writing (1993), and will provide a spatial resolution of 10 m in panchromatic, or 20 m in colour. Much better spatial resolutions (of the order of 1 or 2 m) can be obtained when MSS systems are mounted in aircraft.

Once the radiation for a particular pixel is captured, it is dispersed into its various spectral components by means of a prism or diffraction grating system. This splits the incoming radiation into a series of spectral channels, or 'bands'. An array of electronic detectors, placed at an appropriate position behind the grating, detects the strength of radiation within the wavelength region to which it is sensitive. The amplified signal is then digitized, and either recorded (in the case of aircraft-based systems) or transmitted to a ground satellite-receiver station.

For Spot satellites each image covers some 3600 km2. Individual digital images cost between FF7000 and FF19000 at the time of writing, and must then be processed on computer to produce the desired end-product. Satellite image processing is a complex task, beyond the scope of the book. A concise guide to satellite imagery and the available processing techniques is given in Kennie and Matthews (1985). The application of satellite remote sensing images in site investigations has, to date, been limited by considerations of cost (both of the digital data and subsequent processing) and spatial resolution. In remote areas, however, satellite imagery may be a most important source of information for preliminary studies (for example in selecting highway routes), for environmental and water resource engineering, and in the search for construction materials. The reader is referred to Kennie and Matthews (1985) for further information.

THE WALK-OVER SURVEY

The walk-over survey involves an inspection of the site and surrounding area on foot, the examination of local records concerning the site, and the questioning of local inhabitants about the site. The object of this exercise is to confirm, amplify and supplement the information collec.ted during earlier stages of the site investigation (Dumbleton and West 1976a). It is essential that all the information concerning the site is studied thoroughly before carrying out a walk-over survey. This will allow a greater understanding of the significance of features seen on and around the site and enable more effective research of local records.
In general, walk-over surveys may be divided into two operations:

- site inspection; and
- local enquiries.

The site inspection involves a thorough visual examination of the site and its environs making full use of maps (topographic and geological), site plans, and air photographs. Before carrying out the site inspection, permission to gain access to the site must be obtained from both the owner and occupier. It is important when inspecting a site to be suitably equipped. The list given below (based on that given by Dumbleton and West (1976a» gives some guidance on the necessary equipment for this operation:

notebook, pencil, measuring tape, compass, clinometer, camera, binoculars, Abney level, topographic and geological maps, site plans, preliminary geotechnical map, air photographs, pocket stereoscope, 'chinagraph' pencil, wooden pegs, portable hand auger, Mackintosh prospecting tool, geological hammer, trenching tool, polythene bags, ties, labels, waterproof marker pen, penknife, hand lens, dilute hydrochloric acid, plumb line.

Many features may be observed during a site inspection. Only with experience can the relative importance and significance of these features be interpreted in the field. The checklist given below details those features which should be inspected and noted.

(A) GEOMORPHOLOGY

1. General features. Note slope angles, types of slope (convex or concave) and sudden changes in slope angle. This information can give a guide to geology. For example, hard rocks resistant to erosion often form steep scarp slopes.

2. Glacial features. Note the presence of mounds and hummocks in more-or-less flat country. These features are often associated with glacial deposits such as till and glacial sand and gravel. Glacial landforms such as 'U'-shaped valleys and overflow channels should be noted where recognized.
3. Mass movement. The presence of hummocky broken or terraced ground on hill slopes should be noted since these features are normally associated with land-slipping. Landslip areas present a potential engineering hazard and therefore must be inspected thoroughly. The extent and type of landslip should be noted on the site plan. The air photographs will aid the classification and mapping of landslip areas in the field. The relative age of the landslip should be noted where possible. In the case of rotational landslips the amount of degradation of the rear scarp may give an indication of relative age. Structures situated on or adjacent to a landslip should be inspected for structural damage. The alignment of fences and hedges crossing these features should be compared with maps and air photographs for evidence of recent movement. The positions of tension cracks and ponds associated with the landslip should be noted on the site plan. The presence of small steps in hill slopes and inclined tree trunks are indications of soil creep and hence should be noted. Evidence of soil creep is particularly noticeable where a hedge or other barrier traps the creep material on the upslope side.

