Postgraduate training of engineering geologists for lowland countries: The experience at Tudelft

DOMINIQUE NGAN-TILLARD[1]

[1]*Delft University of Technology. (e-mail: d.j.m.Ngan-Tillard@citg.tudelft.nl)*

Abstract: The developing field of geo-engineering provides a broad framework for postgraduate training at the Delft University of Technology (TUDelft), focussed on the needs of densely populated lowland countries such as the western part of the Netherlands. Here most construction sites are located below sea level and the groundwater is generally close to the surface. Furthermore, the shallowest 5-20 m or so of the subsurface consists of soft materials (clay, peat or sand) and is notoriously heterogeneous.

These are challenging conditions for ground engineering projects. Successful construction and sustainable development of such lowland countries needs civil engineers and engineering geologists working side-by-side on practical solutions.

Delft University's vision for geo-engineers is based on a broad education embracing the fundamental disciplines, presented as a compulsory core for all postgraduates. This supports a number of specialist programmes, each comprising a compulsory suite of courses (some of which are offered as options for other programmes) and a selection of electives. The geo-engineering programmes are designed to provide the student with a high level of competence in the basics, a working knowledge of applications within industry, and an ability to adapt to new technologies and environmental conditions. Specialist Masters degrees (MSc) are currently offered in Engineering Geology, Geomechanics, Geotechnical Engineering and Underground Space Technology, all of which are delivered in English to a student cohort drawn internationally. The character of Engineering Geology is used as the focus of this paper, drawing attention to the special demands of the Netherlands and its increasing urbanisation, with concomitant needs for development of infrastructure protected by reliable water defences.

Résumé: Le savoir que l'on peut acquérir à l'Université Technique de Delft en géo-engineering bénéficie du l'environnement spécial des Pays-Bas. La partie occidentale du pays est densément peuplée. La nappe phréatique affleure la surface du sol et la plupart des constructions sont situées au-dessous du niveau de la mer. En plus, les premiers 5 à 20m du sous-sol sont constitués de matériaux mous ou meubles réputés pour leur hétérogénéité.

Ces conditions sont des défis pour tout projet de construction et le développement durable des basses terres. Ingénieurs du génie civil et géologues ingénieurs doivent travailler côte à côte à des solutions à ces défis. Ils sont aussi éduqués côte à côte dans le nouveau program de Master en géo-engineering à l'Université de Delft.

La vision de Delft en matière d'éducation des géo-ingénieurs est basée sur une éducation générale placée au cœur du programme de tous les étudiants. Le programme commun permet d'acquérir une profonde compréhension des fondements et supporte un nombre de spécialisations, chaque spécialisation comprenant une suite de cours obligatoires et une sélection d'électives. Les spécialisations sont conçues pour donner aux étudiants un haut niveau de compétence dans les sujets de base, un savoir-faire pratique et la capacité à s'adapter aux technologies nouvelles et aux changements des conditions environnementales. Des spécialisations en Géologie de l'Ingénieur, Géomécanique, Géotechnique et Technologies de l'Espace Souterrain sont offertes en anglais à des étudiants venus du monde entier. L'identité de la spécialisation Géologie de l'Ingénieur est soulignée dans cet article vis-à-vis de la contribution de ses étudiants au développement d'une infrastructure urbaine moderne et bien protégée de l'assaut des eaux.

Keywords: Education and training

INTRODUCTION

While some may consider engineering geology to be encountering difficulties within higher education worldwide (Griffiths & Culshaw, 2004; Hatheway *et al.*, 2005), the Faculty of Civil Engineering and Geosciences at the Delft University of Technology (TUDelft) has continued for more than 30 years to develop and support a comprehensive programme of teaching, training and research across the full spectrum of geo-engineering disciplines pertinent to the needs of lowland countries and their adjoining areas, including engineering geology. New staff members have been appointed to maintain full support for programmes relevant to ground engineering, both on and off shore. In 2006 a new Masters course specifically entitled Geo-Engineering is being launched, providing foundation in parallel with the specialisation of Engineering Geology, Geomechanics, Geotechnical Engineering or Underground Space Technology.

