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TU Delft Spain fieldwork and other outdoor activities

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ABSTRACT: Delft University of Technology offers a Masters programme in Geo-engineering 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, site excursions, and an intensive fieldwork programme based on observation, analysis and communication. TU Delft has a long tradition in engineering geology fieldwork in the coastal range and plain around Falset and Cambrils in northeast Spain. The region is appreciated for its climate, numerous (not yet stabilised) cuttings and variety of geological terrains. The modest complexity of the local geology allows students to concentrate on geo-engineering aspects rather than puzzle on geological questions. The Spain fieldwork is an essential step of the TU Delft pragmatic approach to engineering geology. It is during the fieldwork that the integration of knowledge, hands-on experience and independent judgment culminate. Over the years, the fieldwork pedagogy has been modified to cope with difficulties encountered by students and adapt to new technologies. Glossop's advice (1968) "*What you look for should be suggested by the natural environment and by the nature of the construction problem to be solved*" has been adopted. Realistic feasibility projects are defined during the preparation week. The analysis of large rock mass movements has been added to the assessment of a slope in the context of a potential damages claim. Bounds with local knowledge centres have developed. TU Delft and the Geological Institute of Catalonia signed an alliance that facilitates exchange of data and knowledge and promotes research collaboration. For financial reasons, it is essential that the fieldwork is coupled to staff research objectives. Excursions in the Netherlands complete the student exposure to site conditions. These site visits are central to developing the students' motivation to study, highlighting links between research and the industrial practice, and introducing some professional practice not dealt with in the classroom.

1 INTRODUCTION

One of the particularities of the TU Delft education in geo-engineering is its focus on the environments encountered by the Dutch civil engineering, offshore and dredging industries. Wetlands with their soft soils and high ground water table are, therefore, central in the course programme. As Dutch companies are active worldwide, on seas and land, engineering in "exotic" soils and rocks is covered in the programme. The dredging industry, for example, requires a wide range of geo-engineering expertise. Land reclamation does not only involve moving sand from a borrow area to the land fill site to consolidate local soft soils, raise the ground surface, and allow ground construction. Dredging can require cutting through weak rocks or blasting hard rocks. The new land or the new harbour needs to be protected from sea attacks. Rocks of appropriate size and quality have to be found to erect a sea water defence. Quarry sites are selected, developed, and exploited. Access roads to the quarries are built. In new harbours, jetties might be founded on rock rather than sand. These engineering works fall within the expertise of Delft-trained engineering geologists.

In 2011, TU Delft re-structured its Masters programme in geo-engineering introduced in 2006 to increase its multi-disciplinarity and flexibility. 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. In addition to convergence courses and a compulsory core of geo-engineering courses, students have the freedom to choose courses from different poles of geo-engineering, i.e., engineering geology, geomechanics and geotechnical engineering, included underground space technology. The former specialisations (engineering geology, etc…) can still be selected within the new structure. Next to these, hybrid profiles can be defined.

In the engineering geology courses, students are progressively exposed to the complexity of the subsurface and its dynamic changes through the study of idealised case studies, real case histories and an intensive fieldwork programme based on observation, analysis and communication. Students draw knowledge from courses attended, guest lectures and site visits, and are trained to seek additional knowledge separately in order to apply and solve the conceptual equations of geo-engineering (Price, 2008) in the context of a wide range of applications and environments. Ngan-Tillard et al. (2008) presented the type of engineering geological exercises that encourage TU Delft students to adopt an active attitude to learning and give them confidence in tackling more challenging problems in their future work environment. This paper focusses on students exposures to the field, especially during the "Spain Fieldwork".

