Geo-engineering, a co-production of applied earth sciences and civil eng.

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ABSTRACT: Civil engineers and engineering geology students are trained side by side in the TU Delft Master in Geo-Engineering, first, to face the challenges of the Dutch subsurface: soft soil conditions with high water table, second, to support the ever-growing economic development of the country while protecting it from flooding and third, to provide innovative solutions for the Dutch dredging, offshore and construction industries, within the Netherlands and worldwide, in the context of a variety of construction projects and contrasting range of environments. Four specialisations are currently offered, in: Engineering Geology, Geomechanics, Geotechnical Engineering and Underground Space Technology, all of which are delivered in English. Expertise gained can be exported to any country with coastal areas, soft soil conditions and/or limited space in respect to its thriving economy. Here, the historic development of the MSc programme is exposed. Lessons are drawn from the short existence of the programme and marketing actions are suggested.

1 INTRODUCTION

1.1 *Adaptative training programmes*

In the last 10 years, TU Delft training programmes in both Civil Engineering and Applied Earth Sciences have sustained major modifications in order to comply with the 1999 Bologna agreement. Programmes had to become more efficient. Some of them had to be integrated into inter-faculty programmes to reach the critical mass of students. All had to allow for the mobility of students within Europe, outside Europe and between Dutch universities. Some programmes took an international dimension by alliance with IDEA league partners. All programmes had to permit the entry of "polytechnics" students. Then, at the demand of the Dutch government, they had to expose bachelor students to other academic disciplines by introduction of broadening next to deepening minors. And, last but not least, all programmes had to adapt to the internet generation, enhancing their creativity and motivation using project-based and problem-based learning approach while fighting against delays in studies.

As a small community in comparison to Civil Engineering, Applied Earth Sciences is flexible with plenty of scope for staff and student interaction. Its programmes are broad-based with a strong international character. They can be tailor-made to accommodate the profile and domain of interest of incoming students. Applied Earth Sciences adapted swiftly to new rules in comparison to Civil Engineering, being more rigid due to its size, traditions and number of intertwined programmes.

1.2 *Creation of the MSc in Geo-Engineering*

In 2006, the shift from the five-year programmes to the three- and two-year BSc and MSc programmes respectively has been seized upon as an opportunity to create a MSc in geo-engineering under the hospices of both Applied Earth Sciences and Civil Engineering. The MSc builds upon expertise in engineering geology and geotechnical engineering in view of new societal and technological developments (Ngan-Tillard 2006). Its programme comprises a total of 120 ECTS (table 1). Its 20 ECTS core, common to all geo-engineering students, includes subjects that are deemed to be essential for a Geo-Engineer. Each of the 4 specialisations, i.e. geomechanics, geotechnical engineering, underground space technology and engineering geology offers a suite

of compulsory courses ranging from 12 to 46 ECTS in total and gives room for 12 to 46 ECTS electives of which a number is imposed or recommended in the field of geo-engineering (table 2). This structure allows students, depending on their taste, to acquire a profile that is more theory, engineering, management or geology oriented. A course may be compulsory for a specialisation and taken as an elective for another geo-engineering specialisation. It can also attract students from fields as diverse as geomatics, mining, petroleum, offshore or structural engineering and can be hosted by other MSc tracks. The 42 ECTS MSc graduation project occupies a large part of the second year and allows further deepening.

Table 1. Structure of the MSc in Geo-engineering

Core	20 ECTS
MSC thesis	42 ECTS
Specialisation	12 to 46 ECTS
Electives	12 to 46 ECTS
Total	120 ECTS

