# A Report Proposing the Adaptation of the ASCE Body of Knowlege Competency-based Approach to the Assessment of Education and Training Needs in Geo-Engineering.

**Progress Report**
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**for the**

**Joint Technical Committee JTC-3: Education and Training**

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# A Report Proposing the Adaptation of the ASCE Body of Knowlege Competency-based Approach to the Assessment of Education and Training Needs in Geo-Engineering.

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## 1.0 INTRODUCTION

### 1.1 Foreword

The last 2 to 3 decades have shown a very strong process of globalisation in civil engineering construction. Large projects are carried out now by consortia composed of companies from different countries. This has resulted in a growing need for international cooperation and mutual understanding of design and construction codes and practices; it has also caused a strong mobility of Geo-Engineering experts. While these trends exist on a world-wide basis, hence are often referred to as "globalisation", they have been especially strongly developed within the European Union.

These trends have also brought forward the need to understand the qualifications and quality of Geo-Engineers from different educational and practical national backgrounds. Furthermore, this process has made apparent that the professional expertise of civil engineers and geologists in the different countries are often overlapping. This has led to competition, rather than cooperation, as specialists from both backgrounds seek opportunities to perform certain tasks and duties in site-investigation, design, and construction of Geo-Engineering projects, as well as the identification, evaluation, and mitigation of geo-hazards.

### 1.2 Initiatives of IAEG, ISRM, and ISSMGE

In response to these developments, the three principal international professional societies – the International Association of Engineering Geologists (IAEG), the International Society for Rock Mechanics (ISRM), and the International Society for Soil Mechanics and Geotechnical Engineering (ISSMGE) – undertook studies of the educational aspects of their professional responsibilities.

For example, in the early 1990s, the ISRM Commission on Education compiled a "Geotechnical Curriculum Guide" that was a set of course outlines whose purpose was to assist in the planning and updating of curricula in the earth sciences, geotechnical engineering, and mining. Standardization was not the intent, nor did the ISRM Commission on Education suggest that the Guide could serve as anything more than an indication of the course content needed for accreditation. The main objective was to help teachers identify overlooked topics, and to adjust the selection of topics to achieve a more comprehensive and better-balanced curriculum. Similar efforts were initially conducted by each society, but it became apparent that collaboration among the societies would produce much superior results.

#### *1.2.1 The Joint European Working Group*

In July 2002, a Joint European Working Group on the professional competencies of engineering geologists and geotechnical engineers was formally established by the Presidents of ISRM, ISSMGE, and IAEG. The Joint European Working Group was seen as a means of strengthening the co-operation across the three international societies and identifying common ground. Under the chairmanship of Dr. Helmut Bock, the Joint European Working Group addressed five tasks, of which the first three are pertinent to the current report. The Joint European Working Group issued an initial report in 2004 (Bock, et al., 2004) and a revised version of the report in 2008 (JEWG, 2008). The tasks undertaken by the Joint European Working Group were:

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.

At the IAEG Conference held in Liege, Belgium, in 2004, Joint European Working Group Chairman Helmut Bock presented an excellent discussion of the Joint European Working Group Report, which was also published in the conference proceedings (Bock, et al., 2004). The Joint European Working Group report recommends that further steps be undertaken to develop guidelines for the education of the different disciplines (JEWG, 2008). The revised report also suggested that "competencies" be used for the definition of the three fields of expertise: soil mechanics, rock mechanics, and engineering geology. These are reproduced in Appendix A.

### *1.2.2 Establishment of the Joint Technical Commission 3 (JTC-3)*

The *Joint Technical Committee on Education and Training (JTC-3)* was established in 2006 under the umbrella of the Federation of International Geo-engineering Societies (FedIGS). The JTC-3 Terms of Reference define 9 topics and activities; among them is a specific request to develop and maintain a *"State-of-the Art Report on Education and Training in Engineering Geology, Rock Mechanics, Soil Mechanics and Geotechnical Engineering*".

The JTC-3 held an inaugural meeting in September 2006, at Nottingham, UK, during the 10th IAEG Congress. At that meeting the JTC-3 agreed to take advantage of a major international conference on geotechnical engineering and training scheduled to be held in Constantza, Romania, in June 2008, and was already in advanced planning stages. The Constantza conference proceedings (Manoliu, et al., 2008) contain several papers by JTC-3 members among the 82 papers presented.

At Constantza, Rengers & Bock (2008) recommended the use of the "competencies" approach as defined by the Joint European Working Group as the basis of developing Geo-Engineering curricula for the three different disciplines in Geo-Engineering. This recommendation was further discussed at a subsequent JTC-3 meeting in Madrid in September 2008 that was attended by mostly IAEG members.

This report has been developed to provide all JTC-3 members with a document that explains the merits of using a competency-based assessment of the educational and training needs for all specialisations within the Geo-Engineering field.

## 1.3 Organisation of this Report

This report is organised with five major sections, including this Introduction section.

Section 2 lists the "Efforts Undertaken So Far", including tasks related to literature review.

Section 3 summarizes the "Body of Knowledge (BOK)" approach adopted for evaluating the entire civil engineering field by the American Society of Civil Engineers (ASCE). This approach represents a major effort that has extended over a decade by the ASCE Committee on Academic Prerequisites for Professional Practice. It appears that the approach is robust, meets international norms, and can be readily adapted to an assessment of Geo-Engineering.

Section 4 provides additional details of existing evaluations of "competencies" required by the major specialisations comprising Geo-Engineering. It also provides a very preliminary and conceptual comparison of the different "Competency Profiles" that distinguish these specialisations. It concludes with an example of how the JTC-3 members can, in the future, undertake the task of assessing the existing ASCE assessment matrix (in ASCE terms – the "Rubic") and creating an assessment matrix related to the competencies needed by Geo-Engineers.

Section 5 proposes a schedule of "Next Steps and Tasks for JTC-3" that will allow for the ultimate presentation of a completed report to FedIGS in 2012.

This report also contains a set of important references that are cited in the text. It also contains an Appendix that reproduces earlier competency definitions developed by Rengers & Bock (2008) and contained in the revised Joint European Working Group report (JEWG, 2008).

## 2. EFFORTS UNDERTAKEN SO FAR

During the period 2008-2009, a fairly comprehensive series of tasks have been completed. They include the following:

1. An overview of a fairly extensive literature review,
2. An assessment of the competency-oriented approach proposed by Rengers & Bock (2008) and also used by others (Tepel, 2009),
3. An evaluation of the competency-based Body of Knowledge approach adopted by the American Society of Civil Engineers (ASCE) to assess the entire field of civil enginering.,
4. A description of how the JTC-3 might take advantage of the ASCE approach,
5. A demonstration of how competency-based assessments can aid in comparing the major specialisations (sub-disciplines) within Geo-Engineering, and
6. A proposed set of tasks for JTC-3, and a timetable leading to the release of a final JTC-3 report in 2012..

In regard to Task 1, a multi-page bibliogaphy identifying over 100 pertinent publications was provided in May, 2009. The remaining tasks are reported on the the following sections of this report.

# 3. THE ASCE BODY OF KNOWLEDGE (BOK) APPROACH

Review of curriculum development approaches in other disciplines has shown that the American Society of Civil Engineers (ASCE) has followed a competency-based approach for civil engineering in the USA (ASCE, 2008). For simplicity reasons, but also to allow for better communication and cooperation between Civil Engineering and Geo-Engineering organisations, much of the methodology used by the ASCE can and should be used in the work of JTC-3 for the development of the Geo-Engineering curricula.

The ASCE defines the domain of knowledge and experience that is considered to be essential for a qualified expert in civil engineering as "the ASCE Body of Knowledge (BOK)"

The ASCE has used the term "outcome" with an almost identical meaning as "competency" in the Joint European Working Group Report (JEWG, 2008) and by Rengers & Bock (2008). However the ASCE has further defined the degree to which the outcomes are mastered in terms of "level of achievement", instead of defining each competency in terms of the number of educational credits, the approach used by Rengers & Bock (2008). This is certainly an important improvement and is recommended also for the work of the JTC-3.

The following sub-sections give a short summary of the ASCE method and terminology.

## 3.1 "Outcomes"

The ASCE defines the Body of Knowledge (BOK) for Civil Engineering according to (24) "Outcomes", which are comparable with the term "competency" used in the JTC3 discussions. Table 1 describes these 24 "Outcomes" described in the ASCE report; each outcome defines a certain part of the domain of knowledge and experience that is considered to be essential for a qualified expert in civil engineering.

## 3.2 Level of Achievement – Use of "Bloom's Taxonomy"

Some "Outcomes" (competencies) are more important for the profession than others; so a definition of the level at which each Outcome has to be mastered is required. The ASCE approach uses for this definition the concept "level of achievement" that is described according to the standards of "Bloom's Taxonomy", an international standard used worldwide by educational specialists (Bloom, et al., 1956).

Although more than 50 years old, Bloom's taxonomy remains highly relevant and is used worldwide by educational specialists to define levels of achievement of the educational process. As the task of JTC-3 is to develop guidelines for education and training programs, the application of Bloom's taxonomy in its original setup thus seems to be a good approach. The following link may be useful to JTC-3 members, although it does not add new information on the taxonomy: http://www.nwlink.com/~Donclark/hrd/bloom.html

The current ASCE efforts focus on the cognitive domain because that domain addresses many conventional learning outcomes associated with engineering. [Possible future actions by ASCE in the affective domain are discussed in Appendix G of the BOK2 report (ASCE,2008)]. Bloom's taxonomy assesses the cognitive domain according to six ***levels of achievement***. These levels of achievement are defined in summary form in Table 2. Appendix F of the BOK2 Report (ASCE, 2008) provides a more complete set of these definitions. Table 1 shows, by use of codes L1 through L6, the appropriate levels of achievement for civil engineers for each outcome, for Civil Engineering.