Before the Spain fieldwork, Masters students are made aware of real ground conditions and the procedures and protocols for data collection with the aid of laboratory practicals, and short field works in the Netherlands and neighbouring countries. Routine and more advanced site investigation techniques are exposed in the traditional Site Characterisation and Testing, Shallow Depth Geophysics and Environmental Geotechnics lectures. A large number of them are practised in the laboratory and in situ (see Table 2 in Ngan-Tillard et al. (2008). Students apply the Total Engineering Geology approach advocated by Ngan-Tillard and her co-authors (2010a, 2010b) for line infrastructure in soft soil countries to a site near Delft. Some of them are confronted, for the first time, by rock mass description and discontinuity characterisation during the excursion to the Ardennes organized in the convergence course on Geology for Engineers. Students have the opportunity to further develop their observation skills during the "Spain Fieldwork".

2 SPAIN FIELDWORK

It is during the 7 weeks fieldwork programme in Spain that the integration of knowledge and independent judgment culminate for TU Delft students. 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 (sieving of coarse materials, dynamic cone penetration and borehole permeability testing), 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.

The modest complexity of the local geology allows students to concentrate on engineering geological aspects rather than on puzzling geological questions. It is during these fieldworks that late Prof. Price, Nick Rengers and Robert Haak developed iteratively SSPC, the Slope Stability Probability Classification (Hack, 1998, Haak et al., 2003) and allowed TU Delft and ITC students to experiment with it. In 2003, Hack and his co-authors explained the SSPC as follows: "The SSPC is based on a three step approach and on the probabilistic assessment of independently different failure mechanisms in a slope. First, the scheme classifies rock mass parameters in one or more exposures and allowance is made for weathering and excavation disturbance. This gives values for the parameters of importance to the mechanical behaviour of a slope in an imaginary, unweathered and undisturbed 'reference' rock mass. The third step is the assessment of the stability of the existing slope or any new slope in the reference rock mass, taking into account both method of excavation and future weathering. From the large quantity of data obtained in the field, the Slope Stability Probability Classification (SSPC) system has been proposed, based on the probabilities of different failure mechanisms occurring." The SSPC has now reached its maturity and has been exported to other countries: Austria, South Africa, New Zealand, the Dutch Antilles (Haak et al., 2003), Australia, Bhutan, China and Malaysia (Haak, 2012). SSPC is still used by TU Delft students during their Spain Engineering Geological fieldwork. Every year, Robert Hack, now at Twente University, kindly answers questions from TU Delft students about the SSPC. Usual questions target the objectivity of the site observations, the slope stability analysis for a layered rock mass, and the extension of the SSPC to other applications (tunnels or foundations), in seismic regions, under, possibly, less favorable climatic conditions.

At least two excursions are organised and provide the opportunities to see new field application areas. The technical visits can include: the Canelles dam (Goodman, 1989) of which the reinforcement of its karstic and jointed abutments cost as much as the dam itself, the Flix dam constructed on soluble Tertiary gypsum layers, Cardona, the medieval village where a salt mine bisected a river, and the Ebro Delta where human intervention affects the balance between sediment deposition by the Ebro and removal of this material by wave erosion.

After a preparation period of one week in Delft, the fieldwork lasts about 3 weeks in Spain. Back in Delft, 2 weeks are allocated for laboratory testing, data analysis and reporting. During the whole fieldwork duration, students share responsibilities and work load. On some occasions, they have to work out conflicting interpersonal/intercultural relationships or working methods to induce efficiency and creativity. At any time, safety in the field is paramount.

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 given by the student to the staff is compared to the student self-assessment and peer-assessment.

From the staff point of view, the organization of the Spain Fieldwork is light. The fieldwork area is well known. Data has already been gathered and the logistics optimized.

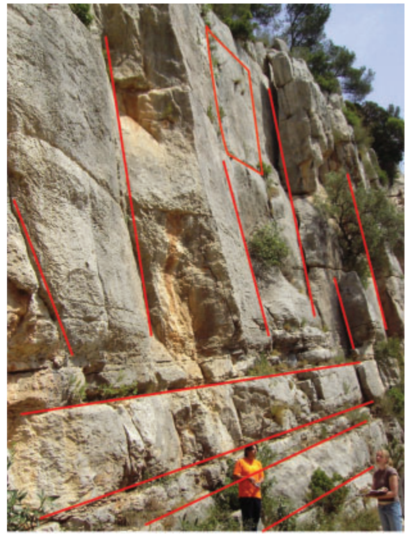

Figure 1. Collecting data for SSPC characterisation of the rock mass.

