1

INTRODUCTION TO GEOLOGICAL ENGINEERING

1. Definition and importance of geological engineering
2. The geological environment and its relation with engineering
3. Geological factors and geotechnical problems
4. Methods and applications in geological engineering
5. Information sources in engineering geology
6. How this book is structured

1.1 Definition and importance of geological engineering

Geological engineering is the application of geological and engineering sciences to design and construction in civil, mining and petroleum engineering, and to the environment. The aim of this discipline is to ensure that the geological factors which affect engineering activities are considered and adequately interpreted, as well as to mitigate the consequences of geological and environmental hazards.

Although there are differences between **geological engineering** and **engineering geology**, in this book both terms are considered to be equivalent (*Box 1.1*).

Engineering geology emerged with the development of large-scale civil engineering projects and urban growth, and by the mid 20th century had become established as a separate, specialized branch of the geological sciences. While engineering development made rapid progress in the last century, it was the catastrophic failure of several large engineering works that pointed out the need of geological investigations applied to engineering. Among these events were the failure of dams for geological reasons and their grave consequences, including the loss of hundreds of human lives, as in the dam failures in San Francisco (California, 1928), at Vajont (Italy, 1963) and at Malpasset (France, 1959), landsliding during the building of the Panama Canal in the early decades of the 20th century and the collapse of slopes on the Swedish railways in 1912.

The development of other related sciences, such as **soil mechanics** and **rock mechanics,** was the basis for modern **geotechnical engineering,** where engineering geology provides solutions to construction problems from a geological point of view (*Figure 1.1*). Geotechnical

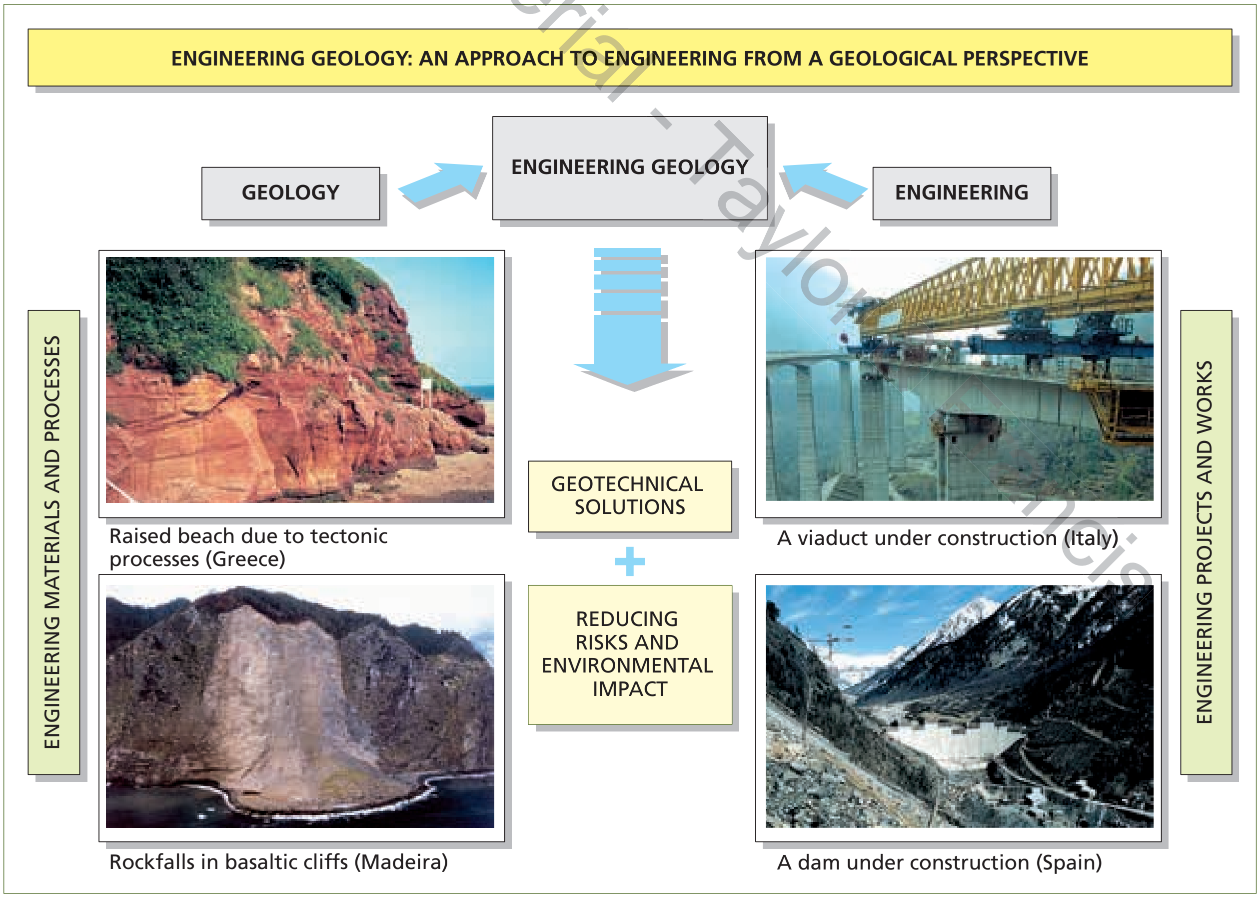
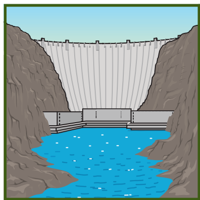


Figure 1.1 Engineering geology, geology and engineering.



