Chapter 1

The Basis of Engineering Geology

1.1
Development of Engineering Geology

While ancient man must have had some intuitive knowledge of geology, as evidenced by the feats of mining and civil engineering performed in the distant past, the present science of geology owes much of its origin to the civil engineers working in the eighteenth century. These engineers, while constructing the major engineering works associated with the industrial revolution, had the opportunity to view and explore excavations in rocks and soils. Some, intrigued by what they saw, began to speculate on the origin and nature of rocks, and the relationships between similar rocks found in different places. Their ideas and theories, based on the practical application of their subject, formed the groundwork for the development of geology as a science. Engineers such as Lewis Evans (1700–1756) in America, William Smith (1769–1839) in England, Pierre Cordier (1777–1862) in France and many others were the ‘fathers’ of Geology.

Their interest in geology often stemmed from a ‘need to know’. They were confronted with real engineering problems which could only be solved with the help of both a knowledge and understanding of the ground conditions with which they were confronted.

In the later nineteenth century both geology and engineering advanced, geology becoming a more-or-less respectable natural philosophy forming part of the education considered suitable for well brought up young ladies. Engineering, characterised by the canal and railway construction carried out by the ‘navvy’, on the other hand, remained as an eminently practical subject. The theoretical understanding of engineering was driven by practical engineering problems. The geological knowledge of the engineer, confronted by increasingly difficult engineering challenges, did not progress as rapidly as geology, advanced as a science under the leadership of geologists such as James Dana (1813–1895) in America, Albert Heim (1849–1937) in Switzerland and Sir Archibald Geikie (1835–1924) in Britain. Thus, by the end of the nineteenth century the majority of civil engineers knew relatively little about geology, and very few geologists were concerned about, or interested in, its engineering applications.

This widening division between geology and engineering was partly bridged in the nineteenth and early twentieth century by the development of soil mechanics by engineers such as Charles Coulomb and Macquorn Rankine, who developed methods of calculating the deformations of earth masses under the stresses imposed by engineering works. The great leap forward may be considered to have taken place with the publication of “*Erdbaumechanik*” by Karl Terzaghi in 1925, which brought together old knowledge, and added new theory and experience to establish soil mechanics in its own right as a discipline within the field of civil engineering. Subsequent publications by Terzaghi and others have continued to recognise a clear understanding of the

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Failures of engineering works in particular, such as that of the Austin Dam in Texas in 1900 and the St. Francis Dam in California in 1928, showed that there was often a lack of appreciation of the importance of geological conditions in engineering design.

Such failures emphasised the need for expert assessment of geological conditions on civil engineering sites and there was, by the 1940s, a trend for civil engineers to employ geologists in an advisory capacity. However, while certain gifted individuals, such as Charles Berkey in the United States (Paige 1950) and Quido Zaruba in Czechoslovakia (Zaruba and Mencl 1976), performed this function very well it was not always a successful liaison. Few geologists had sufficient engineering knowledge to understand the requirements of the engineer and few engineers had more than the most superficial knowledge of geology.

Despite these problems the recognition that liaison was required slowly brought to the fore a new breed of earth scientist, the 'engineering geologist'. Most of the early engineering geologists were geologists who had gravitated into engineering employment, educating themselves by study and experience. Certain notable engineers, such as Robert Leggett in Canada (Legget 1939), developed their geological knowledge to achieve the complementary aim.

Eventually engineering geology became sufficiently developed for the subject to form part of university curricula. Thus, in Imperial College, London, engineering geology was taught at postgraduate level to both geologists and engineers as early as 1957 under the guidance of John Knill. Courses progressively developed elsewhere in England, Europe, America and Canada during the subsequent decades. Now there are few countries in the world where engineering geology, in some form or other, is not taught as an academic discipline.

While educational opportunities developed, the number of practising engineering geologists increased until in California in the United States they were sufficiently numerous to band together to form a professional association. This expanded in 1963 to become the Association of Engineering Geologists (AEG), covering all the United States and now with an international membership. In 1967, the International Association of Engineering Geology (IAEG) was formed. This provides, for engineering geology, the international association equivalent to the International Society for Soil Mechanics and Geotechnical Engineering for soils engineers and the International Society for Rock Mechanics for rock mechanicians. Reputable journals for engineering geology have also developed, such as "*Engineering Geology*", published by Elsevier. Both the AEG and the IAEG have their own publications. National groups also began to publish journals of high reputation, such as the "*Quarterly Journal of Engineering Geology and Hydrogeology*" published by the Engineering Group of the Geological Society of London

Hopefully, having read this short description of the origins of engineering geology, the reader is convinced that the subject exists. The next question is "What's it all about?"

1.2
Aims of Engineering Geology

Every discipline must have an aim and purpose. The Association of Engineering Geologists includes in its 2000 Annual Report and Directory the following statement:

> "Engineering Geology is defined by the Association of Engineering Geologists as the discipline of applying geologic data, techniques, and principles to the study both of a) naturally occurring rock and soil materials, and surface and sub-surface fluids and b) the interaction of introduced materials and processes with the geologic environment, so that geologic factors affecting the planning, design, construction, operation and maintenance of engineering structures (fixed works) and the development, protection and remediation of ground-water resources are adequately recognised, interpreted and presented for use in engineering and related practice."

The IAEG has produced a statement on similar lines which sets out the redefinition of its mission in 1998 as The International Association for Engineering Geology and the Environment.