## 3.3 How Can a Level of Achievement Be Acquired?

The ASCE BOK2 report emphasizes that acquiring the appropriate levels of achievement is generally not a quick or simple process, and certainly is not a process that is restricted to formal education in a bacccalaureate program of study. The ASCE approach suggests three broad components for fulfilling a level of achievement:

- The basic levels of achievement are typically fulfilled through formal study in a baccalaureate program,
- More advanced levels of achievement are fulfilled through a the master's degree or equivalent instruction directed toward a specialised technical area and/or professional practice area related to civil engineering, and

Table 1. The ASCE defines the Body of Knowledge (BOK) for Civil Engineering in 24 Outcomes
(SOURCE: ASCE,2008, Table 1)

Key: Ll through L6 refers to these levels of achievement:

Level 1 (L1) – Knowledge
Level 2 (L2) – Comprehension
Level 3 (L3) – Application
Level 4 (L4) – Analysis
Level 5 (L5) – Synthesis
Level 6 (L6) – Evaluation

| Outcome number and title | To enter the practice of civil engineering at the professional level, an individual must be able to demonstrate this level of achievement. |
|---|---|
| Foundational Outcomes | |
| 1 – Mathematics | Solve problems in mathematics through differential equations and apply this knowledge to the solution of engineering problems. (L3) |
| 2 – Natural sciences | Solve problems in calculus- based physics, chemistry, and one additional area of natural science and apply this knowledge to the solution of engineering problems. (L3) |
| 3 – Humanities | Demonstrate the importance of the humanities in the professional practice of engineering (L3) |
| 4 – Social sciences | Demonstrate the incorporation of social sciences knowledge into the professional practice of engineering. (L3) |
| Technical Outcomes | |
| 5 – Materials science | Use knowledge of materials science to solve problems appropriate to civil engineering. (L3) |
| 6 – Mechanics | Analyze and solve problems in solid and fluid mechanics. (L4) |
| 7 – Experiments | Specify an experiment to meet a need, conduct the experiment, and analyze and explain the resulting data. (L5) |
| 8 – Problem recognition and solving | Formulate and solve an ill-defined engineering problem appropriate to civil engineering by selecting and applying appropriate techniques and tools. (L4) |
| 9 – Design | Evaluate the design of a complex system, component, or process and assess compliance with customary standards of practice, users and project's needs, and relevant constraints. (L6) |
| 10 – Sustainability | Analyze systems of engineered works, whether traditional or emergent, for sustainable performance. (L4) |
| 11 – Contemporary issues and historical perspectives | Analyze the impact of historical and contemporary issues on the identification, formulation, and solution of engineering problems and analyze the impact of engineering solutions on the economy, environment, political landscape, and society. (L4) |
| 12 – Risk and uncertainty | Analyze the loading and capacity, and the effects of their respective uncertainties, for a well-defined design and illustrate the underlying probability of failure (or nonperformance) for a specified failure mode. (L4) |
| 13 – Project management | Formulate documents to be incorporated into the project plan. (L4) |
| 14 – Breadth in civil engineering areas | Analyze and solve well-defined engineering problems in at least four technical areas appropriate to civil engineering. (L4) |
| 15 – Technical specialization | Evaluate the design of a complex system or process, or evaluate the validity of newly created knowledge or technologies in a traditional or emerging advanced specialized technical area appropriate to civil engineering. (L6) |
| Professional Outcomes | |
| 16 – Communication | Plan, compose, and integrate the verbal, written, virtual, and graphical communication of a project to technical and non-technical audiences. (L5) |
| 17 – Public policy | Apply public policy process techniques to simple public policy problems related to civil engineering works. (L3) |
| 18 – Business and public administration | Apply business and public administration concepts and processes. (L3) |
| 19 – Globalization | Analyze engineering works and services in order to function at a basic level in a global context. (L4) |
| 20 – Leadership | Organize and direct the efforts of a group. (L4) |
| 21 – Teamwork | Function effectively as a member of a multidisciplinary team. (L4) |
| 22 – Attitudes | Demonstrate attitudes supportive of the professional practice of civil engineering. (L3) |
| 23 – Lifelong learning | Plan and execute the acquisition of required expertise appropriate for professional practice. (L5) |
| 24 – Professional and ethical responsibility | Justify a solution to an engineering problem based on professional and ethical standards and assess personal professional and ethical development. (L6) |

Table 2. Brief definitions of the Six Levels of Achievement in Bloom's Taxonomy

(SOURCE: ASCE, 2008, Appendix F)

*Level 1: Knowledge*
Knowledge is defined as the remembering of previously learned material. This may involve the recall of a wide range of material, from specific facts to complete theories, but all that is required is the bringing to mind of the appropriate information.

*Level 2: Comprehension*
Comprehension is defined as the ability to grasp the meaning of material. This may be shown by translating material from one form to another (words to numbers), by interpreting material (explaining or summarizing), and by estimating future trends (predicting consequences or effects).

*Level 3: Application*
Application refers to the ability to use learned material in new and concrete situations. This may include the application of such things as rules, methods, concepts, principles, laws, and theories.

*Level 4: Analysis*
Analysis refers to the ability to break down material into its component parts so that its organizational structure may be understood. This may include the identification of parts, analysis of the relationship between parts, and recognition of the organizational principles involved.

*Level 5: Synthesis*
Synthesis refers to the ability to put together to form a new whole. This may involve the production of a unique communication, a plan of operation (research proposal), or a set of abstract relations (scheme for classifying information).

*Level 6: Evaluation*
Evaluation concerns the ability to judge the value of material for a given purpose. The judgments are to be based on definite criteria. These may be internal criteria (organization) or external criteria (relevance to the purpose) and the individual may determine the criteria or be given them.

- Other levels of achievement can only be gained through practical field experience that must be acquired prior to professional licensure.

The assumption in the above statements is that experience is needed, in addition to formal education, to enter the practice of civil engineering at the professional level.

The ASCE BOK2 is of course directed to the much broader entire field to Civil Engineering. Yet these comments are directed at both the "education" and "training" components of the JTC-3 objectives. In proceeding, the JTC-3 discussion should clearly distinguish between the competencies (outcomes in ASCE terminology) that are acquired by four methods:

1. Formal higher education, at both the baccalaureate and masters levels,
2. Continuous education beyond the formal higher education – sometimes called "life-long learning",
3. Experience gained by geo-engineering practice prior to professional licensure
4. More advanced/specialised professional geo-engineering experience gained through membership in professional societies.

While methods 1 and 2 above are clearly within the scope of JTC-3, the activities in methods 3 and 4 appear to fall, at least to some considerable degree, within the scope of JTC-4 "Professional Practice." It thus appears likely that future discussions may require a degree of coordination between JTC-3 and JTC-4.

Figure 1 illustrates the ASCE Outcome Rubric (***in JTC3 terminology "Competency profile"***) for Civil Engineering, which was developed according to the procedures discussed in the following Section 3.4. It shows the 24 outcomes, each with its necessary level of achievement and a code that explains when and how, through formal teaching and training or by experience, the competency may be developed.

Evaluation of the ASCE BOK2 report (ASCE, 2008) reveals five characteristics that can be identified by examining Figure 1. These characteristics are largely also true for the disciplines within Geo-Engineering:

1. All 24 outcomes – with the exception of outcome 15 (technical specialization) – are fulfilled, at least through achievement level 2 (comprehension), via formal education in a baccalaureate program. The bachelor's degree lays the foundation for all outcomes and provides a broad background in the natural sciences, the humanities, the social sciences, and engineering.

2. For six outcomes (1-6), the necessary levels of achievement are fulfilled entirely through the bachelor's degree. Coupled with the preceding observation, this emphasizes the importance of a broad baccalaureate education that provides a solid foundation for higher-level master's education (M/30) and prelicensure experience.

3. The masters (M/30) helps to fulfill three outcomes (7, 8, and 15) and is the primary means by which outcome 15, technical specialization, is accomplished. Outcome 15 and the supporting role of outcomes 7 and 8 at the M/30 level provide the greater technical depth in the BOK.

4. For almost two thirds of the total outcomes (outcomes 9-13 and 15-24), experience is needed, in addition to formal education, to enter the practice of civil engineering at the professional level. This reinforces the need for education/experience partnerships in fulfilling the BOK.

5. As suggested by the dominance of the B cells in Figure 1, most of the formal education in the BOK occurs during the bachelor's degree program.

Some have questioned the need for using all six levels of achievement defined by Bloom's Taxonomy in developing a competency profile such as shown in Figure 1. For example, they note that all 24 competencies are shown to require levels 1 to 3. While this is true, the levels of achievement for each competency, and so each cell in the matrix, is provided with a code defining the method recommended for its achievement. While most of the cells in the lower achievement levels contain the letter "B", indicating they are fulfilled by formal education at the baccalaureate level, not all cells are so indicated. The civil engineering competency profile shown in Figure 1 has a single competency labelled "Technical Specialization." Competency profiles developed for geo-engineering specialisations will have this category evaluated in much greater detail. While the Civil Engineering competency profile (Figure 1) shows this category being fullfilled at the master's level, it is likely that the different geo-engineering specialisations will have different approaches to fulfilling these more explict competencies.

Thus at the present time we are recommending that the JTC-3 continue to use all six levels of achievement in undertaking its evaluations of geo-enginering, in part because:

- Bloom's Taxonomy is widely known and understood within the education community and its application to engineering education is documented in the literature. Thus levels of achievement based on Bloom's Taxonomy have broader legitimacy than any internally developed taxonomy would likely have.

- Bloom's emphasis on the use of measurable, action-oriented verbs linked to levels of development creates understandable and implementable outcome statements that will support consistent and more effective assessment.

| *Outcome Number and Title* | *Level of Achievement* | | | | | |
| --- | --- | --- | --- | --- | --- | --- |
| | *1* | *2* | *3* | *4* | *5* | *6* |
| | *Knowledge* | *Compre-hension* | *Application* | *Analysis* | *Synthesis* | *Evaluation* |
| *Foundational* | | | | | | |
| 1. Mathematics | B | B | B | | | |
| 2. Natural sciences | B | B | B | | | |
| 3. Humanities | B | B | B | | | |
| 4. Social sciences | B | B | B | | | |
| *Technical* | | | | | | |
| 5. Materials science | B | B | B | | | |
| 6. Mechanics | B | B | B | B | | |
| 7. Experiments | B | B | B | B | M/30 | |
| 8. Problem recognition and solving | B | B | B | M/30 | | |
| 9. Design | B | B | B | B | B | E |
| 10. Sustainability | B | B | B | E | | |
| 11. Contemp. issues & hist. perspectives | B | B | B | E | | |
| 12. Risk and uncertainty | B | B | B | E | | |
| 13. Project management | B | B | B | E | | |
| 14. Breadth in civil engineering areas | B | B | B | B | | |
| 15. Technical specialization | B | M/30 | M/30 | M/30 | M/30 | E |
| *Professional* | | | | | | |
| 16. Communication | B | B | B | B | E | |
| 17. Public policy | B | B | E | | | |
| 18. Business and public administration | B | B | E | | | |
| 19. Globalization | B | B | B | E | | |
| 20. Leadership | B | B | B | E | | |
| 21. Teamwork | B | B | B | E | | |
| 22. Attitudes | B | B | E | | | |
| 23. Lifelong learning | B | B | B | E | E | |
| 24. Professional and ethical responsibility | B | B | B | B | E | E |

Key:

| | |
| --- | --- |
| **B** | Portion of the BOK fulfilled through the bachelor's degree |
| **M/30** | Portion of the BOK fulfilled through the master's degree or equivalent (approximately 30 semester credits of acceptable graduate-level or upper-level undergraduate courses in a specialized technical area and/or professional practice area related to civil engineering) |
| **E** | Portion of the BOK fulfilled through the prelicensure experience |

Figure 1. ASCE Outcome Rubric (in JTC3 terminology: "Competency profile" ) for the Body of Knowledge (BOK) that is considered to be essential for a qualified expert in civil engineering

### 3.4 Establishing the ASCE "Outcome Rubic"

The ASCE BOK2 Committee developed the ***outcome rubric*** which is a matrix composed of 24 rows (one for each Outcome (competency) shown in Table 1) and 6 columns ( one for each "level of achievement" according to Bloom's taxonomy). The entire rubic is presented in detail as Appendix I of the BOK2 Report (ASCE, 2008), but it can be summarised graphically as shown by Figure 1. The rubric communicates the following BOK characteristics:

- The *24 outcomes*, categorized as foundational, technical, and professional and, within each category, organized in approximate pedagogical order while not reflecting relative importance.
- The recommended *level of achievement* that an individual must demonstrate for each outcome to enter the practice of civil engineering at the professional level.
- For each *outcome*, the portion of the *level of achievement* to be fulfilled through the bachelor's degree, the portion to the fulfilled through the master's degree or equivalent, and the portion to be fulfilled through prelicensure experience (training).

