Version 4 – with changes put forward by EFG Working Group on Engineering Geology

Professional Tasks, Responsibilities and Co-operation in Ground Engineering

Report for:

- **The President of the International Society for Soil Mechanics and Geotechnical Engineering (ISSMGE)**
- **The President of the International Society for Rock Mechanics (ISRM)**
- **The President of the International Association for Engineering Geology and the Environment (IAEG)**

In conjunction with

- **The President of the European Federation of Geologists (EFG)**

Prepared by

The Joint European Working Group of the IAEG, ISRM and ISSMGE

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1. Introduction

In July 2002, a Joint European Working Group on the professional competencies of engineering geologists and geotechnical engineers was formally established by the then Presidents of the ISRM (Panet) and ISSMGE (van Impe) and by the President designate of the IAEG (Rengers). IAEG, ISRM and ISSMGE are learned societies in the broader field of ground engineering.

The need for such a Working Group stemmed from the fact that in recent years and across several European countries there was a debate on the particular contribution and responsibilities of Engineering Geologists and Geotechnical Engineers in the solution of problems in ground engineering. This was emphasised by differing professional definitions and accreditation rules that existed for geologists and engineers within different European countries, and by the growing demand for geologically and technically sustainable, cost effective and safe geo-engineering solutions. Internally, the Joint Working Group was seen as a means of strengthening the co-operation across the three international societies and to identify common ground.

The members of the Joint Working Group were nominated by each of the three international societies involved (ref. Attachment 1). The European Federation of Geologists (EFG) is represented on the Working Group as observer at present.

The Working Group was established on the 20-21 March, 2003 in Brussels. The inaugural meeting agreed the Terms of Reference (ref. Attachment 2). It identified the need for two documents, namely:

1. A document for the three international learned societies on the professional competencies of engineering geologists and geotechnical engineers, including a specification of the interfaces and areas of co-operation between them, and

2. A document with relevant recommendations for an input to EU Directives.

This Report represents the outcome of the Working Group’s deliberations on the professional competencies of Engineering Geologists and Geotechnical Engineers within civil or structural engineering. For the purposes of this Report, Geotechnical

Engineers are Soil or Rock Mechanics practitioners. After approval by the three international societies involved, this Report will be the basis for the second document of the Working Group to be prepared for the appropriate EU Authorities. It is intended to have representatives of both EFG and FEANI involved as full members of the Working Group in the preparation of the second document.

2. Ground Engineering and Society

Ground Engineering is construction or development on or affecting the ground and subsurface and so involves development with, on or in geological materials.

Ground Engineering is essentially based on the professional input of Geologists and Engineers. It specifically includes the scientific disciplines of Engineering Geology, Soil Mechanics and Rock Mechanics as described in this Report.

Ground Engineering is paramount for the well being and advancement of society, in the efficient construction of structures for use and in the identification of limitations and controls on development by geo-hazards and geological processes.

Examples include:

- safety of residential and industrial structures (foundations of dwellings and industrial plants)

- cost effective design and construction of the engineering infrastructure (all types of transportation routes, pavements and tunnels; buried lines of power, gas, water, sewerage, electricity and communication cables),
- supply of water, energy and minerals (groundwater; hydro-power energy from reservoirs and underground caverns; oil and gas from wells; coal, metals and minerals from open-cast and underground mines),

- mitigation of geological hazards (geologically compatible urban and regional planning including flooding, earthquakes, landslides, volcanic activities, liquefying and/or collapsing ground),
- alleviation of human-induced hazards (ground pollution; land remediation; unstable ground in abandoned mining areas; sub-surface emplacement of chemical and radio-active waste in geological repositories), and,
- sustainable development (conservation of the environment including geological habitats, historic monuments, landforms and artefacts in local, urban and regional development)
- advice on interaction of planning, construction and natural processes (land use planning and impact assessment to local, regional and national government).

The importance and benefits of Ground Engineering structures are not fully appreciated by the general public as most solutions are not apparent to view . In particular, the benefit of such structures is generally not understood by all levels of government. Ground Engineering structures are often large. They represent major challenges in engineering and construction and, when successfully completed, are testament to substantial technological and intellectual achievements. Continued research and development of methods is required if Society is to reap the full rewards that are possible from Ground Engineering.

