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Geo-engineering, a co-production of applied earth sciences and civil engineering- 2nd phase

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ABSTRACT: Ngan-Tillard et al (2008a) presented the first steps made at TU Delft to train civil engineering and engineering geology students side by side in the Geo-engineering Masters programme. In this paper, lessons are drawn from the first phase of integration and changes introduced in the second phase of integration are presented. Convergence courses (16 ECTS, maximum) are still organized to ensure that all candidates have a common base of knowledge and skills when they take courses of the regular programme. The core of compulsory geo-engineering courses (26 ECTS) consists of subjects that are deemed to be essential for a Geo-engineer. It has now been re-designed. More emphasis is put on Soil and Rock Behaviour before modelling aspects are introduced. Coupled Processes in the Subsurface provides the theoretical background necessary to tackle environmental geo-engineering issues. Risk and variability in geo-engineering has replaced the holistic course on Geo-risk Management. The specialisations in Geomechanics, Geotechnical Engineering, Underground Space Technology, and Engineering Geology have been abolished. Students are free to define their individual profile by selecting a package of geo-engineering electives (34 ECTS) from a pool of courses (67 ECTS in total). Before embarking on their graduation thesis (40 ECTS), students have multiple options (20 ECTS) to deepen or broaden their expertise, or have a hands-on experience. The new structure of the programme encourages cross-fertilisation of ideas from different fields, without compromising student competences in geo-engineering. It is found to be more attractive by students, eager to master their future, according to the programme evaluations organized by the student association, before and after the launch of the new programme.

1 INTRODUCTION

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 auspices of both Applied Earth Sciences and Civil Engineering. The MSc built upon expertise in engineering geology and geotechnical engineering in view of new societal and technological developments (Ngan-Tillard et al., 2008a). Its programme comprised a total of 120 ECTS. Its 20 ECTS core, common to all geo-engineering students, included subjects that were deemed to be essential for a geo-engineer.

Four specialisations were offered to students with various backgrounds, in: Engineering Geology, Geomechanics, Geotechnical Engineering and Underground Space Technology. Each of the four specialisations offered a suite of compulsory courses ranging from 12 to 46 ECTS in total and gave room for 46 to 12 ECTS electives of which a number were imposed or recommended in the field of geo-engineering. This structure was experienced as complex and rigid by the students, the staff, the administration, and the industry. It resulted into the fragmentation of the pool of geo-engineering students into small groups of 4 to 8 students. Moreover, the number of first year geo-engineering students stagnated to about 14 plus or minus 5.

For these reasons, the MSc programme was restructured in 2011. The Geo-engineering section decided to go further into the integration of Applied Earth Sciences and Civil Engineering students. It abolished the specialisations. It drew lessons from the first phase of integration and revised its Convergence courses, re-defined its Core programme (26 ECTS), and re-modelled its Geo-engineering Elective courses (34 ECTS). On several occasions, students were consulted, and encouraged to make suggestions and give feedback during formal programme evaluations and less formal discussions. Before embarking on their graduation thesis (40 ECTS), all geo-engineering students have now multiple options (20 ECTS) to deepen or broaden their expertise, or have a hands-on experience. The new structure further encourages cross-fertilisation of ideas from different fields, and gives more freedom to students, when designing their individual study programmes. The former profiles can still be selected within the new structure. They form the 4 poles of the programme: Environmental Engineering Geology, Geomechanics, Geotechnical Engineering and Underground Space Technology. Next to them, hybrid profiles can be defined.

In the paper, the main changes in the general structure of the Masters programme are first exposed. Then, aspects specific to the programme are highlighted. The new programme has been launched in September 2011. Its evaluation can only be partial. Future programme developments are foreseen because of the changing environment of the University.

2 NEW STRUCTURE FOR THE MSC IN GEO-ENGINEERING

Figure 1 presents the detailed structure of the Geo-engineering MSc programme. The number of ECTS is indicated for each component and each course of the programme. Competence and expertise matrices for each course are being created.

2.1 *Convergence courses*

Three convergence courses are organised to ensure that all candidates to the MSc programmes have a common base of knowledge and skills when they take courses of the regular programme. The convergence courses consist of Geology for Engineers, Soil Mechanics and Foundation Engineering and Flow in Soils and Rocks.