Table 2. MSc courses in geo-engineering

	GM	GE	UST	EG	
Engineering geology					
Geology for Engineers		f	f	f	f

Eng. Geology of Soils and Rocks	e	e	e	s
Site Characterisation, Testing and Physical Modelling	c	c	c	c
Shallow Depth Geophysics (Theory)	e	e	e	s
Shallow Depth Geophysics (Fieldwork)				s
GIS Applications in EG	e	e	e	s
Engineering Geology Fieldwork				s
Geoemechanics				
Material Models for Soil and Rocks	c	c	c	c
Continuum Mechanics	s	e	e	
Soil Dynamics	e	e	e	
Numerical Geomechanics	s	e	e	
Non-linear Methods in Computational Mechanics	s	e	e	
Geohydrology				
Theory of Consolidation	e	e	e	
Ground Water Mechanics and Geohydrology	f	f	f	s
Environmental Geotechnics	e	e	e	s
Geotechnical Engineering				
Numerical Modelling of Geotechnical Problems	c	c	c	c
Rock Mechanics Applications	e	e	e	s
Soil Mechanics Applications				s
Offshore Soil Mechanics	e	e	e	
Subsidence	e	e	e	s
Foundations Engineering and Underground Construction	e	s	s	
Bored and Immersed Tunnels	e	s	e	
Underground Space Technology Special Topics	e	e	s	
Trenchless Technologies	e	e	s	
Embankments and Deep Excavations	f	f	f	
Geo-synthetics in Civil Engineering	e	s	e	
Probabilistic Design	c	c	c	c
Professional Practice				
Ethics for Civil Engineers	f	f	f	f
Geo Risk Management	c	c	c	c
Professional Practice in Engineering Geology				s
Subsurface Management	f	f	f	
Use of Underground Space	f	f	f	s

GM: geomechanics, GE: geotechnical engineering, UST: underground space technology, EG: engineering geology

c: core course, s: specialisation course (compulsory)

e: elective geo-engineering course; (f): convergence course compulosry in either the BSC or MSc programme

1.3 *Creation of the "Soil" and "Applied Earth Sciences" minors*

The creation of the Master in geo-engineering led to the re-organisation of the BSc courses and the formation of a "Soil" and an "Applied Geology" minor, both 30 ECTS and allowing for a mixture of disciplines in the third year of the BSc programme (see table 3).

Table 3. The "Soil" and "Applied Geology" minors

Soil minor (30 ECTS)	Applied Geology minor (30 ECTS)
Geology for Engineers	Minerals and Rocks
Soil Mechanics	General Geology
Fundamentals of Ground water Mechanics and Geohydrology	Geological Maps
	Geology of the Netherlands
	Sedimentology
Fundamentals of Foundation Engineering	Structural Geology
Use of Underground Space	Introduction to Applied Earth Sciences
Geo-engineering project	Excursion
and	Petroleum Geology
one of the following electives	Foundations of Engineering Geology
Hydraulic Structures	Introduction to Reflection
Embankments and Deep	

Excavations Seismics

Subsurface Management

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2 STRUCTURE OF THE MSC PROGRAMME IN GEO-ENGINEERING

2.1 *The core of the MSc programme*

The core of the Geo-Engineering Master programme provides students with a conceptual understanding of the mechanical and hydrological interactions between sub-surface materials and engineered structures. It is primarily designed for students to obtain a sound understanding of the fundamentals of geo-engineering and also to encourage cross-fertilisation of ideas from different fields. Probabilistic design, ground risk and its management have an increased visibility (van Staveren 2008) and (Barends 2008), reflecting the aim of the Geo-Engineering Section: to reduce ground uncertainty with the aid of geological and geotechnical engineering expertise in order to limit risk in construction and to assist the sustainable development of low-land countries, their near-shore and offshore areas.

2.2 *The 4 specialisations*

For each specialisation, next to the core (c), a number of compulsory courses (s) are specified and a number of electives ((e) and (f)) taken in a pool of courses are recommended to cover a wide range of geo-engineering sciences and applications (table 2).

A student may use the time available for electives to:

- Further deepen the knowledge within the selected specialisation, by choosing remaining elective courses in the corresponding domain;

- Broaden his/her views by choosing courses offered by the alternative Geo-engineering specialisations

- Further broaden his/her knowledge by taking courses in hydraulic engineering, transportation and planning, geomatics, management, etc (figure 1).