Ground Engineering constitutes a major and growing part of the construction industry. It is a major employer and accounts for a sizeable share of the gross national products. Overall, Ground Engineering adds very considerable value to Society and, importantly, within the context of sustainable development.

3. Peculiarities of engineering with the ground

Ground Engineering is characterised by a number of special features that makes it different from many other branches of engineering. This derives predominantly from the nature of the ground which comprises solid materials (soil and rock) and liquids (water and gases). Unlike man-made construction materials such as concrete, steel, glass and brick, soil and rock are:

- formed in a wide range of natural conditions,
- not fully known in their composition and structure prior to, and during construction unless appropriate geological studies are carried out,
- commonly heterogeneous in composition and anisotropic in structure,
- variable in their mechanical properties in both space and time,
- porous and water saturated giving complex solid-fluid interactions, and,
- often split by discontinua such as fissures, joints, bedding planes and faults.

The scientific discipline of Engineering Geology is concerned with the identification and specification of the ground conditions. The concept of effective stress, derived from solid-fluid interaction, provides the basis for Soil Mechanics as a free-standing scientific discipline. Similarly, the concept of discontinuous, fractured media provides the basis for Rock Mechanics as a free-standing scientific discipline.

All the above points are evidence that complexity and uncertainty are major constituents in Ground Engineering. Uncertainty in ground conditions contribute to the risk that projects will not meet budget or programme targets, or could even fail. Consequently, specific efforts have to be undertaken by Ground Engineers to ensure that adequate geological and geotechnical studies are carried out so that the ground conditions can be evaluated, uncertainty resolved and risk managed. These efforts have to be in conjunction with the whole project team including the client. In this way, a successful project can be produced.

4. The elements of Ground Engineering

Ground Engineering is a foremost intellectual, technical and economic challenge. It regularly impinges on major public concerns. Solving Ground Engineering problems requires input from many professionals including clients, urban and regional planners, funders, civil, structural, mining and petroleum engineers, lawyers, economists, surveyors and geoscientists.

The highest professional exposure is given to Geologists and Engineers with competency in Ground Engineering. Their position within Ground Engineering is shown schematically in Figure 1, the details of which are described in the following paragraphs. The respective concerns of Engineering Geologists and Ground Engineers are represented by three major aspects that, in line with Knill (2002), are grouped in subject specific interaction triangles.

The investigation or survey of the site and the underlying ground conditions must be designed to produce information and data to inform three models (see Figure 1)

- the Geological Model representing the spatial distribution of the natural materials, including their structures, the effect of natural processes, and the presence and nature of contained fluids at the site and within the area affected by the site,
- the Geomechanical Model representing the behaviour and character of the soil and rock materials comprising the site, the fluids within those materials, and
- the Ground Model representing the anticipated behaviour of the ground during and after construction.

4.1 The Triangle of Geomechanics: Soil Mechanics and Rock Mechanics

Ground Engineering is founded in the sciences of Geology and Geomechanics, and is based on a sound understanding of the mechanical behaviour of geological materials and a thorough understanding of the geological model of the site. The assemblage of solids and fluids in space (Geology) and their intrinsic nature within a fractured system, the mechanical behaviour of geological materials must incorporate the principles of Solid Mechanics, Fluid Mechanics and the Mechanics of Discontinua (Geomechanics).

Within the triangle, the relative positions of Soil Mechanics and Rock Mechanics can be located as shown in Figure 1. Soil Mechanics is the discipline that is characterised by the mechanical interaction between solids and fluids, whilst Rock Mechanics has a strong adherence towards the mechanics of discontinua with major influences from solid and fluid mechanics.

Soil Mechanics and Rock Mechanics, like solid mechanics, fluid mechanics and the mechanics of discontinua, are branches of Material Science. Due to its major field of application, Material Science in general and Soil and Rock Mechanics in particular, are commonly considered as engineering disciplines. Beyond Ground Engineering, Soil and Rock Mechanics are also indispensable in the mechanical understanding of geological processes such as sedimentation, faulting and jointing. Over-thrust faulting, for example, with its many implications in rock and petroleum engineering, can only be properly understood by the occurrence of high excess pore water pressures and their mechanical interpretation in terms of the effective stress principles developed in Soil Mechanics.