To develop the rubric, the ASCE BOK2 Committee first "filled in" the entire rubric, that is, all six of Bloom's Taxonomy levels for 24 outcomes (144 cells), prior to selecting the levels of achievement needed for entry into the practice of civil engineering at the professional level. And only after those levels were established did the committee, working in reverse, make decisions concerning the recommended roles of bachelors, masters and experience (training) in the rubic, and defined as or "B","M/30",and "E" in Figure 1.

### 3.5 Adapting the ASCE BOK Approach for Geo-Engineering

The ASCE approach described above can be adapted to readily support the task given to JTC-3: the development of recommendations for the curricula of the Geo-Engineering sub-disciplines. Prior JTC-3 meetings in Constantza, Romania, as well as in Madrid, approved the curriculum development approach through definition of competencies.

The ASCE classification of "Outcomes" (competencies) into the three major categories: Foundational competencies, Technical competencies, and Professional competencies appears equally valid for the Geo-Engineering field. However, the 24 competencies in the ASCE document must be reviewed carefully. Of course the earth-sciences must be included in a more prominent way.

The ideal Geo-Engineering matrix may, or may not, have the same 24 outcomes – maybe more, maybe less – but it should have the same 6 levels of achievement, based on the accepted Bloom's taxonomy approach. In fact, many of the outcomes appear equally valid for Geo-Engineering, and thus they may not change. This is especially true for Outcomes 16-24 in the Professional competencies category. However the descriptions within their cells may change to reflect the particular focus of Geo-Engineering.

Additional or modified outcomes (competencies) are probably required to fully define the Geo-Engineering characteristics. For instance, ASCE outcome 2 (Natural Sciences), and outcomes 5-9 (Materials Science, Mechanics, Experiments, Problem Recognition, Design) may need to be substantially revised and expanded to reflect the scope of Geo-Engineering and allow later differentiation among the various professional specialties. Similarly, adjustments will be needed to ASCE outcomes 14 and 15 (Breadth and Technical Specialization) for the same reason.

In any case the development of a new Geo-Engineering matrix should reflect the Geological Modeling approach of Fookes (Fookes, 1997), and the importance of the observational method first promoted by Terzaghi, plus all the other concepts of relationships and professionalism within the geo-engineering community.

#### *3.5.1 A Proposed Starting Point.*

Table 3 presents a preliminary set of suggested modifications to the existing 24 ASCE outcomes (competencies). These have been proposed by Niek Rengers as a starting point. They should be seen as *a proposal about which the JTC3 members will have to give their comments*. Table 3a lists the existing ASCE outcomes, while Table 3b lists the proposed Geo-Engineering competencies.

The following comments refer to the proposed changes shown in Table 3b:

- a new foundational competency, called "Earth Sciences", including geology and geomorphology and related fieldwork, should be added, bringing the number of Foundational competencies 5.
- Most of the critical changes relate to the "Technical competencies 5 to 15" of the ASCE list. It is proposed that:
  - Nr. 5 could remain the same but can include more specifically the topic of "materials testing"
  - Nr. 6 mechanics could remain as it is, but the content should be modified considerably to reflect "Applied Mechanics" topics
  - Nr. 7 could be replaced by "site investigations and 3D geo-engineering modelling (physical and numerical)"
  - Nr. 8 could remain as it is.
  - Nr. 9 could be renamed "design of geo-structures" including foundations, slopes, excavations, tunnels, etc.
  - Nr. 10 could remain as it is
  - Nr. 11 could be left out
  - Nr. 12 could remain as it is
  - Nr. 13 can remain as it is
  - Nr. 14 to be renamed "civil engineering"
  - Nr. 15 technical specialisation be redirected to Geo-Engineering specialisation

### *3.5.2 Should There Be A Single Set of Competencies for All of Geo-Engineering?*

A second question to be answered by the JTC-3 membership is: ***Can a single, all-inclusive, set of competencies be used for all sub-disciplines in Geo-Engineering?*** The alternative would be to develop lists that are applied to each sub-discipline individually.

An appropriate task for a later stage of the work of JTC-3 is the assignment of different levels of achievement for each sub-discipline for each of the competencies in the master list. As shown in Section 4.8, the use of a single universal list of competencies allows for the development of a "Competency Profile" for each sub-discipline. This allows for the appropriate sub-discipline roles to be readily understood. The potential applications of this approach are discussed in Section 4.7, with reference to conceptual competency profiles for Engineering Geology, Geological Engineering, Rock Mechanics and Soil Mechanics shown in Figure 2.

### *3.5.3 Establishing Levels of Achievement*

The ***final stage of the work of the JTC3 is to assign levels of achievement*** to the competency lists for each of the sub-disciplines in geo-engineering. This work is defined as tasks 4 and 5 in the proposed schedule of tasks (Section 5).

**Table 3.** Comparison of Existing ASCE Outcomes with Possible Geo-Engineering Competencies, as Proposed by Rengers

### Table 3a: Competencies List for Civil Engineers (from ASCE BOK2 Report)

***Foundational***

1. Mathematics
2. Natural Sciences
3. Humanities
4. Social sciences

***Technical***

5. Materials science
6. Mechanics
7. Experiments
8. Problem recognition and solving
9. Design
10. Sustainability
11. Contemp. issues & hist. perspectives
12. Risk and uncertainty
13. Project Management
14. Breadth in civil engineering areas
15. Technical specialisation

***Professional***

16. Communication
17. Public policy
18. Business and public administration
19. Globalization
20. Leadership
21. Teamwork
22. Attitudes
23. Lifelong learning
24. Professional and ethical responsibility

### Table 3b: Proposed Competencies List for Geo-Engineering Professionals (This is only a first suggestion and is to be commented by the JTC-3 members)

***Foundational***

1. Mathematics
2. Natural Sciences
3. Earth Sciences
4. Humanities
5. Social sciences

***Technical***

6. Natural materials science and testing
7. Applied Mechanics
8. Site investigations & 3D modelling
9. Problem recognition and solving
10. Design of geo-structures (incl. found. tunnels)
11. Sustainability
12. Risk and uncertainty
13. Project Management
14. Civil Engineering
15. Geo-engineering specialisation

***Professional***

16. Communication
17. Public policy
18. Business and public administration
19. Globalization
20. Leadership
21. Teamwork
22. Attitudes
23. Lifelong learning
24. Professional and ethical responsibility

# 4. SPECIALISATIONS WITHIN GEO-ENGINEERING

In response to the complexity of modern engineering design, several specialty disciplines have developed within the field of geo-engineering. These specialties focus on resolving design factors related to conditions at the interface between natural earth materials and engineered structures, the use of naturally occurring materials in facility construction, and environmental or hazard mitigation considerations.

In recent decades, in response to environmental protections on the one hand, and to technological advances and economic forces on the other, engineering projects have become much more complex – bridges and tunnels are longer, and high-speed transportation links have become common. Population growth has pushed developments into more complex geological locations where site conditions are less optimal and geohazards more likely. These trends naturally led to an increase in geo-engineering specialisations.

The recognition and acceptance of the appropriate professional stature and roles for geologists and engineers has become of increasing concern. Because geo-engineering practitioners are increasing likely to become involved in litigation, professional liability is becoming an important concern in many countries. These concerns have led to increased professional registration options for both geologists and engineers, although the exact methods of achieving this vary from country to country.

The following sections further amplify these topics, which naturally vary with different legal and societal forms in different parts of the World, as well as with differences in geology, climate, and environment characteristics. Since the primary goal of the JTC-3 activities is to provide an international and global perspective to the education and training needs of the geo-engineering community, it is important that all proposals are developed with a clear understanding of the underlying reasons for the development of geo-engineering specialisations, and why some particular specialisations have special relevance or importance in some countries or regions.

Section 4.1 provides brief descriptions of the major specialisations that currently exist within the geo-engineering community along with some reasons for their development or importance in certain countries. Section 4.2 discusses one area of possible confusion that has special importance to some regions, the difference between geological engineering and engineering geology. Section 4.3 briefly addresses the topic of professional recognition of the various specialisations, a topic that influences the acceptance and importance of several specialisations in different countries, and is an area where future collaboration between JTC-3 and JTC-4 ( the Joint Technical Committee on Professional Practice) may prove beneficial.

## 4.1 Describing the Specialisations

This section provides basic descriptions of the major specialisations that have developed within the field of geo-engineering. Some specialisations, and the terminologies describing them, have special importance in certain countries or regions, but most specialisations are recognized and accepted globally.

The term "*Engineering Geology*" is widely used throughout the world in two contexts – to describe the application of geological principles relevant to engineering works, environmental concerns, and societal concerns, and to define specialist geologists ("*Engineering Geologists*") who are involved in such studies. The Joint European Working Group report provides further discussion of Engineering Geology, which has been reproduced in Appendix A (see pages 36-37).

The environmental movement has impacted geology and engineering, and how these disciplines relate to the demands of society. In many countries, environmental concerns and demands for new and renovated infrastructure to support increasingly large urban populations (transportation, community expansion, water supplies and waste disposal) have resulted in the development of a subject called ***"Environmental Geology,"*** which most engineering geologists consider being largely part of their field of expertise. An important aspect of this increased environmental awareness is the demand for assurances on safe and clean water supplies on the one hand, and their protection through the careful disposal of wastes on the other. Water is becoming the dominant factor in development throughout the world as populations increase and demands are placed on diminishing supplies. As a consequence, many individuals practicing within the geo-engineering community are specializing in water-related topics, commonly considered the realm of ***"Hydrogeologists."***

***"Geotechnical Engineering"*** is a specialty that applies earth sciences to the solution of civil, environmental, and mining engineering problems. Geotechnical engineers typically have expertise in soil mechanics and rock mechanics, and relatively little geological science knowledge. They are dominantly civil engineers and are capable of designing structures for foundations in soil or rock. For some projects their training limits their ability to account for the heterogeneity or complexity of naturally occurring geological features. Under such circumstances, a consultation with specialists having more in-depth knowledge of geological processes is desirable. The Joint European Working Group report provides further discussion of the Soil Mechanics Engineer, a component of Geotechnical Engineering, which has been reproduced in Appendix A (see pages 32-33).

The field of ***"Rock Mechanics"*** is taken to include all studies relative to the physical and mechanical behaviour of rocks and rock masses and the applications of this knowledge for the better understanding of geological processes and in the fields of engineering (ISRM Statutes). The Joint European Working Group report provides further discussion of Rock Mechanics Engineering, which has been reproduced in Appendix A (see pages 34-35).

In many countries the term ***"Ground Engineering"*** is used whenever soil mechanics or rock mechanics principles are employed in actions that modify the properties of naturally occurring materials. Usually these actions are directed toward making the materials stronger – capable of supporting larger structural loads, for example – or reducing the permeability of some units – to reduce the inflow of water into an excavation, for instance.

*Geological Engineering* has developed as a relatively small and unique specialty field within the broader engineering professions. Geological engineering is especially relevant to geo-engineering practice in North America, where it first became established in response to the combination of legal and technological conditions that exist within the USA and Canada. Similar technological developments elsewhere generated very similar demands for individuals with appropriate technical skills, but without the legal requirements to also meet professional engineering registration standards. The following section provides additional explanations concerning the relationships between geological engineers and engineering geologists.