Geology for Engineers is designed, mainly for the TU Delft Civil Engineering students, who, since 2010 are not introduced to Geology in their Bachelor programme. The course covers basic geology. It is not an engineering geology or a rock mechanics course. Delft approach to geology for civil engineers is in phase with recommendations made by Watkins (1972) in response to Cawsey and Francis (1971), Baynes (1996) and Fookes (1997). The lectures are complemented by tutorials on mineral and rock identification and geological map reading and an excursion to the Ardennes, Belgium during which the role of geology in geo-engineering is illustrated. The course is given by geologists of the Department of Geoscience and Engineering.

Soil Mechanics and Foundations Engineering is designed for Applied Earth Sciences students who received more education in rock mechanics than in soil mechanics during their Bachelor. The course is also taken by a large number of Offshore Engineering students with a mechanical engineering background. Basic concepts of soil composition, effective stress, dependence of strength and stiffness on current states, interplay between rates of loading and drainage are (re-) introduced. Their implications for applications, i.e. settlement predictions (consolidation and creep), bearing capacity of shallow and deep foundations, retaining structures (e.g. sheet pile, quay wall), analysis of slope stability (dams levees), tunnelling in soft soils and ground improvement techniques, are explained. Soil Mechanics by Prof. Verruijt (2011) is used as textbook.

Flow in Soils and Rocks is mainly meant for Civil Engineering students who have selected a specialisation different from Geo-engineering during their BSc programme, and graduated without a basic course on either ground water mechanics or geohydrology. The Geology for Engineers and Flow in Soils and Rocks courses correspond to the regular courses of the Bachelor programmes.

Master students only receive half of the credits allocated to bachelor students for the same work load; Master students ought to be more efficient in their learning process. The convergence courses are taken at the expense of the geo-engineering electives of the MSc programme and contribute to the 120 ECTS for obtaining the Geo-engineering degree.

Ethics and Technical Responsibilities can be considered as the fourth convergence course. It has to be taken in the Master programme if missing from the student pre-Master background.

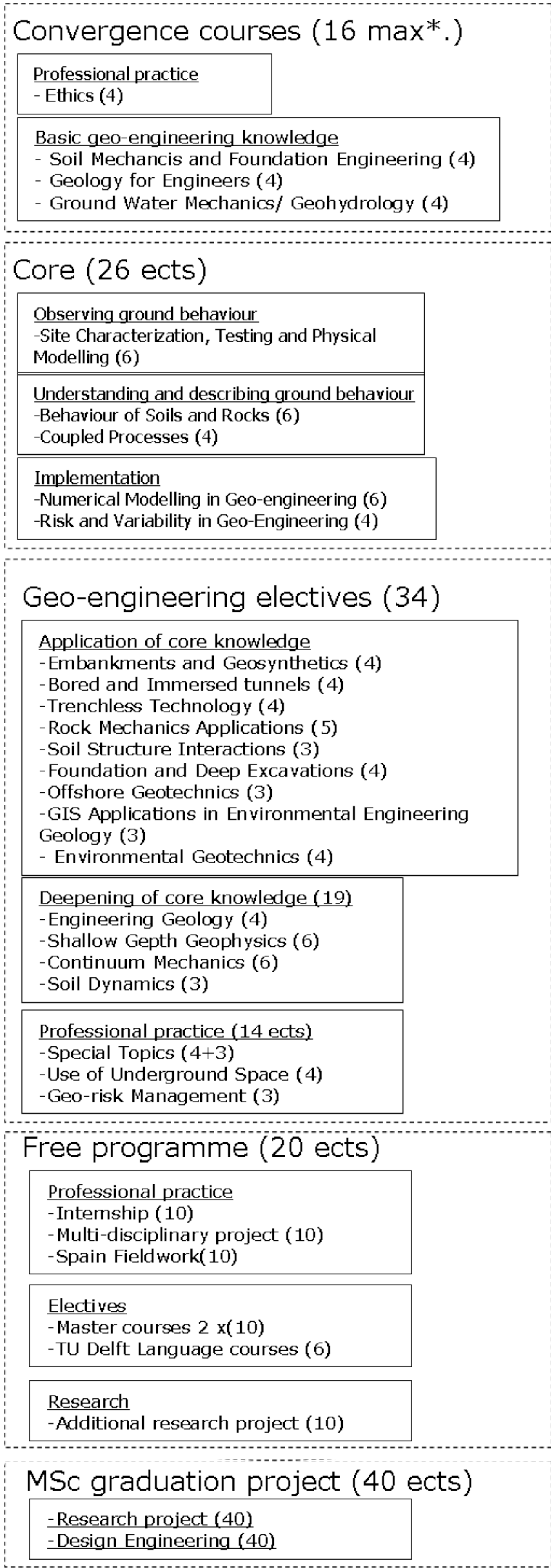
The convergence courses are tailored to the general needs of applicants with a background in Civil Engineering or (Applied) Geosciences from other Universities. As course titles and contents vary from one University to another, it is difficult to judge whether or not a student lacks knowledge and understanding in a given field, based on his/her grade transcript. The decision to take a convergence course is taken at the start of the academic year, after an interview of the student. Implementing a computer entry test to check the basic background of students was found to be inadequate, considering the relative low number of "outsiders" (less than 10).