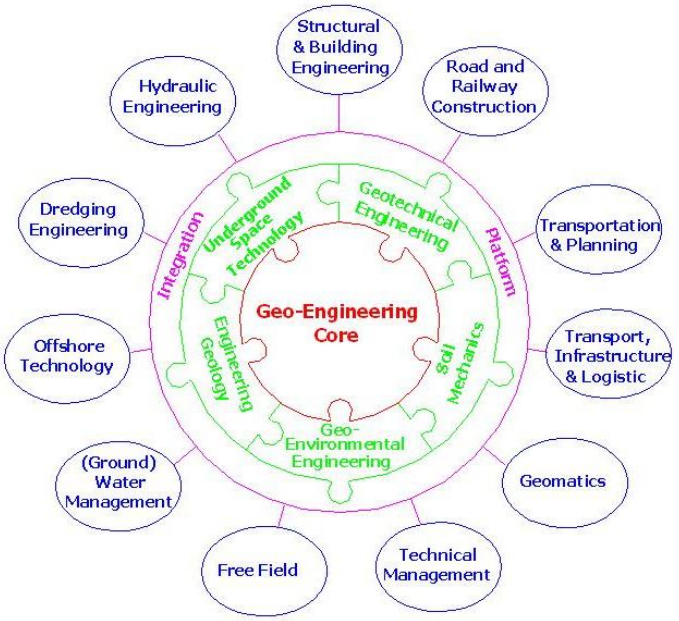

Figure 1: Structure and place of the TUDelft Geo-Engineering programme at Masters level

Although, the programme does not include an internship as a compulsory element, participants can choose to dedicate 11 ECTS from the elective courses for an internship.

Geomechanics is concerned with the fundamental description of soil behaviour. Students who opt for Geomechanics learn to develop and apply all kinds of calculation methodologies, ranging from rules of thumb to advanced analytical and numerical methods in order to make reliable predictions about soil processes

Geotechnical engineering focuses on soil-structure interactions. A number of major civil engineering challenges, such as deep foundations and underground constructions in weak soil, soil improvement and the application of geosynthetics are analysed. Each project is treated as a prototype. Students learn how to apply the tools developed by the Geomechanics in order to solve problems that arise during the design, contract or operational management phase of construction projects.

Underground space technology focuses on every aspect concerning the use of underground space. Students learn about infrastructure for traffic as well as utility systems, underground storage, multiple use of land and space, safety, legal aspects. They become familiar with various building techniques such as tunnel boring, immersed tubes and trenchless techniques.

Engineering Geology trains students to combine geological knowledge with an understanding of the geotechnical information that is relevant to engineering design and construction. This requires a sound understanding of geological processes and how they affect the behaviour of rock, soil and groundwater within an engi-

neering context. Students develop the expertise and confidence they need to identify and tackle soil-related problems by building on a high level of competence in the basics, a working knowledge of industrial applications, and an ability to adapt to new technologies and environmental conditions.

2.3 *The MSc graduation thesis*

Integration of knowledge, individual thinking and managerial tasks culminate in the 6-month MSc graduation project. Students are encouraged to take part in the section research activity. Carrying out research for graduation projects in organisations outside the TU Delft, for example at the Deltaris Institute recently created or with industrial partners active internationally in the field of geo-engineering as contractors or consultants, is welcomed.

Excellent facilities are offered to students for their graduation research or engineering project. Students may conduct fieldwork and field testing within the framework of a project run by the section. They may use the laboratory facilities of the Department of Geotechnology, including the geotechnical centrifuge, the photoelasticity and the X-ray CT scanner and nanotom for measuring and characterizing ground behaviour and ground-structure interactions. They may work on a geotechnical design project and use in house-developed or commercial finite element codes to predict soil-structure interactions. Most of the MSc theses involve the integration of theory with data derived from field observation, field tests or laboratory work.

Conditions to start the MSc graduation work are stricter than in the past to limit the number of students leaving the university after their graduation work without a diploma. Supervision by a multidisciplinary examination committee encourages cross-fertilisation of ideas from different fields. Publication of final works in conference proceedings and journals is stimulated. A number of prizes and “geo-oscars” are given by the University and Professional Associations to reward the best MSc graduation theses.