Box 1.1

Geological engineering: education and professional practice

Education in geological engineering is based on a sound knowledge of geological and engineering sciences, the mechanical behaviour of soils and rocks, and their response to changes imposed by engineering works. Site and ground investigation methods to analyse and model geo-materials and geological processes form an essential part of this discipline.

Engineering geologists and geological engineers have a scientific and technical education, and a training applicable to the solution of the geological and environmental problems which affect engineering, and therefore they should be able to answer the following questions:

1. Where to site a civil engineering facility or industrial plant so that it will be geologically secure and economically feasible.
2. How to select the alignment for communication or transportation infrastructure to ensure favourable geological conditions.
3. How to assess that building foundations are geologically and geotechnically safe and economically feasible.
4. How to excavate a slope that is both stable and economically feasible.
5. How to excavate a tunnel or underground facility so that it is stable.
6. How to locate geological materials for dams, embankments and road construction.
7. The remedial measures and ground treatments needed to improve ground conditions and control instability, seepages, settlements, and collapse.
8. The geological and geotechnical conditions required to store urban, toxic and radioactive wastes.
9. How to prevent or mitigate geological hazards.
10. What geologic and geotechnical criteria must be taken into account in land use and urban planning, and to mitigate environmental impact.

Applied geology, engineering geology and geological engineering

— *Applied geology* or *geology for engineers* is the geology used in engineering practice. This is the branch of geology which deals with its application to the needs of civil engineering. It does not necessarily imply the use of engineering geological methods for the study and solution of geological problems in engineering.

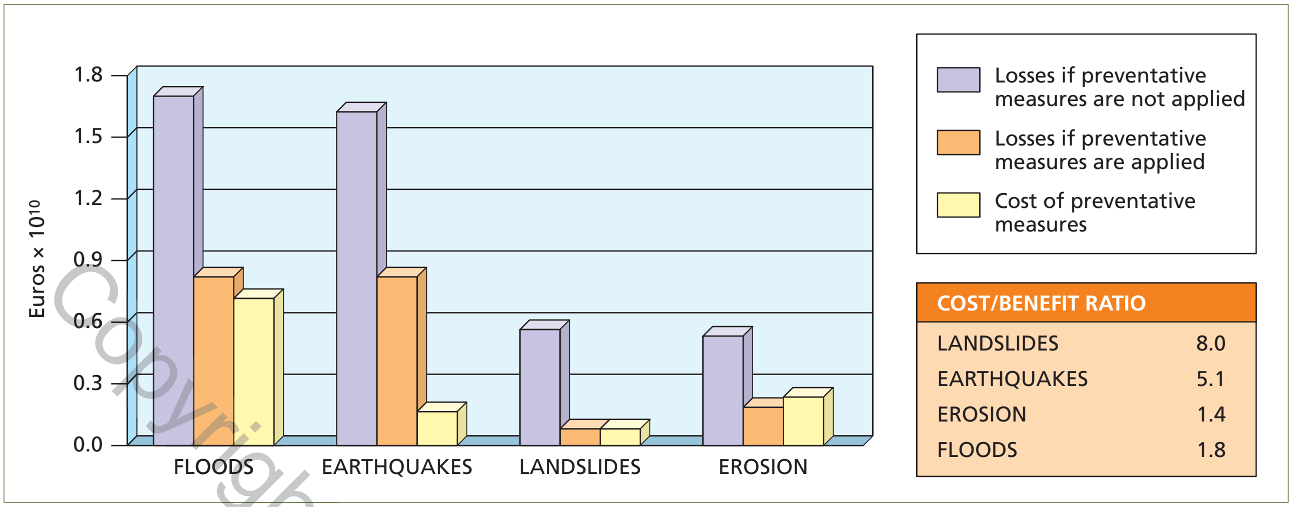
— *Engineering geology* and *geological engineering* are different from applied geology in that in addition to geological knowledge, education and training is required in the problems of the ground for engineering works, site investigation methods and the classification and behaviour of soils and rocks in relation to civil engineering; this field also includes practical knowledge of soil mechanics, rock mechanics and hydrogeology (Fookes, 1997).

— *Engineering geology* and *geological engineering* are equivalent disciplines, although in some countries there is a difference depending on whether the university where these courses are offered is oriented more towards a geological training (engineering geology) or towards engineering (geological engineering). An engineering geologist can be defined as a specialist geologist (scientist) in contrast with geological (or geotechnical) engineers who are trained as engineers with additional geological knowledge (Turner, 2008).

engineering integrates ground engineering techniques applied to foundations, reinforcement, support, ground improvement and excavation, and the disciplines of soil mechanics, rock mechanics and engineering geology mentioned above. Recently, the term **geo-engineering** has been coined to describe the field that deals with all aspects of engineering geology, rock mechanics, soil mechanics and geotechnical engineering (Bock *et al*., 2004).