## 4.2 Geological Engineers and Engineering Geologists

At first glance the terms "geological engineer" and "engineering geologist" appear synonymous. Because the two terms employ essentially the same two words – "geology" and "engineering" – although in reverse order, the opportunity for confusion is great. The word choices may be unfortunate, but the two terms represent distinct, although related, concepts concerning educational and professional endeavors.

### *4.2.1 Geological Engineer*

A geological engineer is educated as an engineer – but an engineer with a broad understanding of applied geological science.

"Geological Engineering" first developed in the early 20th Century in the USA in response to a combination of technical opportunities and the established legal processes for obtaining professional engineering registration. Because the minerals and petroleum industries required increasing numbers of specialists with engineering training combined with geological knowledge, a number of universities and mining schools in the western United States began to offer engineering programs leading to a degree in "Geological Engineering". In Canada, similar pressures resulted in the establishment of additional geological engineering programs at several universities (Turner 2005; 2008).

Most of the early geological engineers did not work on civil engineering projects; they were more likely to work on minerals exploration and exploitation projects with mining engineers, or on petroleum exploration and production projects with petroleum engineers. In the latter half of the 20th Century, major civil engineering projects following World War II placed new demands for specialists to work with civil engineers. Many recent geological engineering graduates are now employed in civil engineering applications and ground water evaluations. Graduates often continue to specialize with more advanced degrees in such areas as geotechnical engineering, rock mechanics (for tunneling and underground construction), hydrogeology, contaminant transport to evaluate ground pollution issues, or various geohazard mitigation studies, including landslides, earthquakes, or floods (Higgins 1991).

#### *4.2.2 Engineering Geologist*

The engineering geologist remains a scientist – albeit a rather applied geologist (Tepel 2009). The term "Engineering Geology" became widely accepted as the demand for geological specialists to advise civil engineers developed in the last half of the 20th Century. The scope of engineering geology practice has expanded beyond its original close connection with civil engineering. Many engineering geologists currently work closely with land-use planners, water resource specialists, environmental specialists, architects, public policy makers, and property-owners, both public and private, to prepare plans and specifications for a variety of projects that are influenced by geologic factors, involve environmental modifications, or require mitigation of existing or potential effects to the environment (Mathewson 1982).

However, in some countries, the role of engineering geologists is restricted by the legal system. For example, in North America, professional engineers are held solely responsible for the safety and integrity of their works. Thus the engineering geologist is typically considered as a specialist advisor to the design team, and may hold a position similar to an architect or other design specialist. In the USA, engineering geologists formed their own professional association (the Association of Environmental & Engineering Geologists – AEG) while other geo-specialists typically belong to other more "engineering-oriented" organizations. In Canada this division is not so clearly defined, as in recent years geoscientists and engineers are often professionally recognized by a single association and thus cooperation is more readily achieved. The Canadian Geotechnical Society (CGS) also bridges the divide among specialties, as it is associated with both the Engineering Institute of Canada and the Canadian Federation of Earth Sciences. The CGS has seven divisions, including divisions for Soil Mechanics and Foundations, Rock Mechanics, and Engineering Geology.

## 4.3 Professional Recognition.

The issues surrounding the professional recognition of various specialisations within the field of geo-engineering are complex and often specific to each country, as the legal basis for professional recognition varies from country to country. Part of the complexity arises because aspects of geo-engineering practice frequently involve scientific studies and engineering design topics to varying degrees. In many countries, there are long-standing legal separations that divide engineering from other scientific endeavours.

As noted in Section 4.2 previously, the separation between engineering and science activities in North America resulted in the establishment of geological engineering (Turner 2005; 2008). Within the United States and Canada, individuals employed in professions that affect public safety and welfare – including engineering, medicine, and law, as well as many others – are required to meet two criteria: (1) an appropriate university degree and (2) an assessment and recognition of their credentials enforced by official State (USA) or Provincial/Territorial (Canada) regulations. The assessment and recognition process is slightly different in the two countries, but typically takes the form of two stages of written examinations and an extensive review of documentation defining both education and subsequent working experience. In Canada the process leads to "licensure," while in the USA the process is generally referred to as "professional registration" or "certification."

In both the USA and Canada, the professional registration of engineers has been legislated at the state/provincial level since the early 20th century and has been accepted as needed to protect the public interests. The case for an equivalent registration of geologists has not been so clearly accepted.

Professional registration of Geologists within the USA has been debated for about 20 years. Geologists employed in petroleum and mineral exploration have generally been opposed to calls for registration, while geologists involved in engineering, hydrogeology, and environmental projects, where public health and safety issues are readily apparent, have generally favored registration efforts. Currently, 26 out of the 50 states require registration of geologists. State boards of registration, independent of the engineering boards, supervise the registration procedures for geologists in their state, and these boards cooperate through the National Association of State Boards of Geology (ASBOG). In those states that require professional geological registration, many regulations now give registered professional geologists approval authority for appropriate design documents, equivalent to the authority granted to professional engineers, but situations do arise where there are disputes. In states lacking geologist professional registration requirements, engineering geologists must act as specialist advisors to a design team headed by an engineer who makes the final legal approvals.

In Canada, the provincial legislatures delegate the professional licensure process to professional associations, and in the majority of the provinces a single association supervises the licensure of engineers and geologists. Within the past decade, most Canadian geologists have accepted the need for professional liicensure, because geologists involved in mining and exploration activities had to establish their credentials as a "qualified person" in making official reports, as required by new laws developed after the 1997 Bre-X scandal (Pinsker 2002). Thus, in contrast to the USA, a majority of Canadian geoscientists have professional licensure. Many individuals working in engineering, hydrogeology, and environmental topics hold dual registrations as engineers (P.Eng.) and geologists (P.Geo.). This is made easier when a single association supervises both designations, as is the case in the majority of provinces and territories.

Tepel (2009) provides additional views on the situation within the USA. The situation in other countries is often quite different. Bock (2009) provides some details of the contrasting situations in several European countries, including Germany, the Netherlands, and Austria. The recent report by the Joint Commission on Professional Practice (JTC4 2009) provides additional perspectives.

## 4.4 Overview of Specialisations

In summary, the following points should be understood:

- The term "Geological Engineer" was developed in the USA in response to a combination of technical opportunities and the established legal processes for obtaining professional engineering registration in the USA.
- The initial demands for geological engineers came from the minerals and petroleum industries; the demand for significant numbers of specialists to work with civil engineers (in engineering geology) only developed in the latter half of the 20th century.
- The term "Geological Engineer" is thus most widely used in the USA. The term is also used in Canada, which has a slightly different professional registration structure, and only to a limited extent and more recently in other parts of the World.
- The term "Engineering Geology" is widely used throughout the world in two contexts – to describe the application of geological principles relevant to engineering works, environmental concerns, and societal concerns, and to define specialist geologists ("Engineering Geologists") who are involved in such studies.
- In contrast to the "Geological Engineer," who is trained as an engineer with additional geological knowledge, the "Engineering Geologist" remains a scientist. This difference has ramifications for professional licensure and legal authority, especially in North America.
- Because engineers and scientists may be equally held liable for public safety and welfare issues; issues of certification, licensure, or registration increasingly affect the field of engineering geology, and the geological engineers, engineering geologists, and others involved in major engineering works. These issues are resolved in many forms in different parts of the world.

## 4.5 Existing Definitions of Competencies

The Joint European Working Group (JEWG) prepared a list of competencies for Engineering Geologists and Geotechnical Engineers in 2004, and subsequently revised and expanded these definitions to describe Soil Mechanics Engineers, Rock Mechanics Engineers, and Engineering Geologists in 2008 (JEWG, 2008). Rengers & Bock (2008) discuss the concepts developed by the JEWG. Appendix A provides the extracted competency definitions described in the revised version of the JEWG Report (JEWG, 2008). Subsequently, Prof. J.D. Higgins, a professor at the Colorado School of Mines, created a draft competency model for Geological Engineers specializing in Engineering Geology and Geotechnics. Tables 4 and 5 reproduce the competency tables summarizing the competency characterisitcs for all four specialisations.

The competency list for Geological Engineers, as compiled by Higgins, tends to bridge the competencies for the Engineering Geologists and the Soil Mechanics Engineers and Rock Mechanics Engineers defined by Rengers & Bock. In the USA, and in Canada, it is the geological engineering programs that are educating many of the individuals who ultimately become engineering geologists. Geological Engineering programs are apparently successful in Portugal and Spain, and these educational directions will no doubt affect instruction in South America. Geological Engineering programs also exist in other countries as well.

Table 4. Competencies for Engineering Geologists, Rock Engineers and Soil Engineers (Rengers & Bock, 2008, Table 2; modified and extended after JEWG, 2008)

| | Soil Engineer | Rock Engineer | Engineering Geologist |
|---|---|---|---|
| Key Competence | Understanding of the mechanical behaviour of soil and granular masses (solid-fluid interaction)<br>Setting up of site-specific Ground Models, in particular with:<br>• soil parameters (information from lab / field / data base)<br>• knowledge of the degree of geotechnical uncertainty<br>Analysis and design of structures on, in or with soil<br>Soil improvement techniques<br>Construction supervision (soil) | Understanding of the mechanical behaviour of rock and fractured materials<br>Setting up of site-specific Ground Models, in particular with:<br>• rock parameters (information from lab / field / data base)<br>• knowledge of the degree of geotechnical uncertainty<br>Analysis and design of civil and mining structures on, in or with rock<br>Rock improvement and fragmentation techniques<br>Construction supervision (rock) | Understanding of geological features and processes and the genesis of geological formations<br>Setting up of site-specific Geological Models, in particular:<br>• Assembly, interpretation and synthesis of fragmented geologic and technical data<br>• Site investigation (specification of the ground composition)<br>• Geo-hazard identification, quantification and prevention (specification of geological boundary conditions) |
| General Competence | • Familiarity with the pertinent scientific methods in civil and structural engineering.<br>• Basic knowledge of the geo-scientific terminology, working methods, geological processes and Quaternary Geology | • Familiarity with the pertinent scientific methods in civil, structural, mining and reservoir engineering.<br>• Basic knowledge of the geo-scientific terminology, working methods, geological processes and identification of most common rock types | • Familiarity with the pertinent scientific methods in geo-, mining and reservoir engineering<br>• Basic knowledge in geomechanics and of the design methods in geotechnical and mining engineering |
| Competence in Specialised Fields | • Lab / field testing methods to cope with the natural characteristics of soils (e. g. oedometer test)<br>• Numerical modelling coping with the structural diversity of geology and being based on complex constitutive laws (e.g. non-linear, anisotropic and time-dependent material behaviour as well as plastification).<br>• Design, construction and contractual procedures adjusted to the geotechnical uncertainty (e. g. "Observational Design Method"). | • Lab / field testing methods to cope with the natural characteristics of rocks (e. g. post-failure compression test)<br>• Numerical modelling with particular emphasis on the discontinuous nature of rock masses (plastification of intact rock and of discontinuities).<br>• Coupled thermo-hydro-mechanical modelling<br>• Design, construction and contractual procedures adjusted to the geotechnical uncertainty (e. g. "NATM – New Austrian Tunnelling Method"). | • Site-related work and field testing.<br>• Handling of cartographic documents and geo-information systems.<br>• Observation, documentation and analysis of geological data as keys in contractual disputes.<br>• Familiarity with fractured, slaking and ageing materials; soil-rock transition processes (lithification; weathering)<br>• Familiarity with geological risk scenarios. |

Table 5: Competencies for Geological Engineers, as proposed by Higgins (2009).