The exact phraseology, and interpretation, of such statements varies from country to country depending upon national and local practice. Thus many "engineering geologists" are essentially geologists who deliver basic geological data to engineers, without interpretation. At the other end of the scale some engineering geologists might design foundations and slope stabilisation, thereby spending much of their time as geotechnical engineers. Much clearly depends on the training and experience of the geologist involved, and the attitudes of the organisation in which he or she is employed.

A particular problem lies in the field of hydrogeology (or geohydrology). In some countries much of exploration for sources of potable water is carried out by engineering geologists. In other countries this is undertaken by specialised hydrogeologists who are quite separate from their engineering geological brethren. Again the national culture of science and engineering influences the trend.

Engineering geology may exist under, or be a part of, other titles, such as "*geological engineering*", "*geotechnical engineering*", "*earth science engineering*", "*environmental geology*", "*engineering geomorphology*" and so on. If there is a difference in the content of the disciplines described under these names it probably lies in the training and experience of the practitioner. Engineering geology is taught in some countries as a postgraduate (Masters) degree course following on from a first degree or other qualification. If the first degree is in geology then the product after the Masters degree will be that of an engineering geologist; if the first degree is in engineering then the product may be considered as a geotechnical engineer.

Whatever their origins and training, engineering geologists contribute to the task of providing a level of understanding of ground conditions that ensures the engineering works are constructed to estimates of time and cost. In addition, such works should not fail as the result of any misunderstanding or lack of knowledge about the nature of the ground conditions. Engineering failures may cost lives and cause injuries, will certainly cost money, and will result in consequential delay. To prevent such failures and incidents occurring, the influence of the geology of the site on the design and construction of the engineering work must be determined, understood and clearly explained. The problem is how to achieve this level of understanding or, in other words, how to attain the aims of engineering geology.

1.3
Attaining the Aims

Behind every discipline there must be a basic philosophy or a way in which that discipline approaches its problems. The philosophy of engineering geology is based on three simple premises. These are:

1. *All engineering works are built in or on the ground.*
2. *The ground will always, in some manner, react to the construction of the engineering work.*
3. *The reaction of the ground (its "engineering behaviour") to the particular engineering work must be accommodated by that work.*

The first premise would seem to be fairly obvious but it would appear that, not uncommonly, the work of designing and executing a project is sub-divided between various types of engineers, architects and planners so that no single person may have a comprehensive overview of the complete project. Thus the vital concept that *the structure is but an extension of the ground* may be lost, or even never acquired, by a particular member of the team in the course of his contribution to the work. The premise that the ground will always react to the construction of the engineering work also seems self-evident. The problem is to assess the magnitude and nature of the reaction of the ground to both the construction and the operation of the project. This ground reaction, the engineering behaviour of the ground, could be small and insignificant, or massive and perhaps disastrous, depending on the nature of site geology and the engineering work. It must, however, be known in order to fulfil the third premise, namely that the engineering work be designed so that it can be constructed and will operate within the bounds of the site geological conditions without sustaining significant damage as the result of the reaction of the ground.

To determine the engineering behaviour of the ground the engineering properties (in the broadest sense) of the ground mass and the proposed design of the engineering work must be known. These two streams of data must be brought together and processed in order to determine, by calculation, the engineering behaviour of the ground. It is of vital importance that the acquisition and processing of data is done systematically to ensure that no significant factors are omitted from the analysis. The problem is devising a system to do this. Some years ago John Knill of Imperial College and David Price of THDelft began writing a book on engineering geology together. This died still-born after a few chapters, but one of the joint products was the concept that the sequence of operations to be followed to arrive at the engineering behaviour of the ground could be expressed by three verbal equations. These were:

material properties + mass fabric = mass properties

mass properties + environment = the engineering geological matrix[1]

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[1] The original term used was "*situation*" (Knill 1978). Matrix implies a database in which the relationship of the components is defined – a highly desirable but rarely achieved goal in engineering geology.

the engineering geological matrix + changes produced by the engineering work = the engineering behaviour of the ground

1.4
Materials and Mass Fabric

The terms used in these equations require some explanation. *Materials* may be rocks, soils and the fluids or gases contained within them. *Material properties* are the properties which are of significance in engineering, such as density, shear strength, deformability and so forth. *Mass fabric* describes the manner in which the materials are arranged within the mass (in beds, dykes, veins, sills, etc.) and includes the discontinuities (joints, faults, etc.) which ramify through the mass. It is not possible to calculate the reaction of the ground mass to engineering construction unless it is known how all the various materials are distributed within the volume of ground stressed by the construction.

In Fig. 1.1 the building at the top left sits on compressible clay of uniform thickness overlying effectively incompressible rock; deformation of the clay and settlement of the structure into the ground is uniform. Under the building in the centre the clay is not of uniform thickness. Settlement in this case is differential, being larger over the greatest thickness of clay. The building will tilt, and may crack, but may not suffer great damage. However, where the clay thickens towards both ends of the building with rock nearest to the ground surface under the centre, as in the top right drawing in Fig. 1.1, differential settlement may produce disastrous results effectively breaking the back of the building. This simple example shows the importance of understanding the subsurface distribution of materials.