The understanding of the mechanical behaviour of geological materials is expressed in terms of idealised models, formulated within the disciplines of Soil and Rock Mechanics.

4.2 The Triangle of Engineering Geology

Ground Engineering requires the project specific delineation of the sub-surface ground conditions. The principal aspects involved constitute the "Triangle of Engineering Geology". The triangle is centred around the main Engineering Geological activities of site investigation and synthesis based on the genetic understanding of geological materials, structures and processes.

The objective is the setting up of a comprehensive Geological Model. This model requires the specification of two general features, namely, composition and boundary conditions. The composition includes solids (soil and/or rock) and fluids (groundwater and gases). Soils and rocks have to be specified by their geological age, material type, distribution, structure (e. g. bedding) and state conditions (e.g. normally or over-consolidated). The groundwater and gases have to be defined by their physical and chemical characteristics, pressure, prevalence and type (e.g. water, hydrocarbons, air, and methane).

The model boundary separates those parts of the ground that are affected by the engineering structure (near field) from those in which its influence is negligible (far field). The boundary has to be specified with regard to location (lateral extent, depth) and mechanical conditions (the boundary conditions). In a specific project, the boundary between the near and far fields, and thus the size of the model, is dependent on the geological conditions and the Ground Engineering Structure. The boundary conditions (stresses and/or displacements) are controlled by natural geological processes prevailing in the far field. Examples of these processes include active and residual tectonic stresses, landslides, subsidence collapse, earthquakes and volcanic activity.

The composition of the ground and the geological processes prevailing at the site are most clearly identified and specified if they are considered within a genetic context. This places Engineering Geology firmly within Geological Science.

Current geological conditions and landscape are the result of past and ongoing geological processes, which can pose a hazard to Ground Engineered Structures. The design and construction of sustainable structures requires understanding and accommodation of these processes.

4.3 The Triangle of Ground Engineering

The “Triangle of Ground Engineering” encompasses the main engineering activities which are the analysis and design of Ground Engineering Structures and the supervision and monitoring of their construction. The focus is to predict the ground behaviour that is the key to cost effective and safe structures.

Ground Engineering is based on a Ground Model that incorporates the Geological Model and the relevant engineering parameters and material properties (Figure 1).

For the analysis and design, the Ground Model is subjected to a series of modelling investigations, either alone or in combination as conceptual, physical or numerical models. Of particular importance is numerical modelling for which a wide range of specific computer codes has been developed. The ground is analysed under the influence of external and internal, natural and man-induced, static and dynamic forces. The analysis includes the safety of the ground against various types of failure and the deformational behaviour that might impair the performance of the structure. An optimal configuration of the design parameters is established and provided in project drawings and specifications for tendering, contracting and construction. During the construction the ground performance is monitored and the actual behaviour compared with the predictions. In the case of major discrepancies adjustments may be implemented usually in line with scenarios considered as part of an observational design procedure.

In the analysis and design, a particular concern is the ground–structure interaction. In Figure 1, this is shown as the interaction between Ground Engineers and Structural Engineers. In this context, the term “Geotechnical Engineering” is commonly used instead of the more general “Ground Engineering” term. Usually at this stage, a liaison between Geotechnical and Structural Engineers is required (Katzenbach and Turek, 2003). Similar transitions occur between Ground Engineering and other fields of engineering such as civil, mining and petroleum engineering.

4.4 Ground Engineering

Ground Engineering in its broad sense comprises the three triangles shown in Figure 1, and described in Sections 4.1 to 4.3 above, which are:

“Geomechanics (Soil Mechanics and Rock Mechanics)”, “Engineering Geology” and “Ground Engineering” (in its narrow sense).

When auxiliary terms are eliminated, the terms reduce to

“Mechanics” , “Geology” and “Engineering”

The latter three terms constitute the fundamental elements of Ground Engineering.

