Organisation, Design and Reporting of Site Investigations

Practical experience has shown that for a site investigation to be successful it must be well planned and undertaken in an orderly manner, using appropriate and well maintained field and laboratory equipment, operated by experienced and skilled personnel.

Expertise in the mechanics of investigation (boring, testing etc.) is a routine requirement in all investigations. The most difficult problem is how and where, and when, to use the various 'tools' available to the site investigator. A philosophy of site investigation has built up over recent years which proposes the idea of the developing investigation advancing in stages to a satisfactory conclusion, each stage being built on a sound foundation of knowledge established by the previous stage.

7.1 Stages of Investigation

The stages of investigation described below are but the expression of a principle. The stages do not need to be separate; they may merge into each other and additional stages may be inserted.

7.1.1 Project Conception Stage

After the decision to initiate a project has been taken, a desk study is undertaken of all available geotechnical, geological and topographical data. The proposed site and its environs should be examined by an experienced engineering geologist. The objective of this stage is to try to identify potential problems that may arise from site geotechnical conditions in relation to the proposed engineering work. Here it may be noted that the term *Site Investigation* is taken by many to represent the investigation of the site per-se, including its previous use, ownership, access etc. An investigation of the ground at a site is thus a *Ground Investigation* and but part of a Site Investigation. The engineering geologist is usually concerned with both these aspects of the work. The geotechnical, geological and topographical data should include:

- all available topographic maps,
- all available geological and hydrogeological maps, memoirs and published articles in the scientific journals,
- aerial photographs at all scales,

- records of natural hazards such as earthquakes, hurricanes, avalanches etc.,
- site investigation and construction reports for adjacent engineering projects; published articles on the geotechnical properties of the geological units to be found on the site,
- hydrogeological and hydrological data,
- records of any past, present and future human activities which have, are or could influence the geological environment.

The recommendation that the site be examined by an experienced engineering geologist may perhaps be considered to verge upon self-advertisement in a book written by an experienced engineering geologist. However, there is no doubt that the significance and even the presence of important geological features on the site can most quickly be recognised by those who are skilled in this work. A few days work by an experienced engineering geologist may save much time and trouble; i.e. money.

7.1.2 Preliminary Investigation Stage

The evaluation of a project at its conception stage may reveal significant gaps in basic knowledge of the site, so that no recognition of likely problems is possible. In such a case some preliminary investigation may be required to establish that basic knowledge. This would be undertaken using relatively simple and inexpensive techniques, such as existing records (maps, photographs, etc.), geological and engineering geological mapping, geophysics and perhaps some boreholes. The boreholes could be undertaken partly as an experiment to determine the best method for the boring, sampling and in situ testing to be undertaken in the main stage of investigation. At the end of this stage there should be sufficient knowledge of the site to allow design of the main ground investigation.

The first two stages of investigation are sometimes described as the *reconnaissance investigation* or *feasibility investigation*. If a number of sites are being investigated prior to choosing one for development the feasibility investigation may give sufficient information to allow the choice to be made.

7.1.3 Main Investigation Stage

In the main investigation stage the work done should recover the information required to design the engineering project. This information is obtained by whatever means are appropriate to the ground conditions and the nature of the engineering work. It is possible that some of the investigation work may be difficult and expensive to undertake because of problems of access to the locations of boreholes or in situ tests. Often these problems are easier to overcome during the construction of the project when earthmoving equipment is readily available and there is a great temptation to postpone necessary investigation until construction begins. This temptation should be resisted for it is possible that postponed items of the main investigation could reveal ground conditions which would invalidate project design. The client always pays for a ground investigation; the cheapest way is to commission one and the most expensive way is to "save" on one, but pay for it later with the delay and redesign that can follow a problem which was not foreseen. *No project should be designed on the assumption that the ground conditions will prove to be satisfactory.*

7.1.4
Construction Investigation Stage

One of the unfortunate facts of site investigation is that the prognoses made in the investigation reports resulting from the main investigation are seldom absolutely and totally correct. The construction of the project quite often reveals discrepancies between the ground conditions forecast and the ground conditions encountered. However, if the investigation is well done the client will have been warned that some variations in particular aspects of the ground (e.g. depth to bedrock) must be allowed for and in this way these variations need not cause significant project re-design and can be accommodated in the contract. The ground conditions encountered must be monitored, recorded and assessed. If no satisfactory assessment can be made on the basis of the information recorded then additional investigations must be undertaken to obtain further data and thence resolve any anomalies.

A theoretical example of what might happen is given in Fig. 7.1 which shows a geological cross-section (Fig. 7.1a), composed from the observations on the samples from two boreholes and an outcrop, and indicating uniformly dipping sandstones and shales overlain by soil. Dips were measured on cores and outcrop and appeared to be more-or-less uniform. However, when the soil over rockhead was removed a fault was observed. There was no way this could be forecast from the data available. It has probably only a small displacement but may well be found in the diversion tunnel and the question is whether or not it will have any significant effect on tunnel construction. Clearly further investigations should be initiated to gain more data on fault location, displacement and openness to assess its significance, but the prudent engineering geologist would have ensured that the client had a reserve for just this sort of "unknown". *The secret is to be aware of what you do not know* – in this case the engineering geologists should be aware that nothing was known about the location of faults.

