Pragmatic training in Engineering Geology

D.J.M Ngan-Tillard & P.M. Maurenbrecher
Delft University of Technology, Delft, Netherlands

J. van der Schrier
Royal Haskoning, Nijmegen, Netherlands & Delft University of Technology, Delft, Netherlands

Arjan Venmans
Deltares, Delft, The Netherlands & Delft University of Technology, Delft, Netherlands

Robrecht Schmitz
RWE-Power AG, Niederzier, Germany & Delft University of Technology, Delft, Netherlands

ABSTRACT: Delft University of Technology offers a Master programme in Engineering Geology in which exposure to the complexity of the subsurface and its dynamic processes is progressively developed through the study of idealised case studies ("games"), genuine case histories and an intensive fieldwork programme based on observation, analysis and communication. 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. This is supported by a strong alumnus organisation. The overview of the training provided via the cases and field visits is exposed in the form of matrices. The first rows of the matrices present the wide range of geo-engineering applications, geological conditions and environments covered. The last rows list the fundamental knowledge, skills and techniques required and/ or developed. Examples of cases and field assignments are developed in the paper. From the first matrices, a second series of matrices with fundamental knowledge, skills and techniques as sorted entries and project type and conditions as output are derived.

1 INTRODUCTION

The philosophy underpinning the training of Engineering Geology students at Delft University of Technology can be summarised by the solution of the following conceptual equations, developed as a basis of engineering geology by TU Delft and Imperial College (Price & de Freitas, 2008):

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

This approach was first implemented by the late Prof. D.G. Price between 1975 and 1993. MSc graduates in Engineering Geology from TU Delft are employed worldwide by engineering consultancies, contractors, local authorities, national and international government agencies and financial institutions that assess engineering challenges and geohazards. Many of the Delft trained engineering geologists work for the Dutch dredging and offshore industry on the construction of harbors and artificial islands or the foundations of oil platforms and wind farms. Many of them are also involved in the Netherlands, in tunnel construction, motorway widening, dike strengthening or durable development of new areas. Some sign up for PhD research, again all over the world. Employers appreciate the skills acquired by the TU Delft-trained engineering geologists, and particularly their broad education and knowledge of geology and geological processes both within and beyond the Netherlands. They also value their practicality and ability to integrate environmental constraints with a pragmatic approach to problem solving. The students knowledge of the first two Price equations combined with their basic technical engineering training provides them with the necessary tools to successfully implement the 'factor geology' in the design process (the third Price equation), the latter including their ability to 'deal with all type of uncertainties' that are linked to building on natural grounds (being either rock and/or soil).

The particularity of the TU Delft training is the progressive exposure of students to the complexity of the subsurface and its dynamic changes through the study of idealised case studies, case histories and an intensive fieldwork programme based on observation, analysis and communication. TU Delft students draw knowledge from attended courses, guest lectures and site visits, and are trained to seek additional knowledge separately in order to apply and solve the conceptual equations of engineering geology in the context of a wide range of applications and environments. The paper presents the type of engineering geological exercises that encourage students to adopt an active attitude to learning and give them confidence in tackling more challenging problems in their future work environment. An overview of the whole MSc programme in Geo-Engineering, included the engineering geology specialisation is given in (Ngan-Tillard et al. 2008).

2 CLASSROOM EXERCISES

2.1 *Three types of case studies*

The classroom exercises are solved in parallel to traditional lectures and present an increasing degree of realism. They are based on fictive geo-data and fictive projects (the "Site Investigation Games in Priceland"), on real geological maps and fictive projects (the "UK Site Appraisal Exercises") or on real geo-data and real projects (the "Engineering Geology Professional Practice Cases"). The training provided through each type of exercise is synthesised in the form of a matrix. Table 1 & 3 are given as examples. The first rows of the matrix present the wide range of geo-engineering applications, geological conditions and environments covered together with the related geotechnical aspects. The last rows list the fundamental knowledge, skills and techniques required and/ or developed. Superscripts from 1 to 3 (not shown here) are used to indicate the degree of expertise reached by students; 3, being the highest.