The Engineering Geology MSc at TUDelft is aimed at ground that is encountered within lowland countries worldwide including, of course, the Netherlands. Its objectives include creating real co-operation between earth scientists and civil engineers, which is felt to be necessary for effective prediction of the response of the near-surface to both engineered and natural influences. Electives allow further specialisation in a wide range of construction applications related to the special environments encountered within the low-lying countries (notably soft soils and weak rocks, significant heterogeneity, high groundwater, and potential for flooding) and the response of adjoining areas including the impacts of the dredging and offshore industries.

THE NETHERLANDS: A COUNTRY WITH CHALLENGING GROUND CONDITIONS

The deltaic and estuarine environments that dominate the western part of the Netherlands are not favourable to construction works and infrastructure development. The land surface is flat, and much has sunk below sea level, exacerbated by groundwater and mineral abstraction as well as by pumping water-bearing soils over historical time as an aid to land reclamation. As may be expected, the groundwater table is high, and several natural and artificial waterways meander through the country (see Fig. 1, the case for the river de Waal). The western part of the country is where many of the major cities are located. These areas were largely reclaimed from the sea by constructing earth walls and dewatering polders, aided by windmills and dikes. The shallowest 5 to 20 m consists of Holocene sediments deposited by either the sea or by rivers, predominantly clay, peat, silt and sand. These soils tend to be compressible and are soft (clay) or loose (sand) (see Fig. 2, left). When loaded, clay and peat consolidate and creep. When dewatered, they shrink, the land subsides and more effort is required to keep the land surface dry. The near-surface is not only of poor quality, it is also heterogeneous. Tidal channel systems interrupt the continuity of marine deposits with their anastomosing patterns. Crevasse splays cut through the levées of meandering river channels and disgorge onto their clayey and peaty flood plains. River channels of marginal marine deposits have migrated, lost and regained their activity several times during their geologically short history. Their clayey/sandy beds are now found buried within thick peat and clay layers. As a result of such geological processes, differential settlement (Fig. 2, middle) and highly contrasting permeability and strength are ever-present threats for lowland ground engineering projects.

Figure 1. Providing room for the river Waal

Figure 2. Squeezing of soft layers revealed during widening of a motorway (left). An “inverse” landscape (middle). Dike failure during a dry summer (right, from van Baars, 2005).

In brief, it is a major challenge to predict the variability of the subsurface below most Dutch cities. It is also a challenge to develop linear infrastructure and utility facilities. Keeping construction costs low, minimising impact on the environment and marginalising maintenance costs are also targets. Nevertheless there is a pressing need to develop the Dutch near-surface, to excavate Metro tunnels and create underground space for car parks, warehouses or sports facilities (e.g. skating rinks). Any human interference to the local ground structure, and any climatic change, can generate significant ground deformation. In addition, artificial subsidence is caused by oil and gas extraction, salt mining, and groundwater abstraction, placing existing structures and water defences at risk (Fig. 2 right).

When the top 40 m below ground surface does not suffice for founding a structure, soils at greater depth must be considered, but are often found to have surprising (*i.e.* unexpected) characteristics. For instance, stiff Pleistocene and Tertiary clays stick to machines (Fig. 3 left and middle left), and interlocked Tertiary sands dilate when they are sheared (Fig. 3, middle right). If dilatation is prevented, high stresses are generated which are capable of causing substantial damage to excavation tools (Nieuwenhuis, 2004).

Rock, as opposed to soil, in outcrop within the Netherlands is generally weak, deteriorates with time and is prone to collapse when exposed to an increased overburden, for example due to heavy rain. Large scale collapse of abandoned pillar and stall limestone mines are a permanent threat in the South Limburg area, (Fig. 3 right, from Bekendam 1998).

Despite potentially adverse ground and groundwater conditions, the Netherlands has experienced development of a high degree of urbanisation. Its geo-engineers are being trained to bring pragmatic and innovative solutions to bear on local problems.

TUDelft has responded to the needs of the Dutch construction industry since inception of the engineering geology Masters programme in the 1970s, prior to which many projects had been realised with limited (engineering) geological input and judgement impaired by a lack of attention to geologically-related aspects of engineering ground response. Recognition of the added value that engineering geology can bring to the Dutch environment emerged as risk reduction related to the implementation of novel technologies became paramount.