7.1.5
Post-Construction Investigation Stage

The behaviour of the completed engineering work will have been computed on the basis of data acquired in the earlier stages of investigation. Certain features of behaviour, such as settlement, may take many years to become complete after construction of the project. If observed behaviour is not the same as anticipated behaviour this may indicate that the properties of the ground are affected by some unforeseen and previously undetected factor. Further investigations may be required to resolve this anomaly.

Monitoring of behaviour of the engineering project and comparison with predicted performance is of vital importance for all engineering works although contract arrangements often seem to hinder such monitoring. It must be remembered, however, that major engineering disasters mostly take place some time after completion of the work. The importance of post construction monitoring is thus clear. Anomalies of

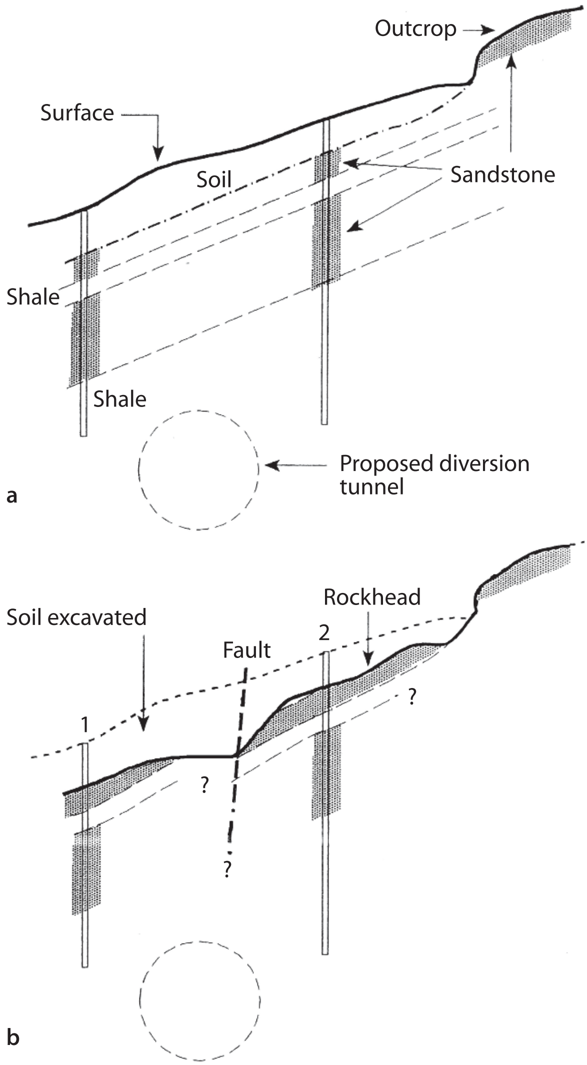


Fig. 7.1. The contrast between geology forecast (**a**) and rockhead geology found after the removal of soil cover (**b**) suggests that the diversion tunnel might encounter some difficulties due to the presence of the previously unsuspected fault

project behaviour must be observed, their cause established and remedial measures undertaken before severe damage or perhaps failure can occur.

7.2 Design of Site Investigations

While the concept of the development of site investigations in stages provides a philosophy of investigation procedure it does not answer the question "*…but what do I actually do?*" which is so often asked by engineers when they are confronted with the need to design an investigation for a particular project.

The answer to this question may be found by reviewing the purpose of investigations, *which is to determine the behaviour of the ground in response to the construction of the engineering work*. This 'behaviour' is calculated using the procedures, formulae etc. established in the various branches of engineering and applied earth sciences. Before the calculations can be made data dealing with the properties of material and mass, location of layer boundaries, and discontinuities and so forth, must be available so that it can be introduced into the calculation procedures; only then is it possible to obtain a numerical assessment of ground behaviour. What sort of data and how much data is needed depends upon the geological conditions and materials that are considered to be present, and the form of analyses that is to be used. The analysis will attempt to predict stability and deformation of the ground during construction in response to the unloading and subsequent re-loading it will experience. Most analyses require representative geological inputs. It is for this reason that engineering geologists should be acquainted with the rudiments of soil and rock mechanics and better still, a working knowledge of these subjects. Similarly, geotechnical engineers should be aware of the constraints that can be imposed by geological materials, structures and conditions upon the theories they intend to use for calculating their predictions. To all this must be added the subject of ground water as it influences the effective stress in the ground and can promote volumetric changes in some rocks and soils. In this regard fine grained sedimentary rocks and soluble sedimentary rocks should be considered with great care. Use should always be made of *Case Histories* – a much neglected and often forgotten source of invaluable knowledge. The size of this model will depend on the volume of ground which will influence or be influenced by the engineering work.

As the number of different materials present and the regularity and way with which they are distributed depends upon the geology of the site so the intensity of investigation (the number of boreholes, samples, geophysical traverses etc.) will in part depend upon the complexity of site geology. Complex geological situations will generally require a greater intensity of investigations than simple geological situations.