At the beginning of the 21st century, one of the top priority areas for engineering geology is sustainable development. The inevitable confrontation between consequences of progress and geological processes, the uncontrollable sprawl of modern cities into geologically adverse areas and the damage caused by natural hazards can easily threaten the environment's fragile balance.

Nowadays, the need for geological studies of the ground before initiating large-scale works is fully recognized, and such studies are an obligatory part of engineering practice. This requirement also applies to works on a smaller scale, but often with a more direct impact people's daily lives,



30 year projection, considering the maximum risk hypothesis.
Cost/benefit ratio: losses from geological hazards less losses if preventative measures are applied, divided by the cost of the preventative measures.

Figure 1.2 Economic losses from geological hazards in Spain (IGME, 1987).

such as home and building construction, where geotechnical surveys are also needed.

The importance of engineering geology is particularly important in two main fields of activity. The first is engineering projects and related works where the ground constitutes the foundation, excavation, storage or construction material. Included in this field are the main types of infrastructure projects: buildings, hydraulic or maritime works, industrial plants, mining installations, power stations, etc. The role of engineering geology in these projects is fundamental to ensuring safety and economic viability. The second field is the prevention, mitigation and control of geological hazards and risks, and the management of environmental impact of public works and industrial, mining or urban activities.

Both of these fields are of great importance to a country's gross national product as they are directly related to the infrastructure, construction, mining and building sectors. However, the impacts of geo-environmental hazards on society and the environment can be incalculable if no preventive or control measures are taken (*Figure 1.2*).

1.2 The geological environment and its relation with engineering

The geological environment is in continuous evolution through processes affecting rock and soil materials and the natural environment as a whole. Anthropogenic environments, such as cities, infrastructures or public works frequently intrude on regions which are geologically unstable, modifying the geological processes or sometimes even triggering them. The search for harmonious solutions between the geological and the anthropogenic environments requires an understanding of the factors which set them apart, in order to avoid erroneous interpretations. The most important differentiating factors are:

— Geological and engineering scale.
— Geological and anthropological time.
— Geological and engineering language.

The study of geology begins with a spatial view of Earth's physical phenomena, on a range of **scales** from the cosmic to the microscopic. **Time** is measured in millions of years. In engineering, spatial and time scales are adjusted to the reach of human activities. Most geological processes, such as orogenesis or lithogenesis, take place over millions of years and shape such diverse phenomena as the properties and characteristics of materials and the occurrence of seismic or volcanic processes. Man as a species appeared in the Quaternary period, some 2 million years ago, quite recent compared with the 4,600 million years of the life of the planet Earth. However, human activity can dramatically affect specific natural processes such as erosion, sedimentation, and even climate. Whether natural processes can be speeded up or modified is one of the fundamental questions to consider in engineering geology. Many of the geotechnical properties of geological materials, such as permeability, alterability, strength or deformability, and processes such as dissolution, subsidence or expansivity, may be substantially modified by human action.

Box 1.2

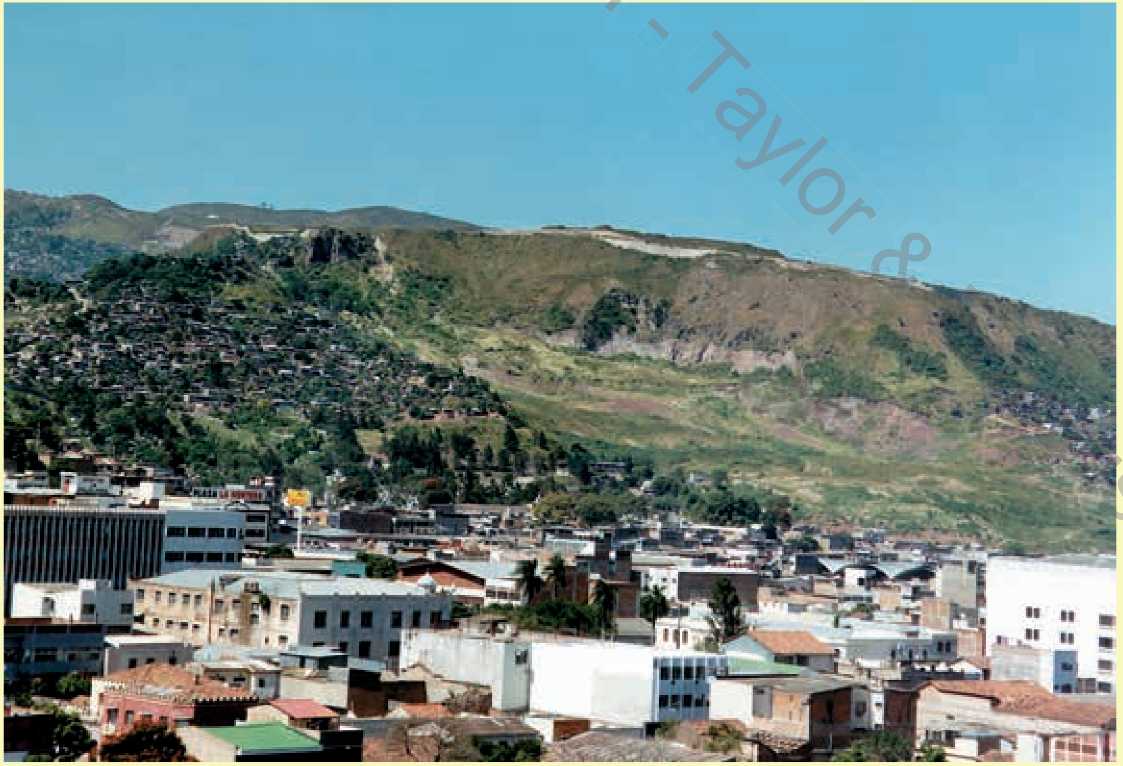
El Berrinche landslide, Tegucigalpa (Honduras)