5. The integrated approach to solving Ground Engineering problems

Ground Engineering is essentially a serial process (reading of Figure 1 from left to right). Effective Ground Engineering requires feedback between and interaction across the various disciplines involved (interaction arrows within Figure 1). This, in particular, applies to the “central oval” of Figure 1 which is characterized by the links between all three triangles considered in Sections 4.1 to 4.3.

The development of the Ground Model is central to this process and includes the embedment of engineering parameters and material properties. This embedment requires the specification of constitutive laws appropriate for the soils and rocks in the model, the derivation of their mechanical properties in laboratory and/or field testing and interpretation in terms of characteristic values. The transfer from derived to characteristic values is based on the evaluation of the sampling and testing procedures, possible scale effects, regional context and experience of the materials.

An integrated approach is required. All aspects must be kept in balance and no pertinent aspect should be omitted.

6. Competencies of Engineering Geologists and Geotechnical Engineers: Tasks, responsibilities and co-operation

The competencies of Engineering Geologists and Geotechnical Engineers in solving Ground Engineering problems is illustrated within Figure 1. Within the diagram, there is a gradual transition from the scientific aspects (left) to the engineering design aspects (right). Soil and Rock Mechanics (top left) have their scientific base in the engineering discipline of Material Science, whereas engineering geology (bottom left) has its base in Geological Science. All three disciplines, Soil Mechanics, Rock Mechanics and Engineering Geology, are focussed on solving Ground Engineering problems, bringing together the different education and training backgrounds within the various disciplines to achieve the solution of complex interactive problems.

As shown in Section 5, the tasks identified in Figure 1 are highly interdependent. No strict boundaries are identifiable between any of the aspects shown. Consequently, no strict rules are justifiable in defining those tasks to be carried out by Engineering Geologists and by Geotechnical Engineers. The task should always be carried out by the person with the relevant competence.

Notwithstanding the above, there are definite preferences for Engineering Geologists and Geotechnical Engineers to carry out specific tasks and to accept professional responsibility. These are described in Attachments 3 and 4.

The requirement for formal linkage and feedback between the various professional practitioners is project specific. It is highest in projects of the Geotechnical Category 3 as defined in Eurocode 7. This encompasses the most demanding geotechnical projects. The dominance gradually decreases with the Geotechnical Categories 2 and

1. Accordingly, the degree of explicit co-operation between Engineering Geologists and Geotechnical Engineers can be linked to the Geotechnical Categories as specified in Table 1.

Geotechnical Category Eurocode 7 – *PROVIDE DEFINITIONS*	Co-operation
1 – simple ground problem	Optional
2	Desirable
3 – complex ground problem	Essential

Table 1 Level of co-operation between Engineering Geologists and Geotechnical Engineers

Engineering Geologists and Geotechnical Engineers are unified in their overall objective to create a geologically and technically sustainable, cost effective and safe engineering solution. It is the case that co-operation between engineering geologists and geotechnical engineers Is always desirable – the second column in Table 1 identifies the level of co-operation that is necessary.

Ground engineering with its fundamental elements Soil Mechanics, Rock Mechanics and Engineering Geology is not only based on scientific methods and engineering principles, but also on the interpretation and judgement of complex geological and technical settings in the laboratory and on the construction site. In order to qualify for recognition as a competent professional, several years of relevant experience is essential in addition to the formal training at tertiary level.

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Glossary of terms

Engineering Geology	Application of geology to obtain information and understanding of geological structures, materials and processes, as needed for analysis and design in engineering and environmental problems which may arise as the result of the interaction between geology and the engineering activities of man, as well as to the prediction and of the development of measures for prevention or remediation of geological hazards.
Environmental Geology	Application of geology to obtain information and understanding of geological structures, materials and processes, as needed for the solution of environmental problems.
Geological Engineering	Application of a combination of geology, engineering sciences and other technologies to design, involving rock, soil, groundwater and mineral resources.
Geological Model	Project specific idealisation of the ground incorporating the spatial distribution of materials, their composition and boundary conditions.
Geomechanics	Branch of Material Science that is concerned with the mechanical behaviour of geological materials. It includes the disciplines of soil mechanics and rock mechanics.
Geomechanical Model	The understanding of the distribution of the materials and fluids that constitute the ground that will be affected by the works, and their properties
Geotechnical Engineering	Application of the sciences of soil mechanics, rock mechanics, engineering geology and other related disciplines to the design and construction of civil engineering and environmental projects.
Geo-environmental Engineering	Application of a combination of geology and engineering science to the