7.2.1 Building the Geotechnical Model

The process of building up the geotechnical model begins with a first appraisal of the geology based on available existing information, perhaps followed by geological mapping of the site on a large scale (say 1:1 000 or 1:500). This information is interpreted by standard geological procedures to establish a *prototype geological model*. A study of this model should indicate certain locations on the site where boreholes may most appropriately be sunk and perhaps geophysical work undertaken to verify or modify the geological model. The aim of this work is to determine layer boundaries and to establish an idea of the nature of these layers. If boreholes are used samples must be taken. If soils are being investigated then probably the first type of boring would be the percussion borehole, recovering tube 'undisturbed' samples and disturbed bag samples. Normally in such work the driller is instructed to take samples at regular intervals, say at every 1.5 m for tube samples, or at changes in strata. This rather low quality and quantity sampling is just to get an idea of the nature of the materials. In rock the initial boreholes are rotary core drilled, often at a somewhat larger diameter than may later prove to have been necessary in order to assure good recovery. This is done because subsequent drilling in rock may be undertaken in order to determine strata boundaries and open-hole methods could be used if there is good initial knowledge of the litho-stratigraphy.

The materials recognised in the samples belong to geological bodies which were penetrated by the boreholes. The shape of these bodies determines the distribution of materials under the site. Shape can be assessed by correlation between boreholes but this assessment can be greatly aided by the use of geophysical techniques (such as seismic refraction or reflection, ground penetrating radar or electrical resistivity) to determine boundaries. The 'model' distribution of materials built up from these data must then be tested for geological credibility. In other words whether the way in which the groundmass appears to be built up from the evidence available seems likely in the light of the known geological history and structure of the region.

This first model is then examined further by boring, geophysics or other methods, *to verify the concept* and *to obtain the samples* that may be necessary to deal with the particular problems posed by the combination of ground conditions and engineering work. Thus for some problems special samplers may be necessary to obtain high quality samples for drained triaxial tests or consolidation tests. The quality of sample is related to the degree of accuracy and reliability of test results required.

Samples may be taken from boreholes but also 'samples' may be tested in situ – access to these sample locations may be gained by boreholes, trial pits, trenches or shafts.

The degree of precision required in the assessment of ground conditions relates to the likely magnitude of ground reaction as a consequence of the construction of the engineering work. If the reaction is likely to be such that the success of the engineering project is in doubt then the quantity and quality of sampling, testing and interpretation must be high. Unfavourable ground behaviour could come about as the result of a simple structure being built in difficult geological conditions or a very complex engineering work being executed in simple geological conditions. It follows then that each investigation, whose design relates to both geology and the nature of the engineering project, is unique. *Thus there is no standard form of site investigation for a particular type of work. Each investigation is a completely new venture.*

7.2.2 Guidelines for Design of an SI

Although each investigation should be considered as individual many share common objectives and the actions needed to achieve these provide guidelines which may help the design of an investigation. These are:

- Determine the nature of the engineering work as far as is possible. It is necessary to know size, loads imposed, depths of excavations etc. desired by the client's proposals before planning the investigation.
- Determine the geology, geomorphology and hydrogeology of the area of the site and its environs.
- Determine the nature of the geological environment and the likely influence of any human activities on the site.

- Establish the size and location of the ground mass that could influence or be influenced by the engineering work.
- List the data which must be acquired to allow the necessary calculations that relate to the proposed engineering work to be made.
- Consider the best means of acquiring the data.
- Design a preliminary stage of investigation.

A good principle of design is to consider that each investigation must be economically efficient in the sense that the cost of the investigation must be money well spent. The investigator must be able to justify each and every item in the site investigation in terms of the value of that item in building up the geotechnical model. The investigator must be able to show good and sufficient reason for undertaking each part of the investigation.

While the idea of being able to justify each item of the investigation imbues the investigation with a sense of purpose and discipline (and will also prove popular with finance administrators) there is a danger that the investigator might become fixed on a wrong path and try to prove pre-conceived ideas rather than find the true situation. There is some justification for the 'random' investigation, undertaken almost at the completion of the geotechnical model, which tests the validity of this model. The more complex the geology and the more important the project, the greater is the need for this '*insurance*'.

7.3
Progressive Evaluation of Site Investigation Data

The data that is recovered from a site investigation must be evaluated in the course of the investigation and not left as an exercise to be undertaken once the fieldwork is over, so that, if necessary, the location of boreholes, trial pits etc., may be altered. It is easy to forget that *the principle purpose of a ground investigation is to understand the ground*, and this is best acquired whilst the investigation is in progress. The investigation data will refer mostly to two types of knowledge, first the location of engineering geological unit boundaries (layers, bands, discontinuities, etc.) and second the geotechnical properties of mass and materials.

The first sort of investigation data is most readily displayed on cross-sections and maps. Data received from boreholes or geophysics may be shown on borehole records or on profiles. Study of these records, together with the results of any testing on the samples retrieved, should allow the investigator to recognise boundaries between engineering geological units (layers of material with similar geotechnical properties) and to determine their level (relative to the datum plane of the site map). These levels may then be plotted on the map and *strikelines* (contour lines on geological surfaces) may be drawn for the boundaries. The results of the investigation in terms of the distribution of materials all over the site may then be seen.

The distribution of these strikelines, together with any other published information about the geology of the area, may give the investigator a theory about the nature of the geological structure being investigated and subsequent investigation works may be planned with the intention of proving or changing the first theory. If this idea is followed it ensures that at all times the investigation has a plan and a purpose.