2.1 *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 student strategy and walk-along survey plans conclude the preparation week.

The feasibility projects expose 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 scarcer 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 three 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 many classifications as possible (Figure 1). Data is continuously archived, sorted, interpreted, presented in terms of the construction project in tables, graphs and maps and confronted with published data: aerial photos, maps, etc. Meetings are organized with staff to discuss and review progress and difficulties. Guidance in the field is provided. On several occasions, former staff involved in the Spain fieldwork spent their May holidays in Cambrils, and shared their expertise with students, while trekking with them, or sipping a café freddo or a café con leche on a terrace at Cambrils, Pradip or Falset. Towards the end of the field mapping period, students in the role of the consultants' engineering geology expert present to the client, a staff member just flown to site, their findings, the project shortcomings and proposals for dealing with the shortcomings.

Over the years, the fieldwork pedagogy and scope have been modified to cope with difficulties encountered by students and adapt to new technologies. Sets of semi-transparent pocket cards have been introduced to facilitate the objective description of rock masses (Maurenbrecher and Ngan-Tillard, 2010). A soil logging exercise in coarse more or less cemented soils has been broadened. A block size prediction exercise is being designed at the quarry site where material was extracted to build the Riudecanyes dam (Maurenbrecher and Ngan-Tillard, 2010). The estimated block size is compared to the actual size of the blocks forming the dam. The exercise is relevant to applications involving rock fragmentation (mining and quarrying for aggregates or armourstones). Aerial photographs, orthophotographs as well as manual map drawing and data storage have been (partially) abandoned for the benefit of Google Earth, Digital Terrain

Elevation models at a high resolution (5 × 5 m), GIS and use of iPad and iPhones. Students do not hesitate to propose their iPhone for determining their position and the dip and dip directions of discontinuities. They run stereographic analyses of slopes on the spot on their iPad.

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

2.2 *Site study of a hazardous slope*

The fieldwork area is appreciated for its pleasant Mediterranean climate and its variety of landscapes and geological terrains but also for its numerous (not yet stabilised) rock cuttings. The third week is allocated to the site study of a hazardous slope in small groups. Back at Delft, students determine from information provided and assembled in the field and in 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 (Figure 2). 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 method(s) has to be justified. Results are compared and assessed before recommendations for laboratory testing, slope stabilisation and/or slope maintenance are given. Students report on the role of the engineering geology consultants commissioned by the Province of Catalonia.

2.3 *Bonds with local institutions and mapping projects*

Over the years, bonds between local Universities and Institutes have also developed thanks to sabbatical leaves, student mobility and networking at conferences. This has extended the catalogue of (guided) technical visits organized during the fieldwork to expose students to new field applications and local problems. In 2010, a collaboration agreement between TU Delft and the Geological Institute of Catalonia (IGC) has been signed. The IGC staff members have presented to TU Delft their approach to urban geological mapping, geo-hazard mapping and quantification, and the peat problems in the Ebro delta. In exchange, TU Delft demonstrated the use of rock characterization (SSPC) along the N420 road and field testing on peaty soils.

2.3.1 *Tarragona and urban geological mapping*

The urban mapping project objective is to provide geological information of county capitals and 131 towns of more than 10000 inhabitants in Catalonia at a detailed scale (1:5000). TU Delft students have kept records of the lessons learned from the excursion in (Baltoukas et al, 2012).