2.4 *Entry level*

Entry to the Masters programme is open to BSc graduates with a background in Civil Engineering or (Applied) Earth Sciences, or closely related disciplines. In addition, for students with an international degree, a BSc Grade Point Average of at least 75% of the scale maximum, a proof of English language proficiency (TOEFL or IELTS), a motivation letter and an extensive résumé are requested. The documents are screened by the International office of the University before an intake committee consisting of the student advisor and MSc co-ordinators decides upon the final admission.

2.5 *Convergence courses, deficiency courses and pre-masters*

Because of a large variability in the background of incoming BSc students, which is further increased with the introduction of the 30 ECTS minor in the BSc programmes, convergence courses tailored to individual needs are organised to ensure that all candidates have a common base of knowledge and skills when they take courses of the regular programme.

The convergence courses mainly consist of a selection of geo-engineering courses offered in the “Soil” or “Applied Geology” minors (see table 3). They are the (f) courses in table 2. They are taken at the expense of the electives of the MSc programme and contribute to the 120 ECTS for obtaining the Geo-Engineering degree.

A distinction is made between deficiency, which is a lack of knowledge of general and predominantly mathematical subjects, and convergence, a lack of Geo-Engineering knowledge.

For talented Bachelors of Engineering from related polytechnic programmes, the Geo-Engineering MSc provides an opportunity to progress to academic level. A 30 ECTS pre-master programme in ground engineering or engineering geology allows them to develop further their mathematical, geo-mechanical and geological skills.

3 EVALUATION OF THE NEW PROGRAMMES

3.1 *Benefits*

After several brain-storm meetings and a period of optimization, the new programmes are reaching a mature stage. They have been able to improve the pre-existing situation for students in a number of ways.

The BSc minors in “Applied Geology” and “Soil” render possible cross-fertilization between disciplines.

In the BSc programme in Civil Engineering, the “Geology for engineers” has its focus on the Quaternary, thereby emphasising the active geological processes that are of such importance to all low-lying countries, and to improve understanding of the potential impacts of climate change.

Sustainable development and the multidisciplinary use of the Underground are debated within the BSc curriculum. This helps to raise awareness among students of any possible ethical, social, environmental, aesthetic and economic implications of their work, to which they will act appropriately.

The core of the MSc programme exposes students to the whole geo-engineering process, from site investigation, to material modelling, to physical, analytical and numerical modelling of geotechnical problems, probabilistic design and ground risk management.

All geo-engineering MSc students acquire proficiency with site investigation practice and laboratory testing of ground materials. They are made aware of real ground conditions and the procedures and protocols for data collection (field and laboratory). This helps to their understanding of heterogeneous ground conditions and likely boundary conditions.

Those with an (applied) Earth sciences undergraduate background are better able to appreciate the parameters within which the civil engineer has to operate, and thereby improve their ability to communicate relevant information in a timely and effective fashion.

All geo-engineering MSc students are able to gain a greater insight to the ways in which numerical techniques can integrate geotechnical characteristics with prediction of ground engineering structures.

Risk management and probabilistic design now occupy a strong position as a component of the MSc core programme.

Project-based learning helps students to raise their self-confidence and to make a rapid transition from university to practice (Ngan-Tillard et al. 2008). Case histories concerning ambitious projects such as the excavation of the new Metro tunnel in Amsterdam, the construction of a new offshore airfield, and renewed extensions of the Dutch coastline act as effective stimulants to the students’ learning process. Site visits and guest lectures by industrial partners are central to developing the students’ understanding of the subject as well as helping forge stronger links with potential employers.

And last but not least, in line with the TU Delft philosophy of training, students take an active part in the design of their MSc programme and are responsible for their studies. By selecting their specialisation, choosing relevant electives and conducting their MSc graduation thesis on a well chosen topic, students can prepare for a research, engineering or management career in the field of geo-engineering. Students who specialise as engineering geologists are equipped to work competently within and beyond the Netherlands, and in both onshore and offshore projects, in both rock and soil environments while students taking the civil engineering specialisations excel in ground constructions on soft soils in built-up environments. Thanks to their broad knowledge, TU Delft geo-engineers can readily cross borders between different disciplines and propose innovative solutions to challenging construction and geo-environmental problems.