This landslide occurred on October 30, 1998, in the aftermath of Hurricane Mitch. The hurricane devastated Central America, causing more than 25,000 deaths and incalculable economic losses. Its effects were aggravated by intense deforestation and urban encroachment on unstable hillsides. Landslides on some of the shanty-covered, overpopulated slopes surrounding the city of Tegucigalpa wreaked tremendous damage. Hundreds of households lost members of their family and experienced permanent economic setback in what was perhaps the costliest natural catastrophe in the history of a country, with major social losses and economical damages, in terms of homes destroyed and people affected by the landslides.

The El Berrinche landslide destroyed the neighbourhood of same name and partially affected others. It caused the blockage of the Choluteca River, which diverted its course into inhabited areas, flooding the lower parts of the city and causing many deaths. A river of mud swept along huge amounts of vegetation, carrying with it vehicles and parts of houses, and reaching a height of several meters above the street level, damaging the city infrastructure.

In Tegucigalpa, these areas were known to be within a risk zone, and some maps had even been prepared to that effect. In 1958, during a previous event, a large number of houses were destroyed on the slopes located in front of the El Berrinche hillside.

The intense rainfall that Hurricane Mitch released onto Tegucigalpa became a true test of the evaluation of the ground behaviour and its susceptibility to landslides. Clearly different behaviour was noticed between areas as a function of the type of geological material present, with lithology controlling the relative stability of slopes. In fact, the largest landslides took place in slopes formed in mudstone and siltstone with intercalations of greywake and clayey sandstone (Valle de Angeles Group), all highly degradable and weathered, while in the other lithologic group outcroppings in the zone, and formed by massive tuffs (Padre Miguel volcanoclastic Group) only isolated rock falls occurred.



A view of the landslide affecting part of the city of Tegucigalpa.

Comparing geological and human time is fundamental to appreciate the possible consequences of geological factors and hazards. Most projects are expected to have a service life of 50–100 years; it is, however, accepted practice to demand geological and environmental safety guarantees of periods of 500–1000 years in areas which can be affected by flooding, earthquakes, etc. There are cases where geological stability must be ensured for even longer periods, such as in the storage of radioactive waste, where periods of more than 10,000 years are envisioned.

On a human scale, many geological processes and most large-scale natural hazards have a very low probability of occurrence. Engineering planning and design must take into account the great variability in the frequency with which geological processes occur, from almost instantaneous processes, like earthquakes, to very slow ones, such as dissolution and erosion.

Mapping scales as a means of spatial representation are another differential aspect to be considered. In geology, the scales are adjusted to the dimensions of the phenomena or the geological units, formations and structures which need to be represented. Most geological maps use scales of between 1/1,000,000 and 1/50,000, whereas in engineering the most frequent scales are between 1/10,000 and 1/500. Regional geological maps allow factors to be identified which, although not within the specific project area, may be necessary in order to appreciate regional geological aspects or the presence of hazards whose scope may affect the zone under survey. Small-scale geological maps are the norm in geotechnical, lithological and thematic cartography, where discontinuities, hydrogeological data, materials, etc. are represented on the same scale as the project documents.

Another problem which often arises when integrating geological data into engineering projects is the lack of **communication** between these two fields. Independently of the geological or engineering terminology itself, there tend to be differences in approach and in the evaluation of results, depending on the point of view from which the problem is being addressed. Engineering deals with materials whose properties vary within narrow margins, do not change substantially over time, and can be tested in laboratory, such as concrete, steel, etc. In geology, however, the majority of materials are anisotropic and heterogeneous, they have extremely variable properties and undergo alterations and changes over time.

In an engineering project the data must be quantifiable and allow modelling. In geology, numerical quantification is not always easy, and simplification of a wide range of variation in properties to figures that fall within narrow margins can be difficult and, at times, it is impossible to achieve numerical precision that satisfies project requirements. While in engineering very precise knowledge of construction materials is usually available, geological and geotechnical information is generally based on a limited number of surveys. As a result, there is an uncertainty factor present in geotechnical studies which affects most projects. An understanding of these differences and the use of a common language appropriate to the aims of a project is fundamental to the practice of engineering geology. Engineering geology has methods at its disposal to quantify or express geological data in a way which allows them to be integrated into numerical modelling and into decision-making processes during planning and construction.