Similarly, once testing has been undertaken to establish the geotechnical properties of the various materials the results of this testing must be compiled to allow assessment of the engineering geological units. This compilation is best done in tabular form. After the first compilation the data may be recompiled into units with similar geotechnical properties – property boundaries must be established by the investigator with regard to the nature of the engineering work.

7.4 Investigation Progress and Engineering Design

Engineering design of a project begins immediately after project conception and often before any significant site investigation can take place. The first design is thus based on assumed, generally favourable, ground conditions. If the assumptions are proved false then the project must be partially or wholly re-designed.

While project re-design is almost inevitable in the early phases of the development of a project, re-design due to faulty knowledge of ground conditions should be reduced once site investigations have commenced by the continuous interchange of information between investigator and project designer. *This liaison is essential to prevent wasted effort in design and in investigation.* Table 7.1 shows where, in the progress of an investigation, such liaison is appropriate.

Table 7.1. Stages of investigation and the progress of engineering design

Site investigation stage	Investigation activities	Information exchange	Design and construction progress
Project conception ↓	Ground conditions required Basic knowledge of ground conditions Recognition of major problems	← →	Basic design concepts (start here) Confirmation or amendment of basic design concept
Preliminary ↓	Preliminary field investigations Design of main investigation	← →	 Preliminary detailed design
Main ↓	Information recovered during investigation Main investigation report	⇄ →	Modifications to detailed design Final design of project
Construction ↓	Recording ground conditions as found Response of ground	→ ⇄	**Construction** Modifications to design as necessary Modifications to design and possible need for ground treatment and/or support **Completion of construction**
Post construction	Monitoring behaviour	→	Operation Maintenance of works (end here)

7.5
Tender Visits

Engineering projects (including site investigations) are generally put out to tender. The first man to visit the site may then be an estimating engineer, on site to collect the contract documents and view the site with other contractors. Such a visitor should return to his office with information that will be of help to engineering geologists and geotechnical engineers for their part of the project. It is important that this information should be adequate, particularly if the site is in some far distant land which is difficult and expensive to visit. It is always useful to bring back:

i topographical maps of the area in which the site is situated;
ii geological maps and reports;
iii aerial photographs;
iv details of transport infrastructure;
v addresses of government agencies;
vi photographs of the site.

In some countries any of the above items could be considered a subject of national security and attempts to obtain one or more of them can result in the innocent enquirer being "detained"; be prudent!. Sometimes samples of rock or soil may be brought back, particularly if the project includes the use of natural materials for construction purposes. Any samples should be of a size and volume to be representative of the material from which they were collected (Table 7.2).

7.6
Supervision of Investigating Works

Having won the contract for a ground investigation and designed both its content and organisation, it is necessary to ensure the work is conducted properly. This requires it to be supervised by an engineering geologist. Much can happen during these investigations that needs an informed decision to be made at the time. For example, a borehole being drilled according to required standards, may collapse. Should the drilling crew (*a*) abandon the hole; (*b*) grout the hole in the region of the collapse and try to re-drill; (*c*) investigate the cause of the collapse or (*d*) just move to another point a few metres away and start again? Or again, a trial pit may be 1.5 m below ground level when one of its faces collapses and the pit half fills with water. Should the pit (*a*) be continued to its designated depth of 2 m; (*b*) be abandoned; (*c*) back filled immediately; (*d*) relocated? An engineering geologist is best able to sensibly answer these questions so as to move the investigation forward in a positive way. Unsupervised work provides, at best, an inadequate record of the ground and at worst a wrong record, from which will be made incorrect predictions of the ground and its reaction to the engineering works proposed – the precise situation the investigation was commissioned to avoid! There is no substitute for careful supervision and *a site investigation that has been supervised will always provide more trustworthy data than one that has not*.

Table 7.2. Minimum sample size required for useful testing

Purpose of sample	Material	Weight or volume of bulk sample	Diameter and length of tube or core sample (mm)	
			Diameter	Length
Chemical composition	Clays and silts	0.5–1.0 kg	38	75
	Sands	0.5–1.0 kg	38	75
	Gravels	3.0 kg	90	200
	Rocks	0.5 kg	38	75
	Groundwater	2.5 l		
Structural characteristics incl. grain size, porosity etc.	Clays and silts	0.5–1.0 kg	90	90
	Sands	1.0–2.5 kg	90	200
	Gravels	4.5–45 kg	90	200
	Rocks (coarse grained)	0.3 m^3	90	90
	Rocks (fine grained)	0.15 m^3	75	75
Strength characteristics incl. elastic moduli, shear strength, consolidation etc.	Clays and silts	$(0.3\ m)^3$	38	75
	Sands	$(0.3\ m)^3$	38	75
	Gravels	$(0.5\ m)^3$	0.2	0.3 m
	Rocks (weathered)	2 of $(0.3\ m)^3$	90	200
	Rocks (unweathered)	1 of $(0.3\ m)^3$	75	150
Hydraulic characteristics incl. permeability, etc.	Clays and silts	$(0.15\ m)^3$	38	75
	Sands	$(0.2\ m)^3$	38	75
	Gravels	$(0.5–1.0\ m)^3$	0.2	0.4 m
	Rocks (coarse grained)	$(0.3\ m)^3$	90	200
	Rocks (fine grained)	$(0.15\ m)^3$	75	150
Comprehensive examination	Clays and silts	20–45 kg	90	200
	Sands	20–45 kg	90	200
	Gravels	45–90 kg	0.2	0.4 m
	Rocks	2 of $(0.3\ m)^3$	90	200
	Groundwater	4.5–10.0 l		