2.2 *The core*

The core of the Geo-engineering Master programme reflects the whole sequence of processes followed in most geo-engineering projects, i.e. site investigation, material testing and modelling, ground modelling and design. Design covers the following aspects: numerical implementation of models, modelling of geo-engineering problems using diverse approaches (physical simulation as well as analytical or numerical approaches), understanding of coupled processes in the subsurface and analysis of risk and variability. The core provides students with a conceptual understanding of the individual processes taking place in the subsurface as well as their interactions.

Figure 1. Detailed structure of the MSc programme. The weight of the different programme components and courses is indic-

ated between brackets. * The convergence courses are taken at the expense of the geo-engineering electives.



The core is primarily designed for students to obtain a sound understanding of the fundamentals of geo-engineering and also to encourage lateral thinking. Professional practice and training have been excluded from the core. Thus, Geo-risk Management (van Staveren 2008, Barends 2008), present in the core of phase 1, has been shifted to the pool of geo-engineering electives. In the core, more emphasis is put on the behaviour of soils before soil modelling is undertaken. The importance of numerical modelling has been strengthened by merging a former introduction core course and a specialised elective. The focus on coupled processes is new. The need for such a course was positively received by other programmes (Applied Geophysics, Petroleum Engineering, and Bio-technology). Risk and variability in geo-engineering has replaced the course on Probabilistic design, less focussed on the subsurface. Some of the specificities of the core courses are developed in Section 3.

2.3 *The pool of geo-engineering electives*

A student may use the time available for electives to further deepen his/her knowledge related to one pole of expertise, or broaden his/her views by choosing courses related to different poles (Figure 1). Rock mechanics receive most attention in the Engineering Geology courses. Students are taught the basics of rock mass description and modelling and the principles of rock excavation, support and stabilisation before applying those to several applications; some, like rock cutting and quarrying, are tuned to the need of the Dutch dredging industry.

Students have to select 34 ECTS within a large pool of electives (67 ECTS). Some find it frustrating to have to choose and eliminate a few courses from their study programme! To reduce the staff teaching load, a number of elective courses have been merged with courses offered by other programmes. This is the case for GIS applications in geo-environmental engineering geology. Students learn about GIS and develop their basic GIS skills with the Geomatics students and they apply their knowledge to solve a practical problem, such as mapping of geo-hazards or soil contamination with the geo-engineering staff. Soil dynamics is being re-defined to suit the need of other MSc programmes such as Structural Engineering, Road and Railways and Offshore Engineering.

By spreading the courses over the year, the Geo-engineering section interferes with the choice of electives made by the students. It proposes about 13 to 17 electives per period, with the aim to optimize the number of students per course in order to maintain the viability of each course.

2.4 *The free programme (20 ECTS)*

Before embarking on their graduation thesis (40 ECTS), all geo-engineering students, included students from Applied Earth Sciences have now multiple options (20 ECTS) to deepen or broaden their expertise, or have a hands-on experience. These options are: additional electives of master level taken at any Dutch University, language courses offered at TU Delft, an internship, a research project or a multi-disciplinary project. Each option except the languages courses (6 ECTS max.) is worth 10 ECTS. The additional electives option is the only option which can be taken twice. The Spain geo-engineering fieldwork has the administrative status of a multi-disciplinary project, even if its study goals are different and staff supervision is more intensive (Ngan-Tillard et al., 2012).