Statistics is an important tool for the analysis of very variable or even random data. The study of certain phenomena with insufficiently known periodicity can be approached from probability analysis with acceptable results, as is the case in specific geological hazards. The quantification of a set of engineering geological properties for construction applications is possible through systems of **geomechanical classifications** of rock masses. The **factor of safety** concept, normally used in engineering to express the degree of stability of the work underway, is also integrated into geological engineering practice. By including these and other procedures, with relation above all to knowledge of the geological medium and its interaction with construction activities, geological factors affecting safety and engineering issues can be defined, evaluated and integrated.

1.3 Geological factors and geotechnical problems

Given the diversity of the geological environment and the complexity of its processes, engineering solutions must be found for those geological factors that may create problems for project execution.

The most important problems are related to geological hazards which may affect the safety or viability of a project. Of a secondary but still crucial importance are all the geological factors which affect the technical or economic aspects of the project. These factors and their influence on geotechnical problems are shown in *Tables 1.1* to *1.4*.

Tables 1.1 and *1.2* show the possible influence of lithology and geological structure on the geotechnical behaviour of rock and soil materials. *Tables 1.3* and *1.4* show how water and materials are affected by different geological processes, causing geotechnical problems. To sum up, the following conclusions are reached:

— Geological factors are the cause of most geotechnical problems.
— Water is one of the factors with the highest incidence affecting the geotechnical behaviour of materials.

Table 1.1 **INFLUENCE OF LITHOLOGY ON THE GEOTECHNICAL BEHAVIOUR OF THE GROUND**

Lithology	Characteristic factors	Geotechnical problems
Hard rocks	— Hard and abrasive minerals	— Abrasivity (Photo A) — Excavation difficulties
Soft rocks	— Medium to low strength — Alterable minerals	— Slope failures (Photo B) — Deformability in tunnels — Change of properties over time
Hard soils	— Medium to high strength	— Problems in foundations with expansive clays and collapsible soils
Soft soils	— Low to very low strength	— Settlements of foundations (Photo C) — Slopes failures
Organic and biogenic soils	— High compressibility — Metastable structures	— Subsidence (Photo D) and collapse

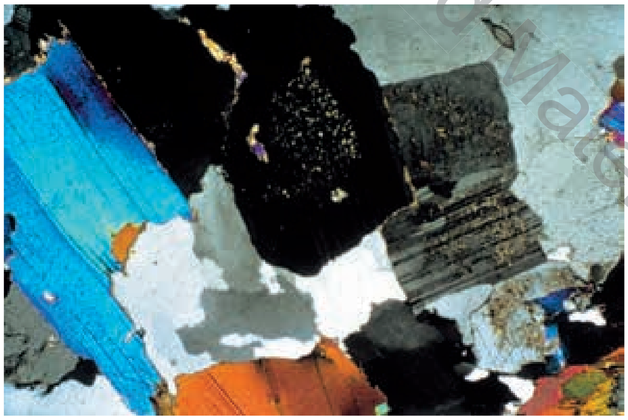


Photo A Granite with quartz, plagioclase and micas.

Photo B Slope failures in open cast mines, southern Spain.

Photo C Leaning tower of Pisa.

Photo D Settlement of the basilica N^{a} S^{a} de Guadalupe, Mexico City, built on soft lacustrine soils affected by subsidence.

Table 1.2 **GEOLOGICAL STRUCTURES AND GEOTECHNICAL PROBLEMS**

Geological structures	Characteristic factors	Geotechnical problems
Faults and fractures (Photo A)	— Very continuous surfaces; variable thickness	Failures, instabilities, seepages and alterations
Bedding planes (Photo B)	— Medium-highly persistent surfaces; little separation	Failures, instabilities and seepages
Discontinuities (Photo B)	— Small-medium persistence; closed or open	Failures, instabilities, seepages and weathering
Folds (Photo C)	— Surfaces with high continuity or persistence	Instabilities and seepages
Foliation, schistosity (Photo D)	— Surfaces with low continuity; closed features	Anisotropic behaviour dependent on the orientation

Photo A Normal fault.

Photo B Strata and joints.

Photo C Folds in quartzite.

Photo D Folded schist.

Table 1.3 **EFFECTS OF WATER RELATED GEOLOGICAL PROCESSES**

Water-related geological processes	Effects on materials	Geotechnical problems
Dissolution (Photo A)	— Loss of material in soluble rocks and soils — Karstification	— Cavities — Subsidence — Collapse
Erosion – piping (Photo B)	— Loss of material, sheetwash — Piping, internal erosion — Gully erosion	— Subsidence — Collapse — Settlement — Piping and undermining — Silting
Chemical reactions (Photo C)	— Changes in chemical composition	— Attacks on cement, aggregates, metals and rocks
Weathering (Photo D)	— Changes in physical and chemical properties	— Loss of strength — Increased deformability and permeability

Photo A Gypsum karst, southeast Spain.