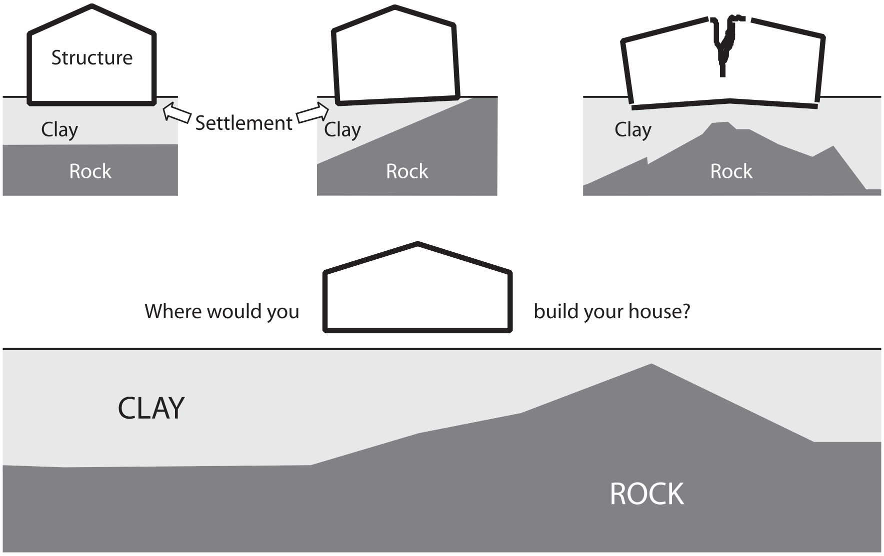
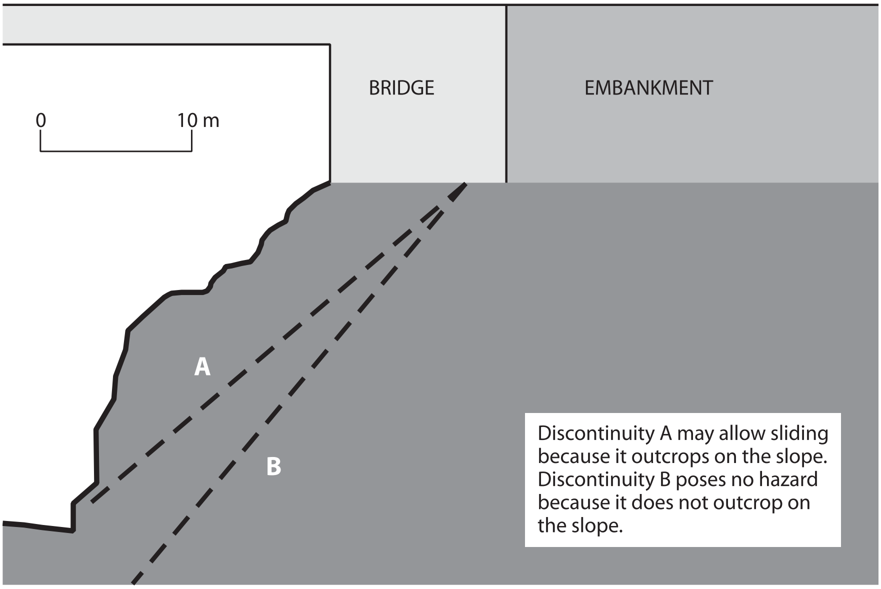


Fig. 1.1. The importance of the distribution of materials in the groundmass relative to the position of the structure

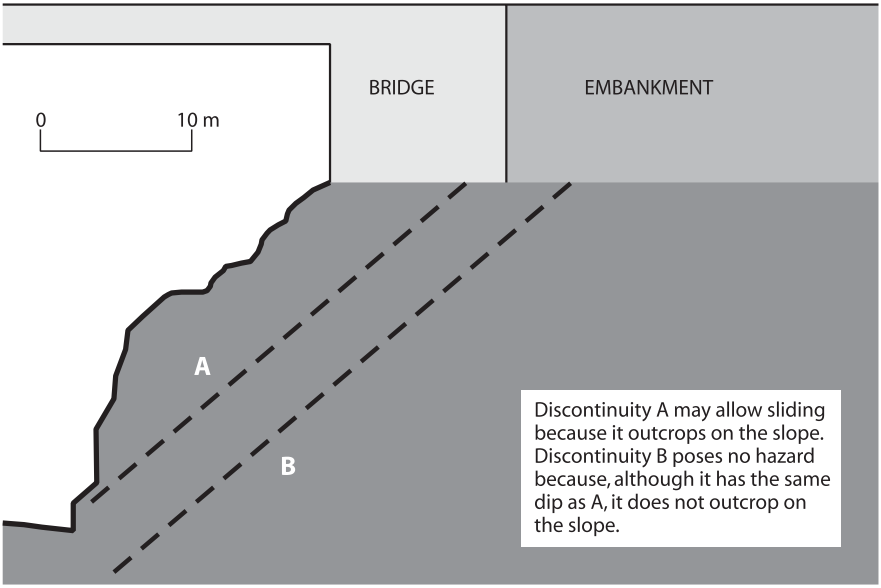
The distribution and orientation of discontinuities, such as bedding planes, faults and joints, is equally important. In the two cases in Fig. 1.2 the discontinuity A could

a The importance of discontinuity orientation



Discontinuity A may allow sliding because it outcrops on the slope. Discontinuity B poses no hazard because it does not outcrop on the slope.

b The importance of location



Discontinuity A may allow sliding because it outcrops on the slope. Discontinuity B poses no hazard because, although it has the same dip as A, it does not outcrop on the slope.

Fig. 1.2. The importance of location and orientation on the engineering significance of discontinuities

permit sliding of the foundation under the bridge because it daylights in (i.e. intersects) the slope face. Discontinuity B, with similar characteristics to discontinuity A, would not pose a hazard even though it has a similar orientation because it does not daylight.