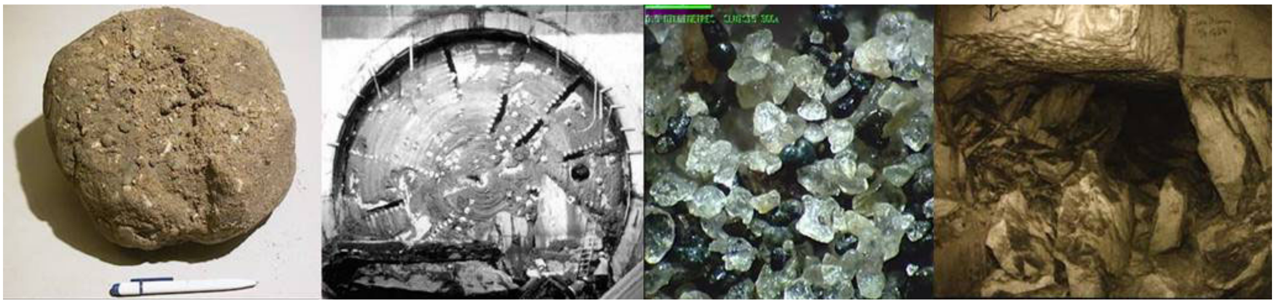

Figure 3. A clay ball from the excavation chamber of a Tunnel Boring Machine (TBM) (left) – note pen for scale. Clay stuck to the cutting wheel of a TBM (middle left). Long straight, convex and concave contacts characteristic of ancient sands (middle right) (P. Verhoef, with permission). Large scale collapse of an abandoned room and pillar calcarenite mine in South-Limburg, the Netherlands (right, from Bekendam, 1998)

TEACHING FROM 1971 TO 1995

In the last quarter of the 20th Century, teaching of ground engineering programmes in the Netherlands has exclusively centred on TUDelft, and has been essentially a postgraduate activity. Masters-level courses of two years duration at that time were taught towards the end of a student's five-year programme of university tuition. Specialisation started in the third year but the extent has been shrinking over the years. Ground engineering education would have begun at the undergraduate level and finished with submission of a thesis for the award of the title "ir." ("ingenieur"), equivalent to a Master in Science (MSci) or in Engineering (MEng) in the UK, a Licentiate in Switzerland, or a Diplom-Ingenieur' in Germany. In practice this meant that students had to be based in either the Civil Engineering Faculty or the Mining Engineering Faculty then, renamed Faculty of Applied Earth Sciences, leading to the corresponding degree; tuition and allegiance was inevitably split also. Although the different faculties would meet on several fronts academically, their individual environments did not encourage a unified approach nor did the students perceive a common focus within their training towards geo-engineering in general, or engineering geology in particular.

Training programmes based on research, leading to award of a PhD, and research itself were similarly split between the faculties. Jointly supervised research programmes enabled individuals to benefit from the broader opportunities available when studying in more than one faculty, but the degree of success depended very much on the personalities involved. Opportunities for collaboration were also sometimes lost, primarily because of lack of direct communication and discouragement due to the financial devolvement from the central administration, with Section- and Faculty-focussed targets.

Differing fields of employment

The training of Engineering Geology Masters students was sufficiently broad to cover conditions representative of environments and climates worldwide, appealing to Dutch contractors concerned with projects beyond as well as within the Netherlands, perhaps in geological conditions very different from those typically found in the Netherlands (Nieuwenhuis, 1994). In fact, these were the only Masters students within the Netherlands to be offered Masters-level courses in applied rock mechanics and field-based engineering geology. Employment was generally with the dredging and offshore industries, both confronted not only by unconsolidated sediments but also by cemented soils, and by weak and discontinuous rock masses. In contrast, courses for the geotechnical engineers focussed their teaching on how to design foundations for structures suitable for the Dutch subsurface. Their employment prospects were primarily with Dutch civil engineering contractors, consultants and public authorities (municipalities, water boards and harbour authorities).