**A. KEY COMPETENCIES**

1. Understanding of geological features and processes and the genesis of geological formations
2. General understanding of the mechanical behaviour of rock, soil, and solid-fluid interaction
3. Setting up of site-specific Geological Models, in particular:
   - Assembly, interpretation and synthesis of fragmented geologic and technical data
   - Site investigation (specification of the ground composition)
   - Geo-hazard identification, quantification and prevention (specification of geological boundary conditions)
4. Contribute to construction of site-specific Ground Models, in particular with:
   - Rock parameters (information from lab / field / data base)
   - Soil parameters (information from lab / field / data base)
5. Knowledge of the degree of uncertainty due to the inherent nonisotropic, inhomogeneous character of deposits; imprecision of sampling and instrumentation; and up-scaling of characteristics to rock and soil masses.
6. Analysis and design of ground stabilization in rock and soil
7. Construction supervision (rock and soil)

**B. GENERAL COMPETENCIES**

1. Familiarity with the pertinent scientific methods in geo- , mining, and ground-water engineering
2. Basic knowledge in geomechanics and the design methods in geotechnical, mining, and ground-water engineering

**C. COMPETENCIES IN SPECIALIZED FIELDS**

1. Site-related work and laboratory/field testing methods in rock and soil
2. Handling of cartographic documents and geo-information systems
3. Observation, documentation and analysis of geological data as keys in contractual disputes
4. Familiarity with fractured and ageing materials; soil-rock transition processes (lithification; weathering)
5. Familiarity with geological risk scenarios
6. Fundamentals of numerical modelling techniques for rock and soil conditions
7. Design, construction and contractual procedures adjusted to the geotechnical uncertainty

### 4.6 The Role and Importance of Evaluating University Curricula

In contrast to the competency-based approach, experience has shown that a compilation of numerous curricular tabulations from different universities has only limited utility. Such a list was compiled by the AEG for USA programs (Higgins & Williams, 1991). These compilations merely show that apparently the same topics are taught in courses with different names, and that it is not even clear that two courses with the same name contain the same subject matter. Rosenbaum (1997) attempted a compilation of environmental geology programs in the UK with much the same result.

As part of the JTC-3 effort in the past year, Professors Azzam and Tiedemann have prepared reports on the German engineering geology curricula, and Professor Kwasniewski has provided a revised "ISRM Rock Mechanics Curriculum Guide." Both of these efforts focus on curricular matters and provide important information. While a strictly curricular-based approach has limitations, for the reasons just presented above, these reports complement the competency-based assessment process.

The proceedings of the Constantza Conference (Manoliu & Radulescu, 2008) contain a number of reports describing the education program for Geo-Engineering sub-disciplines in several countries. The JTC-3 should encourage the development of additional curricular evaluations, perhaps for regions, such as South America and South-East Asia, for which published information remains limited.

### 4.7 Advantages of the Competency-Based Approach

Niek Rengers previously suggested that some discussions by the JTC-3 membership should be directed at indicating an appropriate number of credits needed for each competency. However, competencies ("outcomes in the ASCE report) define the knowledge, skills, and attitudes acquired by individuals through appropriate formal education and experience. A single competency may include topics that might appear in more than one course, or one course might contribute to many competencies, and many competencies can only be fulfilled with post-graduation experience. Thus, while conceivably one competency could encompass an entire course, in most cases the relationship between competency and educational credits is very complex.

Accordingly, it is recommended that the JTC-3 should adopt the competency-based approach and JTC-3 efforts should focus on the documentation of the recommended roles of bachelors, masters and experience (training) in achieving each competency for each specialisation. These can be defined in tables and graphical summaries by using codes, such as the codes "B", "M/30", and "E" used in the ASCE BOK2 Report (Table 2). Because such illustrations show how the different outcomes and levels of achievement can be achieved through Bachelors and Masters degrees, or by Training/Experience, they can be useful in several ways. For instance, an individual can evaluate his/her competencies in such a diagram. The illustrations may also provide additional interesting possibilities, including:

- Development of life-long-learning plans by individuals,
- Demonstration of the relevance of specialist training courses (perhaps at the post-Masters level), or
- Evaluation of professional qualifications of individuals wanting to work at certain levels within the Eurocode structures, or seeking professional licensure.

### 4.8 How Competency Profiles Can Assist the Evaluation of Geo-Engineering Sub-disciplines

In order to provide JTC-3 members with an example of how the competency-based approach can provide benefits to the assessment of educational and training needs for sub-disciplines within Geo-Engineering, a sequence of four conceptual competency profiles have been developed – one profile for Engineering Geology, another for Geological Engineering, a third for Geotechnical Engineering, and a fourth for Rock Engineering (Figure 2).

It must be emphasized that these profiles are conceptual only. They should not be construed as representing definitive descriptions of these sub-disciplines, nor of providing answers to educational and training issues that must still be resolved by the future tasks of JTC-3.

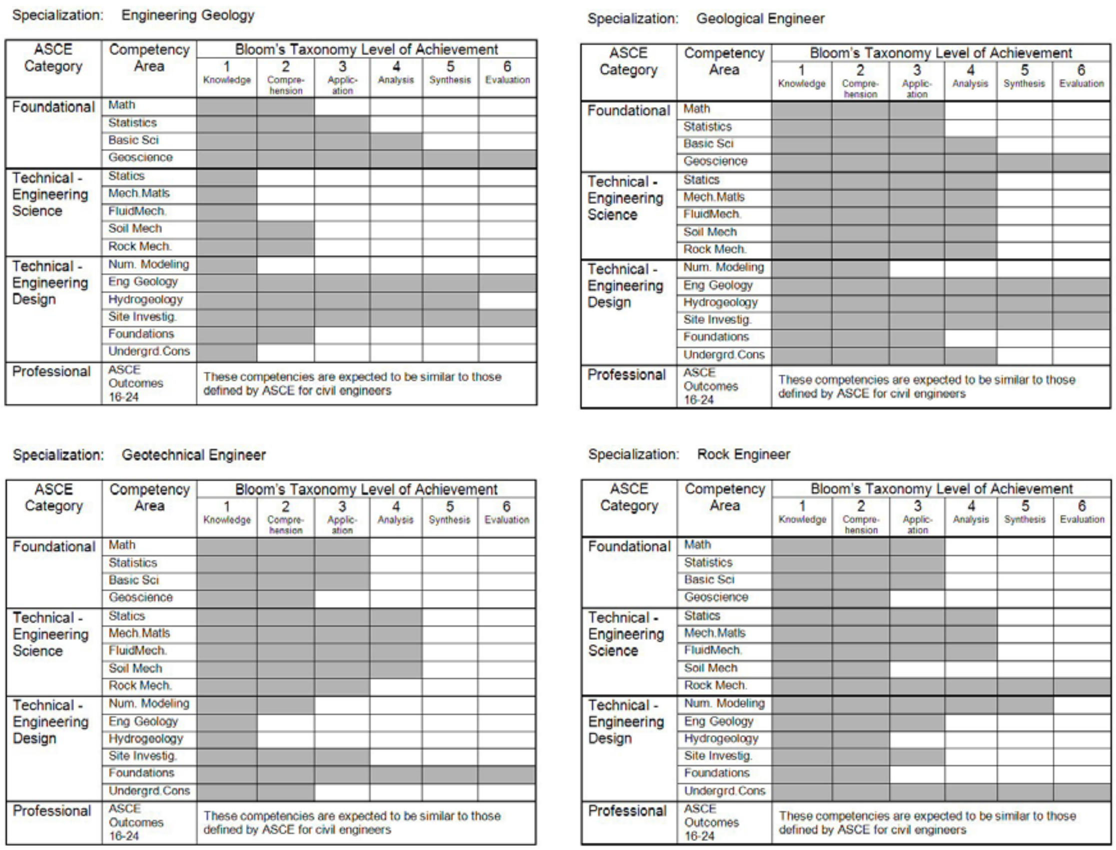


Figure 2. Four *conceptual* Competency Profiles demonstrating how the different Geo-Engineering specializations each have a distinct set of required competencies.

These **conceptual competency profiles** represent the opinions and experience of two indviduals, Professors Turner and Higgins of the Colorado School of Mines. Both Turner and Higgins are Geological Engineers, but they have extensive experience and interactions with Engineering Geologists, Geotechnical Engineers, and Rock Engineers (rock mechanics specialists) within North America. Thus the four profiles shown in Figure 2 represent this collective experience.

The profiles were developed in the following manner:

1. Because the list of 24 Outcomes (competencies) defined for civil engineering by the ASCE BOK2 Report were not considered entirely appropriate for assessing the competencies of Geo-Engineering sub-disciplines, and a full set of such competencies has yet to be established, a representative set of competenciy categories had to be developed.
2. A series of 15 competency classes was established that approximated the ASCE Foundational and Technical categories. There are 4 competency classes in the Foundational category and 11 competency classes in the Technical category. In order to further distinguish components of the Technical category, the classiification of "Engineering Science" and "Engineering Design" topics, previously used by ABET Inc[1] in assessing engineering curricula, were used.

[1] ABET Inc, formerly the Accreditation Board for Engineering and Technology, is the recognized accreditation agency for college and university programs in applied science, computing, engineering, and technology, is a federation of 30 professional and technical societies representing these fields. Among the most respected accreditation organizations in the USA, ABET has provided leadership and quality assurance in higher education for over 75 years. ABET currently accredits some 2,800 programs at more than 600 colleges and universities nationwide. Over 1,500 dedicated volunteers participate annually in ABET activities.

3. The resulting sequence of competencies thus neither entirely conforms to existing assessment criteria, nor is expected to be the selection developed by JTC-3 in the future.
4. The 6 levels of achievement defined by Bloom's taxonomy were used to form the columns of the matrix.
5. Once the basic matrix was developed, guidance was obtained by studying the competency profile for civil engineering developed by ASCE (shown in Figure 1). This provided a base case against which the levels of achievement for each sub-discipline could be raised or lowered.

In the future it is expected that JTC-3 will follow the ASCE procedure of developing a full rubic (competency vs level of achievement matrix) for Geo-Engineering, and then establish the competency profiles for each sub-discipline. A process for undertaking this task is described in Section 4.9

In spite of the limitations imposed by the fact that these are preliminary conceptual representations, a review of the four profiles in Figure 2 show distinct patterns of strength and specialisation for each subdiscipline. Accordingly, Figure 2 demonstrates, on a conceptual level, some of the advanges of a competency-based assessment approach applied to Geo-Engineering with its several sub-disciplines.