1.5
Mass

It is necessary to decide what is meant by *mass*. The ground mass can be defined as that volume of ground which will be influenced by, or will influence, the engineering work. The ground influenced by the engineering work could be, for example, that volume of ground stressed by the extra load of a building, a bridge or a dam. In a tunnel the mass could consist of the volume of ground affected by the withdrawal of support caused by tunnel excavation and that volume of ground from which water has been lost by drainage into the tunnel excavation. The ground mass influenced by the engineering work is generally very much larger than the mass in direct contact with the engineering work. Thus, in a mining area, the engineering construction could be damaged by subsidence resulting from mining deep below the construction. The "mass" would thus extend down to the level of the mined ore body. Dams built in valleys may be endangered by landslides from valley sides – these may be of some antiquity and of natural origin, but new movement may be triggered by the construction process. In such circumstances the involved "mass" would extend into these landslides, which could be situated well outside the construction site.

The mass may also be that of an engineering work constructed from naturally occurring geological materials such as earth and rock fill dams, breakwaters, bunds and dykes. In such cases the material properties are those of the construction material while the mass fabric includes layers and discontinuities incorporated through engineering design and construction.

The reader may wonder why so much attention is paid to mass while, in so many text books, particularly those on soil mechanics, the emphasis is placed on material properties while mass properties appear to be if not totally neglected to be underemphasised. Emphasis is herein given to mass because engineering works are built on ground masses, and it is the reaction of the mass which must be calculated. In soil mechanics many of the traditional methods of calculation assume that the properties of samples of material (mostly measured in the laboratory) are those of uniform, isotropic, horizontal layers which compose the mass. Under many engineering sites soils do lie more-or-less horizontally and their properties may be relatively uniform over distances commensurate with the size of most engineering works. Thus the assumption can, in many cases, be correct. The problems come when the assumption is made without examining the geology, and without confirming that this degree of uniformity is, in fact, present.

The first verbal equation given in Sect. 1.3 above provides sufficient information to make a calculation of the behaviour of the mass with regard to the proposed engineering work. This may be reasonably correct but engineering behaviour is often influenced by externally imposed factors of a more general and fundamental nature which may be grouped together under the general title of the "environment". These factors could have sufficient weight to render all such calculations on the basis of the first formula invalid.

1.6
Environmental Factors

The environment includes such features as climate, stress in the ground, and natural hazards, and can include time. The principal climatic factors are rainfall (amount, time of occurrence, intensity etc.), temperature and wind. Rainfall is of particular importance in that it relates to the moisture content of materials and mass; it is well-known that moisture content is one of the factors which determine the properties of materials and mass. Particular combinations of moisture content and temperature produce such special environments as the permafrost condition and the dry hot (or cold) deserts. Materials and masses of identical lithological and structural nature may behave quite differently under the action of an engineering process depending on the climate in which they exist.

1.6.1
Climate

Every region of the Earth's surface is subjected to a particular climate. This climate might be considered to comprise the yearly average weather, including such factors as rainfall, wind, temperature, hours of sunshine and so forth. In most parts of the Earth none of these factors is constant throughout the year. Thus, in the case of rainfall this may be defined as annual rainfall, seasonal rainfall (the amount in spring, summer, autumn and winter), monthly rainfall or even rainfall intensity. The rain, when it does fall, will not necessarily fall uniformly. In some countries a rainfall of say, 200 mm in a month, might fall in small amounts over a number of hours every day; in other areas all 200 mm could fall in one afternoon. In Papua New Guinea the author experienced a rainfall intensity of about 250 mm in one day of which 50 mm fell in one hour. Similarly, temperature can be considered as the average for the year, season or month, and also as maximum and minimum temperatures for year, season, month or day. Some regions, particularly those near the equator may have remarkably uniform temperatures, with little difference between maximum and minimum throughout the entire annual cycle. Other areas, such as in desert or mountain regions, might have variations of say, 30 °C in the course of one day.

How these climatic variations come about is a long and complex story, outside the scope of this text, but essentially the main factors influencing the nature of the climate of a particular location are its latitude (influencing the amount of warmth received from the sun), its altitude (also influencing insolation as well as rainfall), and its proximity to the sea.

The reader may ask why climate could be considered to be of significance with regard to Engineering Geology and Civil Engineering. Several important engineering geological factors are related to climatic conditions. In almost all engineering geological problems the presence of water and the depth of the groundwater table play important roles in determining the behaviour of the ground mass in response to the engineering process. Many site investigations take place in a relatively short period of time, often in the "dry" season of the year. Depending upon the amount of rainfall, and the infiltration of that rainfall into the ground, it may be found that there are significant variations in level of the water table. Knowledge of the climate of an area can give some indication as to whether it is necessary to undertake long-term observations of groundwater table level or not.

The distribution of rainfall throughout the year will indicate when rainfall is likely to prove a problem in the execution of a civil engineering contract. This is not only an issue of workers not wishing to get wet but also a question of clays softening to the point at which their liquid limit is achieved (i.e. they become viscous fluids rather than soft solids), thus affecting trafficability. Alternatively, very heavy rainfall in areas where infiltration is low, and which have recently been denuded of vegetation, can cause soil erosion leading to extensive gullying. Dry periods with strong winds can cause much dust movement with detrimental effects on workers, machinery and sensitive equipment. Very low temperatures can freeze water lines and thicken lubricating oil. Very high temperatures can thin motor oil to the point where it fails to lubricate machinery adequately and all construction work must cease.

