Geotechnical education for modern practice - Key competences for researcher and consultant

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ABSTRACT
What key competences are required for the geo-engineer, and what does an employer want? And why would an employer wish to hire one who is good at both research and consulting? In light of present geotechnical practice, this contribution highlights future trends, required competence and knowledge gaps, the need for interdisciplinary education and the increasing importance for the geotechnical profession of addressing societal needs.

RÉSUMÉ
Quelles sont les compétences requises pour l'ingénieur géeotechnicien pour qu'il puisse répondre aux défis futurs? Et est-ce un avantage d'acquérir, déjà au niveau universitaire, une bonne expérience de recherche et de maîtriser à la fois recherche et consultation. Tout en traçant une vision pour la géotechnique future, cette contribution suggère de nouvelles compétences à intégrer au curriculum post-gradué des universités, avec beaucoup plus d'interdisciplinarité et plus d'attention sur les issues sociétales.

1 GEOTECHNICAL PRACTICE TODAY

What key competences are required for the geo-engineer? What does an employer need? And why would an employer want to hire someone who can be both a researcher and a consultant? Alfaro et al (2008) correctly state that today's geotechnical engineering is much broader than the traditional soil mechanics. Practice includes soil, rock, snow, frozen soils, hydrogeology, engineering geology, engineered materials, ground improvement, geophysics, geochemistry. In terms of approaches, practice includes numerical modelling, laboratory and in situ testing and to some degree, hazard ad risk assessment.

2 PRESENT AND FUTURE TRENDS

There is a trend towards developing more sites on poor ground or ones that have previously been used for industrial purposes. As a consequence, there will be an increasing need for ground improvement methods involving novel geotechnical processes and innovative equipment. With enhanced urbanisation and the development of mega-cities, construction of underground infrastructure will increase (Burland, 2008). This will require improved understanding of ground-structure interaction. Ground improvement and urban underground construction will entail careful construction control (instrumentation and real-time monitoring). Significant developments in these techniques can be expected.

The benefits of improved management of ground risk should be more widely recognised. There will be increased risk associated with natural hazards, due to global change including climate change population growth and demographic patterns and policies. Ground risk is properly managed by (1) ensuring that the client is advised on the risks, (2) obtaining the right specialist advice early in a project and (3) ensuring that the ground is adequately investigated.

There is a strong demand for geotechnical engineers to solve society's needs for a more liveable environment. New and ever more challenging environmental issues will make the design and construction of new transportation and other facilities depend on reliable predictions of geologic conditions. Increasingly sophisticated designs require the involvement and acceptance of the geo-engineer and engineering geologist.

In North-America, the enrolment of students in engineering and science, especially geosciences, has been falling (Turner 2005). The drop in enrolment is partly a function of demographic trends, but also a reflection that other professions seem more attractive, or the student population is less interested in narrow "specialty" fields without "social" content. At the same time, economic pressures faced by many universities encourage the elimination of "smaller specialist" and high-cost programs.

Geo-engineering is at a crossroads where high-tech solutions meet expanding applications. The scope of geotechnical problems is changing, and yet geo-engineers and geo-scientists are for the most part not prepared to these changes. Engineering solutions need to meet societal and environmental issues. Sustainable development of the built environment and natural resources is now an imperative. Sustainable development will require a new understanding and management of the behaviour of soil and rock materials, which also need to meet economic and environmental goals.

An expansion of the traditional role for geo-engineers will be geo-engineering of systems, to include social, environmental and scientific issues into engineering solutions. This expanded scope will require new types and quantities of data, new benchmarking, and new modelling (NRC, 1999; 2006). New problems will include the legacy and future of energy use, environmentally responsible geo-engineering, economically beneficial solutions for infrastructure in urban environments, especially for the developing world, and the emerging issues of global change (climate, population and policy changes).

2.1 Knowledge gaps

NRC (1999) grouped the societal needs addressed by geo-engineering into seven broad national issues:

1. Waste management
2. Infrastructure development and rehabilitation
3. Construction efficiency and innovation
4. National security
5. Resource discovery and recovery
6. Mitigation of natural hazards
7. Frontier exploration and development

Knowledge gaps continue to challenge the practice of geo-engineering, e.g. the ability to fully characterize the underground; effects of time; effects of bio-geo-chemical processes; stabilisation of soils and rocks; computing, information and communication technologies; and understanding geo-materials in extreme environments.

