SHAKING THE FOUNDATIONS of Geo-Engineering Education

Editors:
Bryan McCabe
Marina Pantazidou
Declan Phillips

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Shaking the Foundations of Geo-engineering Education

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Preface

The higher education sector worldwide is undergoing enormous change. Since about 1960, universities have moved from elite to mass education. For example, in the UK in 1979, just over one in ten young people entered higher education and by 2009, this had risen to over one in three. In many of the established higher education sectors, the proportion of international students has also increased significantly. In Australia (which in 2006, had the highest proportion of international students in its universities of any OECD country), the fraction rose from 8.5% in 1996 to 26.5% in 2007. Other substantial changes include increasing globalisation of tertiary education; diminishing public funding; greater government regulation; increasing student-staff ratios; greater student diversity; changing student expectations and demands; increased use of technology in teaching and learning; growing difficulty in attracting and retaining high quality academic staff; ageing academic workforce; and academic staff under greater pressure to perform in research. Furthermore, several educators predict that the nature of universities may be vastly different in the future, with online education and distance learning coming to the fore.

With this backdrop, it is particularly timely for the geo-engineering education sector to re-examine its position. *Shaking the Foundations of Geo-engineering Education* (SFGE 2012) is an international conference hosted at the National University of Ireland, Galway, Ireland, which seeks to build upon the success of two previous conferences held in Romania – the *First International Conference on Geotechnical Engineering Education and Training* held in Sinaia in 2000, followed by the *First International Conference on Education and Training in Geo-Engineering Sciences: Soil Mechanics and Geotechnical Engineering, Engineering Geology, Rock Mechanics*, held in Constantza in 2008. SFGE 2012 is a major initiative of the ISSMGE's Technical Committee 306 on Geo-engineering Education. An important objective of the present conference, over those that preceded it, is the active engagement with the significant body of learning and teaching research that has been accumulating for many years in the fields of higher and engineering education.

The organizers of SFGE 2012 aspire to deliver a landmark international symposium that will leave an enduring legacy of valuable ideas and innovations to the global geo-engineering education community. The five invited keynote lectures have been chosen to prompt delegates to debate geo-engineering education issues in the context of best practice in engineering education. A further 36 contributed papers offer worthy experiences and insights on the following topics in geo-engineering: what topics should be taught; teaching through case histories; the role of laboratory work and fieldwork; computing and technology; research on engineering education, teaching experiences and student-centred learning. Each of the papers has been peer-reviewed by at least two reviewers. The conference organisers are grateful for the assistance of the reviewers in arriving at this high quality set of papers.

The SFGE organisers are confident that the conference will be memorable, enjoyable and a technically-valuable experience for all in attendance and that the proceedings will be a source of inspiration for effective and engaging geo-engineering education worldwide for years to come.

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Keynote Lectures

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What should geotechnical professionals be able to do?

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ABSTRACT: Geotechnical professionals (geotechnical engineers and engineering geologists) should have skills that enable them to deliver designs of groundworks using information from ground investigations and client requirements, often in collaboration with structural engineers and other construction professionals. To do so they need core skills that can be assessed in terms of the tasks that they can *do* competently. This paper presents the author's perspective on the core skills required of geotechnical professionals and indicates at what stage of their education and training these skills should be acquired.

1 INTRODUCTION

1.1 *Testing skills*

People acquire skills and become competent through education, training and experience and this is a whole-of-life process; we are never too old to learn. At any stage skills can only be assessed by asking what an individual can to do competently and then testing whether or not they can. Any other criterion such as "know" or "understand" can only be assessed by a "doing" test.

1.2 *Acquisition of skills*

Acquisition of skills starts at a young age when children learn to read, write and add up and normally ends with death. The core skills of engineers are acquired by education at school and at university and by training at work.

1.3 *Geotechnical professionals*

Most geotechnical professionals acquire some core skills during undergraduate courses in civil engineering or geology but in both cases geotechnical engineering or engineering geology are only small parts of the whole course. Many acquire further skills through a post-graduate taught course and a few develop specialist skills and deep insights through research. There are different routes along which geotechnical professionals progress and acquire skills and there are mile-stones throughout a life-time of education and training; it is not a case of "one-size-fits all".

1.4 *Computer and hand calculations*

Most ground engineering professionals have access to routine computer analyses for foundations, slopes, retaining walls and other geotechnical structures and they should be able to apply these correctly. But, more importantly, they should be able to analyse simple cases by hand. In what follows the requirements are ability to do the tasks by developing analyses from first principles and performing approximate calculations by hand.

1.5 *Constraints and expectations*

There are constrains on what is possible and there are expectations of employers and society. Universities are constrained by the ability of entrants; this is an issue for schools. They are constrained by the time available and the allocation of time to topics within a course; this is mostly an issue for the university staff. Graduates expect that their qualification will give them earning power and employers expect graduates to be able to contribute to the company. Often employer groups, (in UK it is the Institution of Civil Engineers) validate university courses and so constrain what is in the syllabus but at the same time they are declaring what they expect of graduates.

1.6 *What and how?*

Within the context of this conference there are two basic and distinctly different issues. One is to describe the core skills that geotechnical professionals should have – what they all should be able to do. This is the topic of this paper and it is for discussion. The other is to consider how people acquire these skills through education, training and experience. This is a matter of educational psychology and will be considered by other authors.

2 PROGRESSION AND ROUTES

Table 1 illustrates routes followed by geotechnical professionals as they progress through education and training.

Table 1. Progression of geotechnical professionals.

	Civil engineer	Geotechnical engineer	Engineering geologist	Geologist
School	Science and maths	N/A		Science
UG degree	General civil engineering			General geology
5 years		Ground engineering practice	Ground investigation practice	Other topic in geology
PG Degree	Other topic in civil engineering			
Research	Specialisation	Specialisation	Specialisation	Specialisation

The rows represent progression from school, through university and the first 5 years of post-graduate work which would probably include a post-graduate degree. The columns represent basic job descriptions. The task is to consider how specific skills should fit into the relevant cells – what should civil engineers, geologists, geotechnical engineers and engineering geologists be able to do at various stages of their education and training.

There are no, or very few, undergraduate courses in geotechnical engineering or engineering geology. Post-graduate courses in civil engineering and geology are too broad for engineers or geologists to acquire specialist geotechnical skills. Relevant research should lead to specialization beyond the core skills.

Those with an undergraduate degree in civil engineering and 5 years experience should have some core skills in geotechnical engineering but graduates with an undergraduate degree in geology would normally complete a post-graduate course in engineering geology to acquire core skills in engineering geology.

In practice, engineering geologists focus on ground investigations and creating geological models while geotechnical engineers focus on designing ground works and geotechnical structures from geotechnical models using tools from soil and rock mechanics.

3 HOW TO DESCRIBE SKILLS

In describing core skills there is a conflict between detail and scope. For example descriptions of several separate skills could include:

- find solutions to simple mathematical problems;
- create a geological model;
- determine the strength and stiffness of soil samples from laboratory tests;
- calculate bearing capacity and settlement of a simple foundation;
- design a foundation to support complex and variable loadings.

A competent ground engineer should be able to design a foundation to support complex and variable loadings but this requires skills in all the others. A full list of what ground engineers should be able to do might include all these but the list would then be very long. But a list that contained only items such as "design a foundation to support complex and variable loads" would be short but less helpful. There has to be a balance.

An issue that often arises is whether ground professionals should be able to analyse simple structures from first principles or is it sufficient that they can correctly apply published solutions, codes and standards and perform routine computer-based analyses. For example should a ground engineer be able to derive the bearing capacity factors N_c, N_q, and N_γ? Without deriving these, or at least seeing them derived, users have little appreciation of the assumptions required in the derivations and the limitations of the factors themselves.

Table 2 contains a relatively long list of skills some of which civil engineers, engineering geologists and geotechnical engineers might be expected to have acquired at various stages in their education and training. Some of these, such as solve mathematical problems, are basic skills while others, such as create spreadsheet calculations, require some mathematical ability as a pre-requisite. Similarly determine pore pressure in a flownet requires ability to draw a simple flownet as a prerequisite.

The topics in the list in Table 2 are restricted to geotechnical engineering of common ground structures such as slopes, walls and foundations and include earthworks and aggregate resources. The list does not include specialist ground engineering topics such as tunnels, ground improvement and reinforced soils. Also the topics in Table 2 exclude specific non-engineering topics such as hydrogeology, groundwater resources, contaminant transport and storage and so on.

Most of what is discussed in this paper is applicable to saturated (or dry) soils but in many cases soils in practice are unsaturated. There is currently no simple and realistic theory for strength and stiffness of unsaturated soil similar to the effective stress theory for saturated soil. Clearly ground professionals should know that soils may be unsaturated but, in the absence of a simple theory, detailed analyses for unsaturated soils may be beyond the core skills of most geotechnical engineers and engineering geologists.

Table 2 is my list and it is for debate. Others may wish to add to it, remove items and generally make modifications. But the real task is to insert the various

Table 2. Core skills of geotechnical professionals.

1 Basic skills
 1.1 Write an essay
 1.2 Solve problems using arithmetic, algebra, trigonometry and simple calculus
 1.3 Write a technical report
 1.4 Create spreadsheet calculations
2 Material behaviour and properties
 2.1 Measure ϕ' for dry sand from slope angles and measure undrained strength of clay cylinders
 2.2 Relate s_u of clay to liquidity index
 2.3 Do sandcastle experiments on sand and relate pore pressure to water content
 2.4 Do CU and CD triaxial tests and determine strengths and stiffnesses
 2.5 Do 1D consolidation test; determine m_v and c_v and yield stress
 2.6 Perform and validate numerical analyses
3 Investigations and modelling
 3.1 Describe soil and rock in engineering terms
 3.2 Design and manage a ground investigation
 3.3 Create *geological* model including history
 3.4 Create *geotechnical* model: = geological model + parameters for analysis
4 Groundwater
 4.1 Draw simple flownet and calculate flow rate
 4.2 Determine u at any point in a flownet
 4.3 Determine permeability k.
5 Slopes and walls
 5.1 Calculate limiting undrained slope height and limiting drained slope angle
 5.2 Calculate slope angles with seepage
 5.3 Analyse slope stability in jointed rock
 5.4 Calculate limiting active and passive forces on a wall
 5.5 Design simple gravity walls
 5.6 Design cantilever and propped walls
6 Foundations
 6.1 Calculate bearing capacity and settlement of simple shallow foundations
 6.2 Design a foundation; part buried and variable groundwater
 6.3 Design an embankment on soft ground
 6.4 Determine capacity of a single pile and a simple pile group
 6.5 Design piled foundations
7 Earthworks and materials
 7.1 Determine compaction curve
 7.2 Design earthworks and pavements
 7.3 Assess aggregate resources

items from Table 2, or its revisions, into the cells in Table 1. Before I make my own suggestions I need to discuss the items in Table 2.

4 CORE SKILLS

The ability to write an essay and solve problems using simple mathematics are basic skills and should be taught at school. (It is not clear what universities and employers should do if school leavers and graduates do not have these skills but that is a separate issue.) Graduate civil engineers and geologists should be able to write technical reports which reach logical conclusions and create spreadsheet calculations and employers of engineers and geologists would expect that they can.

4.1 *Material behaviour and properties*

Skills in assessing the behaviour and properties of soils require distinctions between total and effective stress and between drained and undrained loading together with basic definitions of strength, stiffness, friction, cohesion and so on.

Simple measurements of friction angles of sand and undrained strengths of clay do not require sophisticated equipment. Slope angles before and after failure illustrate peak, critical state and residual strengths; liquidity index requires knowledge of the Atterberg limits.

Determination of pore pressures in sandcastles is a test of fundamental soil mechanics. The analyses require construction of Mohr circles of total and effective stress to show how negative pore pressure, coupled with friction, develops unconfined compressive strength. The tests and their analyses also illustrate relationships between water content, suction and grading.

Geotechnical engineers and engineering geologists who specify triaxial and oedometer tests should be able to do them and analyse the results to obtain design parameters. Doing these tests means doing the tests entirely themselves, not watching someone else do them.

Numerical analyses, most often using finite elements, are now more or less routine in ground engineering. Analyses of even simple problems often use numerical models that are more sophisticated than purely elastic and Mohr-Coulomb. Most importantly analyses should be validated by comparison with hand calculations and laboratory tests, by close examination of stress and strain paths in selected locations and other means. Validation of numerical analyses requires common sense, deep understanding of fundamental soil mechanics and ground behaviour but not necessarily high-level mathematics.

4.2 *Investigations and modelling*

Ground information comes from ground investigations including desk studies, field work and laboratory testing.

Objective descriptions of soils and rocks in exposures or in samples require a common language and a common framework. This requires ability to sketch a grading curve from a hand sample, ability to describe the consequences of manipulating samples to assess consistency and weathering and ability to describe discontinuities. All geotechnical professionals should be able to describe soils and rocks using engineering terminology.

A *geological* model consists of a series of 3D block diagrams each showing a significant moment in the past as materials are deposited, weathered, faulted, folded and eroded: An employer would expect a geology graduate to be able to create a geological model.

A *geotechnical* model consists of a 3D block diagram of the site showing locations of materials with the same engineering properties of strength, stiffness and permeability. The geotechnical model is essentially a simplified and idealized version of the geological model with engineering parameters added. It is the basis for analyses of the proposed works. Creation of a geotechnical model requires knowledge and understanding of geological processes and material behaviour and the relationships between soil and rock description and behaviour.

4.3 *Groundwater*

Groundwater influences ground behaviour and geotechnical analyses through pore pressures which control effective stress and rates of flow which determine leakage and requirements for pumping excavations and rates of consolidation.

How pore pressure and drainage influence effective stress, strength and stiffness are included in Section 2 Material Behaviour and Properties. For steady state (drained) conditions the geometry of a flownet governs distributions of pore pressure and, together with coefficient of permeability, rates of flow.

Other aspects of groundwater such as water resources and contamination transport are outside the scope of routine ground engineering.

4.4 *Slopes and walls*

Analyses of stability of simple soil and rock slopes and walls for drained and undrained conditions in soils using hand calculations for simple cases requires knowledge of material behaviour and properties and techniques of stability analyses. The analyses become more complicated for cases that do not have simple geometry and particularly when there is seepage of groundwater.

Design of gravity walls is relatively simple and requires basic skills in determining earth pressures and overall stability. By contrast design of cantilever and propped walls is much more complicated and often requires assessment of movement and loads in the wall and props. There are several competing methods and detailed design of large walls often requires specialist skills.

4.5 *Foundations*

Calculation of bearing capacity and settlement of simple shallow foundations for drained and undrained loading and during consolidation from standard bearing capacity factors and published elastic and consolidation solutions is relatively straightforward. The problem becomes more taxing when the foundation is part buried and lightweight (as in an underground car park), when the applied loads are variable and eccentric and when groundwater conditions vary.

The strength of compacted fill in an embankment on soft ground is usually significantly greater than the strength of the soft ground and the issue is really one of bearing capacity and magnitude and duration of settlement. Design of embankments on soft ground may require staged loading, modified drainage and ground improvement.

Calculation of the capacity of a single pile and a simple pile group using published solutions is relatively straightforward. Design of large piled foundations is much more complicated. This requires, among other things, selection of pile type, analyses for variable and eccentric loadings, calculations of movement and the influences of pile caps. As with the case of large walls, detailed design of large pile groups often requires specialist skills.

4.6 *Earthworks and materials*

A substantial part of ground engineering involves use of soil and rock as a construction material compacted in embankments, fills and pavements and processed into concrete aggregate.

An essential core skill is determination and assessment of compaction and of suitability of material as fill. Design of earthworks and pavements requires, in addition, specification and control of field compaction.

Assessment of aggregates is essentially an issue of chemistry and mineralogy rather than mechanics and engineering.

5 WHAT SHOULD GEOTECHNICAL PROFESSIONALS BE ABLE TO DO?

In Table 3 I have placed the core skills from Table 2 into the career stages and route diagram in Table 1. This is my personal view and it is open to discussion.

Entry to undergraduate courses in civil engineering and geology should require basic numerical and literary skills. A geotechnical engineer with a first degree in civil engineering and 5 years post-graduate experience including a post-graduate degree should be able to do nearly everything listed in Table 2. Without a post-graduate degree a civil engineer should have only the basic geotechnical skills listed but would have developed other skills in structures, hydraulics and management.

The skills of those with a first degree in geology are often limited by lack of mathematics and mechanics including analyses of stress and strain and application of strength and stiffness. With a post-graduate degree, an engineering geologist should be able to do simple analyses of slopes, earth pressures and foundations using standard solutions.

Table 3. Progression of ground professionals.

	Civil Engineer	Geotechnical engineer	Engineering geologist	Geologist
School	1.1, 1.2, 1.4			1.1, 1.2, 1.4
UG Course	1.3 2.1, 2.2, 2.3 3.1 4.1, 4.2			1.3 3.1, 3.3 4.1 7.3
5 years	5.1, 5.4 6.1, 6.4 7.1	2.4, 2.5, 2.6 3.4 4.3	2.4, 2.5 3.2 4.3	
PG Course		5.2, 5.3, 5.5, 5.6 6.2, 6.3, 6.5 7.2	5.1, 5.3 6.1, 6.4 7.1	

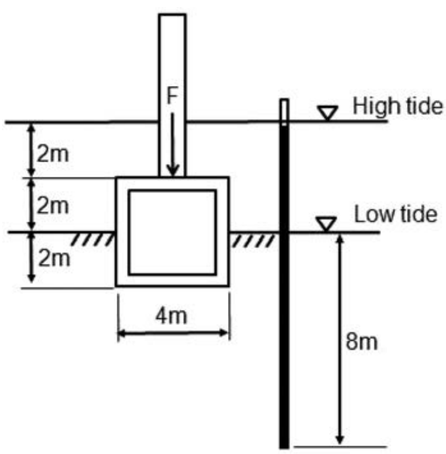

Figure 1. Simple caisson foundation.

6 EXAMPLE: CAISSON FOUNDATION

The apparently simple example of a caisson foundation in Figure 1 in fact contains a number of issues requiring careful consideration. The walls of the hollow caisson are 0.2 m thick. The river is tidal but there are artesian pressures and at a depth of 8 m below the river bed, pore pressures remain constant with a head of 12 m at all states of the tide.

In one case the soils are 50% silt and 50% clay, the plasticity index is 30 and the liquidity index is 0.1. In another case the soils are rounded medium sand and the relative density is 0.9. In both cases the unit weight is 20 kN/m^3. From these data a ground professional should be able to make reasonable estimates of strength and stiffness for preliminary design.

The task is to determine the applied load F to limit the settlement to 10 mm and to determine the difference between this and the load to cause failure. A competent engineer would consider the case during construction before the load F is applied and consider the consequences of rising and falling tide.

The caisson is relatively light weight, it is partly buried and groundwater and pore water conditions vary. It is not easy to apply standard text-book bearing capacity equations. Without the applied loads the caisson floats. For the sand the soil would be drained at all times so at low tide there is upward seepage.