2.2 *"The Site Investigation Games in Priceland"*

Late Prof Price wrote at the front page of his site investigation notes: "These are the hardest of all the courses given in Engineering geology. The examination questions which will be set will require, to set good marks, not just the repetition of the contents of the notes but some insight into the solution of problems which require the application of several fields of knowledge."

To train students at the design of site investigation, he elaborated under a European grant shared with Imperial College, a series of interactive site investigation games.

The games are realistic simulations of site investigations for a variety of fictive construction projects (bridge, land use above old mining workings, quarry for aggregates, harbour and tunnel). All projects are located in "Priceland", the coastal land dreamed by Prof Price to train Delft engineering geologists. As one can expect, landscapes and geology are diverse in Priceland! Alluvial plains with old buried channels and moving meanders, sand bars in river mouths, buried glacial valleys, shales dipping to the valley, karstic limestones with disappearing rivers, dolerite intrusions displaced by faults, carboniferous rocks perforated by abandoned coal mines, etc…can be encountered in Priceland. In most games, the best location for the engineering structure is to be found. Players have limited budget and time to design and execute the site investigation. They are invited to buy geo-information (maps, trial pits, outcrop logging, short and long borehole logs, onshore and offshore boreholes, geophysics profiles, etc…) from the game master at separate occasions. The winner must devise the plan which meets the targets of the site investigation and respects the project environmental constrains, for the least budget and within the time restrains. Long boreholes and boreholes located far from any access road are time consuming and more costly. Boreholes to bedrock without information on the nature of the rock are cheaper than boreholes with rock core indices. Terrestrial drilling units are lost if they are mobilized at wrong coordinates and fall for example, on moving sands or within a river bed, etc…. The winner must also be able to justify his/her site investigation strategy. This limits the influence of the chance factor in the grading. The games have been computerized to facilitate support to students and correction. However, their content has not changed. In 2009, we expect to publish them on a DVD together with other interactive games and exercises designed by Prof Price. The games are appreciated by students as a means to learn how to adapt the set-up, phasing and execution of site investigations to local geological conditions and project type. The emphasis is not on techniques. A limited number of techniques are involved and no very specific technical knowledge is required. In some cases, one would be tempted to swap a test for a more modern one. Routine and more advanced techniques are exposed in the traditional Site Characterisation and Testing, Shallow Depth Geophysics and Environmental Geotechnics lectures. A large number of them are practiced in the laboratory and in situ (table 2). During the games, the accent is put on i) the 3D interpretation of the site conditions, ii) the need to upgrade ground model and next investigation plans as ground investigation results become available and iii) the non-uniqueness of the solution. This last aspect is often found as very upsetting for students accustomed to the traditional teaching methods. Solutions provided by students and best strategies are discussed at the end of each game. Table 1 summarizes the geological conditions and related geotechnical issues of the civil engineering and quarrying projects planned in Priceland. It also lists the fundamental knowledge, skills and techniques developed throughout each exercise.

Table 1. "The Site Investigation Games in Priceland"