7.7 The Engineering Geological Situation

The end product of material and mass properties, of mass fabric, of geological environment and so forth is the description of the engineering geological situation. This presents to the engineer, architect, mine engineer, or whoever is concerned with the proposed project, the data needed in order to determine the reaction of the ground and thence correctly design the engineering work so the ground reaction will not damage the work. This presentation of data and opinion is no light and easy task but it is absolutely essential that it be done satisfactorily. Some clients want only the facts, a *Factual Report*. Factual data must be accurately presented in a matter such that it cannot be misunderstood. Other clients request both the facts and an interpretation of them, an *Interpretative Report*; here opinion must be presented with clarity and objectivity. The main problems in doing this are:

- that accurate presentation of data is an arduous and difficult task;
- that the presentation must be made in terms that are to be readily understood by the reader who may not have the depth of technical knowledge possessed by the writer.

However, despite the difficulties of the task of presentation it must be undertaken. It must not be forgotten that the reports in which the presentation is made (commonly reports on site investigations) may form parts of contractual documents. Claims and lawsuits may be the result of inaccurate or poor quality reporting. Worse still, *misunderstood reports could lead to fatalities* and engineering disasters if the data or opinions they appear to present are acted upon. It must also not be forgotten that the report document, together with any maps, plans, profiles etc. that it contains, represents the cost of the investigations. It is common for projects to be constructed some years after the completion of investigations, when all samples have disappeared, all trenches filled in and so forth. All that remains is the report on whose contents design is then based.

7.8 Investigation Reports

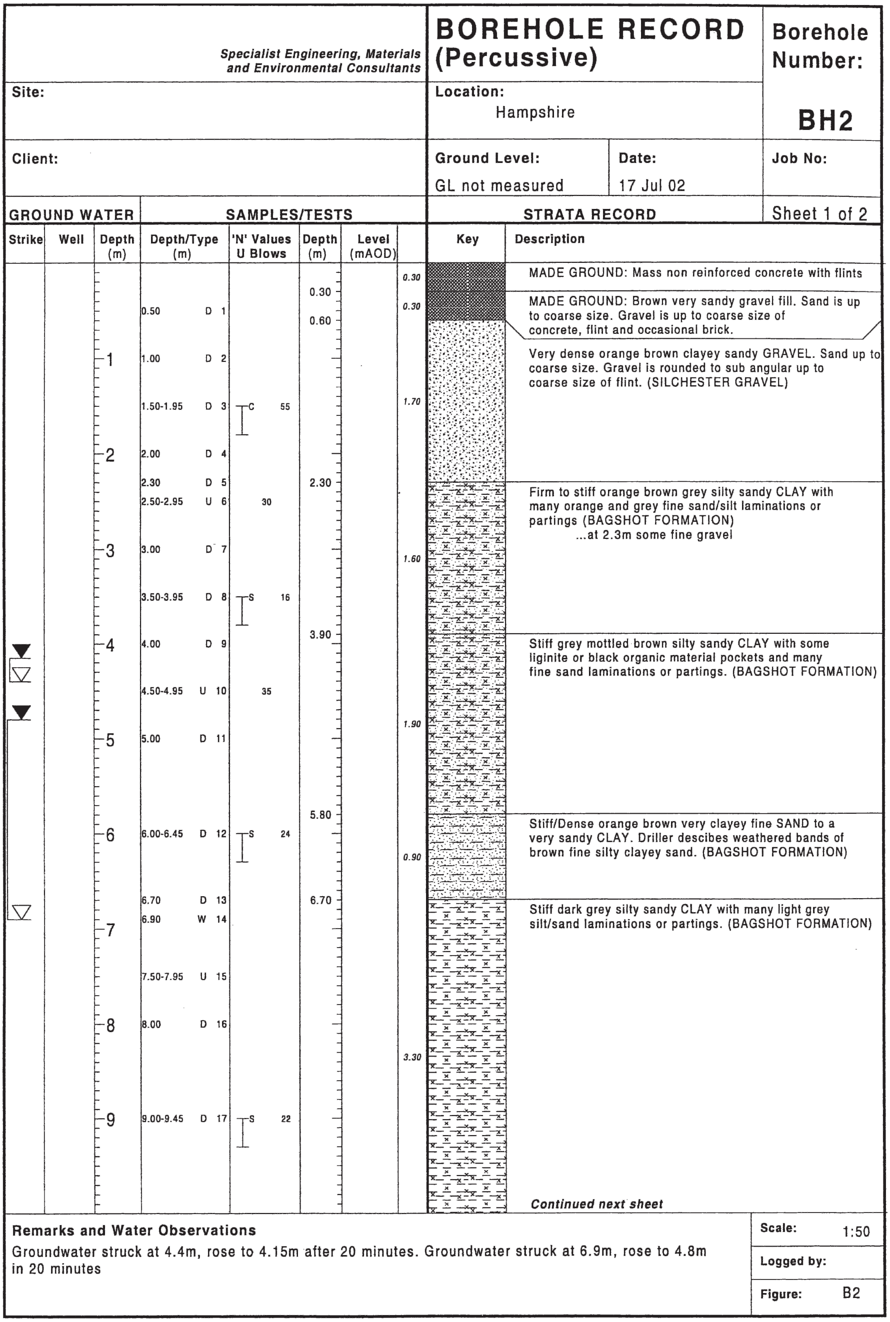
The results of a site investigation are generally expressed in the form of a report. This contains a written text to which are added tables or graphs giving test results, and maps and diagrams illustrating the location of site investigation works, site geology and perhaps the recommendations of the investigator. All reports should be of a good literary standard. Diagrams and illustrations should follow the proposals set out in the section on engineering geological mapping. Borehole records should be prepared to standards similar to those shown in Fig. 7.2. Each illustration or table may, in use, become separated from the main body of the report. They should thereafter be prepared as independent documents containing sufficient data to locate the information they contain to the site in time and space.