In the last few years, the internship and the multi-disciplinary project have been most appealing to students. Before signing their first contract as newly graduated students, students enjoy getting accustomed to the work culture of companies active in the field of geo-engineering by undertaking an internship. They also like facing financial and logistic challenges when organizing their multi-disciplinary project. Recent projects include dam construction on the Mekong river delta or the River Uruguay. Besides its professional training function, the multi-disciplinary project has an educational merit, it works as an eye-opener. Back to Delft, students admit better understanding of the importance of geology in geo-engineering. They fully agree with Steenfelt (2000): "*Failure to observe and apply the genesis and layout of the ground cannot be replaced by precise analysis, use of sophisticated computer programmes or any other of the latest cutting edge research results*".

2.5 *The MSc graduation thesis*

Integration of knowledge, individual thinking and managerial tasks culminate in the 7-month MSc graduation project. Students are encouraged to take part in the section research activity. Carrying out research or design engineering for graduation projects in organisations outside the TU Delft, for example at knowledge Institutes (Deltares) or with industrial partners active internationally in the field of geo-engineering as contractors or consultants, is welcomed. The subject being studied must fall within the expertise of the Geo-engineering section and the graduate student must also be supervised by a staff member of the section.

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 Geoscience and Engineering; including the geotechnical centrifuge, the photoelasticity and the X-ray (micro-)CT scanners 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 creativity. Publication of final works in conference proceedings and journals is encouraged. A number of prizes are given by the University and Professional Associations to reward the best MSc graduation theses in civil engineering and geosciences.

3 A FEW HIGHLIGHTS ON THE PROGRAMME

3.1 *Physical modelling*

A highlight in the MSc education programme is the opportunity for students to design, execute and interpret a physical model test as part of site characterization, testing and physical modelling. These scaled model tests are performed at normal laboratory scale, i.e. 1g, or alternatively at elevated gravity using a geotechnical centrifuge. These facilities are offered next to the more traditional element tests, i.e. oedometer, (advanced) triaxial, direct shear. Teaching physical modelling helps the student in seeing and understanding soil behaviour in boundary value problems in a controlled environment. Even simple mechanisms like slope failure, a soil wedge behind a retaining wall or the penetration of shallow and pile foundations in the soil are very instructive for the student.

For testing at 1g a large calibration chamber equipped with a fluidization system, e.g. for cone penetration testing (CPT), is available. As well as several smaller model setups for investigating soil behaviour in plane strain using optical techniques, such as image correlation and particle image velocimetry to capture displacements in the soil (e.g. White et al. 2003) or even stress (Dijkstra & Broere 2010). Most of these facilities are self-explanatory so that students can work independently after instruction from a tutor or a laboratory technician. Small mechanical changes in the experimental setup are coordinated in conjunction with the laboratory technician and tutor. However, the final go-ahead for these changes depend on available budget, typically from a sister project, and the judgment by the head of the laboratory in order to preserve the usefulness of the setup after the project is finished.

The use of a fully equipped centrifuge in education is rather unique, some universities offer this for a MSc. research project, for an industry project or support of a PhD research project, but for educational purposes only very small centrifuges (radius < 300 mm) are used such as the device presented by Airey & Barker (2010). Nevertheless, this already offers much more substantial testing experience for students. In contrast the centrifuge at TU Delft comprises of a two swing beam design with radius of 1.25 m, many channels of data acquisition and actuators to push and pull objects in or out of the soil as well as to inject fluids into the soil. On top of that a high resolution machine vision camera is installed to observe the deformations in the soil. This centrifuge, however, is still small enough to be operated by one operator or technician and the student; however, for the course typically 2-3 students are grouped together. The preparation and the build-up of the test setup are done by the student(s).

The course work consists of three stages: first a (experimental) research question needs to be formulated and a design drafted for the test setup, using available parts and instrumentation. The focus is on proper scaling, instrumentation and when required actuation of the problem, e.g. anchor impact tests, simulating suffusion, shallow foundations on crushable material. After this approach is approved by a supervisor the test will be built and executed in conjunction with a laboratory technician. Time is too limited for a full series of tests; the focus is on the proof-of-concept test. Finally, the results are interpreted and reported. This report forms the basis for an oral examination. The aim of the course is that students learn all process steps in physical modelling, and their inherent limitations. This includes the scientific method, measurement errors, scaling laws, instrumentation and actuation.