Project type	Bridge	Land Use	Quarry	Harbor Complex	Tunnel
Project description					
Project Contrains	Fixed span and limited range of span directions to connect to existing infra-structure via the cheapest/ shortest route		Low accessibility Best spot for the quarry unknown Fixed quarry floor level Time constrains for site investigation	Best spot for the harbour to be determined Multi-components project Priority ranking of each component Limited budget and time	Limited accessibility Linited budget
Geology	Alluvial plain with old buried sand channels and moving meanders encased in sheets of clay and peat	Carboniferous rocks with coal seams overlain by soil	Filled-in glacial valley Fault Dolerite intrusion Metamorphic rocks	Coastal karstic limestone Anticline Active fault Sand bar in river mouth Loose to dense sand deposits Wave and wind Loading	Faults Fractured and weathered rock masses
Geotechnical issues	Pile bearing capacity Settlements	Subsidence above abandonned mine galleries and shafts	Rock suitability for rock aggregates	Bearing capacity Depth to bedrock Karst related subsidence Seismic loading Liquefaction Durability of sea defences Site suitability for quarry	Rock excavatability Tunnel excavation and support
Learning process					
Fundamental Knowledge	Soil mechanics and geotechnical Engineering Sedimentary Geology	Geo-hazards	Mineralogy Structural geology Rock mass weathering in relation with local paleo-climate Bedrock problem Discontinuous rock Mechanics Geohydrology	Coastal morphology Geotechnical engineering Dynamic soil loading	Discontinous rock mechanics
Skills	Investigation of Foundations for Bridge and Embankment Design of site Investigation based on site geological history non-unicity of	Selection of appropriate of geophysical techniques to localise shaft	Selection of site investigation techniques to identify sound bedrock and large faults	Geological map interpretation Identification of active fault Prediction of engineering properties of rock masses SPT interpretation in terms of relative density	Combination of geo-data
	3D interpretation of ground condutions, non unique ground model, need to upgrade ground model				
Techniques		Geological map constructions	Geological map constructions RMR classification for engineering purposes	Geological map constructions Rock parameters for outcrop logging	Rock mass classsifica classification for rock excavatability and tunnel support

Table 2. Laboratory and in situ testing sessions

Soil laboratory testing
Soil description using Dutch standard Index soil testing (sieving, Atterberg limits, water content, dry and wet density, penetrometer test, hand vane test, pycnometer, methylene blue test) Permeability tests, Oedometer tests, Shear box tests, Triaxial tests
Rock laboratory testing
Rock core logging Selection of rock specimens for laboratory testing UCS, point load test, Brazilian test, equotip, Schmidt Hammer test, Shear box test on discontinuities
Aggregates testing
Proctor test, Micro-Deval and Los Angeles test Slake durability test
In situ testing in soils
Boring and sampling in soft soils Index soil testing (sieving, Atterberg limits, water content, dry and wet density, penetrometer, hand vane, pycnometer, methylene blue tests) Cone penetration testing (piezocone)
Geophysics
Electro-magnetic surveys: GPR and time dependent and frequency dependent em surveys (Gem-2 and Tem-Fast) Seismic surveys (P and S waves refraction and reflection surveys)

2.3 *The "UK Site Appraisal exercises"*

Fictive feasibility studies based on real rather than idealised geological maps are proposed to students in the framework of the course "Engineering geology of soils and rocks". The course provides an overview of the engineering geological characteristics of the major types of soils and rocks, and their impact on engineering design and construction. The didactic of the "UK Site Appraisal exercises is illustrated here with the help of the description of 2 exercises made by Prof Mike Rosenbaum, visiting professor at Delft University. Students make an engineering geological appraisal of a specific site based on landscape interpretation and geological map interpretation. Finally they evaluate the engineering implications and present these as a report to be read by a civil engineer. The projects involve the application of the total engineering geological approach advocated by Fookes et al. (2000). The approach, based on consideration of the geological and geomorphological history and of the current ground surface conditions (Fookes, 1997) is discussed in the course. It is intended to help project developers and financial decision makers anticipate ground conditions which are likely to influence construction. The strength of the approach is based on its catalog of climatic and geomorphological and geological models that need to be selected and combined to create a model relevant to the project under study. Fookes' hand-drawn block diagrams of geological and geomorphological models with their lists of related geohazards and civil engineering disasters, are particularly inspiring to students. To practice with Fookes' models, students have first to construct a total geological model for a deltaic environment in a temperate climate located on the platform of a continental shelf. Through the process, they appreciate the usefulness and limitations of such model.