These brief examples demonstrate the need to recognise the significance of climatic factors when dealing with site evaluation problems and the practicalities of construction work. While the "normal" climatic variations can have influence on the success of an engineering process, "abnormal" climatic events such as hurricanes, typhoons, whirlwinds, etc. may be disastrous. They are not necessarily abnormal when seen in the context of long-term climate characteristics, for they can occur almost every year in certain large regions of the Earth. However, the exact areas that they will effect will not be known in advance so that specific locations may suffer hurricanes, for example, only very infrequently. Because they are, relative to the general climate, of infrequent occurrence, of extreme intensity and may have severe consequences, such climatic events may be treated under the heading of "*natural disasters*".

1.6.2
Stress

All materials exist under certain stress conditions. The magnitude and direction of stress may strongly influence the reaction of the ground to the engineering process, and particularly in the case of underground works. Stresses encountered in the ground may result from the following causes:

Gravity. The weight of the material above any level below the ground surface will cause material at that level to compress. Vertical compression of an unconfined specimen is accompanied by lateral expansion which, in a confined situation, results in the development of horizontal stress. The ratio of horizontal stress (σ_h) to vertical stress (σ_v) is the lateral stress ratio K where:

$$K = \frac{\sigma_\mathrm{h}}{\sigma_\mathrm{v}} \tag{1.1}$$

Tectonics. Tectonic stresses, which may be residual from past tectonic movements or active from present tectonic activity. These stresses appear to be mostly horizontal but are often strongly directional.

Erosion. Topographically related stresses can result from the redistribution of stresses by the erosion of valleys especially in steep mountainous areas. In Norway 'rock bursts' (explosive failures of overstressed rock) occur in tunnels driven beneath the steep slopes on the sides of fjords.

The distribution of stress around a tunnel or within a slope is much affected by the major discontinuities, such as faults, within the rock mass. The problem just quoted from Norway is particularly difficult due to the fact that tunnels tend to run parallel to fjord directions, so that bursting occurs along the entire length of the tunnel.

The stress which is imposed on a soil or rock mass, either naturally or through an engineering structure, is influenced by the presence of water which itself imposes a stress regime determined by the pressure of water. The imposed stress, from whatever source, gravity, engineering loads etc, less the water pressure acting as a water pressure in either pores or joints, is called the "*effective stress*".

1.6.3
Natural Hazards

Many parts of the world are afflicted by recurring natural hazards. The most well known of these in engineering terms are earthquakes, but hurricanes, typhoons, sandstorms, floods, volcanism, tidal waves and snow avalanches can also be included. No engineering work can be undertaken in areas where these problems occur without recognising the significance of such natural hazards. The five most prominent natural hazards are floods, windstorms, volcanic eruptions, earthquakes and mass movements (landslides).

Floods

Of all the natural hazards it is possible that floods are the most destructive. Although not as spectacular as volcanic eruptions or as dramatic as earthquakes, they are of regular occurrence and located in river valleys where people live and work. Commonly they occur in the alluvial plains which are also rich agricultural lands. Floods may not only kill people and destroy property but also kill the animals and destroy the crops which form the food supply and underpin the economy of an area. Thus floods may not only have an immediate effect but also be a blow to short- and long-term subsistence.

The majority of floods fall into two categories. These are the 'rainstorm' flood, associated perhaps with such events as hurricanes or typhoons, and the 'coastal' flood caused by a rise in sea level brought about by storms. It follows then that the majority of floods occur in areas underlain by Quaternary deposits, for it is the recent sediments which form the flood plains and river bottoms. However, the origin of the flood may lie far outside the area which is flooded.

The river and stream beds which traverse flood plains have a limited water carrying capacity and, if the amount of water arriving from the catchment area exceeds this capacity, then floods will inevitably ensue. The excessive amount of water being discharged into the river from the catchment area is the result of infiltration into the ground being unable to absorb the intensity of rainfall in the catchment. The basic cause of low infiltration lies in the geology of the catchment area; if the rocks forming the catchment basin are permeable, such as sandstones or limestones, then infiltration can be high. But if the rocks are impermeable, such as mudstones or crystalline rocks, infiltration is low and can more easily be exceeded by the intensity of rainfall.

This means that in certain areas of the world heavy rainfall on distant mountains can give rise to floods on arid lowlands. The annual flooding of the Nile delta has been considered as a beneficial result of this phenomenon because of the introduction of a new layer of fertile silt, but to the majority of areas this excess water is very seldom a benefit. What this does imply is that no proper study of a flood problem can be undertaken without knowledge of the geology and climate of the whole river basin area.

In low lying coastal areas, dykes and sea walls give protection against sea floods. In such polder areas the dykes serve to protect land which has been reclaimed from the sea by dyke construction and land drainage. Such sea defence works must stand against the forces of waves, winds and tides, and the unfortunate combination of all three in unusual conditions may breach defence works. One of the most dramatic of these events was the flooding which occurred in the Netherlands in January 1953 when 1 490 people were drowned; the damage was estimated at about U.S.$2.5 billion. Since this event the Delta Works have been constructed to prevent this happening ever again. However, in comparison with other major floods, such as those which have occurred in China when the Huang Ho or Yangtze rivers have flooded, this incident can be considered as “minor”.

A solution to these problems lies in the construction of some sort of defence works. In the case of river floods natural levees may be raised or dykes constructed, but by far the most effective technique is to control river flow by the construction of dams within the river basin. Such dams may also provide hydroelectric power (thereby supporting regional infrastructure) or may store water for irrigation in dry seasons. It is one of the ironies of nature that many areas which are damaged by floods in rainy seasons may also suffer from drought for the remainder of the year.