	solution of environmental problems, or environmental aspects fo engineering problems.
Ground Engineering	Application of the sciences of soil mechanics, rock mechanics, engineering geology and other related disciplines to the works of man in the ground, which include civil, mining and petroleum engineering and environmental projects.
Ground Model	Project specific idealisation of the ground incorporating the principal elements of the Geological Model and the relevant engineering parameters and material properties of the ground, and the response of the ground to the engineering or environmental works.
Rock Mechanics	Discipline of geomechanics that is concerned with the mechanical behaviour of rock. The behaviour is predominately controlled by discontinuities and to a certain degree also by the solid and fluid constituents.
Soil Mechanics	Discipline of geomechanics that is concerned with the mechanical behaviour of soil. The behaviour is controlled by the interaction between the solid and fluid constituents of the soil.

Attachment 1

Joint European Working Group

1. Members

Name	Affiliation	Home Town / Country
Bock, Helmut (Chairman)	IAEG	Bad Bentheim / Germany
Broch, Einar	ISRM	Trondheim / Norway
Chartres, Rodney (Secretary)	IAEG	Purley, Surrey / United Kingdom
Gambin, Mike	ISSMGE	Paris / France
Maertens, Jan	IAEG	Beerse / Belgium
Maertens, Luc	ISSMGE	Brussels / Belgium
Pinto, Pedro Sêco é	ISSMGE	Lisbon / Portugal
Schubert, Wulf	ISRM	Graz / Austria
Stille, Håkan	ISRM	Stockholm / Sweden

2. Observer

Norbury, David EFG (Secretary General) Reading / United Kingdom

3. Corresponding Member

Persson, Lars IAEG Uppsala / Sweden

4. Presidents of the International Societies

van Impe, William	ISSMGE	Ghent / Belgium
Panet, Marc (before 2003) van der Merwe, Nielen (after 2003)	ISRM	Sevres / France Johannesburg / South Africa
Rengers, Niek	IAEG	Enschede / The Netherlands

Attachment 2

Terms of Reference

1. Prepare an inventory of current professional regulations in the field of ground engineering for the current EU member and future member countries.

2. Describe and illustrate categories of projects for which the professional input of geotechnical engineers and engineering geologists is required.

3. Specify the individual contributions of geotechnical engineers and engineering geologists in solving ground engineering problems. Detail the respective contributions with regard to competent persons and the methods employed, training, experience, tasks and responsibilities required.

4. Make recommendations for regulations / input to EU Directives in the field of ground engineering.

5. Prepare, for a follow-on Joint Working Group, recommendations for European model curricula in higher education, including post-graduate training and professional experience.

Brussels, 21st March, 2003

Attachment 3

Professional Competencies of Engineering Geologists

In ground engineering, the key competency of engineering geologists is the delineation of the site geology in the form of a comprehensive geological model. The work required is the setting up and carrying out of a targeted site investigation programme and the assembly, interpretation and synthesis of diverse and often highly-fragmented geological and technical data. The geological model is to be transferred into an appropriate and scientifically valid ground model. Such a model is a converted geological model with embedded engineering parameters and is required for the engineering analysis and design. The ground model is usually established in co-operation with geotechnical engineers.

Acquaintance with geological processes and awareness of the natural environment through fieldwork give engineering geologists key competencies in geological hazard prevention and on geo-environmental issues. An example is the assessment of the compatibility of engineering structures with the geological habitat. These competencies are of growing importance in urban and regional planning.

It is also critical for an engineering geologist to be able to communicate to engineers, and others, about the influence of the geology on the engineering. For this communication to be possible, the engineering geologist must have an understanding and appreciation of the way in which geological processes and geological properties of materials influence the engineering behaviour of the materials.