The "UK Site Appraisal exercises" require the understanding of basic geology (geomorphology, stratigraphy (pre-Quaternary and Quaternary), unconformities, folds, faults, geological history (deposition, erosion, tectonic evolution, neotectonics) and their engineering implications (stress field, fractures, weathered profile, strength profile, permeability profile, deformability profile, durability and geohazards).

To find relevant site images and maps and become familiar with the site morphology and historical use, students are invited to use Google and Google Earth. To elucidate the geology and geological history of the site, students analyze Bedrock & Superficial Deposits maps of the British Geological Survey and their accompanying sections, key, legend and booklet. Because the profile of incoming students varies and students holding a BSc in civil engineering have had very limited exposure to geological map interpretation, support is tailored to individual needs.

The first exercise (table 3) is designed to introduce students to techniques that are useful for interpreting medium scale geological maps. Unlike large scale plans, medium scale maps usually give only general details of dip and outcrop and commonly show whole structures rather than portions of structures; this is particularly so in regions of folding. The result is a map that can contain an array of colours and patterns that convey little to a person unaccustomed to using such maps. The steps outlined in the exercise can be applied to most geological maps and will facilitate a reasonably good understanding of the geology of an area. Students are asked to note the scale of the map and the elevations of the contours, to establish the geological succession, to trace the fold structures, locate the unconformities and the faults and to relate folds, unconformities and faults to the geological succession. In the second exercise (table 3), students have to pay special attention to the sections to illustrate the structure of the geology and to the key to the ornament and symbols used on the map. They use the stratigraphic column in the key drawn to scale to determine the thicknesses of various formations. They realise that inclined boundaries in the column describe diachronous contacts (which cannot be used reliably for the construction of strike lines) and that triangular zones in the column indicate rocks which are not distributed across the whole area covered by the main formation on the map. Whilst studying the geological maps students notice that they contain much information that is of direct relevance to engineering construction and planning, e.g. the location of boreholes, wells, mineshafts, adits, landslides, unstable ground, mineral veins, gravel and clay deposits, etc.

The first exercise consists at making an engineering geological appraisal of the Tytherington quarry site based on geological map interpretation in a region of folded and faulted Upper Palaeozoic and Mesozoic sedimentary rocks close to the Variscan Front affected by Late Quaternary periglacial activity and coastal/estuarine processes. Students are commissioned by the quarry operator to consider the feasibility at the quarry of expanding limestone production and developing a landfill site. Their report to the operator should address considerations of slope stability (issues should include rock mass character and weathered profile), potential impact of (or on) groundwater (issues might include water inflow into the pit, flooding, and contamination), and method of quarrying (issues might include diversity of geological materials, excavatability, height of benches, fragmentation, aggregate suitability, waste disposal, impact on neighbouring property). Recommendations for further investigation that would be relevant should also be included.

The second project studying a potential quarry for procuring clay suitable for cement manufacture is located in the Castleton region, in the Peak district of northern England, a region of gently dipping Upper Palaeozoic sedimentary rocks affected by Pleistocene glaciation and Devensian periglacial activity. It is concerned with undertaking an initial appraisal of the suitability for a site of a new quarry that is needed to enable the local cement works to continue production. The Castleton area is well known for having been mined for metals in the historical past. Other than tourism, cement production is the only industry still operating in the region, a popular upland recreation area. In addition to geohazards related to superficial deposits and anthropological activities, students have to consider ground water flow as drinking water is stored in a reservoir and leakage is suspected to be occurring from the reservoir towards the valley just North of the area where the quarry is planned. Students have to produce a geological cross-section to illustrate the ground and ground water conditions, which they predict will be encountered in the quarry together with an appropriate Total Geological History model. Then, they comment on potential ground engineering problems. They suggest the measures which could be used to enable the quarry to be satisfactorily excavated in such ground and secure Planning permission. Finally, they give advice on the company to go ahead or not with the land purchase and, if not, for procuring clay suitable for cement manufacture.