7.9 The Form of the Report

Every organisation has its own way of preparing a report, which may be varied depending upon the project. The following basic scheme of report writing may prove useful for those who have little previous experience of report preparation.

Title page. This should show the name of the project, the name of the organisation or individual preparing the report, the report number (as used in the filing system of the writers), the date of the publication of the report.

Report 'contents' page. This should show the titles of the main sections of the report and the page on which they may be found and also list all figures, tables, borehole records and so forth, that may be included.



Specialist Engineering, Materials and Environmental Consultants

BOREHOLE RECORD (Percussive)

Borehole Number: BH2

Site:

Location: Hampshire

Client:

Ground Level: GL not measured

Date: 17 Jul 02

Job No:

Sheet 1 of 2

GROUND WATER | SAMPLES/TESTS | STRATA RECORD

Depth/Type (m)			'N' Values U Blows
0.50	D	1	
1.00	D	2	
1.50-1.95	D	3	C 55
2.00	D	4	
2.30	D	5	
2.50-2.95	U	6	30
3.00	D	7	
3.50-3.95	D	8	S 16
4.00	D	9	
4.50-4.95	U	10	35
5.00	D	11	
6.00-6.45	D	12	S 24
6.70	D	13	
6.90	W	14	
7.50-7.95	U	15	
8.00	D	16	
9.00-9.45	D	17	S 22

Depth (m)	Level (mAOD)	Description
0.30	0.30	MADE GROUND: Mass non reinforced concrete with flints
0.60	0.30	MADE GROUND: Brown very sandy gravel fill. Sand is up to coarse size. Gravel is up to coarse size of concrete, flint and occasional brick.
2.30	1.70	Very dense orange brown clayey sandy GRAVEL. Sand up to coarse size. Gravel is rounded to sub angular up to coarse size of flint. (SILCHESTER GRAVEL)
3.90	1.60	Firm to stiff orange brown grey silty sandy CLAY with many orange and grey fine sand/silt laminations or partings (BAGSHOT FORMATION) ...at 2.3m some fine gravel
5.80	1.90	Stiff grey mottled brown silty sandy CLAY with some liginite or black organic material pockets and many fine sand laminations or partings. (BAGSHOT FORMATION)
6.70	0.90	Stiff/Dense orange brown very clayey fine SAND to a very sandy CLAY. Driller descibes weathered bands of brown fine silty clayey sand. (BAGSHOT FORMATION)
	3.30	Stiff dark grey silty sandy CLAY with many light grey silt/sand laminations or partings. (BAGSHOT FORMATION)

Continued next sheet

Remarks and Water Observations

Groundwater struck at 4.4m, rose to 4.15m after 20 minutes. Groundwater struck at 6.9m, rose to 4.8m in 20 minutes

Scale: 1:50

Logged by:

Figure: B2

Fig. 7.2. Example of a borehole log through soil

Introduction. A brief description *of the purpose of the site investigation*, which should in itself explain the design of the investigation, the name of the client and of those who designed the investigation, the dates of the beginning and the end of field work and laboratory testing and any special instructions given by the client.

Description of the project. A brief description of the purpose and design of the project.

Topography and geology of the site. A description of the topography of the site at the time of the investigation, including comments on land use and access to the site. The basic geology of the site should be described making a clear distinction between information available before the investigation and that gained during the investigation. Comments regarding possible natural hazards should be made here as well as a review of site climate, if these are of significance.

Site investigation. The site investigation work done is described in this section, which may be divided into sub-sections such as "*Borehole*", "*In situ testing*", "*Laboratory testing*" as appropriate. This section must be factual and correct, for it may be used as a basis for billing the work done in the contract.

Results of site investigation. This section describes the geotechnical model built up from the data discovered in the course of the investigation. It should be divided into engineering geological units and a description of each unit (its location and properties) given.

Influence of ground conditions on project construction. This gives the opinions of the investigator on the likely behaviour of the ground as a response to the construction of the project and also the response of the construction to the behaviour of the ground. Advice on foundation design and construction, excavation techniques and so forth are presented. The section may be divided in relation to the various parts of the project.

Discussion. A discussion may be included in the report. This may consider the reliability of the investigation data, recommendations for further investigations and so forth.