3.2 *Coupled processes in the subsurface*

Many processes in the subsurface show a complex interaction with each other. TU Delft proposes a core course entirely dedicated to the study of coupled processes in geo-engineering in its 2011 programme. In the 2006 programme, the theory of coupled processes was diluted in several courses. An example of coupled processes is of course consolidation during loading of saturated and unsaturated deformable porous media, like soils. Deformations in such media lead to changes in the pore volume and corresponding changes in pore fluid pressures which initiate seepage and affect the general behaviour. Under--standing such coupled processes is of great importance to settlements and stability, in particular when permeability is small, compressibility is large and strength is limited. In delta areas soil with such type of behaviour is everywhere. Dikes, rail and road embankments are composed of it. Consolidation affects the transient stability of slopes, excavations and tunnel shields, and it plays a role in dredging, land reclamation, drainage and pumping systems. Fundamental understanding of these processes allows the student to recognise similar processes in a wide range of application fields such as human bones (knee disc) and the paper industry.

The lectures focus on multi-dimensional and complex, but realistic and practical situations. A solid foundation is laid in order to obtain an understanding of time-dependent interaction of water and soil with special emphasis on peculiar and unexpected behaviour. A survey is given of the available methods in practice and illustrative situations are analysed individually and in teams. Analytical, numerical and simple engineering methods are introduced providing the students with the necessary tools to handle such complicated systems. After laying the foundation for hydraulic and mechanical coupling, additional forms of coupling influencing the behaviour of soils (and porous media in general will be given) will be introduced. Thermo-chemo-hydro-mechanical coupling is a topic addressing the additional impact of temperature and chemical dynamics on the hydro-mechanical properties and what the impact of such coupling can be on underground ground infrastructure. A link is made to the current research of the section on the numerical modelling of nuclear waste disposal in the Boom clay at 500 m depth. Finally, the impact of biology as a driving force for the dynamics of temperature, chemistry, hydrology and mechanics is introduced. As such the students are introduced into the new research field of the Geo-engineering section: BioCivil Engineering.

The course is scheduled at the end of the first year and builds on knowledge acquired in other (pre-) Master courses, included basic knowledge on groundwater flow (Darcy's Law) and solute transport. While chemistry is one of the pillars of BSc programmes in Applied Earth Sciences, it is absent from most BSc programme in Civil Engineering where more focus, is put on mechanics (Atkinson, 2008). The problem is solved by limiting the course entry level to high school chemistry.

One follow-up of the course is Environmental Geotechnics. This course covers the processes and technology involved with the sustainable management of the subsurface. Using the concept of source-path-object concept in risk management, the fundamentals of the essential processes are introduced in relation to several applications (shallow depth geothermal energy, waste management, building with recycled materials and bio-based geo-engineering). The students are introduced to current state of the art technologies for site investigation. They are equipped with (mathematical) concepts for risk management, engineered barriers and remediation.

3.3 *Exposure to non technical issues*

Sustainable development and the multidisciplinary use of the underground are also debated within the electives related to tunnelling and geo-risk management. The specificity of these courses is to help to raise awareness among students of any possible ethical, social, environmental, aesthetic, economic and legal implications of their work, to which they will act appropriately. The importance of the human factor and a clear communication line between all parties involved in a construction project is stressed. Site visits also provide the opportunity to introduce non technical issues, to students not willing to follow a full course on the topic.

3.4 *Field exposure*

The particularity of the TU Delft education in geo-engineering is the progressive exposure of students to the complexity of the subsurface and its dynamic changes through the study of idealised case studies, real case histories including site visits, and an intensive fieldwork programme based on observation, analysis and communication. This aspect is developed in a companion paper (Ngan-Tillard et al., 2012).