In urban areas the problems may be more difficult for there is less freedom to construct major works. In many cities studies are made to map flood plains at risk and, by flood routing studies, determine the effects of river control. The hazard of floods in urban areas may partly originate in land subsidence caused by natural long-term settlement, groundwater extraction (as is the case in Bangkok) or as the result of natural isostatic subsidence. In coastal zones in seismic areas flooding as a consequence of the generation of tsunamis (tidal waves) must also be considered.

Storms

The most well known types of major storms are hurricanes and typhoons which occur in regions of tropical and sub-tropical climate. Hurricanes are found mostly in the area around the Caribbean while typhoons occur in the China Sea. Modern meteorology presents explanations for these phenomena and the frequency and possible paths of these storms can be established. The path and onset of storms can be forecast, and appropriate warnings issued.

Civil engineering structures must be designed to resist wind pressures from such storms in which wind velocities may exceed 100 km h^{-1}. This will mean additional loadings upon foundations; if these are piled then some piles may be need to perform in tension. However, other effects of such storms may be somewhat more serious. In coastal areas there is sometimes a rise in sea level of some metres above the normal which may bring about extensive coastal flooding and erosion.

Such storms may also be associated with extremely heavy and intense rainfall. Apart from the flooding from overcharged rivers that will result, an increase in moisture content of sediments on and within slopes may bring about landsliding. High run-off may cause gullying of cut soil slopes.

Volcanic Eruptions

There are over 500 volcanoes which are classified as 'active' and it is estimated that, in the last 500 years, some 200 000 people have lost their lives as a direct consequence of volcanic eruptions. However, although this is a large number and while all precautions must be taken to prevent such loss of life, volcanic eruptions would appear to be of relatively minor importance in comparison with other natural disasters. Thus, for the sake of comparison, a single storm and the associated floods which occurred in Bangladesh are thought to have killed 500 000 people.

It is not proposed in this book to delve deeply into the various types of volcanic eruption for the hard fact is that there can be little done, other than by very limited civil engineering works, to mitigate these hazards. It should be pointed out that the only sure way to avoid the dangers of active volcanoes is to live somewhere else! Unfortunately, expanding populations creep closer to volcanic hazards (as is the case in Italy around Mt. Vesuvius) and, should explosive eruptions take place, future death tolls may be far greater than those which have occurred in the past.

Earthquakes

Many textbooks handle the problem of earthquakes and civil engineering exclusively from the viewpoint of the consequences to a structure when subjected to earthquake vibrations. In such an approach topics such as the point of origin of the earthquake, the frequency of earthquake events etc. are either not considered, or are given limited treatment. Similarly, some seismological texts, when considering the behaviour of the ground under the earth tremors, do not appear to consider the reaction of the ground at shallow depth. Proper handling of an earthquake problem requires the following components of knowledge:

1. An estimate of the likely strength, frequency and location of future earthquakes. This may be derived from a study of the geology of the region around the construction site and a survey of past earthquake events.
2. A study of site geology in order to assess the likely ground response to a possible future earthquake event. This would determine whether any possibility exists of phenomena such as liquefaction, land spreading, flow slides, etc. which are associated with weak, saturated Quaternary deposits.
3. An assessment of the likely response of the proposed structure to the anticipated tremors and any other ground response events associated with the earthquake.
4. An assessment of tsunami potential generated from earthquakes causing displacement of the sea floor.

Equal attention has to be given to each facet of knowledge to ensure that, at the end of the exercise, a suitably protected construction has been designed.

If the study being undertaken is concerned with the construction of new centres of industry or habitations attention must be given to the effects of earthquakes on the necessary infrastructure (roads, water, electricity, etc.) as well as on the development itself. This is required so that, in the event that a major earthquake takes place, sufficient infrastructure facilities remain to allow relief measures to be implemented.

Mass Movements

Mass movements are essentially landslides, but may also be held to include avalanches; they can occur in almost any material, rock or soil. With regard to mass movements in Quaternary sediments it is probably true to say that the very largest mass movements are commonly associated with earthquake-induced liquefaction. Otherwise most attention is given to slides in river terrace deposits, in superficial soils covering rock slopes, to slides in man-made excavations cut into Quaternary deposits for road, rail and other works, and to slides developed in man-made embankments. Recently the hazards associated with mass movements on the continental slope have been highlighted as these could send tsunami like waves radiating across the ocean surface to affect vastly greater areas of coastal development than the area of the original slope movement.

Manmade Hazards

It may also be considered that the activities of man are also part of the environment (perhaps as "*un-natural hazards*") within which a proposed engineering work will have to exist. These activities would be those not directly concerned with the proposed construction and could include such features as subsidence due to mining, oil, gas or water extraction, generation of seismic activity by pumping into deep wells or impounding reservoirs, and so forth. The effect of such activities must be taken into account when planning new works.

New works may also be affected by toxic land contamination resulting from past industrial activity. Ground-water and surface water may be polluted by leachates from contaminated land or poorly confined waste deposits. The storage and disposal of radioactive waste is a subject of major importance, much debate, and individual concern. No one wishes to live close to such a disposal site but it could be it might be better to live on top of a storage facility contained within safe geological conditions rather than some distance from one located in less suitable geological conditions.

The pressure of human activities on the environment of the Earth has reached a level such that man must now be considered to be one of the significant agencies determining the character of his own environment.