Photo B Erosion and gullies in pyroclastic deposits, Guatemala.

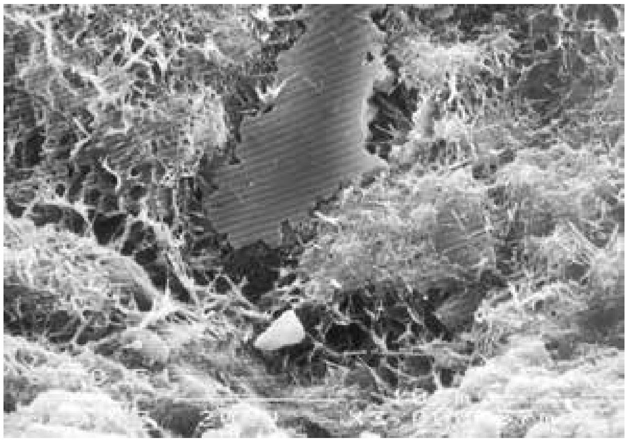


Photo C Concrete attacked by sulphates: formation of ettringite in the form of very fine fibres and carbonate crystals.

Photo D Weathering in Tertiary materials, central Spain.

Table 1.4 INFLUENCE OF GEOLOGICAL PROCESSES ON ENGINEERING AND THE ENVIRONMENT

Geological processes	Effects on the physical environment	Geo-environmental problems and actions
Seismicity (Photo A)	— Earthquakes, tsunamis — Ground movements and failures, landslides, liquefaction	— Damage to population and infrastructure — Anti-seismic design — Preventive measures — Emergency plans
Volcanism (Photo B)	— Volcanic eruptions — Changes in relief — Tsunamis and earthquakes — Collapse and large scale slope movements	— Damage to population and infrastructure — Monitoring systems — Preventive measures — Evacuation plans
Uplift and subsidence (Photo C)	— Long term morphological changes — Long term changes in coastal dynamics and sea levels	— Monitoring and control measures
Erosion-sedimentation (Photo D)	— Medium term morphological changes — Short term hydrological changes — Silting	— Increased risk of flooding and landslides — Protection measures for river beds and coasts

(*continued*)

Photo A Building destroyed in the Mexico earthquake, 1985.

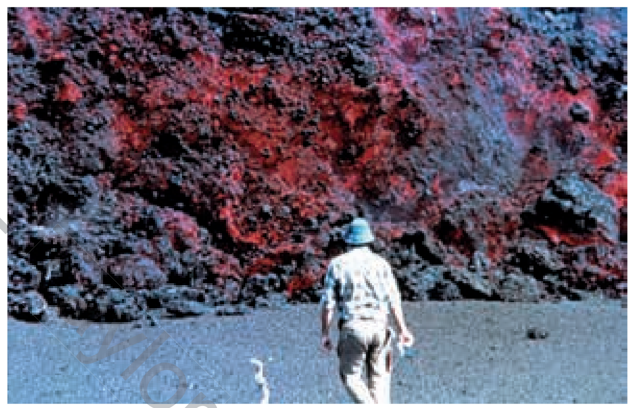


Photo B Lava flow in the Teneguía eruption, Canary Islands, 1971.

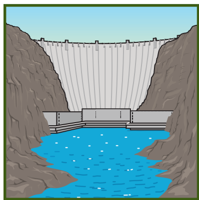
Photo C Palacio de Bellas Artes, Mexico City, affected by the subsidence of the Mexico valley soils.

Photo D Silting of riverbed to above road level, requiring excavation to an artificial channel, northwest Argentina.

Table 1.4 **INFLUENCE OF GEOLOGICAL PROCESSES ON ENGINEERING AND THE ENVIRONMENT (CONT.)**		
Geological processes	**Effects on the physical environment**	**Geo-environmental problems 4 and actions**
Slope movements (Photo E)	– Landslides, rock falls, subsidence – Short and medium term morphological changes, diversion of river beds	– Damage to populations and infrastructures – Impounding of river beds – Stabilization, control and preventive measures
Changes in water table (Photo F)	– Changes in aquifers – Changes in soil properties – Drying out and waterlogging – Subsidence and instability of slopes	– Problems in foundations – Effect on crops and irrigation – Drainage measures
Tectonic processes	– Natural stress – Seismicity – Instabilities	– Rock bursts in mines and deep tunnels – Long term deformations in underground works – Design measures in tunnels and mines
Geochemical processes	– High temperatures – Thermal anomalies – Presence of gases	– Hazards from gas explosion – Difficulties during tunnel construction

Photo E Damage to motorways caused by landslides, southern Spain.

Photo F Subsidence along active faults caused by water extraction from wells, Celaya, Mexico.



Box 1.3

The failure of Aznalcóllar Dam: An example of underestimation of the geological and geotechnical conditions with serious environmental consequences

The tailing dam of Aznalcóllar (southern Spain), owned by the mining company Boliden-Apirsa, was 28 m high when it failed on April 25, 1998. The safety conditions of the dam had been checked three years earlier and both the owners and those responsible for the design confirmed that it fulfilled all construction and safety requirements. This conclusion was reiterated just 5 days before the disaster.