For the silty clay the mean settlement is greatest at the end of consolidation but during a tidal cycle the soil would be undrained.

Correct analyses of the caisson in Figure 1 would require many of the skills in Table 1. Similar examples can be created for analyses of slopes and walls in which geometry and changing water conditions require careful consideration.

7 SUMMARY

In this paper I have listed a set of core tasks that geotechnical professionals – geotechnical engineers and engineering geologists – should be able to do and I have indicated at which stage of their education and training they should acquire these skills.

Although, in practice, analyses of foundations, slopes and walls are done using routine computer programs, ground professionals should be able to do these analyses from first principles and obtain approximate solutions by hand calculation.

Some tasks, such as design of large walls and large piled foundations, require specialist skills and are beyond what could be expected of a competent geotechnical engineer and are certainly beyond the skills of an engineering geologist. Some activities, such as groundwater resources and contaminant transport, while important, are outside the scope of routine ground engineering.

Before there are considerations of when and how geotechnical professionals acquire skills at school, at university and in practice by lectures, exercises, simulations and so on it will be helpful to agree what they should be able to do. In this paper I have made proposals that are intended to form the basis for discussion.

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Engineering education: A tale of two paradigms

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ABSTRACT: Engineering education is in a turbulent period. Chronic industry complaints about skill deficiencies in engineering graduates, high attrition rates of engineering students with good academic performance records, the worldwide adoption of outcomes-based engineering program accreditation, and findings from both cognitive science and thousands of educational research studies showing serious deficiencies in traditional teaching methods have all provoked calls for changes in how engineering curricula are structured, delivered, and assessed. As might be expected, many academic staff members and administrators are less than enthusiastic about the proposed changes, arguing that the traditional system functions well and needs no radical revision. The ongoing debate involves four focal issues: how engineering curricula should be structured, how engineering courses should be taught and assessed, who should teach, and how the teachers should be prepared. This paper outlines two conflicting educational paradigms and the position on each of these four issues that each one reflects—the traditional paradigm, which has dominated engineering education since its inception, and the emerging alternative—and offers predictions about the eventual resolution.

1 INTRODUCTION

Pressures to reform engineering education have existed since the field first began, but a particularly intense series of them arose in the 1980s and still continues.

- Interest in engineering careers has steadily declined among secondary school students, which coupled with the traditionally high attrition rate from engineering curricula raises concerns about whether enough engineering students will graduate in the next decade to meet industry's needs.
- Employers of engineering graduates complain that their new hires lack high-level analytical and critical thinking skills, communication and teamwork skills, and understanding of engineering and business practice.
- Cognitive science and extensive educational research have repeatedly shown that traditional lecture-based instruction is ineffective at promoting learning and high-level skill development, both in general and specifically in engineering education.
- The United States, much of Europe, and countries that are signatories of the Washington Accord have adopted outcomes-based program accreditation systems. These systems shift the focus of accreditation from documentation of what has been taught to assessment of what students have learned and remediation of shortfalls in targeted learning outcomes.
- Significant potential benefits of technology-assisted instruction and distance education have been demonstrated.
- University administrators and staff members have become aware that traditional engineering jobs will increasingly be done in the future by either computers or engineers in countries with low labor costs. To be competitive, future engineers will need to be equipped with skills that have previously not been emphasized in engineering curricula, including critical and creative thinking and entrepreneurship (Felder, 2006a).

Responses to these pressures in the engineering education community have been forthcoming, but progress has been slow. If you walk down the hall of an engineering building at most universities and glance into classrooms, you would still be likely to find professors teaching the same topics that were taught three and four decades ago in the same way they were taught then. Not in all classrooms, however: in some (and at a few institutions, many) of them you would see dramatic differences.

There are thus two competing paradigms for engineering instruction: the traditional one, which has dominated engineering education for at least a century, and the emerging one. This paper first outlines these two schools of thought and then contrasts their positions on four focal issues:

– How should curricula be structured?
– How should classes be taught?
– Who should teach?
– How should staff be prepared to teach?

What is presented is a brief overview of these issues, not a comprehensive discussion of the historical background and methodologies of the traditional and emerging responses to those questions, the obstacles to implementation of the new methods (the author knows from personal experience that they are anything but easy), and examples of their successful implementation. To cover all of that would require a book. Fortunately, one has been written: readers who wish far more elaboration than they will find here should consult Sheppard *et al.* (2008), along with the articles and books cited in the references at the end of the paper.

2 TWO APPROACHES TO KNOWLEDGE, LEARNING, AND TEACHING

The traditional philosophical view of knowledge is *positivism*, which holds that objective reality exists and is knowable through scientific examination of evidence of the senses. The positivist researcher's goal is to carry out objective and unbiased studies to arrive at The Truth. The positivist educator's job is to present material as clearly as possible, the students' job is to take it in and understand it, and their failure to do so indicates either their lack of aptitude or diligence or the instructor's lack of teaching skill. (Many instructors don't admit the possibility of the last option.)

The alternative view of knowledge is *constructivism*, which claims that whether or not there is such a thing as objective reality, human beings can never know what it is. People take in information through imperfect sensory organs and either filter it out quickly or incorporate it into their existing mental structures; in effect they construct their own reality, either individually (*cognitive constructivism*) or collectively with others (*social constructivism*). The constructivist educator has a much more difficult task than the positivist. For anything but simple factual knowledge that can be learned by rote memorization, direct transmission of information that students absorb and understand in its entirety simply doesn't happen. Whether or not difficult concepts and structures and mechanisms are learned and understood doesn't just depend on how accurately and clearly the instructor explains them and on how intelligent students are and how hard they work (although those factors are still vitally important), but also on such things as the students' prior knowledge, conceptions, and misconceptions about the course content, the level of their interest in the subject and their view of its relevance to their needs, and the degree of compatibility between their learning style (the way they characteristically take in and process information) and the instructor's teaching style. *Constructivist education* (aka *learner-centered teaching*) seeks to take those factors into account when designing instruction, presenting new information in the context of what students already know and helping them to develop understanding and skills through activity and reflection rather than making them passive recipients of information.

John Dewey (who in the late 19th century foreshadowed most constructivist methods that don't involve computers), Jean Piaget (who established the principles of cognitive constructivism), and Lev Vygotsky (who did the same for social constructivism) laid the theoretical foundations of learner-centered teaching, and modern cognitive science and extensive educational research have clearly demonstrated its superiority over traditional teacher-centered instruction for virtually any targeted learning outcome [Ambrose *et al.*, 2011; Bransford *et al.*, 2000; Prince, 2004; Sousa, 2006; Svinicki & McKeachie, 2011]. Nevertheless, the traditional paradigm is still alive and well in engineering education at most institutions around the world. The tension between these two approaches to teaching and learning is reflected in every aspect of curriculum and course design, delivery, and assessment. The remaining sections survey some of the principal differences between the traditional paradigm (denoted by T) and the emerging paradigm (E).

3 HOW SHOULD ENGINEERING CURRICULA BE STRUCTURED?

T: *Deductive (Fundamentals → Applications)*. Begin the first year with basic mathematics and science, teach "engineering science" in Years 2 and 3, and get to realistic engineering problems and engineering practice in the capstone course.

E: *Integrated*. Introduce engineering problems and projects starting in Year 1, and bring in the math and science (and communication and economics and ethics) in the context of the problems and projects.

The traditional organization is what might be called the "trust me" approach to education, as in "*You may have no idea why I'm teaching you all these theories and derivations and mathematical models and algorithms now, but trust me, in a year or four years or after you graduate you'll see how important they are*." As any cognitive scientist will tell you, "this will be useful some day" is a really poor motivator of learning. The emerging paradigm infuses the entire engineering curriculum with real engineering problems and introduces fundamental material on a need-to-know basis in the context of solving those problems. Among other benefits, the latter approach gives engineering students exposure to real engineering (as opposed to pure and applied science) before the final year of their schooling.

T: *Curricula and courses emphasize content*.

E: *Curricula and courses balance content and skills (analytical and critical and creative thinking, problem solving, problem formulation, technology, teamwork, communication, entreneurship, foreign languages and cultures,…)*

The fact is that the "content" of engineering practice other than basic principles is changing far too rapidly for engineering curricula to keep pace with. Much of what we teach our students today is likely to be obsolete or irrelevant to what they will need to know when they enter the workforce or soon afterwards. Instead of constantly trying to jam more content into our courses in a futile effort to keep up, we should therefore focus on teaching basic principles and self-directed learning. When the students leave us, they should be equipped to figure out what they need to know when they face new challenges, identify sources of the needed information and learn from them, find colleagues with complementary areas of expertise and team effectively with them, do the analytical, critical, and creative thinking required to meet the challenges, and communicate the solutions clearly and persuasively. Those skills will never become obsolete but will continue to serve the students throughout their careers.

T: *Courses are compartmentalized, self-contained, and taught by an individual instructor.*
E: *Courses are horizontally integrated across subjects and disciplines and/or vertically integrated across years of the curriculum.*

In practice, unlike in school, problems rarely come neatly packaged within the boundaries of a single course subject (thermodynamics, hydrology) or even a single discipline (civil engineering). To solve real problems invariably requires pulling together material from several different subjects and disciplines, both technical (engineering and science) and nontechnical (economics, business, communications,…).

Traditionally, the idea that the material taught in one course has important applications in most other courses is rarely brought up in engineering courses, and so it does not become part of the students' thinking. Every experienced instructor knows what happens if you bring up something in a heat transfer course that is normally taught in a thermodynamics course: mainly blank stares, and if pressed, most students will vigorously deny that they have ever seen anything like it. In the emerging paradigm, the connections between subjects and disciplines are made explicitly clear, sometimes in lectures and sometimes in assignments.

T: *Design is taught in the capstone design courses.*
E: *Design is taught throughout the curriculum.*

First-year engineering students are perfectly capable of designing devices and processes after getting some basic instruction. Their work will obviously be at a lower level of sophistication than they can produce in their fourth year, but they will be able to carry the design knowledge and skills they acquire into subsequent courses and steadily become better engineering designers. Now when they enter their final semester, they will be capable of tackling design challenges that traditional capstone course instructors would never dream of assigning to undergraduates.

4 HOW SHOULD CLASSES BE TAUGHT?

T: *Content is determined by the syllabus* ("*I will cover*…").
E: *Content is determined by learning objectives* ("*The students will be able to*…")

A list of topics to be covered conveys very little useful knowledge to students or instructors about exactly what will be taught in a course, including how deeply the instructor will delve into each topic and what kinds of thinking and problem-solving skills the students are expected to acquire. If instructors instead write *learning objectives* that specify all the things the students should be able to *do* (explain, calculate, derive, model, design, critique,…) if they have learned what the instructor intends to teach, everything changes. The students get a clear understanding of what knowledge and skills they are expected to acquire; the instructor can make sure that all of the lessons, activities, assignments, and exams are pointing toward the same goals (*constructive alignment*), and instructors of subsequent courses know what they can presume about the knowledge and skills of their entering students (Felder, 2006b).

T: *Teaching style addresses only one learning style.*
E: *Teaching style addresses a broad spectrum of learning styles (visual/verbal, concrete/abstract, active/reflective, sequential/global,…).*

Students do not all learn in the same ways or respond identically to specific teaching methods. Those with different learning styles tend to have different strengths, all of which can be vitally important in engineering practice. Instruction that addresses the needs and preferences of only certain types of learners (as traditional engineering instruction does) weeds out students who would make excellent engineers. On the other hand, balanced instruction that alternately addresses the needs and preferences of opposite learning styles gives all students with the basic ability and interest to succeed in engineering a good opportunity to do so. All students are taught sometimes in a manner compatible with their learning style, so they are not too uncomfortable to learn, and sometimes in the opposite manner, so they will get practice and feedback in important skills that they would be perfectly content to neglect if given the option (Felder & Brent, 2005).

T: *Deductively: Principles → formulas & algorithms → applications.*
E: *Inductively: Instructor presents or students discover principles, formulas, and algorithms in the context of problems or projects.* Variations of inductive learning include guided inquiry, problem-based learning, and project-based learning.

The same reasoning that justifies an inductive curriculum also applies to teaching individual courses inductively. Rather than deductively presenting all of the theories and derivations and analytical methods first and then showing applications, the instructor starts with challenges—questions to be answered, projects to complete, or real-world problems to be solved—and teaches the course material (or helps the students teach themselves) in the context of the challenge.

Extensive research has demonstrated the effectiveness of inductive teaching in promoting deep learning and conceptual understanding (Prince & Felder, 2006). Implementing inductive teaching (especially problem-based learning) is not trivial, however, and instructors should first read about the approach and/or get some training rather than just plunging in and learning from their mistakes.

T: *Most in-class activity in non-lab classes is done by the instructor* (*lecturing and occasionally asking questions).*

E: *Active learning is used, with the burden of activity in all courses being shared by the instructor (lecturing, asking and answering questions) and the students (discussing, explaining, brainstorming, questioning, reflecting, computing,…*).

A vast body of cognitive science and empirical educational research has established that people acquire nontrivial knowledge and skills only through practice, reflection, and feedback, not by watching and listening to someone telling them what they are supposed to know (Prince, 2004). *Active learning,* in which students in class work individually or in small groups on short course-related exercises, has been repeatedly shown to produce substantially greater learning than the traditional lecture-dominant approach. Unlike most inductive methods, active learning is fairly easy, and is almost guaranteed to work as long as the exercises are short (as little as 10 seconds up to a maximum of 2–3 minutes) and challenging (asking students to get in groups to answer a trivial question is a waste of class time), and at least some of the time the instructor calls on individuals for the first few responses rather than calling for volunteers every time (Felder & Brent, 2009).

A relatively new approach to active learning involves the so-called *flipped classroom*, in which students study material before coming to class (often by watching on-line lectures and possibly answering and asking questions about them electronically, sometimes by working through on-line multimedia tutorials) and then spend the class time engaged in activities that reinforce and extend the material in the lectures and tutorials (Peer Instruction Network, website).

T: *Homework and tests involve exclusively convergent (single-answer) problems*.

E: *Homework and tests involve convergent problems, divergent (open-ended) problems, and troubleshooting, interpretation, and problem formulation exercises*.

Relatively few real problems, as opposed to academic problems, have the form "Given this, calculate that," where there is a unique answer and the task is to find it. Real problems are sloppy, often poorly defined, and don't come neatly packaged with exactly the information needed to solve them, and if there is a correct or optimal answer it usually begins with "It depends." Since that is the kind of problem our graduates will face throughout their careers, it makes sense to start teaching them to deal with such problems while they are still with us. Felder (1987, 1988) suggests a large variety of open-ended problems that can easily be adapted to any engineering course.

T: *All homework outside of projects and labs is done individually. Working together is considered cheating*.

E: *Some homework is done individually, some cooperatively (with measures taken to assure individual accountability for all the work)*.

Most engineers—in fact, most members of any profession—will do a substantial part of their work in teams, and until they reach a senior position they will have little or no say regarding the team composition. Their ability to work well with their team members, regardless of their differing skill levels, work ethics, and personality traits, is likely to affect their performance evaluation more than their technical skills do. Since teamwork skills (including communication, project and time management, leadership, and conflict resolution skills) are rarely taught before college; providing guidance, practice, and feedback in those skills should be part of the engineering education curriculum.

The best way to provide instruction in teamwork is to use *cooperative learning*, an approach to team assignments that includes positive interdependence (the team members are forced to rely on one another), individual accountability (each team member is held accountable both for the work that he or she had primary responsibility for and the work that everyone else on the team did), and several other criteria. Felder & Brent (2007) define cooperative learning, suggest different things engineering students can profitably be asked to do in teams, survey the research base that demonstrates the effectiveness of the method for addressing almost every conceivable learning objective, and outline strategies for making cooperative learning as effective as possible.

T: *Teaching evaluation is based on student ratings*.

E: *Teaching evaluation is based on student ratings, peer ratings, self-ratings, and what students learn ("outcomes-based assessment")*.

At most universities, student ratings are collected at the end of every course, the ratings are compiled, and copies go to the instructor and into the instructor's personnel file to help inform decisions regarding promotion, tenure if the instructor is eligible for it, merit raises, and teaching award nominations.

Including student ratings in comprehensive assessments of teaching performance is entirely appropriate. There are some aspects of teaching that students are in a unique position to judge, such as the instructor's clarity, attitude, punctuality, availability, etc. Moreover, thousands of research studies have shown that student ratings are consistent with other assessments of teaching, and that criticisms frequently leveled at them (they're popularity contests, the high ratings go to the easy graders, and so on) have little basis in reality (Felder & Brent, 2008).

There are, however, some aspects of teaching that students are in no position to judge. They do not know, for example, whether the instructor is teaching the right material to prepare them for subsequent courses, or if the material is up-to-date, or if appropriate methods are being used for instruction and assessment. Only peers are capable of making those judgments, and so a comprehensive teaching evaluation should always include peer review along with student ratings. Not the usual form of peer review, however, in which a staff member observes a colleague's class session and jots down notes on whatever happens to catch his or her attention, but a well-structured system with multiple raters making at least two observations and using pre-defined and agreed-upon criteria of what constitutes good teaching as the basis of their judgments, and separately rating course materials (syllabus, learning objectives, handouts, visuals, assignments, and tests) (Felder & Brent, 2004). Learning outcomes should also be part of a comprehensive evaluation of teaching (Felder & Brent, 2003): if most students are not learning what the course is designed to teach them, then no matter how highly the instructor might be rated by his or her students and peers, something is clearly wrong with the instruction.

T: *Courses are taught by professors lecturing in classrooms or auditoriums on campuses.*
E1: *Courses are taught by professors lecturing on TV monitors.*
E2: *Courses are taught using interactive multimedia tutorials and other technology-based tools*.

Instructional technology is a two-edged sword. To the extent that it promotes student activity and interactivity (as in E2), it enhances learning; to the extent that it increases passivity (as in E1), it detracts from learning (Felder & Brent, 2000).

There are many things technology can do better than instructors in a traditional classroom. They include engaging students with interactive tutorials that present information, ask questions about it, and provide affirmation or corrective feedback on the student's responses; showing complex schematics and three-dimensional surface plots and video clips; and involving students in hands-on experimentation and exploration using simulations of laboratory or engineering processes. Learning is enhanced when instructors use technology in any of those ways, but it is diminished by having students sit passively through PowerPoint shows or videos of complete lectures. Meaningful learning results from activity and reflection and not from simply watching and listening.

5 WHO SHOULD TEACH?

T: *Ph.D.'s specializing in frontier disciplinary research*.
E: *People specializing in one or more of four diverse forms of scholarship* (Boyer, 1990).
- *Scholarship of Discovery*: frontier research
- *Scholarship of Integration*: applied research that builds on and extends frontier research
- *Scholarship of Application*: applied research that directly benefits society
- *Scholarship of Teaching and Learning*: conducting educational research and using the results to improve teaching and learning.