### 4.9 Proposed Approach for Developing the Geo-Engineering Rubic.

To develop the civil engineering rubric, the ASCE BOK2 Committee first "filled in" the entire rubric, that is, all six of Bloom's Taxonomy levels for 24 outcomes (144 cells), prior to selecting the levels of achievement needed for entry into the practice of civil engineering at the professional level. And only after those levels were established did the committee, working in reverse, make decisions concerning the recommended roles of bachelors, masters and experience (training) in the rubic, thus producing a "competency profile" similar to those discussed in the previous section. Figure 1 illustrates the competency profile developed by the ASCE for civil engineering.

Appendix I of the BOK2 Report (ASCE, 2008) provides a complete definition of this "Outcome Rubic" – taking 9 pages to present the details of the contents of every cell in the matrix. It is proposed that this ASCE presentation be broken down into a series of tables, one for each row in the matrix, describing a single Outcome (competency). Below these definitions one, or several, blank cells can be placed for individuals to add their definitions for a Geo-Engineeering version. These results can then be collated and evaluated and a final Geo-Engineering rubic developed. Figure 3 shows an example of one of these proposed tables.

| Competency Number and Title | | *Level of Cognitive Achievement* | | | | | |
|---|---|---|---|---|---|---|---|
| | | *1 Knowledge* | *2 Comprehension* | *3 Application* | *4 Analysis* | *5 Synthesis* | *6 Evaluation* |
| | | ▭ *To enter professional practice, an individual must be able to demonstrate this level of achievement* | | | | | |
| | | **Foundational Outcomes** | | | | | |
| **ASCE Description** | 1 Mathematics | ***Define*** *key factual information related to mathematics through differential equations* (B) | ***Explain*** *key concepts and problem-solving processes in mathematics through differential equations* (B) | ***Solve*** *problems in mathematics through differential equations and* ***apply*** *this knowledge to the solution of engineering problems* (B) | ***Analyze*** *a complex problem to determine the relevant mathematical principles and then apply that knowledge to solve the problem* | ***Create*** *new knowledge in mathematics* | ***Evaluate*** *the validity of newly created knowledge in mathematics* |
| **Geo-Engineering Description** | | | | | | | |

Figure 3. Example of proposed table for creating the Geo-Engineering rubic, using the ASCE civil engineering rubic as a guide.

## 5. PROPOSED NEXT STEPS AND TASKS FOR JTC-3

The following 8-step program of tasks is proposed to the JTC-3 membership:

- The initial steps of this program are coordinated with the October 2009 ISSMGE Meeting in Alexandria, and the 2010 IAEG Congress in Auckland, New Zealand.
- Later steps will coordinate with two already-scheduled North American conferences: the 54th AEG Annual Meeting held in Alaska in September 2011, and the combined XIV Pan-American Conference on Soil Mechanics and Geotechnical Engineering and V Pan-American Conference on Learning and Teaching of Geotechnical Engineering planned for Toronto, Canada, in October, 2011. It would be desirable to identify additional appropriate regional meetings in other parts of the World that are scheduled for late 2011 or early 2012, so that similar meetings and discussions can be undertaken.
- Final presentation of the completed formal JTC-3 report can then be made at the Federation of the International Geo-engineering Societies (FedIGS) International Conference scheduled in Hong Kong in 2012.

### 5.1 Description of the Eight Steps

Step 1:

As a first step, it appears necessary to consider how to incorporate Geological Engineering into the Joint European Working Group framework, as described by Rengers & Bock (2008). Figure 4 reproduces the Joint European Working Group Report's Figure 1, that illustrates this framework. As noted in Section 4.1, competency criteria have already been proposed for Engineering Geologists, and for Soil and Rock Engineers (Rengers & Bock, 2008), and for Geological Engineers Higgins, 2008). In the USA, and in Canada, it is the geological engineering programs that are educating many of the individuals who ultimately become engineering geologists. Geological Engineering programs are apparently successful in Portugal and Spain, and these educational directions will no doubt affect instruction in South America. Geological Engineering programs also exist in other countries as well.

Thus it appears critical that the JTC-3 studies should somehow modify, or add to, the existing diagrams such as Joint European Working Group Report's Figure 1 (Figure 4), and the Rengers & Bock illustrations (Figure 5) so as to include a Geological Engineering.

Step 2:

This step involves two inter-related tasks:

- Consider the competency lists for Engineering Geology, Soil Engineering, and Rock Engineering proposed by Rengers & Bock (2008) and for Geological Engineering (Higgins), as provided in the attached "Competencies Tables". Update or revise them after reading the ASCE BOK-2 Report and according to the discussions existing comptency lists in Section 4.1.
- Modify the ASCE rubic matrix (of 144 cells, consisting of 24 Outcomes and 6 levels of achievement) into one providing competencies and definitions of Levels of Achievement appropriate to Geo-Engineering. The methods for accomplishing this task are discussed in Section 3.3 (describing the ASCE Rubic), and Sections 4.2 and 4.3 that provide some preliminary suggestions for an appropriate procedure.

Both of these tasks are substantially underway with the materials presented in Section 2, 3 and 4. The review of these tasks should be a major topic of discussion by the JTC-3 membership at the Alexandria meeting. Subsequently, the documents produced by these tasks can be revised, and a draft report prepared, through e-mail exchanges that are circulated to the entire JTC-3 membership following the Alexandria meeting.

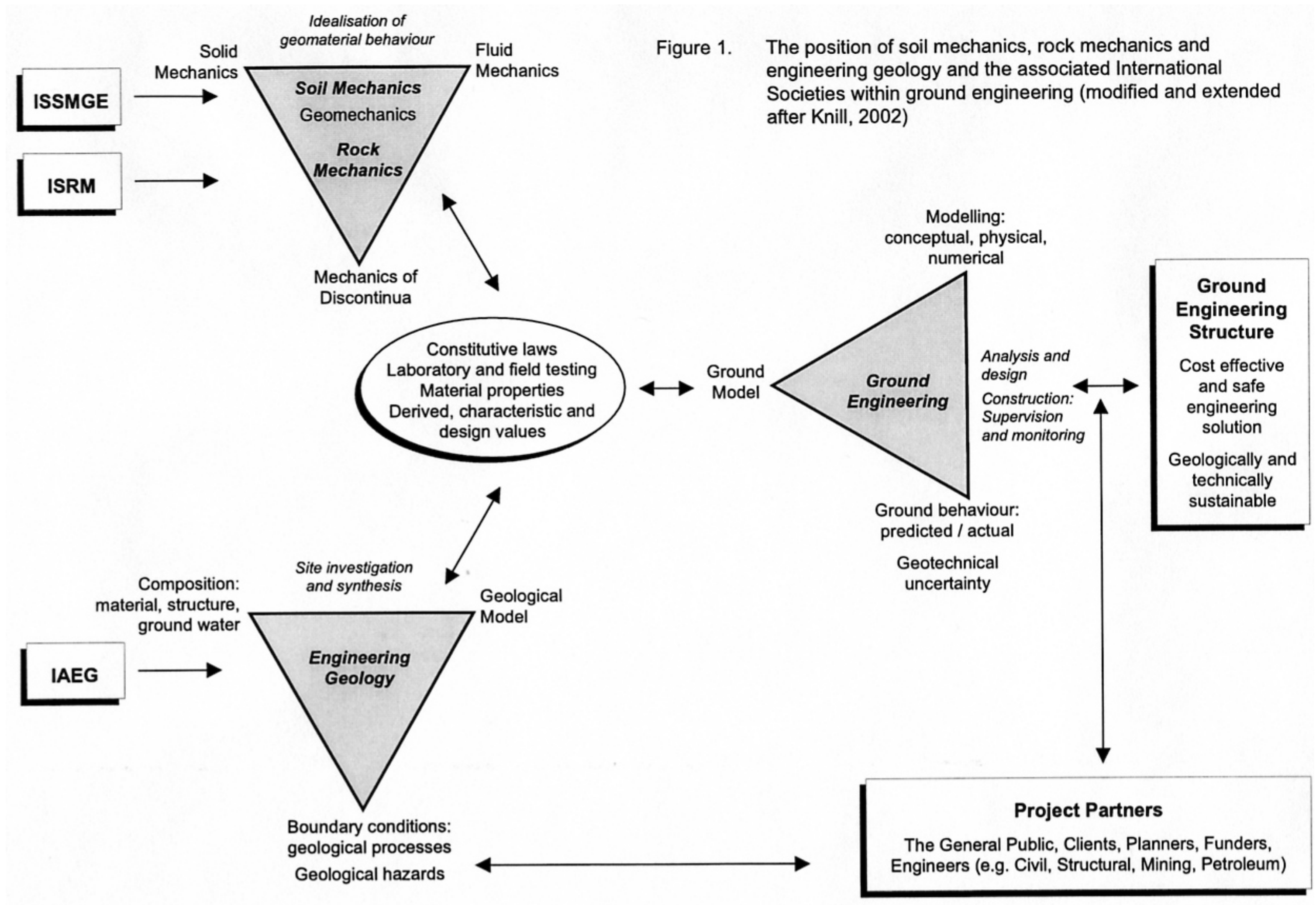


Figure 4. Joint European Working Group Report's Figure 1 illustrates the interactions and relationships among soil mechnaics, rock mechanics, and engineering geology within Geo-Engineering.