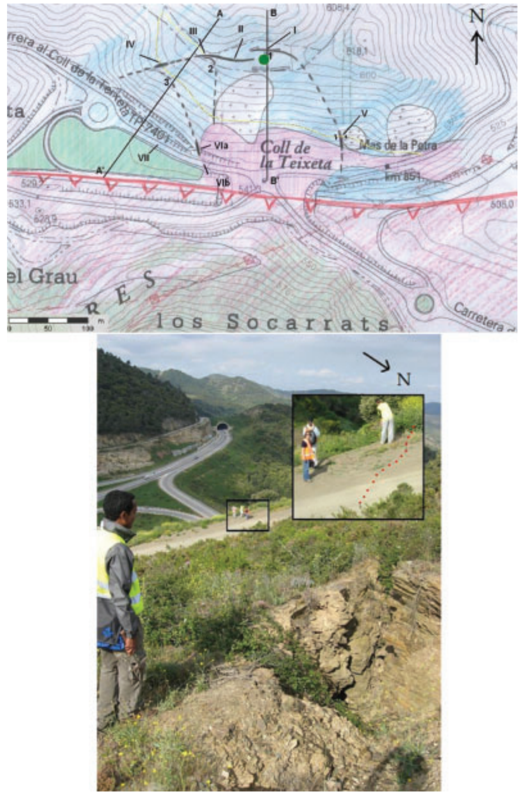

Figure 2. Tacking failure surfaces at Col de la Teixeta, Spain.
Legend: 1 to 3: sliding surfaces, I: Fault near windmill; II: Cavities along crack on top of hill; III: Large cavity within shale; IV–VII: evidence of cracks; A–A′ and B–B′: Cross sections.

2.3.2 *The geological hazard prevention map of Catalonia 1:25 000*

The geological hazard prevention map of Catalonia (MPRG25M) is a multi-hazard map at 1:25 000 scale conceived to be used for land use planning (Oller et al., 2011). It includes the representation of evidence, phenomena, susceptibility and natural hazards of geological processes. These are the processes generated by external geodynamics (such as slope, torrent, snow, coastal and flood dynamics) and internal (seismic) geodynamics. For each published sheet, information is displayed on different maps that represent the hazard levels for each of the phenomena active at the area (e.g. rock falls, landslides, seismicity, flooding, collapses and subsidence). Finally, the main map combines the different hazards. The map is intended to enable government and individuals to have an overview of the territory, with respect to geological hazards, identifying areas where it is advisable to carry out detailed studies in case of action planning.

In May 2011, TU Delft students practised with the IGC methodology for cataloguing geohazards related to coastal erosion during an excursion to Cap Salou. In the future, they could enrich the IGC catalogue of geohazards by describing rock falls, valley bulging above creeping clayey and gypsum rocks, floating islands, and karsts, which are common features in TU Delft fieldwork area. These geological hazards are investigated in the feasibility project and the analysis of a hazardous slope. Instabilities observed on road cuttings fall out of the scope of the IGC geological hazard prevention map project since those are under the responsibility of the road authorities.

2.3.3 *Subsidence in the Ebro Delta and peat problems*

Recent soil mapping of the Ebro Delta showed the extent and thickness of peat deposits (IGC, 2009). Within the IGC's project "Subsidence in Catalonia", it is planned to characterize and quantify the contribution of decomposition of organic soils in the measured subsidence observed in the delta plain. TU Delft was invited to share with local researchers its expertise on field techniques to characterize organic materials. A visit at the Delta del Ebre Natural Protected Areas was organized to characterize the thicker peat deposits (5–10 m). The measures used in the Netherlands to distinguish peat from organic clays were demonstrated. The sources of disturbance inherent to peat sampling and the limitations of in situ vane testing in fibrous peat deposits were illustrated. The latest recommendations made by Irish and Dutch researchers (Boylan et al., 2011; den Haan, 2010 and 2011) for the in situ determination of the undrained shear strength of peat, i.e. the use of ball penetration testing rather than cone penetrometer or piezocone testing, were explained.