The failure of the dam released a 4.5 Hm^3 of liquid mine waste into the river Agrio, and from there into the Guadiamar, tributary of the Guadalquivir. The surrounding land was flooded, contaminated with acid water containing heavy metals, affecting all the surrounding ecosystems in the area, including Doñana National Park.

The dam was founded on a Miocene over-consolidated high-plasticity clay formation, known as blue marl, which contains frequent shear surfaces with slickensides.

These blue marls have been extensively studied and the problems they cause were well known, especially in the stability of slopes of roads and railways of southern Spain. Their strength can be very low when they come into contact with water and when high pore pressures are generated along shear surfaces. According to the expert reports, the failure of the dam was due to a failure in the clay substratum, causing the foundation of the dam to slide forward (see Box 11.3, Chapter 11).

After the event, it became clear that the geological and geotechnical factors which caused the dam failure were not adequately taken into account, and that the monitoring systems were not operative, both fundamental aspects in geological engineering.

The Aznalcóllar dam after failure.

— Geological processes may modify the behaviour of materials, affecting the physical medium and causing geotechnical problems.

Thus it is evident that geotechnical problems can often require expensive solutions to be adopted. Depending on the scope of the problems, projects could be modified or sites relocated. For example, foundations might have to be laid more deeply because of the insufficient bearing capacity of the ground at depths nearer the surface. In contrast, favourable geotechnical conditions provide greater security for the work site and also mean work can go ahead uninterrupted, which has a significant influence on the cost and delivery schedule for the completed work.

In general terms, the **conditions a site must meet** to be geologically and geotechnically suitable are as follows:

— The absence of active geological processes which present unacceptable risks for the project.
— Adequate bearing capacity of the ground for the structural foundations.
— Materials with strength enough to be stable in surface or underground excavations.
— Watertight geological formations for storing water and solid or liquid wastes.
— Availability of materials for the construction of earth works.
— Easy extraction of materials for excavation.

The relationship between the geological factors and geotechnical problems, and the difference between favourable and unfavourable geotechnical conditions, make clear that the starting point for any geotechnical site investigation must be geological knowledge. **Interpreting geology from the perspective of engineering geology allows the behaviour of ground to be defined and predicted.** The potential for advances in geotechnical engineering that can be provided by geology is extensively described by de Freitas (2009).

1.4 Methods and applications in geological engineering

Geological engineering is based on geology and on the mechanical behaviour of soils and rocks. It requires a knowledge of site investigation techniques, mechanical, instrumental and geophysical, as well as a knowledge of methods for ground analysis and modelling. Methodology used in geological engineering studies follows the sequence described in *Table 1.5*, in general terms.

To develop the methodological sequence three types of models must be defined (*Figure 1.3*):

Table 1.5 METHODOLOGICAL PROCEDURES FOR GEOLOGICAL ENGINEERING AND ENGINEERING DESIGN

1. Identification of geological materials and geological processes. Analysis of geomorphological, structural, lithological and groundwater conditions.
2. Site and ground investigation.
3. Defining the spatial distribution of materials, structures and discontinuities.
4. Defining the hydrogeological, *in situ* stress and environmental conditions.
5. Characterization of geomechanical, hydrogeological and chemical properties.
6. Characterization of the geological materials to be used in the construction.
7. Selection of design parameters of the ground to be used in stability analyses for excavations, earth structures, foundations, etc.
8. Modelling of ground behaviour under construction and operational conditions.
9. Assessment of ground treatments to control seepages, settlements, instability, etc. and to improve ground conditions.
10. Analysis of geological hazards and environmental impact on engineering design.
11. Geological and geotechnical monitoring and control during construction and operational service.

— The geological model.
— The geomechanical model.
— The ground behaviour model.

The **geological model** represents the spatial distribution of materials, tectonic structures, geomorphologic and hydrogeological data, and other characteristics of the site and its area of influence. The **geomechanical** model gives a geotechnical and hydrogeological description of the materials and their geomechanical classification. The **ground behaviour model** describes the response of the ground during and after construction.

This methodology constitutes the basis for the following applications of geological engineering to civil and mining engineering and to the environment:

— Transport infrastructures.
— Hydraulic and maritime works.
— Urban, industrial and service buildings.
— Power stations.
— Mining and quarrying.
— Storage for urban, industrial and radioactive waste.
— Regional and urban planning.
— Civil defence and emergency planning.