(B) SOLID AND DRIFT GEOLOGY

1. Exposures. Exposures of rock or soil may be found in cliffs, stream and river beds, quarries, pits and cuttings. The material seen in such exposures should be described in the manner outlined in Chapter 2. Samples of soil may be taken for moisture contents and index tests. Note should be made of discontinuities (fissures, joints and bedding planes), seen in rock or soil exposures. This should include the type of discontinuities, the dip and dip direction of major discontinuities, the average spacing and persistence of major discontinuities and the nature of the major discontinuities (for example, open, closed, or infilled). If necessary a detailed rock mass description can be carried out during a later stage of the site investigation.
2. Solid geology. Exposures, geomorphological features, land use and vegetational changes may be used in conjunction with the geological map of the site and air photographs to establish the solid geology where it is not hidden by superficial deposits. An elementary treatment of the techniques used in mapping solid geology is given by Himus and Sweeting (1968).
3. Superficial geology. Superficial deposits are often the cause of geotechnical problems and hence require attention during the early stages of the site investigation. The main types of deposit associated with the site and surrounding area will be known already from the geological map. The extent of such deposits may have been tentatively mapped using air photographs. The site visit serves to check the geological map and any air-photo interpretation, and make a close examination of areas of poor ground. Exposures, geomorphological features, land use and vegetation may be used to aid the location of superficial deposits. For example the flat ground associated with rivers or streams normally marks the extent of alluvium; areas of reeds, rushes and willow trees often indicate wet ground conditions which may be associated with areas of peat. Where it is necessary to sample or prove the extent of certain superficial deposits such as peat, then the Mackintosh prospecting tool or a hand auger may be used.
4. Construction materials. The cost of transporting bulk construction materials, such as sand and aggregates can be prohibitive if the distance between the source and the site is great. It is therefore important to identify potential or existing local sources of such materials. Superficial deposits, such as plateau gravel, river terrace gravels, glacial sands and gravels are often excellent sources of sand and aggregate.

(C) GROUNDWATER CONDITIONS

The presence of springs and seepages should be noted on the site plans. Features observed on air photographs which have been interpreted as springs or areas of wet ground should be inspected. Vegetational features such as unusual green patches, reeds, rushes and willow trees can aid the identification of wet ground conditions. Special note should be made of any evidence of seepage erosion. Shallow wells (not generally included in the BGS collection of records) located on or near the site may give a reasonable indication of groundwater levels.

(D) SURFACE WATER AND EROSION

Note should be made of ponds and streams which are not shown on the maps of the site. The likelihood of flooding should be assessed for the site and surrounding area. Any history of flooding in the area may be obtained through local enquiries. Any evidence of active soil erosion by surface water, such as gullies, should be noted.

(E) SITE ACCESS

Site access for drilling equipment and other site vehicles should be assessed, making full use of air photographs in the field. It should be pointed out that different types of drilling rig require different types of access. The shell and auger drilling rigs is perhaps the most versatile in terms of access requirements. In situations where access is limited, such as inside a building, the shell and auger rig can be dismantled outside and reassembled over the borehole location. Furthermore, in situations where access is made difficult because of steep gradients of poor trafficability, this type of rig can be winched into position. Lorry-mounted drilling rigs cannot usually be driven up steep gradients in off-the-road situations and access is further limited by the large turning circle required by these vehicles. The access of small track-mounted rigs is not as restricted by trafficability and manoeuvrability as that of lorry-mounted rigs.

In view of the problems of access in terms of time and cost of getting the drilling equipment into position, care should be taken to site boreholes for easy access wherever possible. For example, siting boreholes over ponds should be avoided unless absolutely necessary. The siting of boreholes directly beneath overhead cables should be avoided as this can prove dangerous, particularly if they are high voltage cables. Where boreholes are sited beneath electricity cables, the local electricity board should be informed of the times when drilling is to take place since it is possible to have the electricity turned off in these cables.

All entrances (for example, gates and openings in walls or hedges) should be photographed. Such photographs are often useful if any outrageous claims are made by local farmers and landowners for damage done by vehicles during the subsequent stages of the site investigation.

(F) DAMAGE OF EXISTING STRUCTURES

Structures situated on or near the site should be inspected for damage. The pattern and extent of cracks in damaged structures should be noted. Measurements of cracks may be made and the damage classified using a system such as that outlined in Table 3.9. Other signs of distortion, such as non-verticality of walls should be noted. Photographs of the damage should be taken for future reference, or as a defence against any claims that construction has caused damage to existing structures adjacent to the site. Photographs, however, are unlikely to show signs of slight damage very clearly. It should be pointed out that cracks and other signs of distortion of a structure may represent an accumulation of many movements over a long period of time and hence cannot always be interpreted meaningfully without studying the history of damage, and in particular a record of cracking. The type of foundation and the foundation material are also important considerations when interpreting damage to existing structures. Information of foundations for small structures may be obtained from local builders.