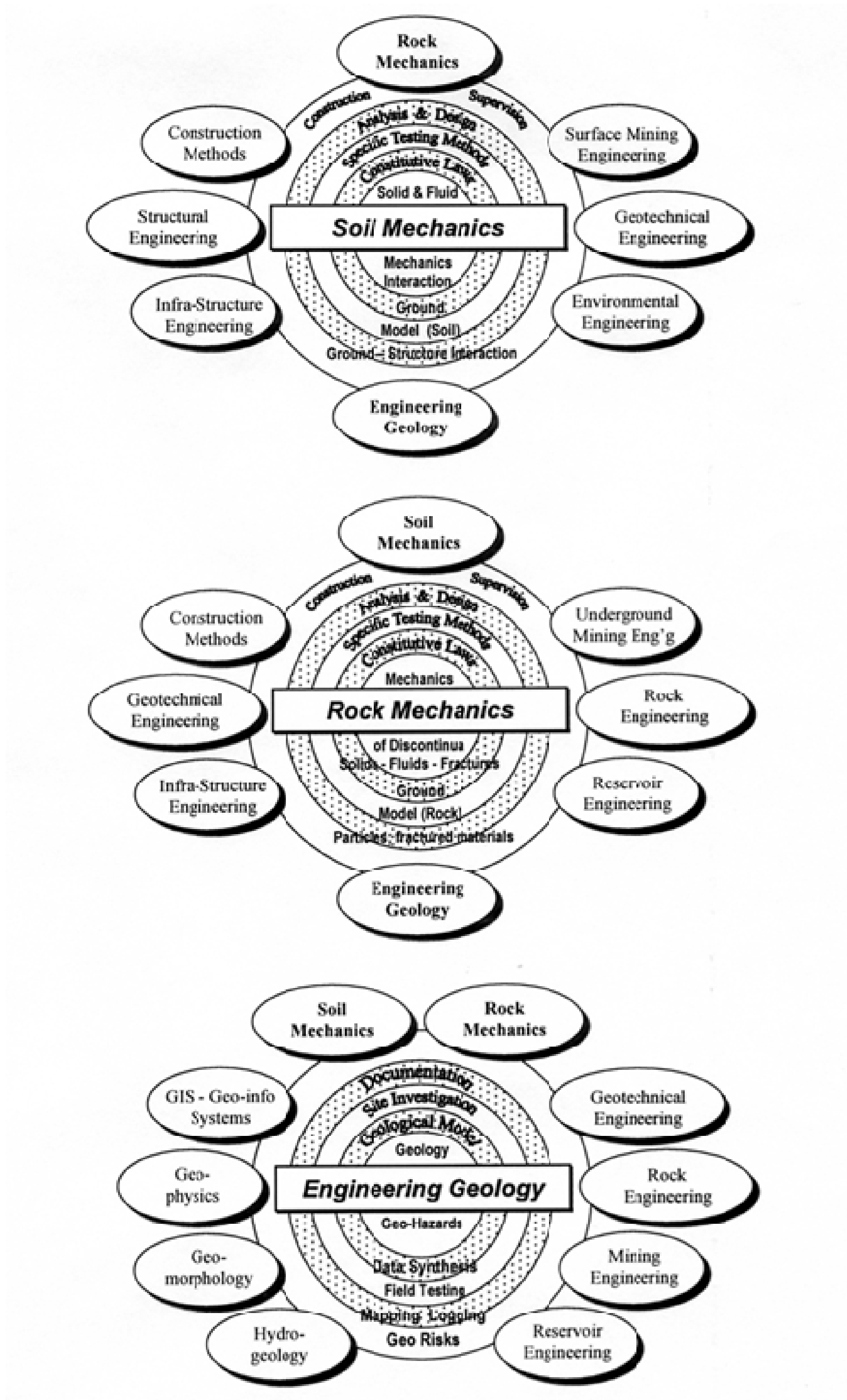


Figure 5. Competencies for Soil Mechanics (top), Rock Mechanics (center) and Engineering Geology (bottom)
(SOURCE: JEWG, 2008, Figures 2-4)

Step 3:

This step is to define a single comprehensive set of competencies covering the whole field of Geo-Engineering. It can be accomplished by reviewing the materials produced by the tasks undertaken in Steps 1 and 2, and the discussions at the Alexandria meeting. Step 3 can be completed by e-mail exchanges among the entire JTC-3 membership immediately following that meeting. Step 3 will produce an overall set of competencies required for the entire field of geo-engineering.

Step 4:

After completion of Step 3, Step 4 undertakes the definition of a desired competency profile for each of the 3 (or 4, including geological engineering) specialisations in the field of geo-engineering. A desired competency profile defines the minimum acceptable levels of achievement required by an individual desiring acceptance as a professional in the specialisation.

Preliminary guidance that should govern this step has been provided in Sections 3.5, 4.7 and 4.8. This process will use the new Geo-Engineering rubic matrix accepted in Step 3, and follows the decision making process adopted by the ASCE in producing a profile for the general field of civil engineering. To be fully implemented, this process must also develop "narratives" or "explanations" – similar to those developed in the ASCE Report Appendix J – for each of the 4 specialisations (Engineering Geology, Geological Engineering, Geotechnical Engineering, Rock Mechanics).

For practical reasons, these competency profiles should be prepared and reviewed by subgroups of the JTC-3 members having the appropriate experience and expertise in the specialisation (sub-disciplines) to be able to address the concerns of a particular specialisation (Engineering Geology, Geological Engineering, Geotechnical Engineering, Rock Mechanics). Furthermore, it is very desirable these subgroups should communicate with the relevant professional society, such as IAEG for Engineering Geology, ISSMGE for Geotechnical Engineering, and ISRM for Rock Mechanics. It would also be desirable to interact with as many national groups representing these specialisations as is practical. The aim is to achieve as wide as possible set of representative views and to incorporate regional specifics within an international framework.

This lofty goal may not be achievable, but at least an attempt should be made. Some specialisations, such as Geological Engineering, may present some difficulties. They are important in only some countries or regions. In the USA the Society of Mining, Metallurgy, and Exploration (SME – the modern descendent of the Society of Mining Engineers) has taken responsibility for Geological Engineering accreditation, and this means there is no direct link to IAEG, ISSMGE, or ISRM for Geological Engineering in the USA. However, in Canada, Geological Engineers, Engineering Geologists, Geotechnical Engineers, Hydrogeologists, and several other specialisations have professional links with one or more divisions of the Canadian Geotechnical Society, which is also the Canadian national organization for ISSMGE, ISRM, and IAEG. By being aware of such differences, and also the opportunities for collaboration, the JTC-3 should be able to successfully complete Step 4.

Step 5:

The resulting set of competency profiles, including associated "narratives" and "discussions", developed in Step 4 for each of the 3 (or 4) specialisations (Engineering Geology, Geological Engineering, Geotechnical Engineering, Rock Mechanics) must be discussed/amended/approved at a JTC-3 meeting. These materials can be circulated by e-mail exchanges among the entire JTC-3 membership prior to the meeting. The logical time/location for such a JTC-3 meeting is during the IAEG 2010 Congress in Auckland, New Zealand in September 2010.

Step 6:

Following Step 5, JTC-3 must formally prepare, discuss, and ultimately approve a draft document (including any discussion reports and amendments) describing the process followed by JTC-3. The resulting draft must include materials similar to those shown in ASCE Appendix I for each of the 3 (or 4) specialisations. The JTC-3 members will have to decide who will be responsible for that task. However, it seems that all draft materials can be circulated and reviewed by e-mail exchanges among the entire JTC-3 membership.

Step 7:

Step 7 involves the subsequent discussion/amending/approval process for the draft document produced in Step 6. Once again, it seems that all draft materials can be circulated and reviewed by e-mail exchanges among the entire JTC-3 membership.

Step 8:

This step involves the presentation of the final report of JTC 3 to the Geo-engineering Community.

It appears feasible to consider major presentations of this report to the North American engineering geology community at the 54th AEG Annual Meeting, to be held in Anchorage Alaska on September 19-24, 2011; and to a broader international geo-engineering audience (but with a Pan-American bias) at the combined XIV Pan-American Conference on Soil Mechanics and Geotechnical Engineering and V Pan-American Conference on Learning and Teaching of Geotechnical Engineering, both scheduled for Toronto Canada on October 3-6, 2011.

The formal presentation of the final printed report prepared by JTC-3 to the Geo-engineering Community can then be completed at the Federation of the International Geo-engineering Societies (FedIGS) International Conference scheduled in Hong Kong in 2012. Niek Rengers has suggested this as the most appropriate final completion of the JTC-3 tasks, but at this time a definite date for this meeting cannot be found.

## 5.2 Proposed Timetable

It is proposed that the JTC-3 address these tasks according to the following time-table:

- Steps 1 and 2: These are substantially completed with this report, the remaining portions of these tasks require review by other members before end of July 2009
- Step 3: This can be the major topic of discussion during the JTC-3 meeting in Alexandria, and can be completed by e-mail communications among JTC-3 members in the months immediately following the meeting. It is suggested that this step be completed by December 2009.
- Step 4: It is suggested that this be undertaken over a 5-month period in the Spring of 2010, and be completed in May 2010
- Step 5: This involves circulation of draft materials by e-mail communications among JTC-3 members in the months prior to the IAEG 2010 Congress in Auckland, New Zealand in September 2010. Then the draft competency profiles can be the major topic of discussion at the JTC-3 meeting during the IAEG 2010 Congress in Auckland, New Zealand in September 2010.
- Step 6: Preparation of draft document describing the process followed by JTC-3 and containing all appropriate documentation. This should be completed within a 6-month period, and be finished in April 2011
- Step 7: Discussion/amending/approval process for the draft document produced in Step 6. A 4-5-month period should be sufficient, allowing for presentations to be developed as defined in for Step 8, below.
- Step 8: Presentations of completed draft JTC-3 report to:
    - AEG 54th Annual Meeting, Anchorage Alaska – September 19-24, 2011
    - XIV Pan-American Conference on Soil Mechanics and Geotechnical Engineering and<br>V Pan-American Conference on Learning and Teaching of Geotechnical Engineering<br>(both in Toronto Canada – October 3-6, 2011)

Niek Rengers has suggested that Step 8 be completed at the Federation of the International Geo-engineering Societies (FedIGS) International Conference scheduled in Hong Kong in 2012. At this time a definite date for this meeting cannot be found.

Table 6 summarizes this proposed schedule in a Calendar format; it includes the year 2012 to allow for later entry of the FedIGS Hong Kong meeting.

TABLE 6. Proposed Schedule of JTC-3 Tasks

| YEAR | MONTHS | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | JAN | FEB | MAR | APR | MAY | JUN | JULY | AUG | SEPT | OCT | NOV | DEC |
| 2009 | | | | | ◄— STEPS 1 & 2 —► | | | ◄— STEP 3 | | * | | —►* |
| 2010 | ◄— STEP 4 | | | | —► | ◄— STEP 5 | | | —►** | ◄— STEP 6 | | — |
| 2011 | — STEP 6 —► | | | | ◄— STEP 7 | | | —► | ◄— | | STEP 8 | —► |
| 2012 | | | | | | | | | | | | |

* ISSMGE Meeting, Alexandria, Egypt – October 2009

** 11th IAEG Congress, Auckland, New Zealand – September 2010

XIV Pan-American Conference on Soil Mechanics and Geotechnical Engineering and
V Pan-American Conference on Learning and Teaching of Geotechnical Engineering
(both in Toronto Canada – October 3-6)

2011 AEG Annual Meeting, Anchorage Alaska – presentation to North American audience

## REFERENCES


ASCE Body of Knowledge Committee. 2008. *Civil Engineering Body of Knowledge for the 21st Century-2nd Edition (BOK2)*, American Society of Civil Engineers, Reston, Virginia, 181p. A free downloadable PDF version is available (size 1.1Mbytes) from: http://www.asce.org/professional/educ/

Bloom, B.S., Englehart, M.D., Furst, E.J., Hill, W.H. & D. Krathwohl. 1956. *Taxonomy of Educational Objectives, the Classification of Educational Goals, Handbook I: Cognitive Domain,* David McKay, New York, NY.

Bock, H. 2009. Core Values, Competences and Issues in Engineering Geology: A European Perspective, In: *Engineering Geology for Tomorrow's Cities* (Culshaw, M.G., Reeves, H.J., Jefferson, I. & T.W. Spink, Eds.), Geological Society, London, Engineering Geology Special Publications, Vol. 22, pp. 289-297.

Bock, H., Broch, E., Chartres, R., Gambin, M., Maertens, J., Maertens, L., Norbury, D., Pinto, P., Schubert, W. & H. Stille. 2004. The Joint European Working Group of the ISSMGE, ISRM and IAEG for the Definition of Professional Tasks, Responsibilities and Co-operation in Ground Engineering, In: *Engineering Geology for Infrastructure Planning in Europe: A European Perspective, (R. Hack, R. Azzam & R. Charlier, Eds.)*, Lecture Notes in Earth Sciences No. 104, Springer-Verlag, Berlin, pp. 1-8.

Fookes, P.G. 1997. 1st Glossup Lecture: Geology for Engineers: The Geological Model, Prediction and Performance, *Quarterly Journal of Engineering Geology and Hydrogeology*, Vol. 30, pp. 293-424.