Differing philosophies

The Engineering Geology Masters students generally had a broad educational background in geology, engineering, chemistry and physics. They had the basic competences needed as a professional engineering geologist, i.e. they were able to recognise minerals and rocks, produce and interpret borehole logs, synthesise data, construct and analyse geological maps and sections, use stereonets to calculate rock slope stability, and so on. However, their direct experience of construction site operations and the roles and responsibilities within the civil engineering industry were comparatively limited. By the time their course was complete, they were able to manipulate basic engineering geological tools with dexterity, could tackle them in the field or on site, and knew how to approach the investigation of complex geological situations. In brief, the philosophy underpinning their training can be summarised by the solution of the following conceptual equations, developed as a basis of engineering geology by TUDelft and Imperial College (de Freitas, 2006):

- MATERIAL PROPERTIES + MASS FABRIC = MASS PROPERTIES
- MASS PROPERTIES + ENVIRONMENT = THE ENGINEERING GEOLOGICAL MATRIX
- THE ENGINEERING GEOLOGICAL MATRIX / CHANGES PRODUCED BY THE ENGINEERING WORK = THE ENGINEERING BEHAVIOUR OF THE GROUND

Employers appreciated the skills acquired by the TUDelft-trained engineering geologists, particularly for their broad education and knowledge of geology and geological processes both within and beyond the Netherlands. They also valued their practicality and ability to integrate environmental constraints with a pragmatic approach to problem solving (Maurenbrecher & Ngan-Tillard, 2007).

On the other hand, geotechnical engineers received a more advanced training in soil mechanics. They were well equipped to apply analytical and numerical techniques to predict the response of soft ground to complex engineering structures and to develop effective designs for conventional and novel foundations appropriate to the Dutch environment. Collaboration with structural engineers was an essential tenet, as was the provision of training by hydraulic engineers. Flooding is an ever present threat in the Netherlands, a country lying in large part below sea level with a groundwater table near to ground surface. Coastal defences and water surge barriers had to be built; sea and river dikes had to be strengthened, largely directing the main focus of training within the country's leading technical university (TUDelft).

Differing perceptions

The Engineering Geology Masters students were trained by staff that had formerly been employed in industry, had worldwide experience, firmly believed in the power of the observational method, and were prepared to teach a substantial proportion of the course in the field. Exposure to the complexity of the subsurface and its dynamic processes could therefore be progressively developed through idealised cases (Maurenbrecher & Ngan-Tillard, 2007), case histories, short field trips and an intensive fieldwork programme (Maurenbrecher *et al*., 2008), the latter being located in South Limburg, Scotland and Spain (Fig. 4, left). Geotechnical engineers received less practical training in soil investigation and seldom had the opportunity to study the ground *in situ*. They had a tendency to consider geology as having a text book "layer-cake" stratigraphy, and thereby lacked the tools to tackle the heterogeneity of many Dutch near-surface soils. In their educational programme, laboratory testing became progressively replaced by physical (later, computer-based) modelling (See Fig. 4, right). This enhanced their understanding of the mechanisms of interactions between soils and structures, but at the expense of the possible variability that may be encountered on site.

Figure 4. Description of weak rock mass during the Spanish fieldwork (left). Using the centrifuge to examine the performance of innovative methods of dike stabilisation (right).

A turning point – 1995: the use of underground space

For various economical, political, environmental and safety reasons, a series of underground projects came to fruition in 1995. The Betuwe railway line was built to connect Rotterdam harbour with the German border, requiring the construction of 3 twin-tube tunnels. The Westernschelde road tunnel was excavated to encourage development of the hitherto isolated southern part of the Province of Zeeland. A High Speed railway line linking the country's 4 largest cities (Amsterdam, Rotterdam, The Hague and Utrecht) was planned that would pass underneath the "Green Heart" open country in a 14.9 m diameter, 7.2 km long tunnel, and lead on to connect Paris to Amsterdam in about 3 hours. The main cities of the Randstad (The Hague, Amsterdam and Rotterdam) considered if they could equip themselves with modern Metro lines. New road tunnels such as the Hubertus tunnel in Den Haag began to be designed to reduce traffic congestion in the Randstad. Urban planners thereby became aware of the value of the underground. Proposals for underground projects such as car-parks have subsequently flourished in many towns and cities.