It is vital for engineering schools to maintain strong frontier research programs, since in many of the world's developed countries basic engineering research has all but been abandoned by industry. First-class frontier researchers who are also good teachers should continue to be the mainstay of faculties at research universities. It is also important, however, for some staff members—possibly in collaboration with researchers from other disciplines—to conduct applied research, building on the discoveries of the frontier researchers to benefit industry and/or society. In addition, someone in every academic department should be an expert on pedagogy—knowing the methods we have described and skilled at using them, reading the education literature, attending teaching conferences, developing new instructional materials and methods and importing and adapting materials and methods developed elsewhere, and sharing them with colleagues who are not teaching specialists but are willing to try new techniques to make their teaching more effective.

All of the functions served by those diverse staff members are equally important in the university mission. It is only fair for staff members who engage in each of them to be treated equitably by the university, with performance evaluations and opportunities for promotion and advancement based only on how well they perform their designated functions and not on which functions they perform.

6 HOW SHOULD ACADEMIC STAFF BE PREPARED TO TEACH?

T: *Not at all*.
E: *With courses on teaching for graduate students; staff workshops, seminars, learning communities; and mentorships*.

College teaching may be the only highly skilled profession whose practitioners are not routinely given some training before or after they enter it. The presumption is that if you have a degree in a subject you must also know how to teach it. As every former and current college student knows, this presumption is seriously defective. Effective instructional development for both current and future academic staff can take years off the usual 4–5 year learning curve for most new staff members to become as effective in teaching as they are capable of being.

When universities have instructional development programs, they are frequently conducted for staff in all disciplines by facilitators with no STEM background or knowledge. The programs focus on learning theories and general pedagogy without providing specific examples of how the techniques being described can be applied to technical courses. Participating engineering staff members come away with very little information they can use, and the 4–5 year learning curve follows. Felder, Brent, and Prince (2011) survey STEM-specific instructional development programs around the world that do a much better job of equipping staff to do the kind of teaching we have described in this paper.

7 REMAINING QUESTIONS

(a) Can we afford to do all that?
(b) Can we afford not to do it?

Some of the emerging practices listed in this paper require no resources to implement. If instructors want to write learning objectives or use active learning, for example, after some preliminary reading they can just do it. Other suggestions, such as establishing STEM-specific instructional development programs or mentorships, involve costs (albeit trivial ones in the context of engineering school budgets). In this age of perpetual budget crises, many administrators are reluctant to allocate any more funds to nonessential tasks than they are forced to allocate, and they do not consider instructional development essential.

There are also costs associated with sticking to traditional instruction, however—they may be less easily quantified, but they are real and steep. For one, outcomes-based accreditation systems almost preclude staying with business as usual, and if a program gambles that its evaluators will not take the new criteria seriously it seriously risks losing accreditation.

More importantly, engineering schools are finding it increasingly difficult to attract and retain enough students to meet anticipated demands for engineers, and growing numbers of departments are in danger of falling below the critical enrollments they need to survive financially. The most prestigious research universities will continue to attract students on the basis of their reputations, but other schools will be forced to compete for a dwindling pool of qualified students. The schools that can describe active, student-centered, technology-rich instructional environments in their brochures and demonstrate such environments to visitors, and who train staff members to create such environments and reward those who do so successfully, will succeed. The schools that fail to do so may not.

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Quandary in geomaterial characterization: New versus the old

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ABSTRACT: For the most part, geotechnical engineers have been reluctant to modernize their approach to site investigation, analysis, and design, thereby conveying the notion that it is a mature discipline without need for updating. In reality, acceptance and utilization of new technologies to improve and enhance our capabilities are quite necessary. The problem is exacerbated by many universities with outdated curricula and textbooks that promote an earlier historical basis in soil mechanics, primarily from a laboratory stance, whereas the preponderance of real world data are from field tests, including in-situ and geophysical methods. Over the past century, our discipline evolved through a combination of theoretical, analytical, intuitive, empirical, statistical, and probabilistic solutions towards construction involving geomaterials. Yet, a number of outdated tests, correlations, and methodologies remain in use today due to an unwillingness to leave the old behind and move forward. A high-tech enhancement to geotechnics would certainly benefit the profession with respect to education, professional image, and matters of litigation.

1 PREFACE

Without a proper site characterization, geotechnical solutions are not optimized, thus unconservative as well as overconservative designs can result. As such, the particular issue herein centers on the standard introductory course to geotechnics offered in most civil engineering curricula, where 9 out of 10 textbooks appear to dwell either on the mundane or else cover minutia on special topics in soil mechanics and foundations. For the most part, geomaterial characterization is covered from a laboratory viewpoint. While lab testing has its purpose and benefits, in reality, the large mass of soil and/or rock involved on a project must be evaluated in the field, i.e. *in situ*.

In 2012 and beyond, the focus of the introductory geotechnical course should be more general and offer an integrated and balanced approach to geotechnical site characterization including: engineering geology, geophysics, in-situ testing, and laboratory methods. Moreover, as fewer than 5% of bachelors level civil engineering students go on to specialize in geotechnics, a more positive and modern high-tech spin on the face of subject matter would improve our image to our brethren in structures, water resources, environmental, transportation, and construction, as well as in the general public's eyes. This paper attempts to convey some thoughts and concerns which have arisen during the author's 36 years of experience in geotechnics, both in practice and academia.

2 INTRODUCTION

2.1 *Evolution of geotechnical site characterization*

The first step in any geotechnical involvement is to learn about the existence, location, whereabouts, makeup, depths, and layering of the soil and/or rock materials (*geostratification*) at the project site, with step two being the assignment of geomaterial parameter values for analysis of the particular situation (*geotechnical site characterization*). It is a most challenging task because of the infinite possible permutations, combinations, and assorted varieties of natural soil and rock particles, shapes, sizes, and mineralogies, all from differing geologic origins, ages, environments, and past experienced histories of deposition, erosion, stress, strain, temperature, and weathering.

Construction involving soils and rocks extends back many thousands of years with mankind showing appreciable thought and careful consideration in the planning and execution of these activities (Sowers 1981; Broms & Flodin 1988). In the early part of the 20th century, the official discipline termed *geotechnical engineering* relied on a few auger boring cuttings, simple laboratory index tests, and much judgment in order to arrive at a solution to a particular problem. Following the issuance of *Theoretical Soil Mechanics* (Terzaghi, 1925, 1943), methodologies emerged to permit more of a reliance on mathematical

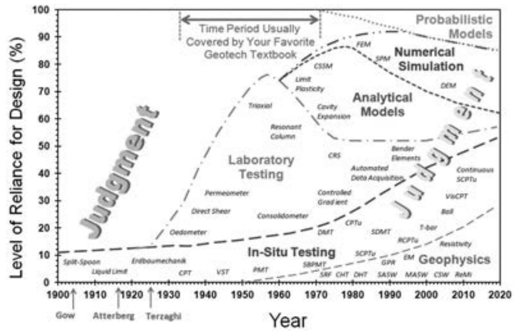

Figure 1. Evolution of geotechnical design basis (adapted from Lacasse 1985).

and scientific data, laboratory apparatuses, field measurements, analytical models, numerical simulations, and risk assessment, such that a more formalized engineering approach was developed (Figure 1). Nevertheless, because of the piecemeal way in which these components were assembled, a number of inconsistencies and conflicts have arisen, causing confusion and contradictions in technical matters, as well as in the education of younger students of the profession.

Perhaps, a good number of these issues in fact can be blamed on many "well-seasoned" senior geotechnical engineers who refuse to relinquish old methods in place of newer available technologies. When *they* studied at university some 3 decades ago, conventional soil borings and laboratory testing were the normal means for site investigation. A single field measurement of N-value from standard penetration testing at 1.5-m depth intervals was considered adequate back then to assess in-place soil parameters. Sieve testing and plasticity indices of soil samples were thought to be sufficient to complete soil classification.

Later, as the profession matured, more elaborate laboratory testing on undisturbed high-quality tube samples developed to include: triaxial, consolidation, direct shear box, simple shear, resonant column, and permeameter. While these tests provide valuable information, a full suite of these tests demands great expense and long laboratory times for completion. They are really only possible on large projects or critical facilities where ample budgets are available. Yet, the laboratory testing approach to the characterization of geomaterials prevails in most available series of textbooks on soil mechanics. Moreover, a majority of university curricula spend an average of 3 weeks on consolidation theory and another 2 weeks on Mohr's circles and strength of soils, yet then offer nothing whatsoever on critical state soil mechanics! Many textbooks seem to be stuck in a time warp of 1935 to 1970 vintage.

2.2 *Current practices in education*

A typical college course on introductory soil mechanics includes laboratory sessions on grain size, liquid and plastic limits, hydrometer tests, compaction (Proctor), oedometers, permeameters, triaxial, and direct shear, spanned over an entire semester term. In contrast, the section on site exploration is often covered in a single lecture or chapter of a textbook. And yet, in almost all geotechnical investigations, small to large, the vast amount of information and primary sources of data arise from field testing operations. A majority of geotechnical textbooks and college courses today fail to explain how to deal with the in-situ test data, excepting a quick rudimentary and/or cursory mention. The lectures and laboratory sessions do not usually cover the various geophysical methods (e.g., seismic refraction, resistivity surveys, spectral analysis of surface waves, electromagnetic conductivity, ground penetrating radar, suspension logging, downhole or crosshole testing) nor the wide selection of in-situ probes (e.g., cone penetration, vane shear, flat plate dilatometer, stepped blade, pressuremeter, piezocone, spade cells, weight sounding, Iowa borehole shear).

As your "typical" civil engineering student has not been exposed to the large variety of field testing methods and their advantages and purposes, once she/he find themselves out in the real world of consulting, construction, government, or industry, they fall back to the historical standard means: subsurface exploration involving rotary-drilled boreholes to procure samples for lab testing. Frankly, the costs in time and money for accomplishing the intended goals via extensive undisturbed sampling operations and detailed laboratory strength/stiffness testing cannot usually be achieved because of tight budgets.

One consequence is that the project geotechnical engineer must now run crude laboratory tests that are within budget; e.g., plasticity tests on clays; percent fines content on sands. The simple indices are then used in some old (likely unreliable) empirical correlations to ascertain soil engineering parameters. That engineer also tends to fall back to a primary reliance on SPT N-values conducted during the boring operations for site-specific field data. An optimized solution for the project may likely not be reached.

2.3 *Lack of progress*

A look at the progress of our situation can be depicted as shown in Figure 2, with a selection of tools of the trade presented for two chosen timeframes: 1948 and 2012. Surprisingly, our engineer is willingly open to adopting new technologies for home life, yet essentially relies on *old school* for her/his professional occupation.

As already mentioned, less than 5% of bachelors level civil engineering students actually go forward to specialize in geotechnics. In a number of major colleges, the outdated curriculum in soil mechanics is driving away the best students because the faculty harp on the mundane issues of old and archaic subject matter within our discipline: i.e., Atterberg limits, Unified Soil Classification System, AASHTO system, soil compaction, time-rate-of consolidation, flow

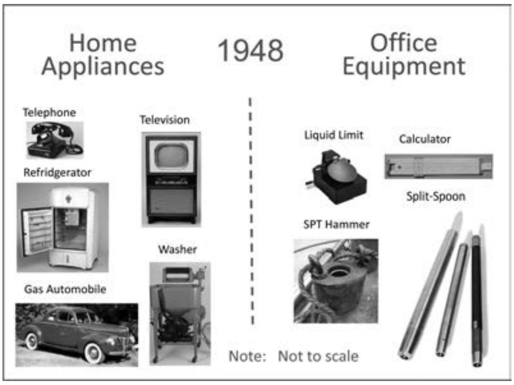

Figure 2a. Favorite toys and tools of the geoengineer in 1948.

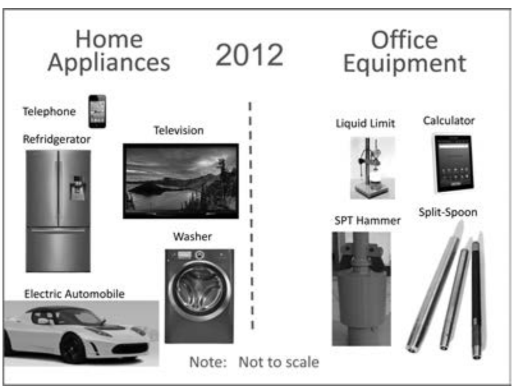

Figure 2b. Favorite toys and tools of the geoengineer in 2012.

nets, creep, and even long-winded sections on bearing capacity of shallow foundations. While these subjects *can be* important, in the author's 36-year experience in the profession, in many cases, they are usually *not important* on many geotechnical projects. Of course, the site-specific geology and locally-occurring geomaterials will govern the actual level of significance and relevance of the topics. However, the tedium of the aforementioned subjects should be addressed in a graduate level course, but certainly not an introductory class in geomechanics.

While the noteworthy problems exist throughout most subdiscipline areas within geotechnical engineering, herein the author will focus on topics related to site characterization in order to get these important points across.

3 GEOMATERIAL CHARACTERIZATION

3.1 *Best available field testing practice*

For a comprehensive site exploration involving drilling, sampling, field testing, geophysics, and laboratory measurements, Figure 3 depicts a program using

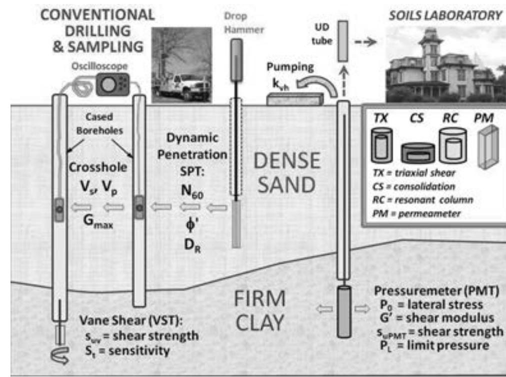

Figure 3. Comprehensive all-out program for geotechnical site characterization using in-situ, laboratory, and geophysics.

a collection of assorted methods towards geomaterial characterization. This might include a series of soil borings that involve the dynamic standard penetration testing (SPT) that consists of drive sampling to procure 38-mm diameter disturbed soil samples and N-values at 1.5-m depth intervals. The SPT is suited for use in evaluating strength of loose to dense granular soils, with extended applications to stiff to hard clays and silts (Stroud 1988).

When soft clays or silts are encountered, the borings can switch to vane shear testing (VST) in which the undrained shear strength (s_u) and sensitivity (S_t) can be assessed (Larsson and Åhnberg 2005). Supplementary in-situ data can be collected using pressuremeter tests (PMT) for modulus evaluation (E' or E_u), as well as strength (either ϕ' in sands or s_u in clays), initial stress state (K_0), and limit pressure (P_L), as detailed in Gambin et al. (2005). Time rate of consolidation can be evaluated using PMT holding tests to assess c_{vh} = coefficient of consolidation. In addition, pumping tests (PMP) can be implemented for measuring the coefficient of permeability (k).

Geophysical crosshole tests (CHT) may be conducted in parallel cased boreholes to evaluate the profiles of compression wave (V_p) and shear wave (V_s) velocities (Wightman et al. 2003). The shear wave data allow the direct assessment of the small-strain shear modulus ($G_0 = \rho_t \cdot V_s^2$; where ρ_t = total mass density). The fundamental stiffness G_0 serves as the initial stiffness of soils, thus the beginning of all shear stress vs. shear strain curves, applicable to both monotonic and dynamic problems (Atkinson, 2000; Clayton 2011). In fact, this well-known fact is also missing from many textbooks, even though G_0 has been shown relevant to practical foundation problems for over 2 decades (e.g., Burland 1989).

3.2 *Sampling and laboratory testing*

In addition to small drive samples, the borings also produce "undisturbed" thin-walled tube samples that are transported to the geotechnical laboratory. These samples usually have nominal diameters

(75 mm < d < 150 mm) and lengths of about 1 to 1.2 m are obtained for laboratory testing of the intact soil materials under carefully controlled conditions using various devices, including: step-loaded oedometer, constant rate-of-strain consolidometer, fall cone, triaxial shear (CK_0UC, CIUC, CIDC, etc), fixed and flexible walled permeameter, direct shear, simple shear, bender elements, and resonant column apparatuses. More specialized tests include: torsional shear, hydraulic Rowe cells, controlled gradient consolidometers, plane strain apparatus, radial permeameter, hollow cylinder, cubical triaxial, and directional shear devices. Laboratory testing on soil specimens can take days to weeks to months in order to obtain results and needed information about the in-place geomaterial stress state, flow characteristics, compressibility parameters, soil strength, stiffness behavior, and hydro-mechanical response.

One funny contradiction in lab testing relates to the two sister tests: direct shear box (DSB) and direct simple shear (DSS). While DSB results are recognized to be effective stress parameters (e.g. $c' = 0$ and ϕ'), it is not utilized for undrained strength determinations on soils. In contrast, the DSS is acknowledged as a preferred test to obtain s_u in clays and silts (e.g., Ladd & DeGroot 2003), yet not recommended for evaluating effective friction angles ϕ' of these soils. Yet, the devices really differ only in the specimen box arrangement, where the DST has fixed sides on two box halves and the DSS has rotating sides, otherwise very comparable tests. In fact, data on Ariake clay by both DST and DSS show nearly identical stress-strain-strength behavior (Tang et al. 1994).

As an aside comment, the author further believes that most geotechnical engineers would be surprised to learn that DSS testing to obtain s_u in clays is actually a *drained test* conducted under conditions of maintaining constant volume. Of course, this concept fits nicely within the framework of critical-state soil mechanics (Holtz et al. 2011).

Of additional difficulty is the realization that laboratory soil samples are often fraught with issues of sample disturbance which are unavoidable (Tanaka 2000; Lunne et al. 2006). In soft soils, improved results can be obtained by using special samplers (e.g., Laval, Sherbrooke, JPN), however at great cost and extra field effort. Moreover, the local drilling operations and field procedures can affect the overall quality of results of lab testing. Undisturbed sampling of granular soils is now also possible by innovative freezing technology (Hoeg et al. 2000), yet also at great cost. [Note: a fellow geoengineer from Exxon-Mobil Corporation indicated to the author in 2003 that he paid $30k per frozen sand sample on a project.]

While this kind of elaborate program can produce the necessary information regarding geostratification and relevant soil engineering properties, it does so at great time and cost. In fact, the full suite of field testing, geophysics, and laboratory testing is so expensive and of such long duration, a program of this level can only be afforded on relatively large scale projects with substantial budgets (say a range of US $300k to $1M+) and lengthy schedules (say 6 months to 2+ years).