1.6.4
Dynamic Processes

It is also important to understand that the processes that modify landscape and geology are dynamic. Such water-associated landscape features as beaches, bars, sand spits, river courses, etc. can be dynamically stable representing a balance between forces operating at any given time. What may be a small change, caused by civil engineering construction, may be reflected at a distant location. Thus the building of dams on the Ebro river in Spain has reduced sediment deposition in the Ebro delta with significant consequences on coastal form, which will eventually influence harbours and agriculture. Other changes, such as the 'greenhouse effect', may be a cause of eventual sea level change, with subsequent potentially disastrous effects. It is perhaps rather arrogant to assume that mankind is the only source of such effects, far too little is known about 'normal' variations in the Earth's environment consequential on deeper seated changes. The human lifespan is too short to view such changes, and stability is often presumed, although knowledge of Quaternary geology shows that there were major climatic and sea level changes in the Pleistocene. It might be appropriate to consider that the present geological environment is but a transient phase in the continuing Pleistocene succession of ices ages.

1.6.5
Time

With regard to time it is well to remember that all materials, whether natural or man-made, are subject to weathering and decay in the progress of time. Consequently the possible change in geotechnical properties of material and mass with time must be considered when assessing engineering behaviour of the ground. The first thoughts of the engineer are generally to consider what may happen during and shortly after the construction of an engineering work. However, consideration must also be given to how the ground may react throughout the whole planned lifetime of that construction. Most engineering geologists have seen cut rock slopes that are stable for a few years after construction but become unstable once weathering has had the chance to reduce the strength of the material from which it was made and the discontinuities it contains. Time may thus be considered to be an environmental parameter.

The majority of engineering works are constructed with the intent that they should be able to operate without substantial maintenance or repair for a certain time. This engineering lifetime is usually not less than 50 years. The behaviour of construction materials (concrete, steel, brick and the like) over such a period of time in a particular environment is generally quite well known and assuming that there are no major construction faults the anticipated engineering lifetime is often an underestimate. However, the ground on which the engineering work is built, or within which the engineering work has been excavated, is also subject to decay by the process loosely described as weathering. Thus, a cut slope designed for a material of a given strength (this strength being measured before the slope is excavated) may well become unstable as the exposed material in the excavated slope becomes weathered. This is a particular problem in the argillaceous rocks.

In soils, whether of Quaternary age or older, it is now generally recognised that in the design of slopes in clay consideration has to be given to both 'short-term' and 'long-term' stability. In the latter case allowance is made, by modifying the strength parameters used in analysis, for the long-term effects of weathering and water pressure on the stability of the slope.

1.7
Analysis

All the factors leading up to the description of the engineering geological situation defined in the three equations set out in Sect. 1.3 may be established through the process of site investigation. Thereafter the engineering behaviour of the ground with respect to the proposed engineering work is determined by calculation and judgement. If the calculated ground behaviour is such that it cannot be accommodated by the construction process and would damage the completed work, make construction or maintenance uneconomic, or in any way impair the feasibility of the project, then the project must be redesigned or moved to a more suitable location. Redesign on an existing location effectively takes place by modifying the size and shape of the ground mass influenced by, or influencing, the construction. Thus if a building cannot be founded on shallow foundations because of the poor quality of the underlying soil (Fig. 1.1) the use of piled foundations could be considered as one method of redesign. This, in effect, means that the ground mass being loaded extends to greater depth, is confined and perhaps incorporates stronger strata than those present at shallow depth.

The three verbal equations describe an approach, in effect a process of thought, which should be followed to give reasonable certainty that the eventual calculation of the engineering behaviour of the ground will be accurate. The organisation of this book follows the pattern of these equations, which provide the link between successive chapters.

1.8
Essential Definitions

Both geology and engineering suffer from a confusion of terminology. Many learned societies and professional institutions have set up committees and working parties to resolve problems of terminology and the resulting reports may serve as guides through the morass of minor terminological confusion. More fundamental terminological problems are sometimes so deeply rooted that change is more or less impossible.

Thus many geologists refer to sands, silts or clays as 'soft rock', presumably working on the principle that, in geological time, they will become 'harder', eventually becoming 'hard rocks'. However, many tunnelling engineers would think of soft rock as shale, weak sandstone, mudstone, etc, rocks which can generally be excavated fairly easily. In civil engineering, naturally occurring geological materials are divided into 'soil' and 'rock'. The 'soil' is not only that of the agronomist but includes also un-cemented granular materials (such as boulders, cobbles, gravel, sand, silt) and cohesive materials (the clays). Granular soils have loose, easily separable, grains; cohesive soils are generally plastic and can be deformed and moulded without breaking.

A rock defined in engineering terms is an essentially rigid and often brittle material, far greater in strength than a soil, which cannot be moulded or bent without breaking. It should be noted that such criteria may also be fulfilled by hard clays which are desiccated, although such material would not be considered as rock but as soil in a special condition.

The distinction between rock and soil would seem to be clear enough but problems arise in practice. One major difficulty is that many excavation contracts are arranged so that there is one rate of payment for excavating 'rock' and another for excavating 'soil'. If all rock is fresh, and all soil of alluvial origin, for example, there need be no problem. However, rock is often weathered to the degree that it has the geotechnical properties of a soil but is still geologically recognisable as a rock. To the academic geologist a weathered rock is still rock; to the geotechnical engineer it is a soil. Weathered rock can be dug out as easily as soil but should payment be made for rock, in the geological sense, or soil, in the geotechnical sense? Similarly, if super-size boulders are found in glacial soils, are these rock because of their size or merely extra-large particles in soil?

Clarification of the confusion is not helped by certain attitudes which have developed over the years. Thus some soils engineers consider that certain of the weaker rocks (such as chalks and shale), which can be sampled and tested using soils boring and testing equipment, are effectively soils. While there is a certain justice to this argument, it could be dangerous in some aspects of geotechnology such as the slope stability of such materials, where slope collapse could take place by sliding on discontinuities not related to material strength which commonly determines soil slope stability.