The use of the subsurface for the development of Dutch infrastructure impacted the geo-engineering training at TUDelft. In 1995 a Chair in Underground Space Technology was created, to facilitate the interdisciplinary character of the multiple use of underground space. New technical courses were introduced, for example on bored technology and trenchless technology, requiring input from a variety of engineering disciplines (e.g. soil mechanics and concrete engineering). Complementary courses on subsurface and risk management were also developed, incorporating not only engineering judgement based on established technologies (civil, mechanical, electrical and chemical) but also disciplines such as engineering geology, urbanism, economics and architecture, and further broadening the spectrum of issues to include logistics, safety, legal and environmental aspects.

In parallel, TUDelft-trained engineering geology alumni became directly involved in ground engineering in the Netherlands, raising awareness of the potential value of their contributions and subsequently increasing demand for additional staff appointments having similar skills. Bored technology was introduced as a non-disruptive alternative to the immersed caissons and open cut methods traditionally employed. As little experience with large diameter tunnel boring machines (TBMs) was available, expertise had to be sought from abroad. Engineering geologists were already familiar with the different construction techniques in use outside the Netherlands, and so were able to effectively contribute to the application of such techniques to Dutch conditions. Risk in tunnelling projects beneath sensitive urban locations had to be reduced, so greater attention began to be paid to the definition of the subsurface (Ngan-Tillard, 2003) and the prediction of its response to engineering change, primarily by the introduction of monitoring programmes.

The training of engineering geologists at Masters level became re-oriented towards a paradigm for a soft heterogeneous subsurface. The focus turned to the application of analytical techniques to available data, including geostatistics (Maurenbrecher, 1994). Greater attention began to be paid to the boundary conditions, significantly to the constraints of the ground model, primarily with respect to river, marine and marginal-marine deposits. Greater focus was placed within the Engineering Geology MSc programme on the investigation and determination of the engineering properties of Dutch soils. A course in shallow-depth geophysics was introduced, to help predict the lateral continuity of alluvial and marine deposits, to identify the pitfalls and interpretation difficulties associated with current geophysical techniques, and to provide an integrated framework for the interpretation of (geophysical) data in combination with geotechnical, geological and geomorphological information. Other courses were correspondingly reduced, for instance in subjects such as numerical rock mechanics and construction materials. Rock engineering subjects remained part of the programme, including rock testing, classification, dredging, excavation, slope stability, durability of armourstones, piling and subsidence above abandoned mines. TUDelft-trained engineering geologists are employed largely by the Dutch construction industry, which is active worldwide. Work is both onshore and offshore, in soft soil and weak rock environments.

TEACHING IN THE 21ST CENTURY

The development of the concept of geo-engineering now provides an effective umbrella for further encouraging training at Masters level and the advancement of research focussed on the need of Dutch industry. TUDelft has responded by the reorganisation of academic disciplines pertinent to integrating this environment whilst remaining focussed on the near-surface, effectively merging the Faculties of Civil Engineering and of Applied Earth Sciences.

Furthermore, the Bologna Accord of the EU has meant in parallel a widespread restructuring of tertiary level education throughout Europe, as part of the striving towards mobility of employment and educational opportunities. An important part of this agreement has been to separate the longer undergraduate courses traditional on the mainland, hitherto often of four or five years duration, into an initial three-year period of broad-based education (similar to the Bachelors level of the British university system) followed by a two-year period of specialist training (comparable to the final two years of the licentiate programme, including a substantial dissertation based on individual research, and twice the duration of the taught Masters courses of the British system). This has provided a good opportunity to review and revise the geo-engineering suite of Masters courses that had already become established at TUDelft, as a result of which a new academic framework has been created, merging the former academic faculties pertinent to ground engineering (including engineering geology) to form the Geo-Engineering Section within the Faculty of Civil Engineering and Applied Geosciences.

The new Geo-Engineering Section is now able to host a suite of MSc courses, currently four: Engineering Geology, Geomechanics, Geotechnical Engineering and Underground Space Technology. In the near future, a fifth course in Geo-environmental Engineering will be added, further widening the spectrum of geo-engineering activities. The whole programme consists of a set of core courses that are common to all specialisations, surrounded by a suite pertinent to each specific specialisation, and with the opportunities to take electives (Fig. 5).