7.9.1 Other Aspects of Report Preparation

Each of the sections described above should contain references to figures, tables etc. which are generally presented after the text. Tables and figures are best presented on separate pages, they should not be included in the text. Each page of the report should be numbered. This may usefully be done describing each page '*X*' of '*Y*' pages, '*X*' being the number of the page and '*Y*' the total number of pages in the report text. The contents page should be Page 1. Any standards, norms, textbooks, scientific articles etc. referred to in the report should be given a reference number in the text which relates to a list of references at the end of the report. References should be given in a uniform way, following one of the systems recommended by the scientific journals.

Appendices. Appendices may be used to give additional information essential to a proper understanding of the report. Such information could be, for example, an explanation of a method of geophysical interpretation or the execution of a laboratory test. Appendices should not contain information generated by the investigation.

7.9.2 Borehole Records

Boreholes are one of the primary tools of site investigation and the way in which borehole data is presented must be carefully considered. A good and uniform standard must be achieved. An example of a good standard of borehole record is given in Fig. 7.2. The method of presentation is to show information in columns and blocks. The blocks at the top of the record deal with the methods of drilling and the reference number and location of the borehole. Those at the bottom give the names of contractor, client, a key to some of the symbols used on the record and observations (remarks) about unusual circumstances connected with the sinking of the borehole. The data derived from the borehole is held within columns between the top and bottom blocks.

To the left, on the binding margin of the record, there are columns showing location of samples, progress of the borehole, water levels, core recoveries and/or results of penetration tests and a column for core size and/or sample type. To the right there is a column for the description of the strata found in the borehole. A centimetre scale is drawn on two of the vertical lines to allow the borehole to be drawn accurately to scale. At a scale of 1:100 the record can present up to 20 m depth of borehole. The symbolic log is placed on the right hand side next to a column in which the levels of strata boundaries (relative to the locally used horizontal datum plane) are given. If all the borehole records presented are kept to the same scale the user may overlap a series of borehole records and compare symbolic logs along a line of section.

Young engineering geologists charged with the task of preparing such records often ask why the various blocks and columns of information are necessary. There is a reason for each information block.

Starting at the top left of the record the blocks entitled "*Drilling method*", "*Core barrel and bit design*" and "*Machine*" tell the skilled borehole record reader whether the drilling equipment used was adequate to drill the strata recorded. If not then loss of core or sample might be attributable to poor drilling rather than poor ground conditions. That the drilling equipment was not suited to the strata to be drilled is not necessarily the fault of the driller or drilling contractor for the geological conditions found might have been totally unexpected. Finding the unexpected by the process of investigation is, after all, the purpose of investigation. Such information is particularly valuable if the borehole reports relate to a preliminary stage of the investigation – appropriate equipment can then be chosen for the main stage. The strata descriptions that are written in the "*Description of Strata*" column must be written with regard to a recognised system for the description of soil and rock materials, preferably that system used in the country in which the investigation was undertaken. It is useful to mention the system used in the text of the main report.

However, while descriptive standards help to decide whether, for example, a sandstone is thinly bedded or thickly laminated, they do not help the sample logger to decide what to call the materials encountered or to decide where to establish boundaries between strata of different types. This is perhaps rather more difficult a problem with rocks than with soils. There are three common problems:

1. *Establishing boundaries in strata that are uniform in nature.* Here the temptation is to say that the rock is uniform while it might be possible to describe differences of a rather more subtle nature than is common on rock description, such as, for example, between "sandy mudstone", "slightly sandy mudstone" and "very sandy mudstone". Whether such subtlety of description is necessary or not will depend upon the nature of the project. For rock dredging it could be of great importance while it could be of no significance for determining the depth of mudstone overburden over limestone to be quarried. The need for subtle distinction between rather similar strata will depend upon the nature of the project. *The real problem comes when the logger must log without much idea of what the project is about.*
2. *In some rock and soil successions there are very frequent but distinct strata differences to be seen.* One which is particularly common is the rapid alternations of shale and fine sandstones that occur, for example, in parts of the Carboniferous. If alternate bands are, say, 2 cm thick then '*very thinly bedded alternating SHALES and fine SANDSTONES*' is appropriate. If the layers are more than a metre or so thick then they could be described separately. The problem arises when the layers are, say, 20 or 30 cm thick. Again as with the first difficulty, *what is done depends upon the nature of the project for which the borehole record is being prepared.*
3. *Constraining strata descriptions* within the type space limitations of the borehole record form. The description should not be too verbose; keep to the point and ensure the essentials are recorded.

An example of a good log in rock is given in Fig. 7.3. Ground levels must be recorded for it sometimes happens that in the initial stages of construction general excavation changes site levels. If it is by chance assumed that the borehole started from the changed site level then calculations with regard to the depths of layers would be incorrect.

Orientation of the borehole must be known in the case of inclined boreholes. This is mostly given in terms of direction of the hole (relative to magnetic north) and dip of the hole from the horizontal. It is very valuable to put a co-ordinate reference, relative to the national co-ordinate reference system, on every borehole record. Most reports contain site plans showing where the borehole was drilled relative to features in the landscape which existed at the time of the investigation. However, between investigation and construction these may have disappeared, perhaps as a result of site preparation. Boreholes can always be relocated on site if the grid reference is known. This should be given to the nearest metre.