Table 3. "The UK appraisal" exercises

Project	Tytherington limestone quarry extension for aggregates production and use of exploited quarry as landfill site	Castleton clay quarry
Project Constrains	Environment sensitive to noise, dust, vibration, smell and ground water pollution, subjected to development restrictions by law	Touristic region
Geological	Region of folded and faulted Upper Palaeozoic and Mesozoic sedimentary rocks close to the Variscan Front and affected by Late Quaternary periglacial activity and coastal/estuarine processes	Peak District, UK Region of gently
Geotechnical Issues	Slope stability Potential impact of (or on) groundwater (flooding, water inflow into the pit, pore pressure and contamination) Ease of quarrying (diversity of geological materials, excavatability, height of benches) Waste disposal Impact on environment	Ground subsidence related to abandoned mine shafts and galleries Ground contamination Slope instability in deposits affected by sollifluction Flooding and ground water flow Drainage Slope stabilisation
Fundamental knowledge	Geomorphology Structural geology Rock mechanics Geohydrology Environmental geo-eng.	Geomorphology Structural geology Natural landslides Rock mechanics Geohydrology Environmental geo-engineering EU-laws on inflow water
Skills	Desk study Internet exploration Geohazard identification and prevention Rock mass properties Written professional skills	Desk study Internet exploration Geohazard identification and preven tion Rock mass properties Written professional Skills
Techni-pretation ques	Geological map interpretation	Geological map intertation Ground water flow net

2.4 *The "Engineering Geological Practice" cases*

A step further towards real situations is made within the framework of the course Professional Practice in Engineering Geology (table not shown here).

Geological and geotechnical information is analysed in the context of a variety of construction pro jects and a contrasting range of environments. These can include a motorway and its associated works in the Western Netherlands, the redevelopment of an urban area in the Netherlands (e.g. Maastricht), a marine dredging project in hard soils/weak rocks in West Africa, the realisation of an artificial island in the Emirates, a road tunnel and cutting in weathered granitic rocks in South East Asia, the construction of dikes around salt pans in the Middle East or the erection of a LNG tank in North Africa. Students assess ground risks related to real construction projects based on analysis and deduction of real data including: (hydro)geological maps, aerial photographs, geophysical records, borehole logs, in-situ tests and laboratory test results. The students then have to present their conclusions in the role of a junior engineering geologist working for a contractor or a consultant (as appropriate) to a senior civil engineer or engineering geologist. The students have to provide the context, propose as appropriate a preliminary geotechnical design, recommendations for further site investigation, and raise awareness of potential geohazards and possible mitigation measures. They experience that 'in the real world', projects will always meet project specific constraints (time-wise, money-wise, technical, practical like un-availability of equipment and/or expertise, problems with the constructeability, etc.). Still their specific knowledge is required. They learn to understand that decissions are to be made, but that the associated risk linked to their decission-making must be put on the table clearly allowing for a proper risk management. The senior civil engineer or engineering geologist then provides feedback and exposes his/her own solution. During the contact hours, the role of the different actors involved in a construction project and the style and form of the professional documents (contract specifications, bill of quantities, feasibility reports, claim cases…) are precised. Students are provided with technical papers to help them in the derivation of ground parameters from geotechnical test data (pressuremeter, cone penetration, SPT data, etc) and in engineering geological design.

A first case is used as a preparatory exercise to the fieldwork intensive fieldwork in Spain. Others cases are scheduled after the Spain fieldwork in the second year to broaden the student field of expertise. 2 former engineering geology graduate students from TU Delft, co-authors of the paper, Joost van der Schier (Royal Haskoning) and Arjan Venmans (Deltaris, formerly Public works) share their experience with students and animate several engineering geological practice cases. The material used can be recycled to illustrate other lectures in next academic years.

3 FIELD TRAINING

3.1 Field exposures

Masters students are made aware of real ground conditions and the procedures and protocols for data collection with the aid of short field works in neighbouring countries (Maurenbrecher & Ngan-Tillard 2004), (Bekendam 2004), (Vuurens 2005), (Schmitz et al. 2007), laboratory practicals and site visits.