2.4 *Future developments*

The alliance with the IGC facilitates exchange of data and knowledge and promotes research collaboration. For the financial viability of the 7 weeks of fieldwork, it is found essential that the student fieldwork is coupled to staff research objectives. The alliance with IGC opens new opportunities. Research interests common to TU Delft and the IGC are, for example, the subsidence of peaty areas and its mitigation and the impact of geology on the construction and maintenance of line infrastructure. In the coming years, the fieldwork will take another dimension with its opening to geomatics students eager to acquire remote sensing data and verify data on site and civil engineers involved in multi-disciplinary projects. The latter solve an actual civil engineering problem in a multidisciplinary team. They integrate several studies and designs into a coherent entity, based on knowledge, understanding and skills acquired in the preceding years. Attention is put on quality control and the evaluation of the design process. Ideally, one engineering geologist joins the team to predict the ground conditions and response to the construction.

3 OTHER OUTDOORS ACTIVITIES

In addition to the fieldwork activities organised by TU Delft, students are invited to join excursions organised by the geo-engineering student association and IngeoKring, the Dutch branch of the IAEG. The site visits introduce students to the largest civil engineering works taking place in the Netherlands at the moment, i.e. in 2011–2012, the strengthening of the peat dikes, the boring of the North-South metro line in Amsterdam, motorway widenings, the Maasvlaakte 2 reclamation works at Rotterdam harbor, and the construction of the A2 cut and cover tunnel in Maastricht in very weak calcarenite. During the visits, students get an insight into aspects such as on-site working conditions, project size, construction techniques, machinery and production cycles. They are made aware of safety and health issues by the computer tests that they have to pass before entering some construction sites, equipped with the full gear of the worker. They are also alerted about the need for interaction between geo-engineers and an assortment of professionals, from investors, politicians, engineers, contractors and possibly lawyers, as well as the general public. During the visit to the North-South Metro Line in Amsterdam, for example, students are not just explained the technical challenges associated with building under a busy historical centre founded on wooden piles, with many dimensional constraints. They also learn about the importance of passenger comfort, functionality of the metro system, durability of the installation and social safety. It is demonstrated how lessons learned from the experiences with the earlier-built East metro line have been integrated into the design of the new line, at the very beginning of the design (Bosch, 2011).

The excursions organized in the Netherlands expose students to professional practice in geo-engineering. They also highlight students the pertinence of the theoretical concepts taught at the University and the relevance of the research conducted by their staff, to current and innovative practice in geo-engineering.

4 CONCLUSIONS

A progressive exposure to the complexity of ground conditions is essential to the education of geo-engineers. Virtual fieldwork cannot replace real field observations. We must remember that it is the interaction between office and field work which attracted many of us to geo-engineering as Prof Marc. Panet rightly indicated, using his own case, during the debate on the future of education in rock mechanics at the Eurock 2010 conference in Lausanne, Switzerland.

TU Delft has a long tradition in engineering geology fieldwork in the coastal range and plain around

Falset and Cambrils in northeast Spain. The fieldwork educates students to investigate environments different than those encountered in the Netherlands. It is a good preparation for the Delft trained geo-engineers, employed by the Dutch industry and involved in the "rock works" of international projects. The interchange with the IGC during the Spain fieldwork emphasizes the need to search for engineering and geological information generated locally, at the very beginning of any construction project. Students have an easy access to digital ground data available in their fieldwork area via the IGC. They are confronted to the new challenge of the engineering geologist: the availability of a mass of digital information that can be easily displayed in a 3D GIS model. The process of making a digital ground model became so fast that the engineering geologist has lost the opportunity he/she had to think of alternative scenarios while constructing manually his/her model. Students are also introduced to the new methodology adopted by the IGC for geo-hazard mapping and urban geological mapping for general engineering geology purposes at a regional and, respectively more detailed scale.

During short excursions organized in the Netherlands, students appreciate that the best non-technical issues that are interconnected to technical issues.

With their site training, students realise that the human factor becomes the main factor of "unforeseen ground conditions", when a site investigation is inappropriate for a given project, in a given geology, when the basics of ground description are not applied, and/or the genesis of the ground profile is poorly understood by lack of geological education. The visits also reveal the vivid interest of the geo-engineering community for novel designs and technologies, proving once again the fact that geo-engineering and its main disciplines, soil and rock mechanics are application-driven sciences.

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