Higgins, J.D. 1991. Geological Engineering Programs as Academic Preparation for Careers in Engineering Geology and Hydrogeology. In Higgins J.D. & Williams J.W. (eds.) *Academic Preparation for Careers in Engineering Geology and Geological Engineering*, Association of Engineering Geologists Special Publication No. 2, pp.7-11.

Higgins, J.D. 2003. Selection and Training of Program Evaluators for ABET Accreditation Evaluations. In C.D. Elifrits (Ed.) *Proc. Symp. Visioning the Future of Engineering Geology: Degree Program Quality and Accreditation, AEG Annual Meeting, Vail, Colorado, Sept. 17, 2003*, Republished as AEG Special Publication 19 (2004), pp. 455-462 [CD-ROM]

Higgins, J.D. & J.W. Williams. 1991. *Academic Preparation for Careers in Engineering Geology and Geological Engineering*, AEG Special Publications No. 2, 83p.

Joint European Working Group (JEWG). 2008. *Professional Tasks, Responsibilities and Co-operation in Ground Engineering*, Report of the Joint European Working Group to the Presidents of the IAEG, ISRM and ISSMGE, 20p.

JTC4. 2009. *Risk, Recognition and Reward in Geotechnical Professional Practice*, Report by Joint Technical Committee JTC4 on Professional Practice, August 2009,109 p. [Available for download from: http://www.fedigs.org/sites/default/files/JTC4-FinalReport-Rev1.pdf]

Knill, Sir J. 2002. *Core Values: The First Hans Cloos Lecture*. Proceedings, 9th Congress, IAEG, Durban, 16-20 Sept. 2002, p. 1-45.

Manoliu, I. & N. Radulescu, (Eds). 2008. *Proceedings,1st International Conference on Education and Training in Geo-Engineering Sciences, Constantza, Romania, 2-4 June 2008,* CRC Press, Taylor & Francis Group, London, 514p.

Mathewson, C.C. 1982. Academic Preparation for the Engineering Geologist, *Bulletin of the Association of Engineering Geologists*, Vol. XIX, No.2, pp. 155-160.

Morgenstern, N.R. 2000. Common Ground, In *GeoEng2000, International Conference on Geotechnical & Geological Engineering, Melbourne, Australia, Vol.1: Invited Papers*, Technomic Publishing Co., Lancaster, PA, USA, pp.1-30.

Rengers, N. & H. Bock. 2008. Competency-oriented curricula development in Geo-engineering with particular reference to Engineering Geology, In: *Proceedings,1st International Conference on Education and Training in Geo-Engineering Sciences, Constantza, Romania, 2-4 June 2008, (I. Manoliu & N. Radulescu, Eds)*, CRC Press, Taylor & Francis Group, London, 2008, pp. 101-110.

Rosenbaum, M.S. 1997. Environmental Geology Courses within University Education, In: *Proceedings of the International Symposium on Engineering Geology in the Environment, Athens, (P.G. Marinos, G.C. Koukis, G.C. Tsiambaos & G.C. Stournaras, Eds.)*,, A.A. Balkema Publishers, Vol. 4, pp. 3655-3666.

Tepel, R.E. 2009. The Core Attributes of Engineering Geology: A US Perspective, In: *Engineering Geology for Tomorrow's Cities* (Culshaw, M.G., Reeves, H.J., Jefferson, I. & T.W. Spink, Eds.), Geological Society, London, Engineering Geology Special Publications, Vol. 22, pp. 273–276.

Turner, A.K. 2004. *Geological Engineering*, Encyclopedia of Geology [R. Selley, R. Cocks, and I. Plimer, Editors], Academic Press, Vol. 3, pp. 35-42.

Turner, A.K. 2008. Education and Professional Recognition of Engineering Geologists and Geological Engineers in Canada and the United States, In: *Proceedings,1st International Conference on Education and Training in Geo-Engineering Sciences, Constantza, Romania, 2-4 June 2008, (I. Manoliu & N. Radulescu, Eds)*, CRC Press, Taylor & Francis Group, London, 2008, pp. 111-118.

Extracted from JEWG Report: Version 2008

**APPENDIX A:**

## Competencies of Soil Mechanics Engineers, Rock Mechanics Engineers and Engineering Geologists: Tasks, responsibilities and co-operation

The diagram of Figure 1 (*reproduced as Figure 4 on page 19 in the main body of this report*) depicts the competencies of soil mechanics engineers, rock mechanics engineers, and engineering geologists in solving Ground Engineering problems. 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 Engineering, Rock Mechanics Engineering and Engineering Geology, are focussed on solving Ground Engineering problems.

As shown in Sections 4 and 5 *(of the JEWG Report)*, the tasks identified in Figures 1 to 4 (*reproduced as Figures 4 and 5 on pages 19 and 20 in the main body of this report*) 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 soil mechanics engineers, rock mechanics engineers or engineering geologists. The task should always be carried out by the person with the relevant competence.

Notwithstanding the above, there are definite preferences for soil mechanics engineers, rock mechanics engineers and engineering geologists to carry out specific tasks and to accept professional responsibility. These are summarized in Table 1 (*reproduced as Table 3 on page 13 in the main body of this report, and so not included here*) and described in some detail in Attachments 3 to 5 *(which are included on subsequent pages of this Appendix)*.

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 soil and/or rock mechanics engineers and engineering geologists can be linked to the Geotechnical Categories as specified in Table 2.

Table 2. Level of co-operation between Soil Mechanics Engineers, Rock Mechanics Engineers and Engineering Geologists.

| Geotechnical Category Eurocode 7 (EN 1997-1) | | Co-operation |
|---|---|---|
| No. | Description / Example | |
| 1 | Small and relatively simple structures with negligable risk | Optional |
| 2 | Conventional geo-engineering structures and foundations with no exceptional risk or difficult ground or loading conditions | Desirable |
| 3 | Very large or unusual geo-engineering structures; abnormal risks or exceptionally difficult ground or loading conditions; structures in highly seismic areas. | Essential |

Soil mechanics engineers, rock mechanics engineers, and engineering geologists are unified in their overall objective to create a geologically and technically sustainable, cost effective and safe engineering solution.

Geo-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.

Attachment 3

## Professional Competencies of Soil Mechanics Engineers

Key competencies of soil mechanics engineers are a sound knowledge of the mechanical behaviour of soils, the design of geotechnical structures and the supervision of their construction. Soil structures are commonly located at or near the surface. 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 soil mechanics 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.

Soil mechanics 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, soil mechanics 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. Examples are the oedometer test (consolidation characteristics of undisturbed saturated cohesive soil) and the pressiometer test in boreholes (deformation characteristics of the in-situ soil).

- *Complex constitutive laws*
  Soils 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). All of these features contribute to constitutive laws for soils, which are more complex and variable than those for other common construction materials such as steel, concrete and glass.

- *Numerical modelling of complex geo-engineering structures*
  The mathematical (commonly numerical) modelling of geo-engineering 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 have all become amenable to modelling in the geoengineering of soil.

- *Size of the ground model and boundary conditions*
  Each geo-engineering 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 the soil mechanics engineer and the engineering geologist.

- *Design procedures and construction methods adjusted for uncertainty*
  Irrespectively 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. Soil mechanics 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 preconceived 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 a soil mechanics engineer are a study in engineering at tertiary level with significant components in civil and structural engineering and several years of practical on-site professional experience.

Attachment 4

## Professional Competencies of Rock Mechanics Engineers

Key competencies of rock mechanics engineers are a sound knowledge of the mechanical behaviour of rocks, the design of rock structures and the supervision of their construction.

Rock structures are often located in the deeper ground and thus are closely linked to the engineering of sub-surface structures such as tunnels, caverns and mines as well as surface structures such as roads and quarries. The design and construction have to be adjusted to the prescribed lifetime of the rock structure. The lifetime may be short (order of weeks, months or years as e.g. in mining), medium (order of decades or centuries as in tunnels and dams) or very long (order of hundred thousand of years as in the geologic disposal of radio-active waste). In a rock design, the two potentially conflicting requirements of safety and cost effectiveness are to be brought together in an optimal manner. Considerations include the stability of the rock structure (e.g. explosive-style rock burst ground failure), its deformability (e.g. squeezing ground), and the hazard potential of fluids (e.g. water inrush in tunnels; explosive gases in underground coal mines). Extensive use is to be made of theoretical-mathematical modelling and of testing and quality controls both in the laboratory and in the field. The investigations are carried out with the view to develop project documents for the various planning, design, tendering, construction, monitoring and maintenance stages.

There is a wide spectrum of further professional tasks that are typically carried out by rock mechanics engineers. The tasks include:

- prevention of rock collapse, e.g. by the design of a rock bolting scheme;
- promotion of rock collapse, e.g. by the design of a drilling and blasting scheme for optimal rock fragmentation;
- stimulation of the hydraulic conductivity of the rock, e.g. by hydraulic fracturing techniques for deep geothermal energy exploitation;
- design of rock improvement measures, e.g. by injection grouting of dam abutments;
- design of rock cutting tools in road headers, TBMs (tunnel boring machines), and other highly specialised rock construction equipment, usually in co-operation with mechanical engineers.

With soil mechanics engineers and engineering geologists they share the concerns for geoenvironmental issues and the specific problems associated with uncertainty and risks.

Rock mechanics engineers are familiar with the pertinent methods of civil, geotechnical and mining engineering. They are knowledgeable on 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, rock mechanics engineers are versatile with specialised 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 rocks. Examples are the post-failure compression test (fracture development of brittle rock beyond failure) and a wide range of in-situ stress measuring and monitoring tests in boreholes.
- *Coupled hydro-mechanical-thermal constitutive laws*
  Rocks, like soils, are multi-phase materials (solids, fluids, gases). Unlike soil, however, rocks are commonly fragmented by joints and faults (rock mass). Inherent geological structures such as bedding and schistosity cause scale and orientation dependencies of the material characteristics. Moreover, rocks are often subjected to elevated temperatures (deep underground mines; drilling for gas and oil;

heat generated by radio-active waste). All of these features contribute to complex and unique constitutive laws for rocks.

- *Numerical modelling of complex rock structures*
  The mathematical (commonly numerical) modelling of rock structures requires methods that are specially adjusted to accommodate the constitutive laws for rocks and to cope with the large structural diversity of geology. Unique coupled hydro-mechanical-thermal models with non-linear, anisotropic, time-dependent material behaviour as well as plastification of intact rock and shearing along discontinuities were developed and are commonly used in rock engineering design.

- *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 rock mechanics deliberations which commonly is significantly higher than in other branches of civil and structural engineering. Rock engineers cope with these uncertainties by specially adjusted design, construction and contractual procedures, particularly in tunnelling construction.

Preconditions for developing the competencies of a rock mechanics engineer are a study in engineering at tertiary level with significant components in civil, structural and mining engineering and several years of practical on-site professional experience.

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Attachment 5

## Professional Competencies of Engineering Geologists

The key competency of engineering geologists in geo-engineering is the characterisation 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 cooperation with soil and/or rock engineers.

Acquaintance with geological processes and awareness of the natural environment through fieldwork give engineering geologists key competencies in geological hazard prevention and on geoenvironmental 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. Uncertainty and risks are fundamental concerns for engineering geologists. Geological observation will always remain partial because most soils and rocks can never be fully exposed, and are either buried or otherwise obscured. 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 soil and rock mechanics 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.

- *Specialised 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.

- *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 geo-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.