3.3 *Routine site exploration*

On small- to medium-size geotechnical projects, economies of time and money restrict the amount of exploration and testing that can be performed. For many projects, the budgets can be <US $10k and times for implementation <2 weeks. Nevertheless, the engineering analyses still demand a thorough knowledge regarding the site-specific geomaterials lying beneath the property of study. In those instances, budgets for investigations are too limited, such that insufficient information is obtained. In the USA, for example, a common occurrence is the utilization of a single field measurement (alias, SPT-N value) and basic lab testing (e.g., grain size and/or PI) are the only input parameters. A usual consequence is that undue conservatism is adopted to offset the dearth of data and information needed to find a rational solution, as well as avoid litigation should more riskier solutions be implemented. This can result in selecting choices for site development, deep foundations, retention systems, and ground modifcation that are unnecessary, unwarranted, and an extra expense for the new facilities.

3.4 *Risks of inadequate site investigation*

A poorly-conducted and inadequate subsurface exploration program can have significant outcomes on the final constructed facilities, including possible over-conservative or unconservative solutions. Some potential consequences may include: (a) high construction costs due to unnecessary use of piled foundations or structural mats, whereas spread footings would have served adequately; (b) extra site preparation time and expenses for ground modification techniques, when in fact, none were needed; (c) unexpected poor performance of foundations, embankments, retaining walls, and excavations; (d) instability or excessive movements because subsurface anomalies were not detected; and/or (e) litigation. Regardless of budget and time, a geotechnical site investigation must still be performed and it needs to provide a reasonably sufficient amount of high-quality and varied types of subsurface data for analysis so that the design produces an efficient, safe, rational and economical solution.

4 PARAMETER EVALUATION

The evaluation of geotechnical parameters is accomplished within a variety of means including: past experience and knowledge of the local geologies, field testing, geophysics, and laboratory testing. The emphasis of most of our educational resources dwells primarily on laboratory tests as the means to this end. Usually, a cursory note on the use of geophysics and/or

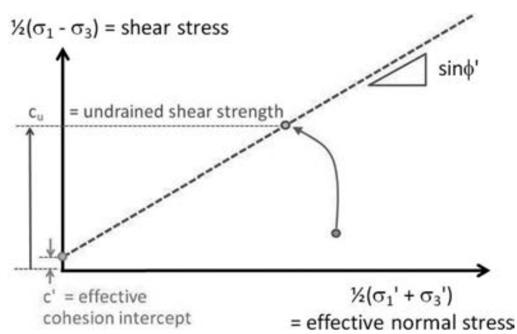

Figure 4. Confusion in cohesion.

in-situ testing is given, with a few ill-chosen correlations or relationships given to relate that information back to the lab framework.

A few pet peeves from the author's perspective are mentioned here to illustrate several dilemmas facing the profession.

4.1 *Cohesion*

The term "cohesion" is perhaps one of the most ill-used and vague terms in our discipline. In one sense, it is used to describe a coherency in the consistency of a soil sample; the particles hanging together as a unit. In the context of shear strength, it becomes nebulous as it can mean either the *undrained shear strength* ($c = c_u$ or s_u) or the *effective cohesion intercept* (c'), a parameter from the well-known linear Mohr-Coulomb strength criterion. The dilemma is depicted in Figure 4 which shows both of these "cohesions" within a q–p′ space.

The issue of "cohesion" is likely made more difficult because of poor textbook coverages on the matter of soil strength and continued use of the old archaic total stress friction and cohesion parameters, rather than the fundamentals of effective stress and critical-state soil mechanics.

In most soft saturated soils, the value of c' is actually small and close to zero. A number of factors can contribute to lab tests showing $c' > 0$ including: strain rates of testing that are too fast, poor quality porewater pressure measurements, inadequate specimen saturation, and choice in effective confining stress levels. In fact, the latter play an important role when considered in light of the boundary yield surface which represents a 3-dimensional preconsolidation of the soil stress history (see Figure 5).

4.2 *Undrained shear strength*

For clays subjected to short-term loading, a major parameter is the undrained shear strength ($s_u = c_u$). On a plot of shear stress vs. shear strain, this is a value of shear stress chosen late in the curve corresponding either to peak conditions (τ_{max}) or to fully-mobilized conditions at $(\sigma_1'/\sigma_3')_{max}$, for the specific case of loading under constant volume. It has found applications in slope stability analysis, footing bearing capacity, pile side friction, embankments, excavations, and numerical modeling. In your normal textbook, it is treated as it were a simple-valued parameter (s_u), yet alas it is one of the most complex and elusive variables in geotechnique.

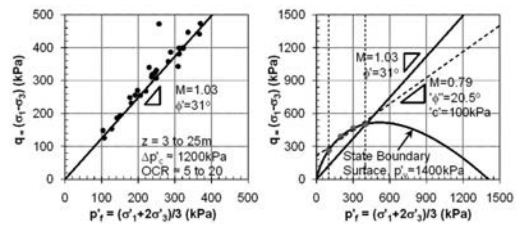

Figure 5. Boundary yield surface and frictional envelope for Milwaukee clay (Schneider 2011).

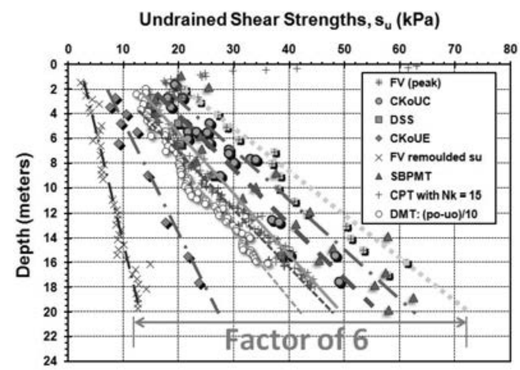

Figure 6. Family of s_u profiles from various tests in Bothkennar clay, UK (after Hight et al. 2003).

The undrained shear strength of any given clay (or for that matter, silt or sand) depends on many different factors, including: initial stress state (K_0), strain rate (μ_R), stress history (OCR or YSR), direction of loading (β), intermediate boundary condition (b), time to failure (t_f), and ageing, as well as the inherent fabric, structure, and sensitivity of the geomaterial. In fact, it is better to think in terms of a suite or family of undrained shear strengths (Kulhawy and Mayne 1990), analogous to a schizophrenic soil with many differing personalities.

A summary of various s_u values from field and laboratory test data from the national geotechnical experimentation site at Bothkennar, UK are shown in Figure 6 (Hight et al. 2003). It is clear that a single value of s_u cannot be assigned to this deposit of soft silty clay. Instead, depending upon the method and mode of testing, a hierarchy of s_u exists, in fact quite a range of sixfold from the lowest to highest values.

4.3 *In-situ test interpretation*

For in-situ tests, no unified theory or framework has yet been put forth towards a general interpretation of all devices (SPT, CPT, VST, DMT, PMT) for a wide variety of various geomaterials (clays, silts, sands, mixed soils). Instead, each particular test has developed rather independently within a particular application. Methodologies are based on theoretical, numerical, statistical, and empirical frameworks.

For instance, data from the vane shear test in clays are usually analyzed within a limit equilibrium solution, whereas pressuremeter results are considered within cylindrical cavity expansion. Alternative theoretical solutions proposed for analysis of CPT data include: limit plasticity, strain path method, finite elements, discrete elements, hybrid cavity expansion-critical state, and dislocation theory. Usually, the approaches are established for two extreme cases of drainage, either: (a) undrained, applied to clays; or (b) fully-drained, applied to sands. In reality, many possible scenarios lie between the two conditions, as discussed by Randolph (2004) and Schneider et al. (2008).

4.4 *Empirical correlations: improper usage*

Because of the complexity of geomaterials, various databases have been compiled to cross-validate the results of laboratory and in-situ tests, check the reasonableness of theoretical solutions, and allow the development of statistical correlative relationships. These may also be used to help identify problematic soils that offer special difficulties in construction and long-term performance of built infrastructure; e.g., organic soils, fibrous peats, calcareous sands, collapsible soils, dispersive clays, loess, carbonates, and loose liquefiable sands and silts.

Unfortunately, the geotechnical community tends to rely on a number of old empirical correlations that were derived from a small and early data set that are not at all applicable to the situations for which they are now applied. Case in point: A rather recent textbook (circa 2008) indicates the following two correlations (cited back-to-back) for use in estimating the undrained shear strength of soft normally-consolidated clays:

$$S = s_u/\sigma_{vo}'_{NC} = 0.11 + 0.0037\ PI\ (\%) \qquad (1a)$$

$$S = s_u/\sigma_{vo}'_{NC} = \phi'/100 \qquad (1b)$$

These two equations are completely incompatible with one another. The first was developed by Skempton (1957) on the basis of raw (uncorrected) vane shear data on 19 soft clays (Figure 7), while the second represents an approximation to laboratory triaxial compression tests on the basis of critical-state soil mechanics (Wroth 1984). These two modes are completely different from one another, so an inevitable inconsistency will be found should the geotechnical engineer go forth and use them.

A common usage for the aforementioned strength ratio $S = s_u/\sigma_{vo}'_{NC}$ is to assess the inplace degree of preconsolidation by inverting the SHANSEP normalization scheme (Ladd, 1991):

$$OCR = \left(\frac{s_u/\sigma_{vo}'_{NC}}{S}\right)^{1/m} \qquad (2)$$

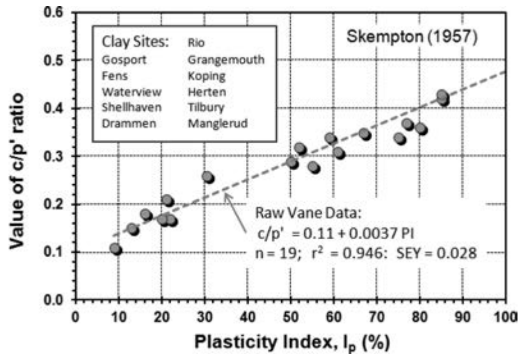

Figure 7. Early trend of c/p′ ratio with PI from raw vane data in soft clays (after Skempton 1957).

where $OCR = \sigma_p'/\sigma_{vo}'$ = overconsolidation ratio, σ_p' = effective preconsolidation stress, σ_{vo}' = effective overburden stress, and m = empirical parameter ≈ 0.80. A more fundamental expression is in fact derived from critical-state soil mechanics for the isotropically-consolidated triaxial compression (CIUC) mode (Wroth 1984):

$$OCR = 2 \cdot \left[\frac{2\cdot(s_u/\sigma_{vo}')}{M_c}\right]^{1/\Lambda} \qquad (3)$$

where $M_c = 6 \cdot \sin\phi'/(3 - \sin\phi')$, $\Lambda = 1 - C_s/C_c \approx 0.80$, C_s = swelling index, and C_c = compression index.

Let us explore the reasonableness and validity of the relationships given by equations (1a) and (1b) in evaluating the undrained shear strength of NC clays.

4.5 *Vane shear data on clays*

Since the time of Skempton's work, a considerable amount of vane shear testing (VST) has been completed worldwide (e.g. Chandler 1988; Mayne & Mitchell 1988; Leroueil & Jamiolkowski 1991). These studies showed that raw vane shear strengths were better normalized by the yield stress (s_{uv}/σ_p') and this ratio increased with PI in a nonlinear manner, but similar in trend to equation (1a). The author has reviewed results from several compiled VST databases (Mayne 2007), with Figure 8 showing a full summary developed from n = 212 tests, indeed confirming the general trend that raw $S = s_{uv}/\sigma_{vo}'_{NC}$ increases with the plasticity index of the soil.

4.6 *Triaxial compression data on clays*

Considerable numbers of laboratory triaxial tests have been performed worldwide on a wide variety of clays and silts over the past four decades and these are documented elsewhere (Mayne, 1988; Kulhawy & Mayne 1990). A summary plot of the triaxial compression data (both CIUC and CK_0UC) are presented in Figure 9 and indicate a rather nice corroboration of equation (1b)

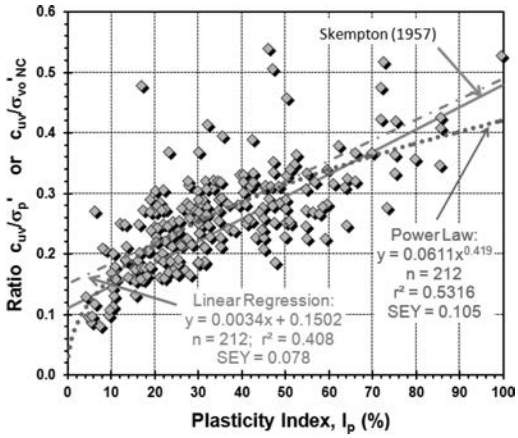

Figure 8. Trend of raw normalized vane strength data in clays with plasticity index (after Mayne 2007).

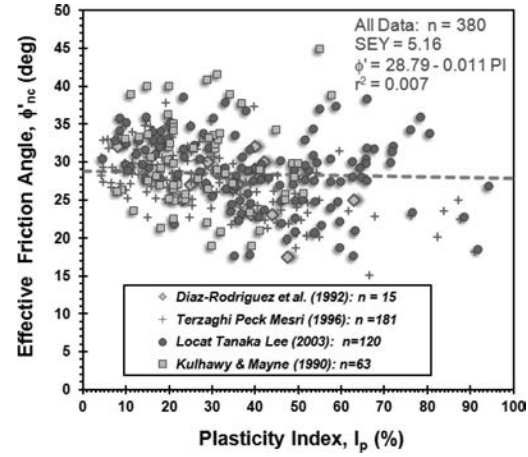

Figure 10. Lack of correlation between ϕ' and PI in clays.

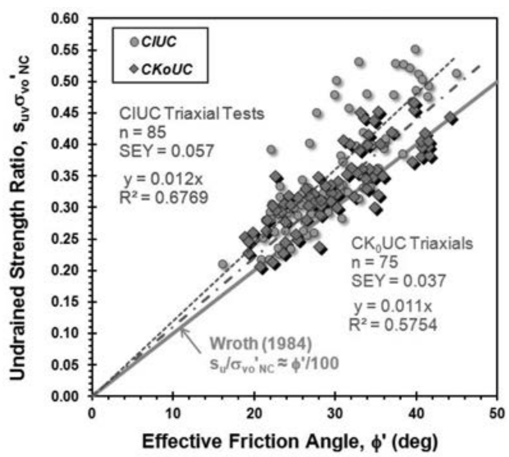

Figure 9. Trends of triaxial strength ratio (S) with effective ϕ' for many clays tested under CIUC and CK_0UC.

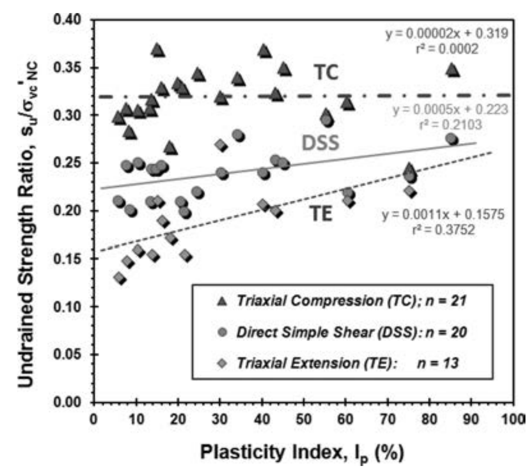

Figure 11. Strength ratio vs PI for clays tested in triaxial compression, simple shear, and extension modes (Ladd 1991).

which serves as a conservative but reasonable lower bound to the data trend.

4.7 *Dilemma for the s_u/σ'_{vo} ratio trends*

As we have now confirmed both equations (1a) and (1b) are valid trends, then the strength ratio S increases with PI and yet S also increases with ϕ', thus a corollary would be that ϕ' increases with PI.

Well, there are certainly no shortages of textbooks and technical papers that would tell you that ϕ' decreases with PI (e.g., Mesri & Abdel-Ghaffar 1993; Terzaghi et al. 1996; Das 2004). Of course, those trends were based initially on select clay powders and minerals with later results from remolded clays. The bulk of natural clays in fact do not follow that trend and a large compilation of triaxial results from various sources has been put together to form Figure 10. The statistics confirm that there is absolutely no correlation between the two parameters ($r^2 = 0.007$). Several reasons negate the well-worn-out relationship between ϕ' and PI include fabric, structure, and the presence of diatoms and forams in the soil mineralogy (Locat et al. 2003). Let's stop promoting this nonsense in our classrooms and discontinue its use in practice. An improvement is to assume $\phi' = 29°$.

One notable reason for the dilemma is the fact that S for triaxial compression mode is independent of PI, as shown by Larsson (1980), Jamiolkowski et al. (1985), and Ladd & DeGroot (2003). The trends from Ladd (1991) are shown in Figure 11 for three lab test modes. Again, drawing from the author's collection of data on a wide variety of clay soils indeed confirms that the S ratio from CK_0UC mode does not vary with plasticity index (Figure 12). For comparison, results are also compiled and presented from available DSS and CK_0UE series on clays. In these cases, S for triaxial

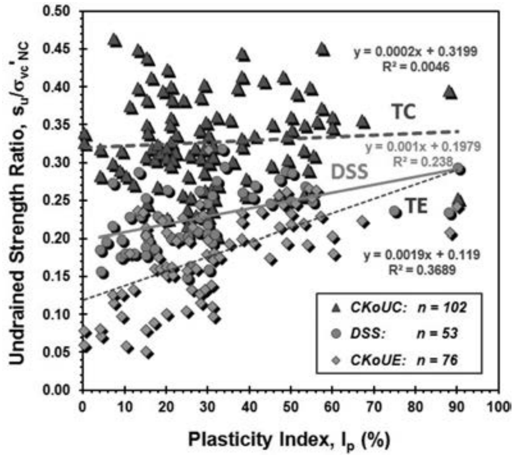

Figure 12. Database trends for strength ratio vs PI for clays tested by CK_0UC, DSS, and CK_0UE modes.

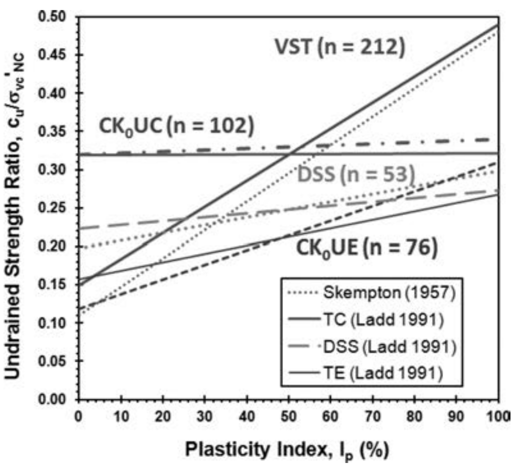

Figure 13. Summary of statistical trends of S vs PI for vane, compression, simple shear, and extension modes.

extension moderately increases with PI while S for simple shear slightly increases with PI.

These larger data sets confirm the past findings of the aforementioned studies on the topic. Figure 13 provides a summary of the latest S trends with PI in comparison with those from Ladd (1991) for laboratory modes and those from the recent VST datasets and Skempton's early work. It can be clearly seen that strength ratios from triaxial compression tests cannot be associated directly with vane shear results, as they are quite different. The consequences have led to conversion factors between TC-VST (Chandler 1987) as well as correction factors for the VST to provide s_u values appropriate for use in stability analyses and bearing capacity calculations (e.g., Larsson 1980; Schnaid 2010).