3.5 *Exposure to Engineering Geology*

Thanks to the new structure, the exposure of civil engineering students to Engineering Geology has increased. The number of participants to Engineering Geology courses has more than tripled. Engineering Geology is present in the Core, as in the 2006 programme, in the Site characterisation, testing and physical modelling course. Engineering geology knowledge is also needed in the new core course on Risk and Variability for the determination of geological correlation lengths which allow interpolation between verticals. In the elective Engineering properties of Soils and Rocks, offered to all students, geology is envisaged from a new perspective. Students learn how to recognize soils and rocks and determine their depositional environment and geological history in order to establish their geometry, both in the vertical direction and horizontal plane. Students are also taught about the impact of genesis, included past and current climate conditions, on the engineering properties (strength, deformability, permeability and durability) of soils and rocks. They get an overview of the engineering geological characteristics of the major types of soils and rocks, and their impact on engineering design and construction. Each lecture presents the lessons learned from a construction project in the material studied. In the case histories, the potential impact of (or on) groundwater is addressed. Moreover, every geo-engineer Masters student can now join the Spain fieldwork (10 ECTS), a traditionally strong component of TU Delft teaching in Engineering Geology. During the fieldwork, the student becomes aware of real ground conditions and skilled at collecting data for specific projects using pragmatic procedures and protocols developed in Delft (Price et al., 2003).

3.6 *Multi-disciplinarity and flexibility*

The main characters of the new programme are its transparency, applicability, flexibility, and multi-disciplinarity. The core of courses imposed to all students guarantees that the fundamentals of geo-engineering are not compromised in individual study programmes. It also cultivates a sense of community. The geo-engineering electives give to the programme its applicability and flexibility. A variety of applications, relevant to the Dutch society, keen on innovation and rationalisation, as well as to the Dutch industry, active world-wide, are treated. Flexibility is deemed to be essential to attract on one hand, students with a vivid interest in one aspect of geo-engineering, for example, tunnelling, and, on the other hand, students with a broad, but not less genuine, interest in geo-engineering. A fair place is reserved to professional practice and non-technical issues in the pool of geo-engineering electives. The industry remains largely involved in the courses having a stronger training than education flavour such as geo-risk management or special topics in geo-engineering or in underground space technology (Ngan-Tillard et al., 2008b). Its senior staff affections the use of a Project oriented Problem Based Teaching approach. They introduce contract matters, codes of practice, and standards. The importance of those, due to their time-dependency and non universality, is relativized, in the core courses.

4 EVALUATION OF THE NEW PROGRAMME

The last re-modelling of the MSc programme was less traumatic than the first. In a climate of ever-increasing demand for cost-efficiency, lateral thinking and innovation, it appeared necessary to the staff to improve the viability of the whole geo-engineering programme. The 2011 programme has been able to improve the pre-existing situation in a number of ways indicated in the previous section. The main concerns about the programme are the low number of TU Delft students, especially from Applied Earth Sciences joining the programme, as well as the high teaching load related to the large variety of courses offered.

The enrolment level of students has increased from 14 on average with a standard deviation of 4.5 in the last 5 years to 28 in 2011. In 2011, about one third of the students came from abroad, as previously. In addition, 1 to 5 (Erasmus) exchange students join the group every year. The rising total number of students cannot be fully attributed to the programme re-arrangement! Students have possibly been attracted by the need for a geo-engineering solution to mitigate damages caused by the natural disasters (storms, flooding, volcanoes, earthquakes and tsunamis) which struck the world, with an exceptional strength, in the last years. However, the demand for geo-engineers, including engineering geologists, in the Netherlands is still higher than that TU Delft can offer. An estimated 40 geo-engineers at an academic level are required each year for the home market alone. Foreign MSc students originating from EU and non EU countries who hold an MSc degree in Geo-engineering from TU Delft have (so far) no difficulties in finding employment in the Netherlands. The Dutch civil engineering and dredging industries are active within the Netherlands and worldwide and not mastering the Dutch language is not an obstacle to employment. Not all foreign students decide to stay in the Netherlands after graduation. Moreover, per year, a couple of Dutch graduated students decide to undertake a PhD abroad or emigrate to Canada, New Zealand or Australia. They enrich the TU Delft network and open opportunities for new research collaborations.

The industry has committed itself to support TU Delft research in geo-engineering provided actions are taken by TU Delft to increase the interest of students in the field of geo-engineering. The "ondergrondse", the geo-engineering student association, supports TU Delft efforts by organizing a variety of events (technical site visits, lunch lectures, information days, and social activities) and dispatching broadly its quarterly Newsletter. Some sponsors allocate the student association a bonus proportional to the increase in the number of new students joining the Master programme.