The core of the programme provides students with a clear conceptual understanding of the mechanical and hydrological interactions between sub-surface materials and engineered structures. It is designed primarily to achieve a profound understanding of the fundamentals of geo-engineering and secondly to encourage cross-fertilisation of ideas from different fields. “Ethics” is a compulsory course for all students at TUDelft

The core course programme in 2006 (Table 1) has been able to improve the pre-existing situation for students in a number of ways, as follows:

- Students with a geological 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 Masters 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).
- 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. Case histories concerning

ambitious projects such as excavation of the new Metro tunnel in Amsterdam, construction of a new offshore airfield, and renewed extensions of the Dutch coastline act as effective stimulants to the students' learning process.

- Sustainable development, respect for the environment, and the multidisciplinary Use of the Underground are debated within the curriculum.
- Risk within geo-engineering now occupies a strong position as a component of the core programme. Ground risk and its management have increased visibility, reflecting the aim of the GeoEngineering Group: to reduce ground uncertainty with the aid of geological expertise, to limit risk in construction, and to assist the sustainable development of low-land countries.

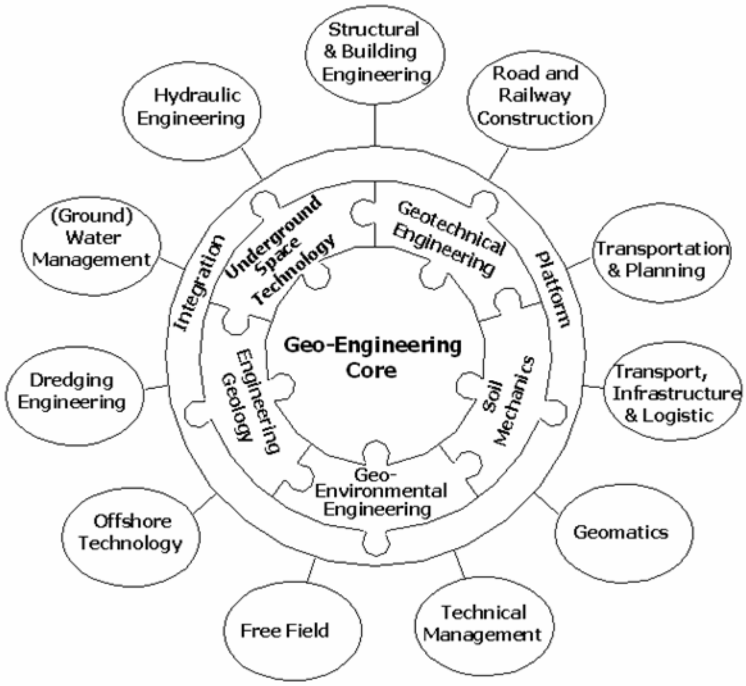

Figure 5. Structure of the TUDelft Geo-Engineering programme at Masters level.

Table 1. Geo-engineering MSc specialisation Engineering Geology

Block	Courses	Core (ECTS)	Specialisation Engineering Geology (ECTS)	Block Weight (ECTS)
Engineering Geology	Engineering geology of soils and rocks		4	21
	Engineering geological mapping		3	
	GIS applications in engineering geology		3	
	Engineering geology fieldwork		11	
Ground Investigation	Ground investigation, including in-situ and laboratory testing	5		11
	Shallow depth geophysics		6	
Geomechanics and Geotechnique	Soil mechanics	4		17
	Rock mechanics		6	
	Numerical geomechanics	4		
	Geotechnical engineering		3	
Hydrogeology	Environmental geotechnics		3	7
	Geohydrology		4	
Professional practice	Use of the underground	3		10
	Probabilistic design	4		
	Risk in geo-engineering	3		
Total core+ specialisation EG		23	43	66
Electives	Flow in fractured media, Offshore soil mechanics, Dredging engineering, Coastal engineering, Soil structures and soil retaining structures, Foundation engineering and bored tunnels, Remote sensing, Foreign languages, Technical management, Ethics,…			12
MSc thesis				42
Grand total				120

The specific programme tailored for the Engineering Geology MSc (Table 1) equips the engineering geologist with the basic skills necessary for professional practice and introduces site investigation techniques and data interpretation. The understanding of geological processes is used as a tool to achieve better parameter determination, in harmony with Price's practical approach. Attention is drawn on soft soils, hard soils and weak rocks to cover the special needs of the Netherlands and its dredging and offshore industries active worldwide. The student is taught by a dedicated team of specialists, all of whom have experience of industrial applications as well as active research and publication profiles. Field visits and guest lectures by industrial partners are central to the development of the students' understanding of the subject as well as helping forge stronger links with potential employers. This course philosophy is reinforced by a strong alumnus organisation.