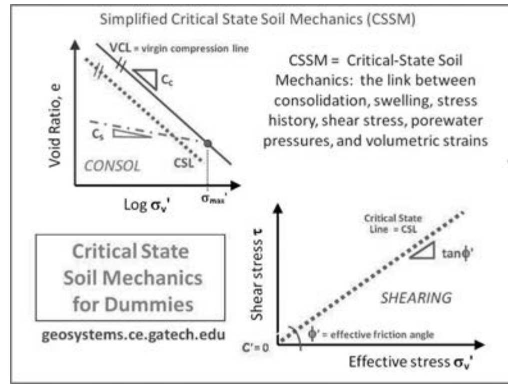

Figure 14. Outline of simplified CSSM framework.

4.8 *Critical-state soil mechanics*

One important subject missing from a number of introductory geotechnical textbooks is critical-state soil mechanics (CSSM). The framework of CSSM offers a rational effective stress coupling on consolidation and compressibility behavior of soils with the response to shearing (Figure 14). The approach easily addresses positive vs. negative porewater pressures, contractive vs. dilative behavior, normally- and overconsolidated states, and drained vs. undrained loading, as well as other possible conditions (partially-drained, cyclic). The large numbers of textbooks omitting CSSM are enumerable. Notably, one introductory book of recent vintage that does cover CSSM is Atkinson (2007).

Within a constitutive soil model of the CSSM type, a hierarchy of the various modes can help to explain the differences amongst different lab tests: CIUC, PSC, CK_0UC, DSS, PSE, CK_0UE, and CIUE (e.g., Kulhawy & Mayne, 1990; Whittle & Kavvadas, 1994). As the DSS is an intermediary mode, it sort of represents a good average value between compression and extension, thus suitable as a liaison between the complex world of strength anisotropy and undergraduates who are obliged to take a bachelors level course on the topic of geo-mechanics. As such, the author developed a simple overview module on CSSM entitled "critical-state soil mechanics for dummies" available as a download from: geosystems.ce.gatech.edu for educational purposes.

Within the simplified CSSM, the undrained shear strength ratio for normally-consolidated clays in DSS can be evaluated as (Wroth 1984):

$$S = s_u/\sigma_{vo}'_{NC} = \tfrac{1}{2}\sin\phi' \quad (4)$$

which is seen to be quite reasonable when placed in comparison with data from well-documented clays (Figure 15). Of final note, the importance of stress history is contained within the CSSM framework and used to express the undrained strength ratio in the general case for DSS:

$$s_u/\sigma_{vo}'_{NC} = \tfrac{1}{2}\sin\phi' \ OCR^{\Lambda} \quad (5)$$

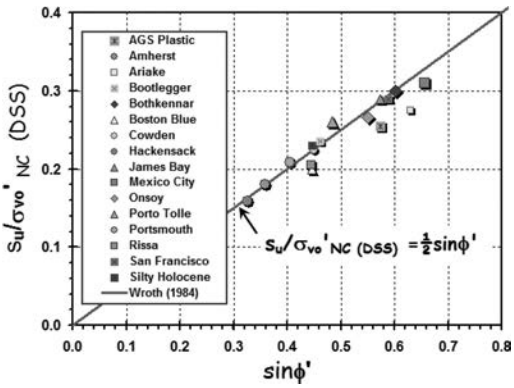

Figure 15. Strength ratio S for NC clays in DSS mode.

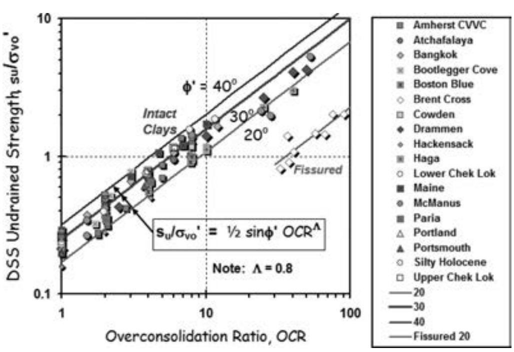

Figure 16. Strength ratio S for OC clays in DSS mode.

The verification of this formulation is shown in Figure 16 and helps to support a simple, yet reliable, approach in teaching undergraduate classes.

The only exception to note is that the strength is reduced to 50% if the clay is fissured because of the extra weakness planes offered by discontinuities.

5 ENHANCED SITE INVESTIGATIONS

One path towards the modernization of an undergraduate education in geomechanics is to update the course materials on site investigation. This can include new sections on available methods for drilling and sampling beyond the routine augering and rotary wash methods, specifically addressing: (1) direct push and (2) sonic technologies that offer faster continuous collection of soils and/or rocks. A full section should be covered on noninvasive and borehole geophysical methods, both electromagnetic and mechanical wave techniques (Campanella 1994). Finally, an entire chapter covering the basic in-situ tests: SPT, CPT, DMT, PMT, and VST should be addressed, complete with recommendations for interpretation and their relationship to the laboratory tests (e.g., Schnaid 2010). Mention to specialized field and in-situ test devices can also be given to illustrate the full range of

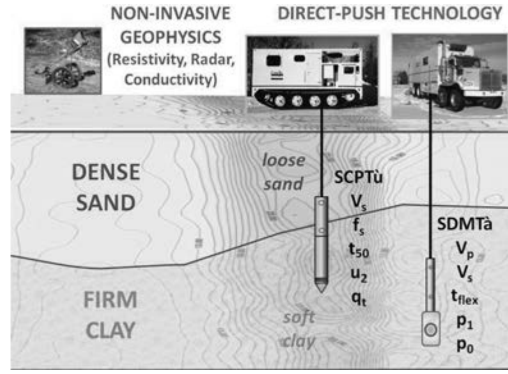

Figure 17. Modern approach to site investigation using combination of noninvasive geophysics and hybrid in-situ probings.

capabilities now available towards assisting geotechs in their challenging task.

5.1 *The new exploration program*

For routine site exploration, a modern approach for the year 2012 and beyond can now be recommended that includes: (a) initial areal mapping via noninvasive geophysical techniques; (b) physical vertical probings by hybrid in-situ tests for "ground truthing" (Figure 17). These together offer benefits in terms of improved coverage, insurance, reliability, productivity, and economics, compared with conventional methods.

In a traditional site investigation, rotary drilled borings or soundings are typically positioned on an established grid pattern over the project building site, say 30 m on center, in an attempt to hopefully capture any lateral variants in geostratigraphy across the site. Of course, this is merely a trial-and-error attempt since the gridded area may or may not coincide with Mother Nature's original coordinate system. For instance, it would be completely plausible that a buried ravine, or old natural stream, or other unknown anomaly might occur between the chosen grid points for the borings. Missing this important feature might result in construction difficulties, changed conditions, ground modification, different foundation system, and/or litigation.

5.2 *Noninvasive geophysics*

A logical solution to detecting heterogeneity is the utilization of high-frequency geophysical methods: electrical resistivity surveys (ERS), ground penetrating radar (GPR), and/or electromagnetic conductivity (EMC) for mapping the site area for relative differences. Not only are these geophysical surveys quick and economical to perform, they offer a chance to rationally direct the probes and soundings of the site investigations towards any variants on the property, thus focusing on the mapping of relative differences in dielectric or resistivity properties.

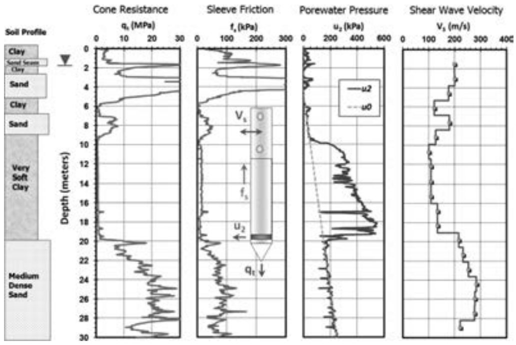

Figure 18. Representative seismic piezocone sounding from New Orleans East, Louisiana.

It is also possible to utilize the geophysical surface wave methods (SASW, MASW, CSW) for such purposes, albeit at higher cost and degree of implementation.

5.3 *Hybrid probes: seismic cone and dilatometer*

Hybrid exploratory devices that combine direct-push electromechanical probes with downhole wave geophysics offer an optimized means to collect data, as information at opposite ends of the stress-strain-strength curve are obtained at one time in a single sounding (Mayne 2010). Coupled with dissipatory phases, these include the seismic piezocone test (SCPTù) and seismic flat dilatometer test (SDMTà). The seismic cone and seismic dilatometer are not new, but were developed three decades ago (Campanella et al. 1986; Hepton 1988).

The SCPTù offers up to 5 separate readings with depth, including: cone tip resistance (q_t), sleeve friction (f_s), porewater pressure (u_2), time rate of dissipation (t_{50}), and downhole shear wave velocity (V_s), as detailed by Mayne and Campanella (2005). Moreover, the data are recorded continuously, digitally, and directly into a computer data acquisition unit for immediate post-processing, so that if necessary, on-site decisions can be made right then by the geotechnical engineer, else sent by wireless transmission to the chief engineer at the office for review. With the newest digital electronic systems, additional modules can provide downhole readings on resistivity, dielectric, and electrical conductivity.

An illustrative example of a representative SCPTù sounding from New Orleans, Louisiana is presented in Figure 18 showing four separate measurements with depth. The sounding was completed as part of the levee restoration project of the suburb area east of the city. The readings clearly show alternating layers of clay/sand strata in the upper 9 m followed by a thick 11-m soft clay layer to 20 m depth, underlain by a 10-m thick sand stratum extending beyond the termination depth at 30 m. A full dissipation is evident at 17 m with partial dissipatory results at 13–14 m and 19 m.

As an alternate or supplement to seismic cone testing, the SDMTà can provide as many as five or six

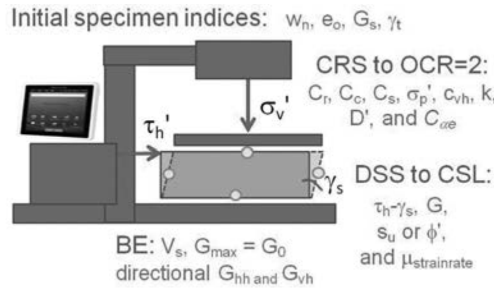

Figure 19. Conceptual all-in-one hybrid laboratory test.

independent readings can be obtained with depth, usually at 0.02m intervals, including: contact pressure (p_0), expansion pressure (p_1), deflation pressure (p_2), time rate decay (t_{flex}), compression wave velocity (V_p), and shear wave velocity (V_s). Details are given by Marchetti et al. (2008).

5.4 *Universal laboratory testing apparatus*

In concert with the above field hybrid tests that obtain multiple geoparameters from a single sounding, similar devices can be developed for the laboratory program. A conceptual device is presented in Figure 19 that would optimize the types and amount of data information collected from each soil specimen. The hybrid lab test would include a combination of constant-rate-of-strain consolidometer (CRS) with a direct simple shear (DSS) apparatus and additional sets of bender elements (BE) to provide a full suite of geotechnical engineering values, including compressibility (C_r, C_c, C_s, D), stiffness (G_{max}, G), strength (τ_{max}, s_u, ϕ', c'), rheological behavior ($C_{\alpha e}$, c_{vh}, μ), and flow characteristics (k), as well as state parameters (e_o, γ_t, σ'_p, OCR or YSR).

6 CONCLUSIONS

Current introductory courses and textbooks on geotechnics focus on a laboratory-based approach to solving problems in our field. While this has merit from a mechanics framework, 95% of the civil engineering students go on to major in different occupations, thus have a distorted view of our profession and its capabilities. Moreover, the 5% who do become practicing geoengineers are ill-equipped to tackle the site exploration program properly, as this is mainly acquired through use of geophysical and in-situ field testing. A consequence is that the practitioner falls back to the conventional methods of rotary drilling and sampling, often without sufficient funding for the extensive sets of lab testing to follow through on the analyses.

In the vast majority of routine projects, the selection of geoparameters is accomplished by resorting to old (sometimes incorrect) empirical correlations based on simple indices, rather than the fundamental values that really require triaxial, resonant column, and/or other significant lab testing. A modernization of the educational focus on the types, advantages, and interpretation of in-situ tests, such as the seismic piezocone and seismic dilatometer, would benefit the geotechnical community in terms of image, understanding, and data optimization, as well as mitigating possible legal issues.

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Using questioning to enhance student engagement

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ABSTRACT: This paper describes the value of questioning as a means of fostering student engagement and creating a dynamic, interactive classroom environment that is conducive to learning. General principles for the development of high-quality questions are outlined, and a series of specific questioning techniques is presented. Each of these techniques is shown to be particularly useful in a specific classroom situation. The paper concludes with a discussion of the necessary preconditions for effective questioning—knowing students' names and personalities, willingness to take risk, planning, and practice.

1 PURPOSE

In the literature on teaching and learning, there is near-universal acceptance of the axiom that effective learning can happen only if the learner is actively engaged in the learning process (Wankat & Oreovicz, 1993, p. 7). In recent decades, a wide variety of active learning approaches have been proposed, with the specific objective of enhancing student engagement. These approaches—collaborative learning, cooperative learning, problem-based learning, role-playing simulations, and many others—have often been shown to produce substantive improvements in student learning. These methods come at a cost, however: in varying degrees, all require a fundamental restructuring of the learning experience—of the students' relationships to the professor and to each other, of the subject matter to be learned, and perhaps even of the classroom itself. Desirable as it may be, such restructuring might not be feasible in a given institutional or individual context. Nonetheless, even in circumstances where these ambitious methods are infeasible, teachers should still seek to achieve active student engagement in the learning process by other means.

In my experience, the most often overlooked technique for stimulating active student engagement is *questioning*—directing questions to individual students as a routine part of classroom instruction. Questioning is often overlooked, perhaps, because it is so simple. It requires no reorganization of content, no fundamental restructuring of the learning experience, no physical rearrangement of the classroom. More likely, however, questioning is underutilized because it is difficult to do well.

Questioning techniques constitute a substantial component of the American Society of Civil Engineers (ASCE) ExCEEd (Excellence in Civil Engineering Education) Teaching Workshop—a six-day faculty development experience that is entirely focused on developing basic teaching skills. (Estes et al. 2010) A unique aspect of the ExCEEd Workshop is that participants are asked to demonstrate their understanding of workshop techniques by teaching three engineering lectures to a group of peers role-playing as students. And in my eleven years of service as a principal instructor for these workshops, I have found that no aspect of pedagogy elicits greater angst and resistance from workshop participants than questioning. In response to the suggestion that teachers should routinely ask questions and then call on individual students, workshop participants typically respond with a variety of creative excuses:

> *"Questioning takes too much time; if I do it, I won't be able to cover enough material."*
>
> *"If I call on individual students, they'll be intimidated or embarrassed; as a result, they'll give me unfavorable ratings."*
>
> *"My students would never play along. They're too cool to answer questions in class."*

We find, however, that many teachers who question the value of questioning have never actually tried it. Others have made half-hearted attempts to teach interactively—but have quickly given up when their students were unresponsive or, worse yet, when students answered every question with "I don't know." Some teachers use questioning in an adversarial way—to identify students who have not done their homework, for example—and then wonder why these same students react negatively to questioning.

In this paper, I suggest that questioning is one of the most valuable tools in the teacher's toolbox. Questioning can significantly increase student engagement, stimulate critical thinking, and enhance interpersonal rapport between the teacher and student. But like any tool, it needs to be used for an appropriate purpose; and like any tool, it must be learned before it can be used effectively.

2 THE VALUE OF QUESTIONING

Wankat and Oreowicz (1993) assert that questioning provides an effective method for emphasizing important points, clarifying difficult concepts, and reviewing previously learned material. They also suggests that questioning can be used to provide feedback about how well students are learning a concept or technique. This latter point can easily be overstated, however. Although questioning can provide the teacher with an overall impression of students' understanding of a concept or technique, the use of questioning to ascertain an individual student's level of preparation is likely to become adversarial. In such cases, the great value of questioning as a means of enhancing student engagement is largely lost. Fortunately, there are far more effective methods for obtaining informal real-time assessments of student learning—most notably the classroom assessment techniques cataloged by Angelo and Cross (1993).

Lowman notes that the learning value of lecturing can be greatly enhanced by providing opportunities for interaction with students. He observes that "conversational intimacy involves students more readily in the flow of ideas." (Lowman 1995, p. 141) He also suggests that in-class dialog benefits *all* students, even those who are not directly involved in answering questions. "When a college teacher initiates discussion with a provocative comment or question," he says, "every student must shift gears." (Lowman 1995, p. 164). In other words, every student must engage mentally with the question at hand.

Lowman also proposes a powerful, empirically derived model of teaching excellence. Based on the research question, "What constitutes exemplary teaching?" this model was derived by culling the adjectives from over 500 teaching award nominations of faculty members widely acknowledged to be exemplary teachers. Lowman's research team found that these adjectives fell naturally into two statistically independent categories, which the research team labeled as *intellectual excitement* and *interpersonal rapport*. To be exemplary, the teacher must excel in both of these domains.

According to Lowman's Model, the teacher stimulates students' intellectual excitement through the clarity of his or her presentations and the ability to stimulate a strong, positive emotional impact among students. When a teacher excels in the intellectual excitement domain, students:

- can distinguish between important and unimportant concepts;
- have a good sense of why concepts are defined as they are;
- find new ideas simple, reasonable, and easily remembered; and
- experience a sense of excitement about these ideas and generally hate to miss class.

According to Lowman's Model, the teacher achieves positive interpersonal rapport with students, first, by recognizing that the classroom is an arena for complex interpersonal interactions and, second, by interacting with students in ways that increase their motivation, enjoyment, and independent learning. When a teacher excels in the interpersonal rapport domain, students:

- believe that the teacher knows who they are and cares about them and their learning;
- believe that the teacher has confidence that they can learn and think independently; and
- are motivated to do their best, in part, so as not to disappoint the teacher's high expectations of them.

It is evident that a teacher's perceived competence in both of these domains can be greatly enhanced through effective use of questioning techniques (Wankat & Oreovicz 1993, p. 99).

One of the strongest cases for questioning can be found in an educational philosophy called *cognitive apprenticeship.* (Collins et al. 1991) This philosophy attempts to re-create in modern educational institutions the positive developmental aspects of apprenticeship, as it was practiced in ancient and medieval farming, construction, textile manufacture, and other craft industries. According to Collins et al., the most important characteristic of traditional apprenticeship is that the *learners can see the process of work*. Conversely, in a modern school setting, learners typically cannot "see" the thought process underlying the problem-solving methods they are attempting to learn. The focus of cognitive apprenticeship, then, is to "make thinking visible." The specific techniques associated with this philosophy include modeling, coaching, scaffolding, articulation, reflection, and exploration. And as the case studies presented by Collins et al. clearly demonstrate, all of these techniques can be greatly enhanced through effective questioning—which can, indeed, make thinking visible.