Table 3.9 Classification of visible damage to walls with particular reference to ease of repair of plaster and brickwork or masonry (after Burland et al. (1977))

Degree of damage	Description of typical damage* (ease of repair is in italics)	Approximate crack width (mm)
1 Very slight	*Fine cracks which can easily be treated during normal decoration.* Perhaps isolated slight fracturing in building. Cracks in external brickwork visible on close inspection	< 0.1 †
2 Slight	*Cracks which are easily filled. Redecoration probably required.* Several slight fractures showing inside of building. Cracks are visible externally and some repointing may be required externally to ensure weathertightness. Doors and windows may stick slightly.	< 5.0 †
3 Moderate	*The cracks require some opening up and can be patched by a mason.* Recurrent cracks can be masked by suitable linings. Repointing of external brickwork and possibly a small amount of brickwork to be replaced. Doors and windows sticking. Service pipes may fracture. Weathertightness often impaired.	5 – 15 † or a number of cracks »3.0
4 Severe	*Extensive repair work involving breaking-out and replacing sections of walls, especially over doors and windows.* Window and door frames distorted, floor sloping noticeably. Walls leaning or bulging noticeably, some loss of bearing in beams. Service pipes disrupted.	15 – 25 † but also depends on number of cracks
5 Very severe	This requires a major repair job involving partial or complete rebuilding. Beams lose bearings, walls lean badly and require shoring. Windows broken with distortion. Danger of instability.	> 25 † but depends on number of cracks

Hairline cracks of less than about 0.1 mm width are classed as negligible

* It must be emphasized that in assessing the degree of damage account must be taken of the location in the building or structure in which it occurs.

† Crack width is one factor in assessing degree of damage and should not be used on its own as a direct measure of damage.

The common causes of structural damage to buildings include: clay heave or shrinkage; excessive differential consolidation settlement; settlement due to made ground; slope instability; groundwater lowering; soil erosion; structural failure of foundations; subsidence due to mining or sink holes; vibration; and chemical attack.

Local enquiries involve the acquisition of local knowledge concerning the site. Such enquiries include the following:

1. Local builders and civil engineering contractors. Information on the types of foundations used in the area together with any construction problems associated with the ground may be obtained from local builders and civil engineering contractors.
2. Local authority engineers and surveyors. Information on flood levels, general ground conditions in the area, and previous uses of the site may be obtained from the local authority engineer's and surveyor's offices. Also further information on existing damage to structures can sometimes be obtained from these sources.
3. Local statutory undertakers. These include: the local electricity utility company, the distributor (e.g., National Grid pIc in the UK) and the central electricity generator; gas suppliers; telecommunications companies (e.g. British Telecom); water utilities; and sewerage and waste-water organizations. Information on the location of services may be obtained from these sources, in order to avoid damage to underground pipes, ducts, and cables during drilling. On occasion, the frequent need for maintenance of pipes may give a clue to the existence of ground movements.
4. Local archives. Old maps held in local archives may provide information on areas of fill or previous works on the site. Records of flooding, landslipping and mining activity may be found in local archives.
5. Local inhabitants. Local inhabitants who have lived in the area for some time are often a useful source of information concerning previous uses of the site, structural damage to buildings on or near site, mining subsidence, the location of old mine shafts, flooding and landslipping. In rural areas information on drainage, landslipping, subsidence and trafficability may be obtained from local farmers. A certain amount of caution should be employed when assessing any information given by local inhabitants as it is sometimes exaggerated, vague or ambiguous.
6. Local clubs and societies. Local clubs and societies can often provide valuable information concerning the site and surrounding area. Such clubs and societies include: archaeology societies; industrial archaeology societies; local history societies; caving clubs; geological societies and natural history societies.
7. Schools, colleges and universities. Local educational establishments, particularly colleges and universities are often a valuable source of local information. Many colleges and universities have Departments of Geology, Geography and Civil Engineering (with geotechnical expertise). It is likely that some of these departments have carried out detailed studies of various local areas at some time. The information from such studies can be most valuable, particularly if the study area includes the site. Unpublished geological records are available for a wide variety of areas from University Geology Department libraries.