Electives allow further specialisation in one or several areas within or outside civil engineering. Popular electives for Engineering Geology Masters students are listed in Table 1.

Geotechnical engineers are more likely to select electives in "Hydraulics Engineering" or "Structural Engineering" whereas students specialising in Underground Space Technology often prefer to take electives in "Technical Management" and "Transport and Planning".

All geo-engineering students with an undergraduate background in civil engineering are now introduced to engineering geology by staff who are practitioners, building on the often rather theoretical programmes previously attended. This helps raise awareness of the potential variability of the ground, and improves their understanding of likely boundary conditions. Focus is put 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.

Students enrolling on the TUDelft Masters programme can have graduated from any acceptable undergraduate programme within the Netherlands or from Abroad. The Masters courses are all taught in English. Because the profile of incoming students varies, electives can be swapped with convergence courses. The convergence courses are organised at the start of the academic year and are tailored to individual needs.

Civil engineering graduates have the opportunity to first put into practice their newly acquired knowledge by undertaking an industrial placement. For the engineering geology students, integration of knowledge and independent judgment are essential components of their 9-week fieldwork programme in Spain. This includes engineering geological mapping, field data acquisition and laboratory testing, feasibility assessments for small construction projects, preparation of a tender document, and expert assessment of a (hazardous) slope or cut in the context of a potential damages claim.

The final MSc graduation thesis is a key tool in preparing and training specialists for the rigours of the industrial world, in particular project management, report writing and presentation skills. The topics addressed are typical of the issues a young engineering geologist will have to contend with in day-to-day business. The academic quality is guaranteed by integrating MSc theses into the research activity of the Department, including collaborative partners from industry, widening the supervisory base to include postgraduate researchers and visiting fellows and encouraging publication of the results.

CONCLUSIONS AND PERSPECTIVES

Geo-engineers trained at TUDelft have a work-related education and are thus well equipped to play a leading role in the sustainable development of lowland countries.

Engineering geologists are often called upon to perform geological site evaluations for construction projects and to minimise the threat of geological hazards. They are often the first to be sent on site, and have the satisfaction of being able to contribute positively to both the project inception and maximise the subsequent enhancement to the welfare of Society.

The TUDelft experience has been that the training regime that has been developed equips their geo-engineering graduates to work competently within and beyond the Netherlands, and in both onshore and offshore projects. Thanks to their broad knowledge, they can readily cross borders between different disciplines and propose innovative solutions to challenging construction and geo-environmental problems.

Their understanding of the interactions between structures and the ground help promote the inversion of ground monitoring data to improve *a priori* models of the subsurface under geological constraints. They are well equipped to build shared models of the subsurface by combining geophysical, geotechnical, geological and environmental information.

Both the inverse model of ground monitoring data and the shared model of the subsurface will help make the Dutch dream true: construction at reduced price, in reduced time with reduced maintenance costs and little disturbance! They can also help resolve the recurrent problems of high groundwater within Dutch cities and associated land subsidence following drainage or groundwater abstraction, sensitive to the impact of impending global sea level rise.

Engineering geologists have a working knowledge of mineralogy, geochemistry, geological processes and geomechanics. They already play a crucial role in pore engineering (Fig. 6, from Cheng, 2006), water development, petroleum and mining, as well as the traditional construction industries. The creation of a Chair in Geo-Environmental Engineering will further help to couple biology and micro-engineering geology with soil remediation and ground improvement projects. It will also help to mitigate the environmental impact of heat pumps and help solve medical geology issues relating to health and forensics.