Uncertainty and risks are fundamental concerns for engineering geologists. Although geological observation will always remain partial because most soils and rocks can never be fully exposed, and are either buried or otherwise obscured, ground investigation can be carried out to resolve or remove uncertainties to an appropriate level, provided the investigation works are properly designed and funded. Uncertainty in ground conditions, whatever the origin, contributes to the risk that a project will not meet budget or programme targets, or could fail. Engineering geologists contribute through formal procedures to risk assessment and management that are also of considerable concern to the insurance industry and in litigation.

In general, engineering geologists are familiar with the pertinent geo-scientific methodologies. They understand the physical, mechanical and chemical behaviour of geological materials and are able to identify and interpret geological events and processes in terms of the site specific project requirements. They are knowledgeable of the basic engineering terminology and methods for communicating with geotechnical engineers and for understanding the engineering requirements for the design and construction of geo-engineered structures. Beyond this, engineering geologists are versatile with specialised methods, in particular:

- ***Synthesis of fragmentary data based on genetic understanding.*** The delineation of comprehensive geological models requires the synthesis of diverse, highly fragmentary data from geological and geomorphological evidence and from geotechnical and geophysical site investigations. Such synthesis is carried out best against the background of a genetic understanding of the site geology. Engineering geologists, like other geologists, are familiar with the genesis of geological materials, structures, processes and landforms.

- ***Training for site-related work***
  Engineering geologists are specially trained in fieldwork. From inspection of the landscape and natural and artificial exposures they are able to identify geological features and processes that are important in geo-engineering. Examples are extensional fractures at the crest and compression structures at the toe of slopes that are indicative of large-scale instabilities, or morphological depressions and dry valleys that may be indicators of karstic terrain.

- ***Specialist in field testing methods – drilling and field testing methods***
  Engineering Geologists are trained and experienced in the selection and use of appropriate equipment and methods to drill boreholes, recover samples and carry out filed and laboratory testing required to determine material parameters. Their work will be supported by appropriate conventional and specialist equipment and procedures. Examples are the field vane test (shear strength), field pressuremeter test (soil stiffness), water injection test (ground permeability), laboratory oedometer test (consolidation characteristics) and compression tests (stress - strain characteristics of soils and rocks).

- ***Versatility in handling of cartographic documents, maps and geo information systems***
  Engineering geologists, like other geologists, are versatile in presenting complex information in space and time in cartographic documents. They have a leading edge in the handling and interpretation of 3-D and 4-D geotechnical data through information technology and a wide range of state-of-the-art ground investigation techniques (e.g. instrumented drilling, 3-D seismic data, satellite images). Engineering geological maps, data banks and geo information systems (GIS) are important elements of a highly developed infrastructure.

- ***Observation and analysis of geological data as keys in contractual disputes***
  Contractual disputes, in particular on unforeseen ground conditions, are increasingly common in today's ground engineering. The costs of arbitration and litigation, and the consequential financial risks, are considerable. This situation places increased demands for proper recording and the documenting of information and for its careful interpretation. Engineering geologists are trained to observe, identify, describe and classify geological and technical phenomena in the field and on the construction site and to then apply analysis and synthesis to the data which have been collected.

- ***Familiarity with fractured and ageing materials***
  Rocks and over-consolidated soils constitute materials which are intrinsically fractured. Such fractures are indicators of past and current geological processes, e.g. jointing, faulting and ageing (weathering). They have significant effects on the mechanical behaviour of soils and rocks. Engineering geologists have developed methods in the evaluation, classification, description and data presentation of fracture planes (e. g. hemisphere projection technique). Furthermore, they have

developed tools for the mechanical analysis and design of fractured systems (e.g. "key block" and rock fall analyses).

Preconditions for developing the competencies of engineering geologists are a study at tertiary level and several years' of practical on-site professional experience. Engineering geologists are best trained through a first degree in geology or a specialist degree in the subject followed by a post- graduate vocational course that provides the foundation to the geo-environment, hazards, hydrogeology, soil and rock mechanics, foundation engineering and underground construction.