A common, but perilous, assumption is that beneath the surface cover of soil all materials found below *rockhead*, the uppermost boundary between rock and soil, will be rock in the engineering sense. This is not so. In many geological formations, perhaps hundreds of millions of years old, layers may be found that have the geotechnical characteristics of soils. Thus in Europe un-cemented sands are found in the Triassic and Permian, and clays occur beneath coals in the Carboniferous Coal Measures. On the other hand 'engineering rocks' may be found in alluvial soils of quite recent origin. Thus cemented sandstones and limestones may be found within recently deposited sediments, mostly in tropical areas, and a hard, cemented layer, a "*duricrust*", may be developed in near-surface dry environments.

The contractual and engineering problems that may originate in the subtleties of distinction between rock and soil can mostly be solved by the application of common sense. However, it is much better for the geotechnologist to develop the habit of thinking of both soils and rocks as simply 'materials' whose behaviour will be determined by their geotechnical properties.

1.9
Training and Professional Development in Engineering Geology

The preceding pages have reviewed the facets of engineering and natural sciences that enter into the content of the discipline of Engineering Geology. This review provides a guide to the content of the training that is required to develop a fully rounded engineering geologist. Some of the basic subjects taught in any training in engineering geology are presented in Fig. 1.3.

Within the limited time available for any university training none of the subjects listed in Fig. 1.3 can be taught to any great depth so, for example, a properly qualified and able soil mechanics engineer must know more about soil mechanics than an engineering geologist. The engineering geologist might then be unreasonably accused by any professionals specialised and expert in one of the subjects listed in Fig. 1.3 as being 'a jack of all trades and master of none'. The recognition and definition of the problems that may come from the interaction of engineering and geology in fact re-

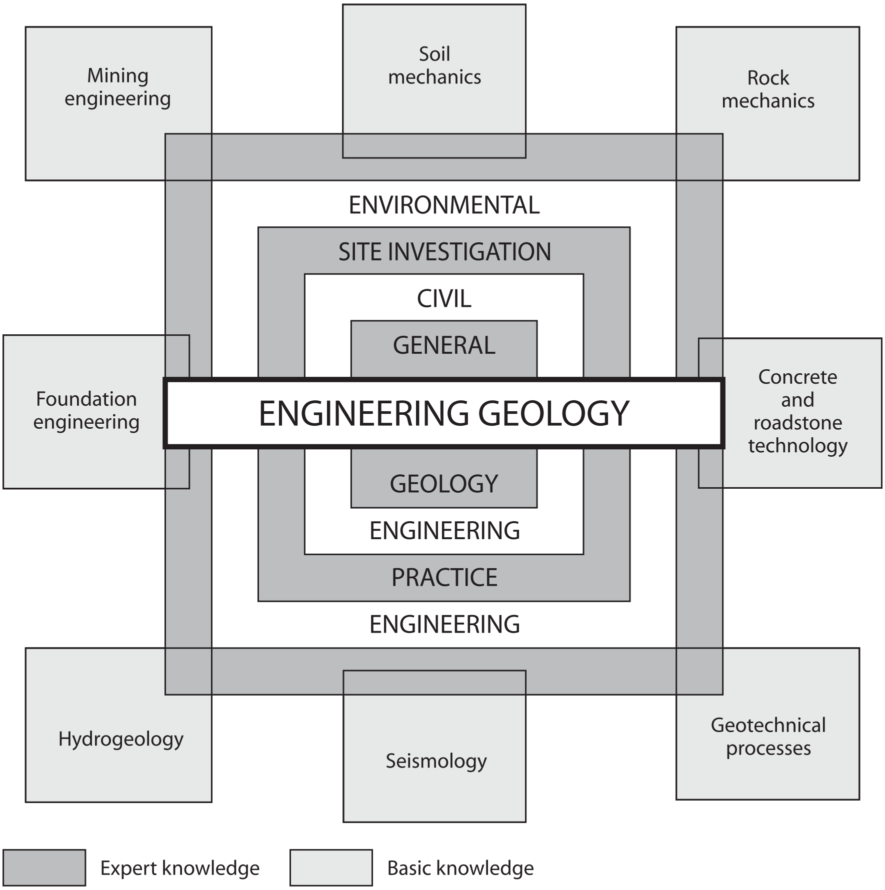


Fig. 1.3. Subjects included in engineering geological training courses

quires such broad knowledge. It has been often found, in the author's experience, that a problem recognised and defined is a problem solved. This solution may not necessarily be provided by the engineering geologist but by the expertise of some other professional; it is not important who solves a problem but that the problem is resolved.

Most engineering geologists, once employed, find themselves drifting into one or another field of specialisation depending upon the character of the company employing them. Thus an engineering geologist employed by a dredging company is unlikely to gain much experience in the construction of nuclear power station foundations and vice versa. Perhaps first employment is best gained on a major project such as the construction of a hydroelectric scheme, or motorway to view as many facets of civil engineering as possible and thereby gain a general feel for the processes and difficulties of engineering.

The engineering geologist must be prepared to learn continually. It is very possible that the young engineering geologist may find him or herself at a day's notice on an aeroplane, off to investigate a possible route for a pipeline through the desert, armed with literature on the geology of the country of destination, sand dune movement, pipeline construction and 'how to survive in a desert'. Such are the attractions of the profession.

Experience counts, and this includes experience gained from others. Thus, in any company employing more than one engineering geologist, while they may have separate duties, they are best retained as a group to learn from each other's experiences as well as their own.

1.10
Further Reading

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