They are strongly invited to join excursions organised by the Dutch branch of the IAEG and the Geo-engineering student disputes. The construction of bored tunnels for the metro in the Randstad offers many visit opportunities. The study tour organised every year by the student dispute in connivance with the staff has proved to be as a valuable addition to the programme from the scientific and cultural point of views. In 2007, Madrid reconstruction works were visited. In 2008, focus was put on engineering in tectonically active zones with the study trip to Istanbul. International students originating from the visited countries facilitate greatly the organisation of the excursions.

In brief, many opportunities are seized by TU Delft engineering geology group to expose in the field students to the complexity of the subsurface and its dynamic changes. They are summarized in a table not shown here.

3.2 Spain fieldwork

3.2.1 General presentation

It is during the 7-weeks fieldwork programme in Spain that the integration of knowledge an independent judgment culminate. The fieldwork was initially designed by Prof Price and Dr Robert Hack in the framework of Robert Hack's doctoral research (Hack, 1998) and has involved many ITC and TU Delft staff as well as visiting staff since then.

The fieldwork area extends from the mountain watershed to the coast South of Tarrogona in Catalonia. It is appreciated for its Mediterranean climate and the diversity of its geology. Rocks of Carboniferous to Miocene age outcrop. The older igneous rocks are affected by intrusions and metamorphism while the younger rocks are often faulted and/or folded. Differential weathering of rocks such as the Bunt Sandstone, the Lower, Middle and Upper Muschelkalk and the Keuper marl has shaped the landscape. Along the coast, the geology consists of alluvial fans of coarse gravels cemented locally into duricrust depending on the source area of gravels and water transporting the sediments. As the Spain fieldwork is carried out in small groups, the area is subdivided into strips chosen to emphasize differences in geology between the groups.

The Spain fieldwork includes engineering geological mapping, field data acquisition and laboratory testing, site testing (SPT), feasibility assessment for a construction project including the preparation of a tender document, and expert assessment of a (hazardous) slope or cut in the context of a potential damages claim.

One or two excursions are organised and provide the opportunities to see new field application areas. The technical visits can include: the Canelles dam of which the reinforcement of its karstic and jointed abutments costed as much as the dam itself (Maurenbrecher, to be pub.), the Ebro Delta where man intervention affects the balance between sediment deposition by the Ebro and removal of this material by wave erosion and Cardona, the medieval village where a salt mine captured a river.

After a preparation period of one week in Delft, the fieldwork lasts about 3 weeks in Spain. Back in Delft, 3 weeks are allocated for laboratory testing, data analysis and reporting. During the whole fieldwork duration, students share responsibilities and work load. At some occasions, they have to work out conflicting interpersonal/intercultural relationships or working methods to induce efficiency and creativity. At anytime, safety in the field is primordial.

Students are assessed individually during oral examinations based on 2 group reports: a feasibility study report including an engineering geological map and a slope stability investigation. During the oral examination, the field impression left by the student to the staff is compared to the student self assessment and peer assessment.

3.2.2 Feasibility projects

The feasibility projects are introduced by staff during the preparation week in Delft. Students acquire, if necessary, basic knowledge on the design of the types of construction required for their projects and get acquainted with their fieldwork area through the study of aerial photographs and geology maps. They are invited to put in practice Glossop's advice: "What you look for should be suggested by the natural environment and by the nature of the construction problem to be solved" (Glossop 1968). The presentation and discussion of the students strategy and walk-along survey plans conclude the preparation week.

The feasibility projects transpose students to situations similar to real life and all include aspects such as site accessibility, multiple use of the subsurface, impact on the environment and project durability. Examples of recent feasibility projects are the construction of small head and base dams connected with an aqueduct and the construction of a harbour in Cambrils with the search of a suitable site for a quarry dedicated to armourstone for seawater breakers. Both projects are very relevant to Catalonia: water resources are becoming more scarce while demand for water keeps rising and the coast is remodelled to welcome tourist boats. The Cambrils harbour project is particularly relevant for students interested in joining the Dutch dredging industry after graduation.