3 QUESTIONING TECHNIQUES

A good question should be short, clear, and unambiguous (Wankat & Oreovicz 1993, p.101). These characteristics may seem obvious; however, many inexperienced teachers find this standard more difficult to achieve than one might expect. There is an inherent conflict between brevity and lack of ambiguity; achieving the right balance is often problematic. A short question might not include enough information to clearly communicate the questioner's intent; as a result, the student may be unable to respond or may respond to a perceived question rather than the intended one. On the other hand, when the questioner attempts to communicate his or her intent by providing ample background information as an integral part of the question, the student often has difficulty assimilating all of this information, gets confused, and asks for the question to be repeated. Some teachers also tend to string two or more questions together, compounding the potential for confusion. Such multi-part questions should be broken up and asked one at a time, allowing students to respond to each one in turn (Hyman, 1982).

It is quite useful to apply Bloom's Taxonomy as a conceptual framework for formulating questions (Wankat & Oreovicz 1993, p. 101). This well-established model for the formulation of educational objectives identifies six levels of cognitive development (from lowest to highest)—knowledge, comprehension, application, analysis, synthesis and evaluation (Bloom, 1956). Particularly in engineering, it is appropriate to ask questions aimed at *all six levels* of cognitive development; however, the teacher must recognize the limitations, as well as the advantages, of questioning at each level.

Questions aimed at the lowest three levels of Bloom's Taxonomy can be highly effective for fostering student engagement, reinforcing basic-level concepts, and maintaining a dynamic, active classroom environment. However, these sorts of questions generally do not stimulate critical thinking. Questions aimed at the upper levels of Bloom's Taxonomy do, in fact, stimulate higher-order thinking; however, they also inevitably slow down the pace of instruction. In a classroom setting, a synthesis-level or evaluation-level question will probably require a lengthy period of time for students to formulate an answer—and might not even be answerable by a given individual. As such, it is generally advisable to focus *most* in-class questions at the knowledge, comprehension, and application levels. Higher-order questions should be used sparingly; and when they are used, better results can often be obtained by having students work in teams to formulate their responses.

The foregoing discussion leads to the most important axiom of effective questioning: *most questions should be planned prior to class*. Although there can be great value in fostering spontaneity in the engineering classroom, inexperienced teachers who attempt to formulate questions spontaneously seldom succeed. As Wankat and Oreovicz (1993) advise:

> Posing a good, clear question which requires some thought to answer but is not beyond the ability of students requires some time and effort to prepare. Prepare ahead of time, and write these questions in your lecture notes. If a good question arises spontaneously, try it and record it in your notes after class.

In planning questions, it is helpful to recognize the variety of different formats available in the teaching toolbox. Each format is best used in a specific situation, and each has its own potential pitfalls. In the following sections, I present five basic questioning techniques, all of which were developed in conjunction with the ASCE ExCEEd Teaching Workshop. In discussing each technique, I provide examples based on the in-class example problem shown in Figure 1 below. This is a relatively straightforward friction problem that might be used in an undergraduate statics course. The teacher of this hypothetical statics course is Professor Q, an expert questioner.

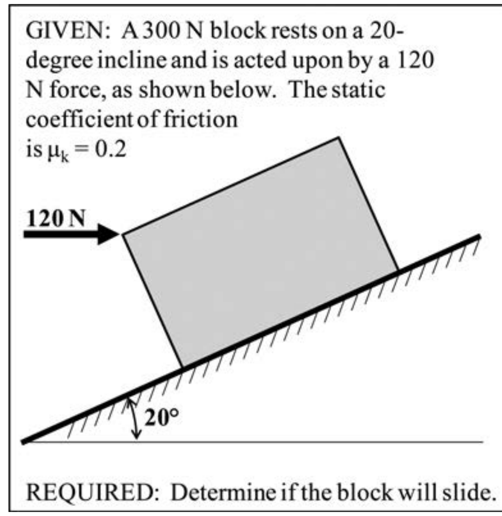

Figure 1. In-class example problem used to illustrate questioning techniques.

3.1 *The default question*

The *default question* is the preferred questioning format for general use. It should be implemented in three steps: (1) ask the question, (2) pause, and (3) call on a student by name. Using the in-class example problem shown above, Professor Q might employ the default question as follows:

Professor Q: *"Let's start by drawing a free body diagram of the block, isolated from its surroundings. What's one force I should draw on the block? [pause] Andy?"*
Andy: *"Huh? Oh…the weight."*
Professor Q (while drawing the weight on the diagram): *"Good! What other forces are there? [pause] Beth?"*
Beth: *"The 120-newton force?"*
Professor Q: *"Yes! Well done."*

Note that Professor Q asks each question of the entire class before calling on one student. In doing so, he prompts all of his students to think about the question and begin formulating an answer. The pause allows this process to play out. During the pause, all students in the class are at risk of being called upon. Meanwhile, Professor Q is scanning the group, deciding which student he will select. He notices that Andy's attention appears to be wandering and calls on him. Andy is initially startled, but he quickly reconnects and answers the question. Note that Professor Q does not admonish Andy for failing to pay attention; rather he praises Andy's answer, affirms it by drawing the force on the chalkboard, and then moves on to the next question.

Next Professor Q calls on Beth. She is bright but somewhat shy; and she is sometimes marginalized by more assertive students, who tend to shout

out answers without being called upon. Though she seldom volunteers information in class, she enjoys having an opportunity to demonstrate her knowledge. When Professor Q calls her name, she responds positively.

Indeed, research has shown that there are significant gender differences in college students' willingness to answer questions (Tannen, 1990). On the whole, men are more likely to answer questions without being called upon; women tend to be more reticent, regardless of how well they know the material. This is, in and of itself, a compelling reason to use the default question format, and to distribute questions more-or-less equally to all students. The professor who only calls on volunteers is likely to be systematically, if inadvertently, excluding women from in-class interaction.

One other important aspect of questioning is evident in this brief exchange. Note that, when Andy was called upon, he could have responded with any one of four correct answers—the weight, the applied load, the friction force, or the normal force. Professor Q was prepared to proceed with the problem solution, regardless of which answer Andy provided. Through this subtle technique, the teacher allowed the students to assume some control of the problem-solving process. By charting their own course through the problem solution in class, the students gain confidence and are more likely to make good decisions when solving similar problems on their own. Finally, note that allowing students' responses to guide the problem solution adds a significant element of spontaneity to the class. Ironically, this spontaneity could only have been achieved through careful preparation by Professor Q.

3.2 *The directed question*

The format of the *directed question* is: (1) call on a student, (2) pause, and (3) ask the question. Given the advantages of the default question, the primary disadvantage of the directed question is evident. As soon as the teacher calls on one student, all of the others are no longer at risk, and some may allow themselves to take a "mental holiday."

Returning to Professor Q's statics lecture, we see the one circumstance where the use of the directed question may be warranted.

Professor Q: "*Charlie…*"
Charlie (startled): "*Huh…?*
Professor Q: "*What other forces should I draw on the free body diagram?*"
Charlie (still a little flustered): "*Ummm…friction?*"
Professor Q: "*Yes, well done.*"

In this case, Charlie was fast asleep. If Professor Q had used the default question format, he would not have captured Charlie's attention until he called the student's name—after asking the question. Charlie would have had no choice but to ask Professor Q to repeat the question. Time would have been wasted, and Charlie would likely have suffered some public embarrassment. Instead, Professor Q uses the directed question format to get Charlie's attention prior to asking the question. As a result, the flow of the class is not interrupted, and Charlie is more likely to be grateful than resentful.

3.3 *The volunteer question*

Let us return once again to Professor Q's classroom.

Professor Q: "*Charlie has correctly noted that we need to add the friction force to our free body diagram. Who can tell me which direction the friction force should be drawn?*"
(Professor Q pauses and raises his own hand to indicate that he is looking for a volunteer. After a full minute, Dawn raises her hand.)
Professor Q: "*Go ahead, Dawn.*"
Dawn: "*Friction should be parallel to the surface; and friction always resists motion. Since the applied force is trying to push the block up the slope, the friction force must be pointing down the slope.*"
Professor Q: "*Good thinking! But are you sure the applied force is pushing the block up the slope? Can anyone see a reason why the block might move in the other direction?*"
(After another long pause, Ed raises his hand, and Professor Q calls on him.)
Ed: "*Maybe the block is trying to slide down the slope, and the 120-newton force is just large enough to prevent it from moving.*"
Professor Q: "*Good! So which direction is the friction force? Dawn? Ed?*"
Dawn and Ed: "*I don't know.*"
Professor Q: "*Exactly! We don't know! So we must simply make an assumption and let the solution to the system of equilibrium equations tell us whether our assumption is correct or not.*"

Here we see an expert use of the *volunteer question*. Professor Q knows that the concept he is asking about is conceptually challenging. Had he used the default question, there is a very good chance that the randomly selected student he called on would not know the answer. There would have been an awkward pause, and the professor might then have had to call on several more students before he could get some semblance of a correct answer.

Instead, he changes the rules of the game, signaling by his own raised hand (or by some other means) that he is seeking a volunteer. Dawn and Ed, two particularly capable students, rise to the challenge. Neither of them can answer the question fully, but Professor Q uses follow-up questions to coach them toward a correct answer. In the end, both Dawn and Ed earn the satisfaction of meeting an intellectual challenge, and their classmates benefit from seeing expert problem-solving manifested through verbal interaction between Professor Q and two of their own peers.

3.4 *The jump ball question*

Professor Q has completed the free body diagram and is guiding his students through the formulation and solution of the corresponding equations of equilibrium. Throughout this process, he has used the default question format almost exclusively, calling on individual students to add each new term to the equations, and to verify that the signs and numbers are correct. Every student in the class receives at least one question. In Professor Q's class, this steady stream of questions drives the lecture forward, creating a dynamic, interactive classroom environment and keeping most of his students fully engaged.

Now there is only one minute remaining before the end of class; the students have used their calculators to solve the equilibrium equations, and the calculated value of the friction force turns out to be a negative number (−10.2).

Professor Q: *"What does the minus sign mean? Anybody!"*
Frank: *"The assumed direction of the force on our free body diagram was incorrect."*
Professor Q: *"Exactly right, Frank! So, for our final answer, the friction force is 10.2 newtons, oriented on a 20-degree angle, down and to the left.*

Here Professor Q is nearly out of time, but he does not want to compromise on student engagement, particularly for such an important learning point. He recognizes that calling on a particular student by name will be risky: if the student is unable to answer, the remaining minute of class time will be used up without bringing the example problem to closure. So he uses the *jump ball* question: (1) ask the question, (2) pause, and (3) "anybody!" By announcing "anybody!" he authorizes any student who knows the answer to shout it out. As a result, Professor Q is able to bring the problem solution to closure quickly, while maintaining student engagement to the very end of the class period.

3.5 *The choir*

As the class period ends, Professor Q wants to make one final learning point.

Professor Q: *"Notice that the equilibrium equations required to solve this problem are actually quite straightforward. As we have seen so many times before in this course, the key to success is careful construction of our all-important graphical problem-solving tool; and that tool is…? [pause] Everybody!"*
All Students: *"The free body diagram!"*
Professor Q: *"You know it! And next class, we'll use this same tool to analyze bodies that can tip as well as slide. See you then."*

For this final point, Professor Q used the *choir question*: (1) ask the question, (2) pause, (3) "Everybody!" This question format works particularly well for reinforcing simple but important points that everyone should know without hesitation. Once students have been trained to recognize the choir question, they almost always respond with enthusiasm.

4 RESPONDING TO STUDENTS' ANSWERS

The challenge of effective questioning does not end with the question. When questioned, the student will respond in some manner, and the teacher must provide appropriate feedback. This feedback is important, not just for the student who responded to the question, but for all of the students in the class. The *content* of the teacher's response is important to all students' learning; and the *character* of this response is equally important to the development of interpersonal rapport between teacher and students.

As Professor Q has demonstrated, questioning can be used very effectively to elicit from students many of a lecture's major learning points. This practice sends the students a powerful message about their own capacity to acquire new learning; however, it also raises the possibility that incorrect or imprecise student responses will lead to broader misconceptions about key learning points. The teacher can avoid such misconceptions through appropriate responses to the student's answer. There are four possibilities:

(1) The student provides a fully correct answer. In this case, the teacher needs only to praise the student and then affirm the answer. The praise and the affirmation are equally important. Praise rewards the student publicly for active engagement, but also contributes more broadly to a positive classroom environment. The affirmation is necessary, because many students will not accept a peer's answer as correct until it is confirmed by the teacher.
(2) The student provides a partially correct response. In this case, the teacher should praise and affirm the portion of the student's response that was correct. If the incorrect portion can be safely ignored, then ignore it. The teacher should explicitly correct this portion of the student's response only if it is necessary to prevent misconceptions.
(3) The student provides an entirely incorrect response. Here the teacher may attempt to elicit a better answer from the same student, either by rephrasing the question or by posing a new question aimed at a simpler aspect of the previous one. This technique is called *scaffolding*. Alternatively, the teacher may turn to another student with the same question, and continue doing so until a reasonably correct response is provided.
(4) The student responds with "I don't know." Here the teacher must make a quick appraisal of the student's underlying motivation. If "I don't know" reflects a genuine lack of knowledge, then the situation is really no different from that of the incorrect response, (3) above, and can be handled

in exactly the same way. But if "I don't know" reflects a belligerent refusal to answer questions in class, then the response is a public challenge to the teacher's authority and must be handled more forcefully. A particularly effective technique is to rephrase the question as many times as necessary, in progressively more simplistic terms, until it becomes logically impossible for the student to respond with "I don't know." The resulting interaction typically produces sufficient discomfort to convince the student to respond more positively to future questions.

5 PRECONDITIONS FOR EFFECTIVE QUESTIONING

The preceding discussion suggests four critical preconditions for the effective use of questioning. First, the teacher must know his or her students' names. Calling on students by pointing at them or by reading their names from a roster significantly reduces engagement and accountability, while virtually eliminating the possibility of building interpersonal rapport. A simple technique for learning students' names—even in relatively large lecture classes—is to ask each student to write his or her first name with a bold marker on a folded piece of card stock placed on each desk, and then take a series of digital photographs of the students. (See Figure 2 below.) These photos provide a means of associating names with faces, with only a moderate amount of study.

Second, to do questioning well, the teacher should know something of his or her students' personalities. The independent student, the gregarious student, the timid student, and the belligerent student will respond to questioning in entirely different ways, as will students from different cultures. For example, timid students typically need to build self-confidence before they can fully engage in classroom interaction; the teacher can foster this sort of development by asking these students relatively straightforward questions in a non-threatening manner. Being aware of students' personal dispositions will enable the teacher to make well-informed decisions about what questions to ask and how to ask them.

Figure 2. Using a digital photograph as a tool for learning students' names.

Third, to use questioning effectively, the teacher must be willing to take a risk. Engaging in questioning requires the teacher to leave his or her "comfort zone," opening the door to all manner of unpredictable responses, some of which might even result in embarrassment or discomfort. This risk can be greatly mitigated through planning and practice. I have also found it quite useful to explain my use of questioning to my students on Lesson 1. The message: *this is not about checking to see if you have done your homework; it is about fostering an engaging classroom environment that will enhance everyone's learning.* And while the risk remains, the potential rewards of questioning are far greater.

Finally, the art and science of questioning can only be mastered through planning and practice. Inexperienced teachers should pre-plan most of the questions they will ask in a given lecture, and include these questions in their lecture notes. And all teachers should practice questioning incessantly, carefully noting what works well and what does not. Practice breeds confidence, and confidence helps facilitate an open, dynamic highly interactive classroom environment that can only enhance student engagement.

6 CONCLUSION

This paper describes the purpose and value of using questioning in the engineering classroom; and it presents a proven set of simple techniques for questioning effectively. Using questioning to enhance student engagement requires practice, planning, and the willingness to take a risk. Questioning can also contribute significantly to interpersonal rapport between the teacher and students, but only if the teacher knows the students names and something of their personalities. The effectiveness of questioning can be greatly enhanced through the awareness and use of a few standard techniques, each of which is best suited to a particular circumstance. Techniques for responding to a student's answer are, in many ways, as important as the question itself. Most important, all of these techniques work best when the teacher remains true to the ultimate purpose of questioning—to create a positive, interactive classroom environment that enhances student engagement. Questioning that is perceived as demeaning, punishing, or impersonal can do more harm than good.

ACKNOWLEDGEMENT

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Equilibrium, strength, strain, dilation and superposition

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ABSTRACT: Some basic principles of mechanics are considered, using examples to show how they are important to practical design. In most of the cases considered, computer programs have been used to carry out calculations, with the user sometimes lacking a full appreciation of the problem or a proper understanding of the calculation and material model in use. Equilibrium is the fundamental requirement of many engineering calculations, and it is important to ensure that all forces can be transmitted into ground that is able to resist them; computer programs that consider only part of the equilibrium may be insufficient. Modern finite element programs are easy to use, but it is essential that users cling to a sound grasp of soil mechanics and behaviour, and constantly ask themselves if the model in use is suitable for the current task; in particular dilation is important in controlling the strength of undrained or confined soils. Engineering courses tend to concentrate on stress states and stress analysis; but strain is much easier to observe and sometimes gives important warnings of impending problems. Finally, the principle of superposition is carefully taught, with emphasis that it only applies in linear situations; but in practice this limitation is often forgotten.

1 INTRODUCTION

Computer-based calculations are now very widely used in geotechnical design. Unfortunately, the power of the computing is sometimes not matched by the understanding and knowledge of the users of programs. Furthermore, the limitations of computer software are sometimes accepted without proper consideration of the range of behaviours and events, the modes and mechanisms that are physically credible.

This paper is a plea that engineering students should be taught a sound appreciation of material behaviour and mechanisms, and encouraged to approach design with enquiring minds, not limited by the software that is readily available.

In Section 2, three situations are described in which the computations carried out for design did not consider the complete equilibrium of the construction. In Sections 3 and 4, analyses associated with two deep excavations are considered. These illustrate the significance of soil models, especially dilation, the importance of considering strains, and some possible pitfalls in assuming that superposition can be applied.

Some of the examples discussed below involve embedded retaining walls. Eurocode 7 contains a set of diagrams that show 30 different failure modes for retaining walls, of which 13 are relevant to embedded walls. Of these, the five shown in Figure 1 are considered within this paper.

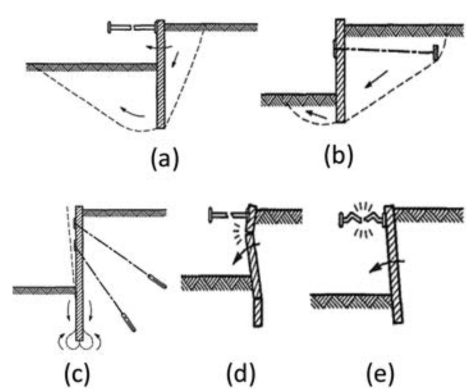

Figure 1. Five failure modes of embedded walls shown in Eurocode 7.