Attachment 4

Professional Competencies of Geotechnical Engineers

Key competencies of geotechnical engineers are a sound knowledge of the mechanical behaviour of soils and rocks, the design of geotechnical structures and the supervision of their construction. In a design, the two potentially conflicting requirements of safety and cost effectiveness are to be brought together in an optimal manner. Both the stability (e.g. ground failure) and the deformation (e. g. settlement differences) have to be considered to guarantee a proper performance of the structure during its construction and prescribed lifetime. Interactions between the ground and any attached surface structures are to be assessed and analysed, usually in liaison with structural engineers. Extensive use is to be made of theoretical-mathematical modelling and of testing and quality controls both in the laboratory and in the field.

There is a wide spectrum of further professional tasks that are typically carried out by geotechnical engineers. This includes the preparation of geotechnical project documents in the planning, design, tendering, construction, monitoring and maintenance stages. It furthermore includes, in co-operation with mechanical engineers, the development and application of highly-specialised ground construction equipment. With engineering geologists they share the concerns for geo-environmental issues and the specific problems associated with uncertainty and risks.

It is also critical for a geotechnical engineer to be able to communicate with engineering geologists, and others, about the interaction of the engineering and the geology. For this communication to be possible, the geotechnical engineer must have a sound understanding and appreciation of geological principles and how they interact to define aspects of the engineering behaviour of the materials.

Geotechnical engineers are familiar with the pertinent methods of civil and structural engineering. They are knowledgeable of the basic geo-scientific terminology, methods and processes for communicating with engineering geologists and for judging the consequences of geological factors and processes for geo-engineering structures. Beyond this, geotechnical engineers are versatile with specialised geo-engineering methods and procedures, in particular:

- ***Specialised testing methods***
  Supported by appropriate equipment, a set of specialist laboratory and field testing methods has been developed to cope with the natural characteristics of soils and rocks. Examples are the oedometer test (consolidation characteristics of undisturbed saturated cohesive soil), the post-failure compression test (fracture development of brittle rock beyond failure) and the pressiometer test in boreholes (deformation characteristics of the in-situ soil or rock).

- ***Complex constitutive laws***
  Soils and rocks are multi-phase materials. They incorporate constituents in three phases: Solids (minerals and rock fragments), fluids (porewater trapped in

interstices, freely moving groundwater) and gases (air trapped in unsaturated soil). The solids often occur in the form of particles (sand, gravel) or as a body that is fragmented by joints and faults (rock mass). Inherent geological structures such as bedding and schistosity cause scale and orientation dependencies of the material characteristics. All of these features contribute to constitutive laws for soils and rocks, which are more complex and variable than those for other common construction materials such as steel, concrete and glass.

- ***Numerical modelling of complex geotechnical structures*** The mathematical (commonly numerical) modelling of geotechnical structures requires methods that are specially adjusted to accommodate complex constitutive laws and to cope with the large structural diversity of geology. Non-linear, anisotropic and time-dependent material behaviour as well as plastification of soil or rock materials and of discontinuities have all become amenable to modelling in geotechnical engineering.

- ***Size of the ground model and boundary conditions*** Each geotechnical model requires the specification of a boundary between those parts of the ground that are affected by the engineering structure ("near field") from those which remain unaffected ("far field" with the natural geological conditions prevailing). The boundary has to be specified with regard to its location (lateral extent and depth) and mechanical conditions (boundary stresses and/or displacements; "boundary conditions" as such). In a given project, the size of the ground model and the condition of the boundaries are highly dependent on the geology, thus requiring a liaison between geotechnical engineers and engineering geologists.

- ***Design procedures and construction methods adjusted for uncertainty*** Irrespective of all of the sophisticated testing and modelling methods there remains a degree of uncertainty in the results of the geotechnical deliberations which commonly is significantly higher than in other branches of civil and structural engineering. Geotechnical engineers cope with these uncertainties by specially adjusted design, construction and contractual procedures. An example is the "Observational Design" method. It is characterised by a systematic set of pre-conceived geotechnical design alternatives which may be implemented in response to observation and performance monitoring data which become available in course of the construction.

Preconditions for developing the competencies of geotechnical engineers are a study in engineering at tertiary level with a significant component in civil and structural engineering and several years of practical on-site professional experience.

Figure 1. The position of soil mechanics, rock mechanics and engineering geology and the associated International Societies within ground engineering (modified and extended after Knill, 2002)