The clarity of the programme also encourages students from fields as diverse as geomatics, mining, petroleum, offshore or structural engineering programmes to enrol geo-engineering courses. Students of the European Mining Courses are particularly keen on completing their managerial programme by taking in Delft technical courses related to geo-technical engineering in the mining industry. Currently, students from (Applied) Earth Sciences represent a minority of the geo-engineering students. The core of the MSc programme requires some understanding of mathematics and physics. Not all students holding a BSc in geology and fulfilling the rules set by TU Delft for foreign applicants are directly admitted to the programme. Some must enter a deficiency programme to build up their mathematics and physics skills. Moreover, even if the MSc programme covers both soils and rocks, the core focuses more on soft soils and students from (Applied) Earth Sciences ask for more emphasize on rock behaviour in the core.

The large number of geo-engineering electives offered to TU Delft students results in a high teaching load for the staff in a budget allocation model that rewards research output more than education. Elective courses with a "low" number of participants over a period of 3 years are stopped or merged, when possible, with a course offered by another programme. Note that the definition of the critical mass of students is left to the appreciation of the course responsible. A large majority of geo-engineering courses enjoy a minimum of 15 students. Three courses attract more than 50 students, including students from other programmes.

5 FUTURE PROGRAMME DEVELOPMENTS

5.1 *Internal co-operation*

The Geoscience and Remote Sensing group, formerly at the Faculty of Airspace Engineering has become the 6th department of the Faculty of Civil Engineering and Geosciences and the sister department of the Department of Geoscience and Engineering to which the Geo-engineering section belongs. It will offer courses on surface observations of the Earth that link to processes taking place in the ground, and allow developing appropriate decision-making tools for land development, early warning systems, etc.

5.2 *International cooperation*

TU Delft encourages International Masters programmes. These reduce the staff teaching load and maintain specialisations that are less popular among students but are considered as essential, at short and long terms, to the Dutch society and the industry. Among these programmes are the European Mining Course (EMC) and the European Geotechnical and Environmental Course (EGEC). The EGEC courses offered by TU Delft belong to the pool of geo-engineering MSc courses. It is important that the coherence of international programmes is regularly evaluated as European partners implement changes in their own educational programme.

5.3 *Re-organisation of the BSc programmes*

TU Delft is revising its BSc programmes to improve cost-efficiency and increase its yield of nominal students. Active learning and self-studying are promoted by limiting the number of lectures per week to less than 20 hours while increasing the number of tutorials supervised by student assistants. The reduction of contact hours forces staff to focus on the essential and adopt modern communication techniques to explain principles that are difficult to grasp for students. The understanding of basic mathematics and physics is enhanced in streamlined block courses. For example, linear algebra is essential for manipulating with ease stress and strains tensors in geomechanics and geo-engineering applications. Linear algebra is coupled in a block course to BSc courses where students meet these tensors, i.e. soils mechanics, rock mechanics, as well as structural geology. The introduction of block courses requires a good communication between lecturers. The geo-engineering lecturers provide some of the "aha-experience" (Steenfelt, 2000); i.e. examples where the basics of mathematics, physics and chemistry are put in practice to stimulate understanding.

Modifying the teaching methodology at undergraduate level and, thus, the learning attitude of the students will have inevitable repercussions on the Masters programme.

6 CONCLUSION

TU Delft made a new step in its co-production of geo-engineers from Applied Earth Sciences and Civil Engineering in 2011. In line with the TU Delft philosophy of education, students take a more active part in the design of their MSc programme and are responsible for their studies. By selecting their geo-engineering electives without any restriction other than that imposed by the detailed course schedules, and by conducting their MSc graduation thesis on a chosen topic, students can better prepare for a research, engineering or management career in the field of geo-engineering. The free programme gives them an additional degree of freedom.

Like in the past, it is in the engineering of soft soils in built-up environments that the new generation of Delft trained geo-engineers with a Civil Engineering undergraduate background excels. The new programme provides them with a better under--standing of engineering geology, which allows them to work competently within and beyond the Netherlands, and in both onshore and offshore projects, in both rock and soil environments. Like in the past, the new generation of Delft trained geo-engineers with an (Applied) Earth sciences basic background perform well in the observation of site conditions and the application of genesis to predict those. The new programme provides them with a sound understanding of geo-engineering applications. They are better able to appreciate the parameters within which the civil engineer has to operate. Thereby, their ability to communicate relevant information in a timely and effective fashion is enhanced.

The TU Delft programme is largely supported by the Dutch construction and dredging industries that suffer from a chronic shortage of geo-engineering graduates.

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