2 EQUILIBRIUM

2.1 *Introduction*

100 years or so ago, engineers had none of our present day computing aids and, in fact, few calculations were possible for geotechnical design. Instead, designers would draw, fairly slowly and laboriously, setting the proposed construction in its context, and in the course of doing so they would ponder whether what they were drawing would work successfully. In contrast, two problems can arise from modern computing, if it is not

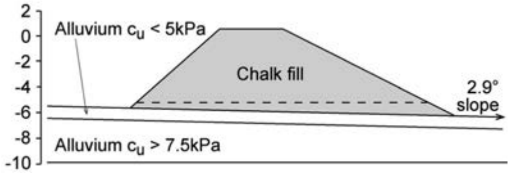

Figure 2. Embankment on very soft river muds.

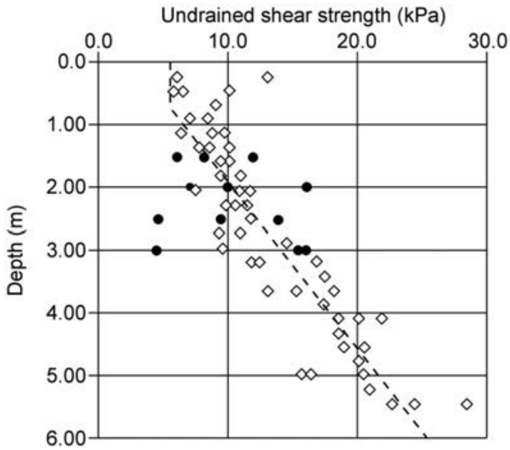

Figure 3. Measured shear strength of alluvium.

well used: (a) the particular item being designed is not seen in its wider context, so potential failure modes are missed, and (b) unreasonable proportions proposed for a new construction may not be recognized.

The following three examples illustrate these points.

2.2 *Embankment on alluvial foreshore*

Figure 2 shows an embankment proposed for construction on a river alluvial foreshore, which had a slope of about 2.9°. Figure 3 shows vane strengths measured in the mud, indicating a lower limit of about 5 kPa. The open diamonds represent data obtained higher up the foreshore where there would be more exposure to air. The solid circles show results from the actual location of the embankment; attention to the ground investigation report reveals that attempts to measure strength in the top 1.5 m had failed because no resistance was found.

The embankment was to be constructed of quarried chalk, with a basal layer of reinforcement. Computer analysis concentrated on the embankment and its reinforcement. Midway through construction, the embankment slipped sideways, remaining relatively intact, somewhat in the manner shown by the finite element analysis in Figure 4, which indicates a combined sliding and bearing failure. Analysis of this mode had not been considered, perhaps because it is quite complex and the significance of the extremely low strength of the muds was not understood, but mainly because of reliance on software that did not include this type of failure.

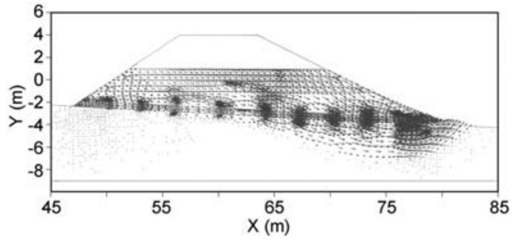

Figure 4. Probable failure mode of embankment.

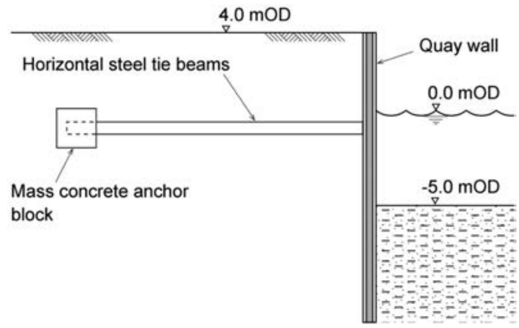

Figure 5. Old anchored quay wall.

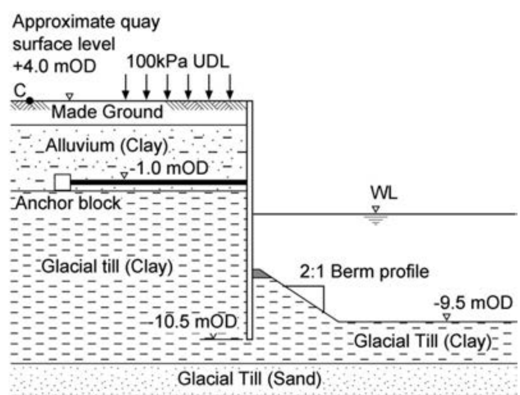

Figure 6. Anchored quay wall with proposed deepening of dock.

2.3 *Anchored quay wall*

Figure 5 shows the original cross section of an old anchored quay wall. To accommodate modern ships, it was required to have a greater depth of water in the dock, so it was proposed to dredge the seabed to give the section shown in Figure 6.

An engineer before the age of computing would probably have drawn Figure 6, noted the very small berm supporting the toe of the wall, and decided that the design looked unsafe. Modern engineers carried out computer analysis but were not alerted by the appearance of the cross section: perhaps they never drew it.

Many commercial computer programs are available for analysis of embedded retaining walls of this type.

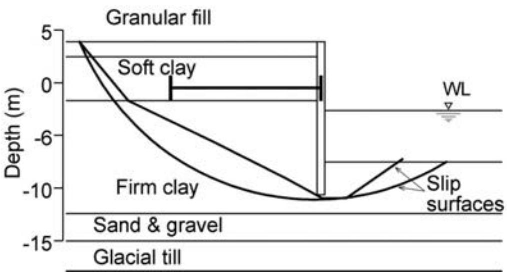

Figure 7. Slip surfaces for quay wall.

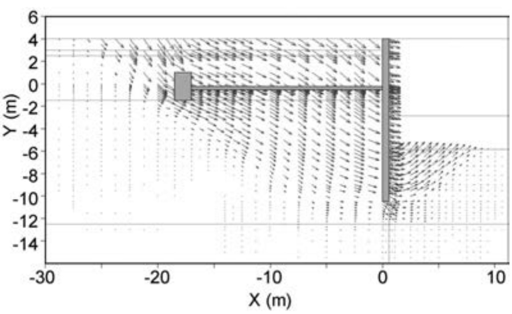

Figure 8. Failure mode shown by FE analysis.

Some consider only stability, whereas others try to compute also displacements and bending moments of the wall, and the tie force needed in the anchor. Factors of safety might be included in such calculations, but generally only the equilibrium of the wall and the earth pressures acting on it are considered. Stability calculations of this type were carried out and the revised design was considered to be acceptable.

However, when dredging was undertaken a crack formed in the quayside at the point marked C in Figure 6. Here again, the major problem was the use of analysis that concentrated on one mode of failure, in this case rotation of the wall about the tie (Fig. 1a), without considering other possible modes, such as shown in Figure 1b.

The strength parameters of the ground were not well known in this case. Figure 7 shows a circular and a non-circular slip analysis modelling the situation at which the crack formed. For the circular slip, a factor of safety of 1.19 is computed. The finite element (FE) analysis shown in Figure 8 became unstable at a factor of safety of 1.1, indicating a more critical failure surface than the circular slip. Figure 7 also shows a non-circular slip surface copied from the FE analysis, a factor of safety of 1.11, similar to the FE analysis. An advantage of the FE analysis is that, unlike the other analyses used here, it does not require a prejudgment of the failure mode and can accommodate the structural as well as the geotechnical elements.

2.4 *Vertical equilibrium*

Figure 9 shows an embedded wall intended for use at a riverside to allow construction of a storage area by

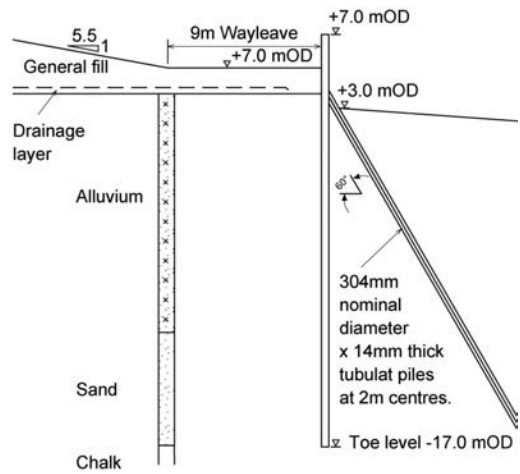

Figure 9. Sheet pile wall supported by tubular piles.

filling behind the wall. The wall was to be supported by steeply inclined tubular piles, and was built in an old dock that had silted up over the last 100 years or so, giving very soft organic clay to around 10 m depth. The displacements of the wall were monitored. It collapsed during backfilling.

As noted in 2.3 above, many available computer programs can be used to compute the performance of this type of wall. Most of the simpler programs analyse the stability of horizontal earth pressures with wall bending moments and the horizontal components of the support forces; they do not consider vertical equilibrium, as illustrated by Figure 1c. As a result, a mode of failure resulting from inadequate vertical restraint was not properly considered, particularly noting the extremely soft nature of the very recent organic clay.

The monitoring showed that the wall failed by first moving upwards and outwards, normal to the inclined piles, until they were bent so much that they failed in bending. At that point, support to the wall was lost, probably due to local buckling of the piles, and the wall started to move downwards.

Once again, analysis had concentrated on use of particular software and had failed to take proper account of all possible failure modes.

2.5 *Teaching points*

Important points to note from the three examples in this section are:

- When using computer analysis, consider all possible failure modes, not only those modelled by the particular program available.
- For tied retaining walls, remember that the tie must be able to transfer the load to stable ground, and consider whether this will be achieved.
- For embedded walls, vertical equilibrium should not be forgotten.

- Note that very recently deposited clays may have extremely low strengths. Measured low values should not be assumed incorrect without very good evidence. Absence of measurements may indicate that the soils were too soft to give a reading.

3 NICOLL HIGHWAY STATION, SINGAPORE

3.1 *Introduction*

A major collapse occurred during the construction of the Nicoll Highway station, Singapore, in April 2004. During the following year, a public inquiry was held, which concluded that many aspects of the design and construction contributed to the cause of the collapse (Magnus et al 2005). The significance of some of these was disputed by involved parties, but it was generally agreed that the most important contributor was a steelwork error in design of the strutting system (Fig 1e). The inquiry concluded that some geotechnical issues also contributed to the collapse, of which three have been selected for their relevance to this paper. A more extensive discussion can be found in Simpson et al (2008).

The collapse occurred during the construction of a station box about 20 m wide and excavated to a depth of about 34 m. The cross section in Figure 10 shows that the excavation was largely in Singapore Marine Clay, which is soft to firm, normally consolidated or possibly slightly under-consolidated in relation to fill placed a few decades ago. The Marine Clay was underlain by layers of alluvial and estuarine clays of similar undrained strength, followed by much stronger Old Alluvium. The excavation was supported by concrete diaphragm walls, designed to extend into the Old Alluvium. Before excavation, jet grout struts had been formed at two levels, one above and one below the final excavation level. At the time of the collapse nine levels of strutting were in place, the upper jet grout strut had been removed, and excavation was underway to the tenth level. It can be seen in the plan of the area that collapsed (Fig 11) that the steel struts were generally placed in pairs. Strut pair S335 was instrumented with strain gauges and had inclinometers, I65 at its south end in the wall and I104 at its north end in a borehole just outside the wall.

The design was based on the results of finite element analysis using the program Plaxis. From this, anticipated wall displacements were derived, trigger values for monitoring were set, and wall bending moments and strut forces were derived.

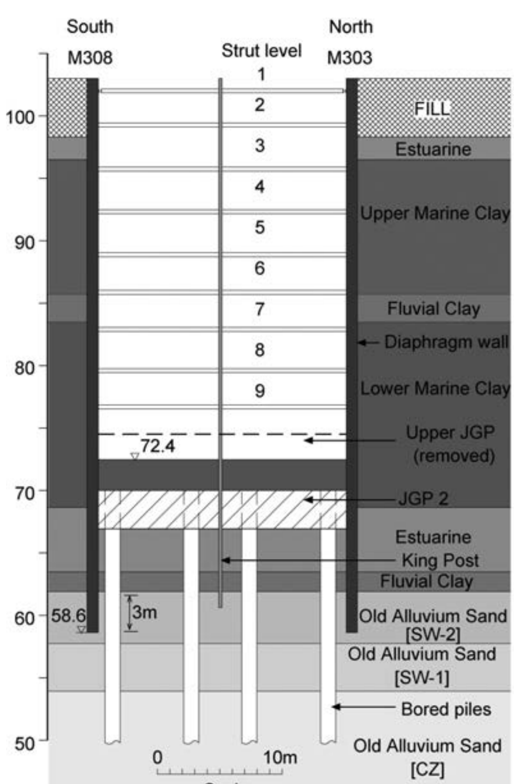

Figure 10. Nicoll Highway – design cross section.

3.2 *Irregular geology*

The design analysis was carried out for the cross section shown in Figure 10. It was assumed in analysis and specified on the drawings that the diaphragm walls were to extend 3 m into the Old Alluvium, to achieve toe support.

In reality, geology is never as simple and regular as could be inferred from Figure 10. In particular, the levels of the interface between the soft clays and the Old Alluvium varied sharply over short distances because the surface of the Old Alluvium had once been ground level and had been eroded irregularly by streams. For example, near inclinometer I104 there was a local dip in the surface and the design requirement for the walls to penetrate 3 m into it was overlooked, and the contractor recorded very little penetration. The geology on section A-A of Figure 11 was more like that shown in Figure 12.

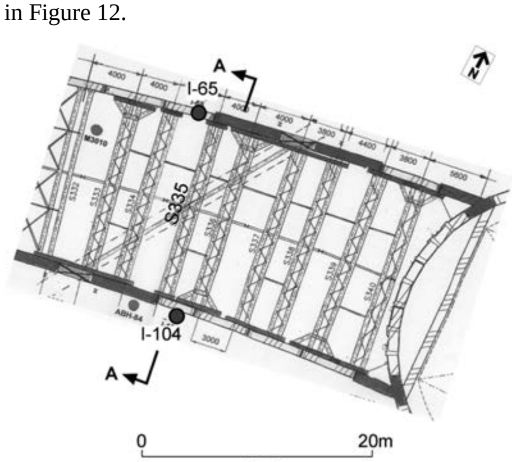

Figure 11. Nicoll Highway – plan.

As excavation proceeded, the measured displacements of the walls exceeded the trigger values at an early stage, particularly at I104. The designers re-calculated, progressively reducing the strength assumed for the soft clay in Plaxis, but without incorporating the information that the diaphragm wall had much less than 3 m penetration into the Old Alluvium. Consequently, their analyses failed to match the distorted shape of the wall actually observed, and computed bending moments were not realistic.

3.3 *Modelling undrained soft clay*

On the north side of section A-A, however, the wall had sufficient toe restraint in the Old Alluvium. Nevertheless, the observed displacements at Inclinometer I65 were roughly double those computed in the design, noted as "Method A" in Figure 13. During the inquiry, it was agreed that this was due to inappropriate modelling of the undrained behaviour of the soft clays.

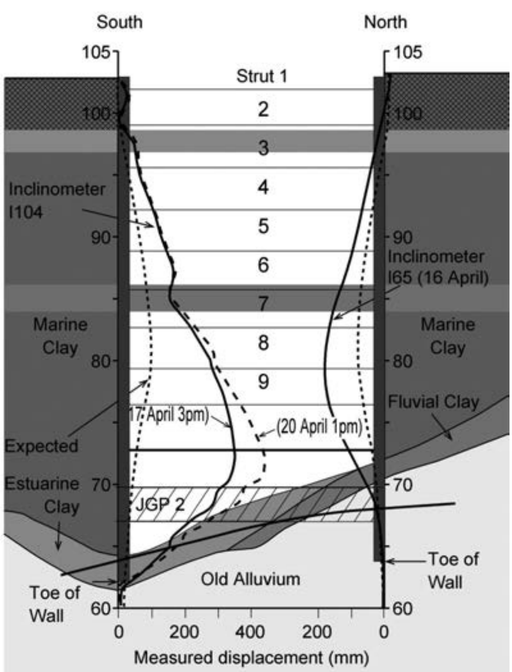

Figure 12. Nicoll Highway – displacements and geology.

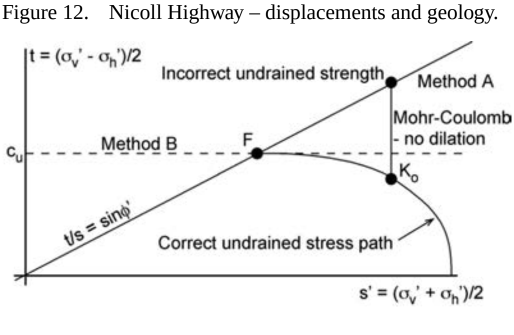

Figure 13. Modelling undrained behaviour – Methods A and B.

The soft clays were modelled using effective stress parameters, assuming linear elastic behaviour bounded by a Mohr-Coulomb envelope ($t/s = \sin\varphi'$). Figure 13 shows a shear stress/normal stress diagram for plane strain, in which the Mohr-Coulomb envelope is marked, together with a typical effective stress path for undrained behaviour of a normally consolidated clay. This path reaches failure at point F on the Mohr-Coulomb envelope with undrained strength c_u.

An element of soil in the ground would be expected to have in situ stress such as point K_0. From this point, the simplest elastic-Mohr-Coulomb model gives the vertical stress path K_0A for undrained behaviour. Because the strength is limited by the effective stress angle of shearing resistance φ', the undrained strength is overestimated by a factor of about 1.4.

This effective stress approach was known in the inquiry as Method A. An alternative approach for undrained behaviour, Method B, is simply to specify the undrained strength of the material, c_u, rather than the effective stress parameter φ'. For purely undrained behaviour this often a reliable and simple expedient, especially for normally consolidated clays. The undrained strength is computed correctly, but the computed pore pressures are still wrong. This becomes more problematic if consolidation is to be modelled following an undrained stage.

The result of the overestimate of undrained strength using Method A was that displacements of the walls were underestimated by a factor of about 2, as shown in Figure 14 for the north side (I65), which conformed more closely to the design stratification. This figure also shows that use of Method B with the anticipated undrained strengths of the clays gave a good

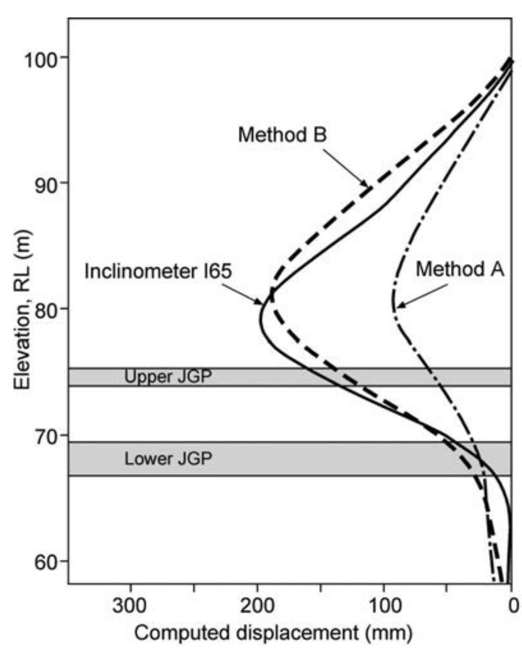

Figure 14. Maximum displacements for I65, computed and measured.

prediction of the displacements for I65. The computed ratio in bending moments for methods A and B was also about 2; this meant that the more correct predictions of Method B significantly exceeded the bending strength envelopes of the design, which was based on Method A (compare mode (d) in Figure 1).