In Spain, the first two weeks are devoted to the feasibility project with the preparation of an engineering geological map of an area, the assessment of the geotechnical properties of the rock and soil units distinguished and the predictions of geo-hazards related to the feasibility projects. The first 3 days are reserved for a geological excursion to introduce the fieldwork area and instructions on field classification of soil and rock masses. Then, students survey and explore their allocated fieldwork area. They record observations relevant to the theme of their construction project in the form of scaled sketches of exposures, landforms (supported with photographs) and descriptions using as much as possible classifications. Data is continuously archived, sorted, interpreted, presented in terms of the construction project in tables, graphs and maps and confronted with published data: air photos, maps, etc…meetings with staff to discuss and review progress and difficulties are organised. Guidance in the field is provided. Towards the end of the field mapping period, students in the role of the engineering geology consultants expert present to the client, a staff member just flown to site, their findings, the project shortcomings and proposals for dealing with the shortcomings.

Back to Delft, laboratory testing is performed, data is synthesised with archive data in maps, tables and graphs and interpreted. The feasibility report is written for an assortment of professionals, from investors, politicians, engineers, contractorsand possibly lawyers, beneficiaries and land owners.

3.2.3 Site study of a hazardous slope

The third week is allocated to the site study of a hazardous slope in small groups. Back to Delft, students determine on information provided and assembled in the field and the laboratory if the slope has been designed and constructed according to the design and construction standards then applicable. The ground mass is described using a standardized geotechnical terminology. The slope flanks and uphill and downhill slopes are also analysed/studied to detect any sign of mass movement. Plan, side elevation and front elevation drawings are prepared together with several cross-sections. Observations are analysed using several slope stability analyses. Assumptions made are stated. The preference for the selected analyses-method has to be justified. Results are compared and assessed before recommendations for laboratory testing, slope stabilisation and/or slope maintenance are given. Students report in the role of the engineering geology consultants commissioned by the Province of Catalonia.

4 INDUSTRIAL INVOLVEMENT

The involvement of the industry in the curriculum under the form of case studies, site visits, guest lectures or occasional student presentations is central to developing the students understanding of the subject. It guaranties the relevance of the programme to current practice. It also helps to forge stronger links with potential employers. This is supported by a strong alumnus organisation and a dynamic student dispute.

5 COMMUNICATION

During the classroom and fieldwork exercises, students are required to argument their chosen solution, through combinations of written, oral or graphical communication. Oral communication skills are improved by the need to communicate effectively both with classmates and staff during presentations. Experience is provided in technical judgement but also team working, negotiating (with other group members) and planning.

6 CONCLUSIONS

TU Delft MSc programme in engineering geology is a coherent package of traditional lectures and project-based problems solved in the classroom or in the field. The student exposure to the complexity of the subsurface and its dynamic processes is progressively developed through the study of idealised case studies ("games"), case histories and an intensive fieldwork programme based on observation, analysis and communication. The involvement of the industry warranties the relevance of the programme to current practice. The style of training adopted helps students to raise their self-confidence and to make a rapid transition from university to practice. It also helps them to provide innovative solutions for the Dutch dredging, offshore and construction industries, active within the Netherlands and worldwide, in the context of a variety of construction projects and contrasting range of environments. Synthesizing in matrices information on learning process and project type, environment and related geotechnical aspects helps the staff and the industry to assess the broadness of the content of the courses on a project-based teaching approach. Matrices (not presented in the paper) with skills and techniques as entry input and project type and related environment have also been built. The use of matrices is found to be an efficient way to capitalize on the contribution of former staff members and to ensure the continuity and broadness of the programme in an economical context where staff mobility is high. A similar strategy based on progressive learning and hands-on exercises has been successfully adopted to redesign the engineering geology courses of the BSc in Applied Earth Sciences.

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