3.2 *Future programme developments*

In 2007, a Chair in Geo-Environmental Engineering was appointed at the geo-engineering section. It couples biology and micro-engineering geology with soil remediation and ground improvement projects. It also helps to mitigate the environmental impact of heat pumps and to solve medical geology issues relating to health and forensics. The viability of a fifth MSc specialisation in Geo-Environmental engineering involving also the department of Biotechnology is under study.

4 E-LEARNING TECHNIQUES TO MARKET GEO-ENGINEERING AT UNIVERSITY

Despite well managed training programmes offering a wide range of specialisations tuned to the demand of the industry and the society, the enrolment level of students is low. The demand for geo-engineers is higher that we can offer. Actions must be taken to increase the interest in the field among potential students.

First, we propose to launch a series of interactive video-conferences on most challenging civil engineering

projects in the world. The seminars are live broadcasted through the internet and are recorded in order to make e-learning possible. During a seminar it is possible to interact with the speakers online. The participating universities prepare each a web seminar with support from their industrial partners. Focus is put on didactic and interaction to differentiate from National Geographic and Discovery TV programs. Links to fundamentals of geo-engineering are made; management aspects and human factors are covered. Projects at different stages of conception, completion and service time life are presented. Ageing and decommissioning of civil engineering structures are debated.

Second, we propose to involve students from different universities in the geotechnical control of the same civil engineering project. The project team makes (part of) its site investigation, construction parameters and ground monitoring data available to students on line. Webcams are installed on site at strategic points in agreement with the different parties involved in the project. Students from different universities compete to interpret ground conditions, ground monitoring data, adjust construction parameters accordingly and forecast unforeseen difficulties. A team of experts define criteria to determine best team.

Third, we propose to emphasize the diversity of the geological conditions, environments and techniques in opposition to increasing globalisation. We plan to develop virtual fieldworks in the context of a variety of construction projects and contrasting range of environments.

E-learning, on-line monitoring, virtual reality and gaming techniques are already available to launch this 3 step marketing plan.

Our Digital Learning Environment BlackBoard can be used to host all kinds of e-learning activities like group work, collaboration possibilities and wiki-like environments to work on papers. Through the discussion board, students can interact with each other in order to exchange data and to develop their thinking about implementing the data.

The interactive Videoconferences are to be hosted at one location and can be broadcasted to other universities. Near-field students can directly ask questions to the speaker. All can take simultaneously an anonymous test pool allowing random checks of knowledge for a rapid overview of the groups attending the video-conference. The instructor can submit its public to subsequent test pools. He can group questions according to topic and difficulty in order to captivate the attention of groups of different maturity and background. An assistant analyses the pools and briefs the speaker, enabling a direct feedback to students. The video-conference is also published integrally or partially on the internet to be viewed anytime and anywhere. Highlights of most challenging aspects of the project and related fundamentals of geo-engineering can be published in the form of short videos. The possibility of using podcasts and vodcasts will be considered.

Technical solutions as Skype, MSN, web logs and wikis will be used to discus content, data etc.

The Joint Technical Committee 3 is thought to be an excellent platform to set up an international collaboration in order to foster the development of video-conferences on mega-construction projects, the international ground monitoring competition and virtual fieldworks.

5 CONCLUSIONS

The knowledge gained from the postgraduate training programmes in TU Delft has been, and is continuing to be, effective when applied to all densely populated coastal and deltaic areas where economic and social demands from a growing population may potentially conflict with care for the environment.

In 2006, the faculty of civil engineering and applied earth sciences introduced the MSc in geo-engineering to exploit the synergy between research groups working in the areas of geomechanics, geotechnical engineering, underground space technology, geo-environmental engineering and engineering geology and better address short and long in long-term fundamental issues of interest for industrial application.

Thanks to their broad knowledge, MSc graduate students in geo-engineering can readily cross borders between different disciplines and propose innovative solutions to challenging construction and geo-environmental problems.

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