Geo-engineering is burdened by a lack of adequate characterisation and paucity of information, which increases uncertainty in design. There is a need for improved technology for site characterisation, improved quantification of the uncertainties, and improved methods for assessing the potential impacts of the uncertainties on engineering decisions. This was aptly described by the book title "Without site investigation, ground is a risk", published by Thomas Telford (Burland, 2008).

Promising opportunities exist for advancing geo-engineering through interaction with other disciplines, e.g. biotechnology, nanotechnology, micro-sensors, geo-sensing, information technology, cyber-infrastructure, multi-spatial, multi-temporal geographical modelling (NRC, 2006), hydrology, social sciences, etc. Recent years have seen a growing emphasis on the importance of recognising geotechnical hazard, assessing the frequency (probability per unit of time) of a danger, assessing the risk (vulnerability and consequences), and contributing to the management of geo-risk.

2.2 Geo-engineering for earth systems

Few activities are isolated in the rapidly changing world. A decision in one location will nearly always have repercussions elsewhere, sometimes with dramatic consequences. There is a need for a wider geo-engineering discipline. Sustainable development provides a new arena for geotechnical practice, where techniques, instruments and scientific advances of multiple disciplines are brought to bear on ever more complex systems.

2.3 Interdisciplinary education and research

Educational institutions are usually organised by discipline. The above needs can be met only if the institutions recognise the challenges and find new ways for education and research. Cooperation must be invited, encouraged and rewarded. A more diverse work force in terms of educational background, technical expertise, application domain, gender, social background, nationality and culture, is required to meet tomorrow's challenge. The author's perception is that the universities are stronger on interdisciplinary research than interdisciplinary engineering education.

3 COMPETENCES REQUIRED

The foremost areas of competence required of geotechnical engineers are (1) a sound understanding of the mechanical behaviour of soils and rocks, (2) the ability to design geotechnical structures, (3) the authority and knowledge to supervise a construction and (4) the awareness that the potentially conflicting requirements of safety and cost-effectiveness are to be implemented in an optimal manner. Both ground failure and deformation have to be considered to guarantee satisfactory performance during construction and prescribed lifetime. Interaction between the ground and structure should also be assessed. Theoretical modelling and testing, both in the laboratory and in the field, are needed.

Table 1 attempts to describe the key competence for the geotechnical engineer (soil and rock) and for the engineering geologist. The listings are not exhaustive, but they provide an indication of the breadth of the knowledge one has to acquire through his university program and practice, and illustrate the similarity and differences between the required competence for the soil and rock engineer and the engineering geologist.

There is a wide spectrum of additional professional tasks carried out by geotechnical engineers, including the preparation of geotechnical project documents in planning, design, tendering, construction, monitoring and maintenance, concerns for geo-environmental issues and the engineering, scientific and societal issues associated with uncertainty and risks.

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

Geotechnical engineers need to be familiar with the methods of civil and structural engineering, and to be knowledgeable of the basic geo-scientific terminology, methods and processes for communicating with engineering geologists and for judging the consequences of geological factors and processes for geo-engineering structures. Beyond this, geotechnical engineers need to be versatile with specialised geo-engineering methods and procedures, in particular testing methods, constitutive laws numerical modelling of complex geotechnical structures, significance of model used for analysis and boundary conditions, design procedures and construction methods, and effects of uncertainties.

4 WHAT DOES THE EMPLOYER NEED?

The fascination of geo-engineering is the fact that the same design never comes twice. The soil conditions are much too variable and involve at all times some uncertainty, and the solutions are never "standard". Geotechnical engineering is a science of experience. One gets really good at it only when one has seen a large number of different soil profiles, laboratory and in situ test results and performance observations. Each soil and foundation has its own story to tell. This is both and advantage and a drawback, especially when trying to attract students to the field.

What does an employer expect from university graduates in geo-engineering? At NGI, an MSc level is seen as minimum requirement. Other expectations, in addition to the basic geo-teaching in curriculum today (see Table 1), include, for an ideal world:

– Basic and fundamental understanding of soil behaviour, and the meaning of the different soil parameters used in the calculations; the candidate should have taken at least one course on laboratory testing and one course on in-situ testing.
– More emphasis than today on geology during the BSc and MSc programs, and a good understanding of the potential problems associated with different formation or geological processes.
– Ability to find new solutions, or, if difficult, knowledge on where to turn (literature, laboratory program, colleagues, university, research organisations) to find the solution to an unfamiliar geo-problem.
– Communication skills, both written and spoken; fluency in more than one language is a great advantage; awareness and adapting one's communication to the particular audience listening is an essential requirement, an area where unfortunately we do err frequently today!
– Ability to work alone, and in a team!
– Versatility, and even eagerness, to solve a variety of geo-problems, without fear of trying out one's skills in a new area. An ability to carry our research and do consulting work is a definite advantage.
– Ability, and perhaps more importantly, interest in communicating across the different expertises within the geosciences, e.g. geology, geophysics, geography and geotechnical engineering.
– Interdisciplinarity outside the geosciences' boundaries is a requirement for both recruiting candidates for our profession and for meeting society's needs.