Every borehole should be numbered. The numbering system should be kept as simple as possible. If boreholes are longer than one record sheet can hold then the use of the "*sheet X of Y*" tells the reader this. Second sheets should, in principle, hold the same amount of block data as the original sheet. Every site has a name and this must be given on the record. One difficulty is that the site name given at the time of investigation is not always that of the construction site. At the bottom of the record there are blocks for the name of the contractor (if a site investigation contractor is used) and for the client. Mostly a contractor or consulting engineer prepares the record and the record would have a printed logo with name and address.

Start date	17 October 1989	Casing diameter	200 mm to 8.00 m 150 mm to 12.00 m 100 mm to 14.00 m
End date	21 October 1989		
Drilling method	Cable percussion to 12.00 m Rotary coring 21.50 m	Borehole diameter	200 mm to 8.50 m 150 mm to 12.00 m 100 mm to 21.50 m
Equipment	T6H core barrel, water flush		

BOREHOLE No. 56	
National grid Coordinates	5423.00 E 4256.00 N
Orientation	Vertical
Ground Level	33.68 m OD

Date and time	Casing depth (m)	Depth to water (m) / Flush return (%)	Sample/core recovery: Depth (m) from to	Type / TCR	No. / SCR	RQD	SPT blows /N / Core size (mm)	Fracture spacing (minimum average measurement)	Description of strata	Depth (thickness) (m)	Level m OD	Legend
			10.00 - 10.50	D	15		kV	(k = 1.0		10.00	23.68	
			10.00 - 11.00	B	16			x 10.6)		10.20	23.48	
									SAND (as sheet 1)			
										(0.55)		
							C 103	25 mm	Probably dense, slightly sandy angular to rounded GRAVEL and COBBLES of quartz and limestone. (ALLUVIAL DEPOSITS)			
	11.00	1.35	11.00	D	17			(k = 5.5				
			11.00 - 11.40	B	18			x 10.6)				
			11.00 - 11.50							11.30	22.38	
							kV		Very weak to moderately weak very thinly bedded grey fine and medium grained LIMESTONE. Fracture surfaces stained orange brown (CARBONIFEROUS LIMESTONE)			
			11.60	D	19							
17.00			11.80 - 12.00	D	20							
18/10	12.00	9.30						10 mm				
20/10	12.00	2.50					76	NI		(0.70)		
08.00		(100)	12.00 - 12.50	30	0	0						
									Recovered as gravel size fragments from 11.30 m to 12.20 m			
										12.70	20.98	
		(100)	12.50 14.00	95	30	6		NI	Moderately weak thinly laminated black carbonaceous MUDSTONE. Fracture closely spaced 45° dip, smooth lightly orange stained. (CARBONIFEROUS LIMESTONE)			
			14.00 - 14.45	D	21			50				
							S 46	175	Sub-horizontal very closely spaced polished striated surfaces from 13.30 m to 14.20 m	(1.15)		
		(100)										
			14.45 - 15.50	100	50	25						
										15.00	18.68	
		(0)							Strong thinly to medium bedded dark grey medium grained LIMESTONE. Fractures medium spaced, dip 45° and 60° rough, stained. Fractures dip 90° up to 0.5 m long, stepped rough, tight, clean (CARBONIFEROUS LIMESTONE)			
							C 50	20 mm				
			15.80 - 16.10	CS	1			50 175 200				
									Sub-horizontal very closely spaced polished striated surfaces from 13.30 m to 14.20 m			
			15.50 - 18.00	90	80	80						
		(0)										
			17.31 - 17.49	CS	2							
18.00								80 250 350	65° fracture with 50 mm day infill at 17.50 m			
20/10	14.00	10.00	18.00 - 19.50				kP	(L = 50)				
21/10 08.00	14.00	11.00								(2.00)		
		(0)										
			18.00 - 20.00	100	85	80				19.00	14.68	
		0.40	19.20 - 19.73	CS	3				LIMESTONE (As sheet 3)			
		(75)								(0.50)		
			20.00 - 21.50				kP	(L = 10)		20.00	13.68	

Remarks
6. In situ borehole vane test carried out at 6.00 m
7. In situ variable head permeability tests (kV) were carried out from 10.00 m to 10.50 m and 11.00 m to 11.50 m depth
8. In situ 'Packer' water injection tests (kP) were carried out from 18.00 tp 19.50 m and 20.00 m to 21.50 m depth
9. Geophysical borehole logging was carried out by ANO on completion

Logged by	DRN 21/10/89
Compiled by	ANO 25/10/89
Checked by	VIP 26/10/89

Project	Contract No.	Sheet No.
CATCAIRN BUSHES, BRISTOL Notable Developments Limited	5903	Sheet 2 of 3

Fig. 7.3. Example of a borehole log through rock (from British Standard BS5930 (1999) and in which other good examples can be found)

The form displayed in the figure has also a very small block for the name of the person responsible for the preparation of the record. It is a matter of some earnest debate to decide whether or not this should appear on a record. Mostly the company employing the logger is responsible under law for the accuracy of the record and it could be argued that omission of the logger's name ensures that he or she would suffer no personal difficulties in the event of dispute. On the other hand it may also be that the user of the record might want to contact the logger for reasons other than legal dispute, perhaps, to ask for an opinion based on personal knowledge which was not requested at the time.

7.10 Further Reading

British Standard 5930 (1999) Code of practice for site investigations. British Standards Institute, London
Clayton CRI, Mathews, MC, Simons NE (1995) Site investigation. Blackwell Scientific Ltd., Oxford