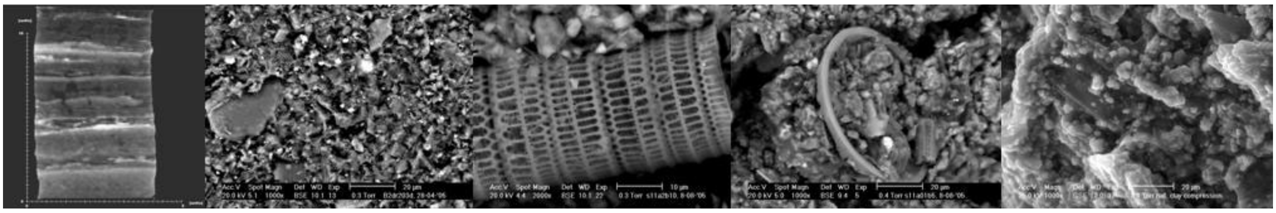

Figure 6. Revealing the secret of why the effective friction angle of Dutch organic soils is so high by observing fabrics and textures at multiple scales using microscopic technologies: Computed Tomography Scanner (furthest left) and Environmental Electronic Microscope (right)) (from Cheng, 2006).

Thus the knowledge gained from the postgraduate training programmes in TUDelft have been, and are 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.

Corresponding author: Dr Dominique Ngan-Tillard, Delft University of Technology, Mijnbouwstraat 120, Delft, 2600 GA, Netherlands. Tel: +31 15 278 33 25. Email: d.j.m.Ngan-Tillard@citg.tudelft.nl.

REFERENCES

BEKENDAM, R.F., 1998. Pillar stability and large scale collapse of abandoned room and pillar limestone mines in south-Limburg, The Netherlands, TUDelft press, 360.

CHENG, X.H. and NGAN-TILLARD, D.J.M., 2006. Revealing the secret of high effective friction angle of Dutch organic soils (to be published).

DE FREITAS, M.H., 2006. Engineering Geology: Principles and Practice – Part 1 of Engineering Geology Essentials by David Price, TU Delft Professor of Engineering Geology. Springer-Verlag (*in press*).

GRIFFITHS, J.S. and CULSHAW, M.G., 2004. Seeking the research frontiers for UK Engineering Geology. *Quarterly Journal of Engineering Geology and Hydrogeology* **37** 317-325.

HATHEWAY, A.W., KANAORI, Y., CHEEMA, T., GRIFFITHS, J.S. and PROMMA, K., 2005. 10th annual report on the international status of geology—year 2004–2005; encompassing hydrogeology, environmental geology and the applied geosciences. *Engineering Geology* **81** 99–130.

MAURENBRECHER, P.M. and HERBSCHLEB, J., 1994. The potential use of geotechnical Information Systems in the planning of tunnels for Amsterdam, *In: Tunnelling and Underground Space Technology*, **9**, 357-365.

MAURENBRECHER, P.M. and NGAN-TILLARD, D.J.M., 2007. Engineering Geology Games – Part 2 of Engineering Geology Essentials by David Price, TU Delft Professor of Engineering Geology. Springer-Verlag (*in prep*).

MAURENBRECHER, P.M., NGAN-TILLARD, D.J.M. and HACK, R., 2008. Engineering Geology Fieldwork – Part 3 of Engineering Geology Essentials by David Price, TU Delft Professor of Engineering Geology. Springer-Verlag (*in prep*).

NGAN-TILLARD, D.J.M., ELKADI, A. and SWINNEN, G., 2003. Dynamic soil modelling for a settlement-driven TBM control system, *In: (Re)Claiming the Underground Space, ITA World Tunnelling Congress, Amsterdam, The Netherlands, Saveur (ed*), BALKEMA, 811-816.

NIEUWENHUIS, J.D., 1994. Developments in engineering geology in the Netherlands (1974-1994). *In: Engineering Geology of Quaternary Sediments, Proceedings of the 20-year Jubilee symposium of the INGEOKRING/Delft/Netherlands, ed Niek Rengers,* Balkema, 1-23.

NIEUWENHUIS, J.D. and VERRUIJT, A., 2004. Tunnelling problems in older sand formations, *In: Engineering Geology for infrastructure planning in Europe, Hack et al. (eds)*, Springer, 538-548.

VAN BAARS, S., 2005. The horizontal failure mechanism of the Wilnis peat dyke, In: Géotechnique, 55 (4), 319-323