The education program should ensure that the engineer can raise awareness on the need for adequate site investigations. A site investigation should be undertaken for every site and every construction. Without a properly carried out, supervised and interpreted site investigation, hazards associated with a proposed design can not be determined. A stakeholder will end up paying for a site investigation whether he had one or not, and probably considerably more if he does not (Burland, 2008).

NGI, a private foundation, does both research and consulting. It prefers to employ candidates who have interest in both research and practice consulting, because the two complement and strengthen each other. In addition, it provides enhanced flexibility, as the portfolio and reserve of projects can vary greatly depending on the research and consulting stakeholders and the funding and contract opportunities.

Universities should give special attention to forming candidates who do good research, enjoy doing it and wish to continue with research outside the academic environment. A geotechnical engineer capable of solving practical problems and capable of taking an abstract problem and staking out research tasks and then leading the research to useful results is a person full of opportunities.

5 CONCLUDING REMARKS

Geo-related knowledge should be the basis for most of the engineering structures in a country. Geotechnical engineering (soil and rock mechanics) is not an exact science with standard answers, but it is not qualified guess-work either. Society and stakeholders need to recognise this. The geotechnical profession is most often not noticed, and seldom in the media, unless a catastrophe occurs (e.g. landslide, dam breach, rock slide, tunnel failure). It is the role of the education institutions to provide an education adapted to the future needs of society, and to ensure adequate visibility. This will be only achieved if focus is set on increased interdisciplinary education and addressing societal needs. It is also the role of universities to ensure that enough and competent faculty is trained to provide the education.

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Table 1. Key competences in geo-engineering profession

Soil Engineer	Rock Engineer	Engineering geologist
Key competence	Key competence	Key competence
– Understanding mechanical behaviour of soil (including pore fluid)	– Understanding mechanical behaviour of rock and fractured materials	– Understanding genesis, geological features and processes of formations
– Setting-up of site-specific ground models with soil parameters (from lab/field/database)	– Setting up of site-specific ground models with rock parameters (from lab/field/database)	– Setting up of site-specific geological models
– Geohazards identification, quantification and mitigation; uncertainty quantification	– Geohazards identification, quantification and mitigation; uncertainty quantification	– Site investigation (specification of the ground composition) and geo-hazard identification (specification of geological boundary conditions)
– Analysis/design on or in soil	– Analysis/design on or in rock	
– Observational method	– Observational method	
– Soil improvement techniques	– Rock improvement techniques	
– Construction supervision	– Construction supervision	
Basic competence	Basic competence	Basic competence
– Familiarity with the pertinent scientific methods in civil and structural engineering.	– Familiarity with the pertinent scientific methods in civil, structural, mining and reservoir engineering.	– Familiarity with the pertinent scientific methods in geo- mining and reservoir engineering
– Basic knowledge of the geo-scientific terminology, working methods, geological processes and quaternary geology for most soils	– Basic knowledge of the geo-scientific terminology, working methods, geological processes and identification of most common rock types	– Basic knowledge in geomechanics and of the design methods in geotechnical and mining engineering
Specialised competence (examples)	Specialised competence (examples)	Specialised competence (examples)
– Lab/field testing methods to model realistically the natural characteristics and the loading of soils	– Lab/field testing methods to model realistically the natural characteristics of rocks and loading of rocks	– Site-related work and field testing
– Instrumentation and monitoring	– Instrumentation and monitoring	– Handling of cartographic documents and geo-information systems
– Numerical modelling to model realistically the structural diversity of geology, using complex constitutive laws (e.g. non-linear, plastic, anisotropic and time-dependent behaviour)	– Numerical modelling, as for soil engineers, with particular emphasis on the discontinuous and particle nature of rock and rock masses (intact rock and discontinuities).	– Observation, documentation and analysis of geological data as keys in contractual disputes
– Design, construction and contractual procedures accounting for geotechnical uncertainty	– Design, construction and contractual procedures accounting for geotechnical uncertainty	– Familiarity with fractured, slaking and ageing materials; soil-rock transition processes (lithology, weathering)
– Earthquake engineering		– Familiarity with geological risk scenarios.
– Hazard and risk assessment, etc		