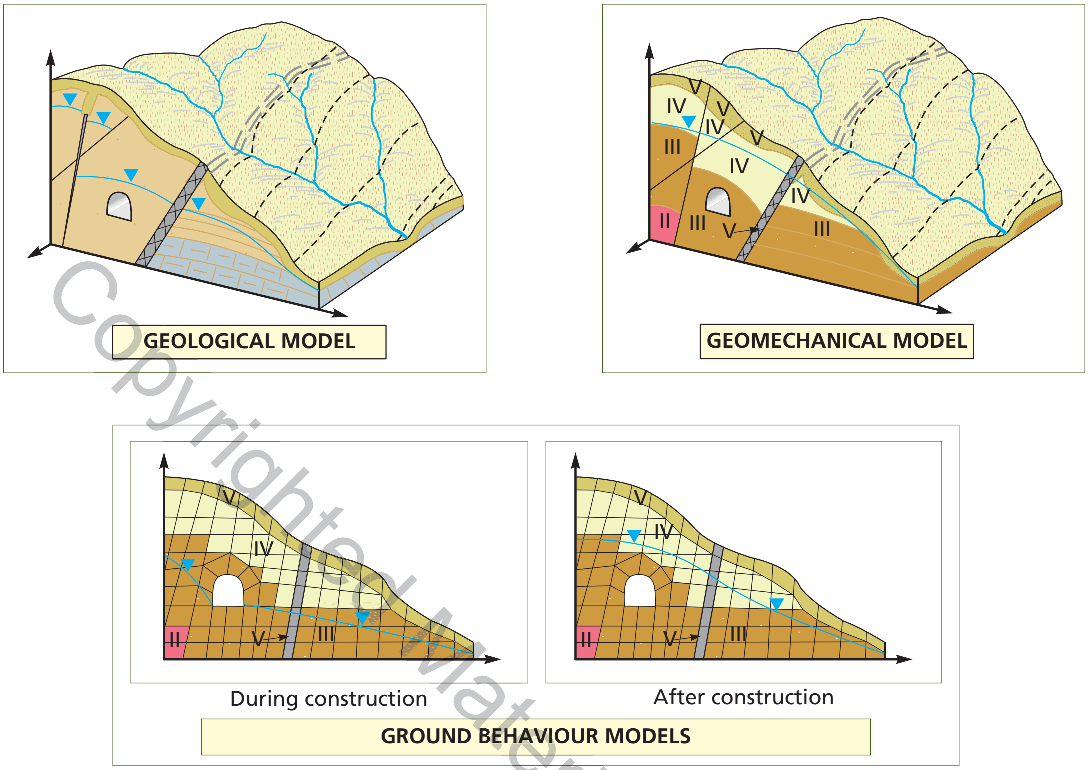


Figure 1.3 Examples of modelling in geological engineering.

1.5 Information sources in engineering geology

The main periodical publications in engineering geology/geological engineering are published by national and international associations, which regularly hold congresses and symposia, as well as publishing reviews or bulletins. The most important associations include:

— International Association for Engineering Geology and the Environment (IAEG)
— Association of Environmental and Engineering Geologists (AEG)
— International Society for Rock Mechanics (ISRM)
— International Society for Soil Mechanics and Geotechnical Engineering (ISSMGE)

Periodical publications include:

— Engineering Geology (Elsevier)
— Environmental & Engineering Geoscience Journal (GSA and AEG)
— Quarterly Journal of Engineering Geology and Hydrogeology (The Geological Society of London)
— Bulletin of Engineering Geology and the Environment, IAEG (Springer)
— Géotechnique (T. Telford)
— Journal of Geotechnical and Geoenvironmental Engineering, ASCE.
— International Journal of Rock Mechanics and Mining Sciences, ISRM (Elsevier)
— Canadian Geotechnical Journal (NRC Research Press)
— International Journal of Geomechanics, ASCE.
— Soils and Rocks, ABMS and SPG.
— Rock Mechanics and Rock Engineering (Springer)

1.6 How this book is structured

This book provides an introduction to geological engineering and engineering geology, their fundamentals and basic concepts, methodologies and main applications. The study of geological engineering requires a sound knowledge of geology. Emphasis has been made throughout the text to point out how the geology is closely related to engineering problems, as this is one of the principal objectives of engineering geology. Examples are given to illustrate these issues. However, this book does **not include basic descriptions of geological concepts.**

This book has 15 chapters, divided into four parts. **Part I** deals with the fundamentals of geological engineering.

Special attention is paid to basic concepts of soil and rock mechanics as well as hydrogeology (Chapters 1 to 4). **Part II** deals with site investigations methods with a description of the different procedures for identifying the properties and geomechanical characteristics of materials (Chapters 5 and 6; geotechnical mapping is included in Chapter 7). **Part III** describes the different applications of geological engineering, focussing on the most important fields of application to foundations, slopes, tunnels, dams and earth structures (Chapters 8 to 12). **Part IV** deals with geological hazards most relevant to geological engineering, focussing on the prevention, mitigation and control. Chapter 13 deals with landslides and other mass movements, Chapter 14 with earthquakes and Chapter 15 with prevention and mitigation of geological hazards.

Recommended reading

General and background to engineering geology

Blyth, F.G.H. and de Freitas, M.H. (1984). A geology for engineers. 7th ed. Arnold, London.

Culshaw, M.G. (2005). From concept towards reality: developing the attributed 3D geological model of the shallow subsurface. Ql. Jl. of Eng. Geol. and Hydrogeol., 38, 231–284.

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Education and training in engineering geology

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