From a teaching point of view, the main issue here is that engineers who will carry out geotechnical FE computations must understand enough about soil behaviour to judge the validity of available models for the problem in hand. In this case, an understanding of undrained stress paths was needed, essentially as they are controlled by dilation during shearing, negative for soft clays and tending to zero as the critical state is approached. The elastic-Mohr-Coulomb model used in the design had no dilation, and it is likely that the issue of dilation was not considered. In the author's opinion, a trained geotechnical engineer should realise that Method A gives an unreliable prediction of undrained strength and certainly is not suitable for normally consolidated clays.

It should be noted that since the time of Nicoll Highway Plaxis have altered the advice given in their manual about modelling undrained behaviour. However, their use of the term "Method A" is different from that used in the Nicoll Highway inquiry. Plaxis include within this term the use of more advanced nonlinear models of soil behaviour, which may give better predictions of undrained stress paths. In the Nicoll Highway inquiry these were termed "Method D", and Method A was used only to refer to elastic-Mohr Coulomb models.

3.4 *Factors of safety*

The public inquiry concluded that the design of the retaining structures had incorporated inadequate factors of safety. Of particular relevance to geotechnical design, no safety or mobilisation factors had been applied to the strength of the ground and no check on the toe stability of the walls had been carried out. It would, in fact, have been possible to satisfy these two requirements simultaneously by carrying out "ultimate limit state" FE analysis with factored strength as required by Eurocode 7 with the UK National Annex. The inquiry also noted that the required values of factors of safety should be determined in relation to the severity of any possible collapse: in this case it caused very great danger to the general public using the adjacent 6-lane highway.

Engineering students should understand that there is uncertainty about the strengths of all materials, particularly those in the ground. Whilst not advocating the detailed teaching of codes of practice in university education, the author suggests that a clear understanding of factors of safety and their roles in design should be part of an engineer's academic education.

3.5 *Observations of strains*

Engineers are taught to think about stresses, forces and their equilibrium. In practice, engineers give too little attention to displacements and strains, despite the fact that these are much easier to observe and measure.

Tests on the type of grout used in the jet grout struts show that it fails in crushing at compressive strains typically around 1%, with a range of 0.5% to 1.5%. A simple calculation using the wall displacements such as shown in Figure 12 showed that, even several weeks before the collapse, the average strain over 20 m between the two walls was about 2% at the level of the jet grout struts. It could be expected that this strain would not be uniform and that some local strains would be much higher. In the author's opinion, this simple observation should have been a cause for major concern: either the jet grout was inadequate from the start, or it had been overloaded and crushed. In either case, its continued effectiveness was very doubtful. Despite this, in pre-collapse analyses to explain the large wall displacements, the designers continued to assume that the jet grout was performing as designed.

As the final collapse was developing, steelwork could be seen to be deforming alarmingly. Although engineers on site were conscious of this, they were more influenced by measurements from the strain gauges on strut pair S335, which indicated that the design loads were not being exceeded. A similar observation was made before the collapse of the Heathrow Express tunnels in 1994 (HSE, 2000): in this case the 9 m invert of the tunnel, supposedly of sound concrete, had been observed over a period of many weeks to have shortened by about 150 mm (about 1.7% on average).

Engineers need to be able to read the signs of unacceptable displacements and strains. An overconcentration in education on stress and strength, rather than the limiting strains of materials, might account for this failure.

3.6 *Superposition*

During the investigation, it was tempting to try to assign percentage effects to the various causes, and to assume that they could be added together. For example, x% for the Method A/B problem, y% for the jet grout problem, z% for the change of toe penetration in to Old Alluvium, so the combined effects would be $x + y + z\%$. However, it was shown that the magnitude of the effect of Method A/B changed significantly depending on the state of the jet grout and assumed stratification, and so on, in a highly non-linear way. In such circumstances, superposition of effects may be grossly misleading.

3.7 *Teaching points*

Important points to note from the Nicoll Highway example are:

- Engineers who will carry out geotechnical FE computations must understand enough about soil behaviour to judge the validity of available models for the problem in hand.
- A clear understanding of factors of safety and their roles in design should be part of an engineer's academic education.

- Besides understanding stress, equilibrium and strength, engineers should be taught to observe displacements and strains, and to consider whether these exceed the limits of the materials.
- In non-linear systems, superposition of effects may be grossly misleading.

4 DEEP EXCAVATION IN STIFF SOILS

4.1 *Introduction*

This example illustrates some important points related to use of finite element analysis in permeable, or semipermeable, ground. A complex situation, involving initial design and a later dispute, will be simplified in order to bring out the points relevant to geotechnical education. The main point of contention was whether time-dependent coupled consolidation analyses were valid, or whether steady state seepage should be assumed.

The cross section in Figure 15 shows the temporary support structure for a proposed excavation about 30 m deep and 29 m wide. The retaining structure consisted of a soldier pile wall with sheetpiles driven as deep as possible between the soldier piles. If the sheetpiles did not penetrate to formation level, it was proposed to spray concrete on the exposed face between the soldier piles. Each level of excavation was expected to take 30 to 60 days.

The geological profile is shown in Figure 16, superimposed on part of a finite element mesh used for some of the analyses. The surrounding ground was mainly a rock formation that had been completely weathered to a residual soil comprising silty sand or sandy silt, sometimes with some gravel, generally somewhat variable in grading. SPT blowcounts showed that it was medium dense or stiff, trending towards dense or hard with depth.

Fill and sand of alluvial or marine origin overlay the residual soils to a depth of up to about 7 m. The residual soil was underlain by limestone, to which the soldier piles extended at this cross section.

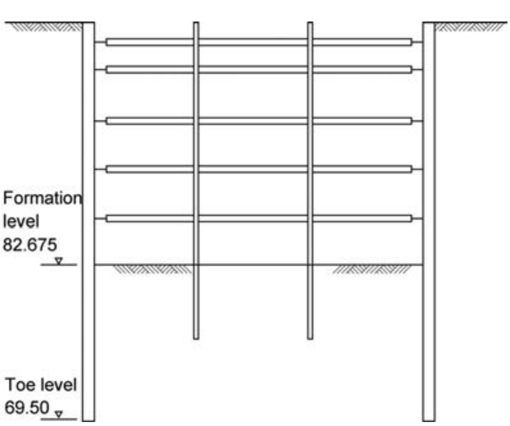

Figure 15. Deep excavation in completely weathered rock.

The properties adopted for finite element analysis are shown in Table 1, in which RS indicates residual soil and LST indicates limestone. Elastic-Mohr-Coulomb models were used for all the work described here. Further comments on the permeabilities shown in Table 1 are given below.

It is noted that this list does not include any parameters related to dilation of the soils or to the wall/ground interface friction. The author recognises that the use of c′ is a debatable topic, but it is not of importance in this problem.

4.2 *Permeability*

Figure 16 shows two profiles of permeability. Initially, a uniform permeability of 1E-7 m/s was adopted for the residual soil, as shown in profile A. However, there was concern that less permeable layers at depth might have an adverse effect on the behaviour of the excavation, so in later analysis the effect of reducing the permeability to 1E-8 m/s beneath excavation level was investigated, as in profile B.

The sand overlying the residual soil was thought to be more permeable and a permeability of 1E-6 m/s was adopted for this, with 1E-7 m/s for the fill.

The underlying limestone was thought to be potentially more permeable. However, it was intended that wells would be installed to relieve any free water at high pressure in the limestone, so the permeability allocated in analyses was as for the overlying residual soil.

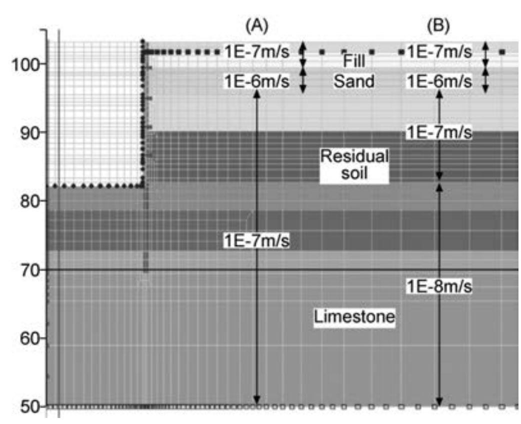

Figure 16. Permeability profiles A and B.

Table 1. Properties adopted for finite element analysis.

Soil	E′ kPa	ν′	c′ kPa	ϕ′ °	γ kN/m^3	k m/s
Fill	8,696	0.3	0	28	19	1E-7
Sand	8,696	0.3	0	30	20	1E-6
RS1	10,435	0.3	5	28	20	1E-7
RS2	38,261	0.3	10	28	20	1E-7
RS3	57,391	0.3	15	28	20	1E-7
RS4	107,826	0.3	15	30	20	1E-7
RS5	45,217	0.3	10	28	20	1E-7
LST	869,565	0.3	50	34	22	1E-7

Reflecting the proposed construction, the wall was generally modelled as impermeable or of low permeability above excavation level, but almost as permeable as the ground below that level. This was not readily achieved in Plaxis, however, because slip layers were used adjacent to the wall, so the full height of the wall was modelled as impermeable.

4.3 *A simple calculation*

In the absence of dilation, the time required for consolidation to be complete is a function of the permeability (k) and compressibility of the ground (m_v), and of the "path-length" (h), which is the distance water has to travel as the transient pressures dissipate. The compressibility and permeability terms can be combined with the weight density of water (γ_w) to give the coefficient of consolidation $c_v = k/m_v\gamma_w$. The time required for essentially complete consolidation is given by h^2/c_v.

From Table 1, a reasonable average Young's modulus for the ground is about $E = 50$ MPa, and the compressibility is roughly $m_v = 1/E$. The default permeability is generally 1E-7 m/s (profile A), and the weight density of water is taken as 10 kN/m^3. Since the water level was maintained near ground surface a reasonable average distance for the seepage path is about 20 m. For these values, the formula h^2/c_v is evaluated as about 9 days, at which point a steady state will apply. On this basis, the steady state will prevail within a period considerably less than the times required for any of the stages of the excavation, assumed to be 30 to 60 days. Any FE results that suggest a markedly different conclusion should therefore be regarded as suspect.

4.4 *Finite element analyses*

Finite element analyses were carried out for this problem by various parties using CRISP, Plaxis and, in investigations by the author's firm, Oasys SAFE. Results from Plaxis and SAFE have been in close agreement, provided strictly equivalent data are used.

FE analyses were initially carried out using both time-dependent coupled consolidation analysis (CCA) and steady state seepage (SSS) in CRISP. The bending moments computed for SSS were, critically, 55% greater than the CCA results. This result is contrary to the simple calculation reported in 4.3 above, which suggested that SSS would be established within the timescale of each stage of excavation.

To check CRISP, an SSS analysis was also carried out using Plaxis, in this case with an impermeable wall to full depth in both programs. As shown in Figure 17, the results from the two programs were in very close agreement. In the author's experience, such close agreement between two FE programs can usually be obtained, but only after extreme efforts to ensure that the input data to the programs are strictly equivalent, which usually takes several iterations. In this case, however, no such iterations had been undertaken.

Careful scrutiny of the data would have revealed two unintended differences: (a) In Plaxis it was assumed that the interface friction on the wall was half that of the ground (ie $\delta/\varphi' = 0.5$) on both sides of the wall, whereas in CRISP this was only applied on the retained side, with full friction on the excavated side. (b) Small differences in the geometry meant that the span of the section of wall at maximum bending moment differed by about 6%. Later analyses showed that these differences in data would have led to increases in bending moment from the SSS analyses (Plaxis assumptions relative to CRISP assumptions) of (a) 14% and (b) 12%. It is therefore clear, in retrospect, that the very close agreement for SSS analyses shown in Figure 17 between CRISP and Plaxis must be fortuitous and, in fact, could not be achieved with correct analyses of the data as used.

Figure 18 shows computed pore pressures for a point just below the level of the final excavated surface,

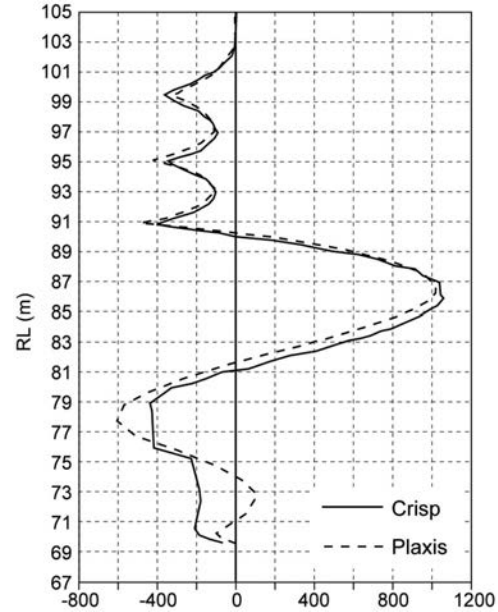

Figure 17. Bending moments computed initially for steady state seepage.

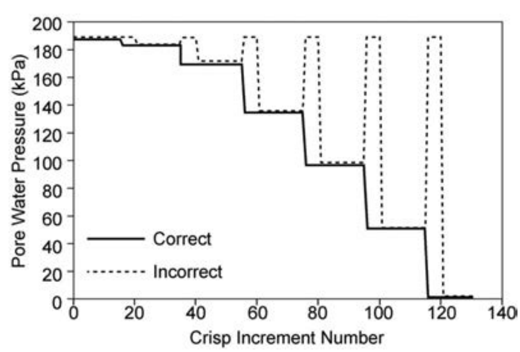

Figure 18. Computed water pressures just below final excavation surface.

in SSS analyses. The "correct" values reduce step-wise with each stage of excavation. However, investigation revealed that in the SSS CRISP analysis shown in Figure 17 the pore pressures were those marked "incorrect". By a data error, very high pore pressures were being specified at the excavated surface immediately after each stage of excavation. This should have led to instability, but the tangent stiffness method used in CRISP did not show this because only five "time increments", effectively iterations in time-independent steady state, were allowed at each stage. Had more iterations been allowed, larger displacements and bending moments would have occurred. The agreement shown in Figure 17 was entirely fortuitous, and very misleading.

Displacements and bending moments at critical stages are often the main results required from retaining wall analyses of this type. However, if the user is to understand the overall behaviour portrayed by the analysis, it is very important to inspect a wider range of output, at all stages of the computation. The author recommends in particular that engineers should examine displacement vectors (as in Figures 4 and 8) and principal stress fields to see the overall flow of displacement and stress, and also water pressures, usually best seen as contours.

4.5 *Dilation*

It was noted above that Table 1 does not mention dilation, a difficult topic that many geotechnical engineers prefer to ignore. For Mohr-Coulomb models, Plaxis and SAFE allow angles of dilation ψ to be specified by the user with default values of zero and a limit to the total amount of accumulated dilation. For its default value, CRISP assumes normality, treating the yield surface as a plastic potential, which, for a Mohr-Coulomb model, implies $\psi = \varphi'$. This is shown in Figure 19 by the vector of plastic strain increments ($\delta\varepsilon^{p}_{vol}$, $\delta\gamma^{p}$) for the plane strain case. All the CRISP analyses reported here use $\psi = \varphi'$, and it is not clear to the author whether this can be varied. Furthermore, dilation continues indefinitely in CRISP if shear strains become very large as shear failure occurs.

The actual dilational behaviour of the materials at this site was not known. It is thought that $\psi = 0$ is a reasonable, cautious value for design, and it is clear that $\psi = \varphi'$ is unreasonable, especially with indefinitely large shear strains.

It is not uncommon that expansion due to dilation is much greater than that due to elastic volumetric recovery. Thus the "h^2/c_v" formula is not applicable when there is significant plastic dilation.

Figure 20 shows a comparison between computed ground movements beneath the excavation for two SSS analyses with (a) $\psi = 0$ and (b) $\psi = \varphi'$, using permeability profile A from Figure 16. It can be seen that with dilation the heave of the surface is much larger. However, the displacement of the wall is similar in the two analyses. In fact, in all correct analyses using permeability profile A, for the cross section analysed

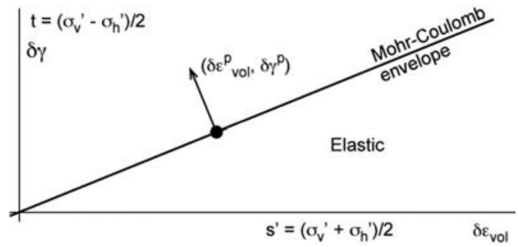

Figure 19. The Mohr-Coulomb envelope as a plastic potential.

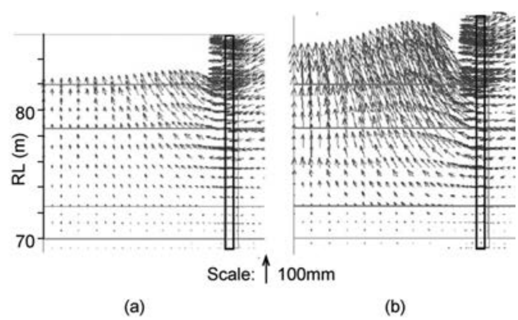

Figure 20. Ground displacements at final excavation for SSS (a) $\psi = 0$, (b) $\psi = \varphi'$.

dilation has very little effect on wall displacements and bending moments.

The situation is different for the lower permeability represented by profile B in Figure 16, however. Figure 21 shows computed water pressures for SSS, and two CCA analyses with $\psi = 0$ and $\psi = \varphi'$, both assuming 60 days for each stage of excavation. In this case, the water pressures for the SSS case and the CCA with $\psi = 0$ are similar, and the computed bending moments also agree very closely. However, the CCA with $\psi = \varphi'$ shows differing water pressures as they take longer to reach a steady state because the expanding ground absorbs more of the inflowing water. The computed bending moments for the SSS and CCA case with no dilation are 40% bigger than for profile A, while the bending moment for CCA with full dilation is much reduced, being less than for profile A.

In summary, the change from $\psi = 0$ to $\psi = \varphi'$ has little effect on bending moment for permeability profile A of Figure 16, but a big effect for CCA analyses with permeability profile B. Likewise, changing permeability profile from A to B causes an increase in bending moments for SSS or CCA with $\psi = 0$, but a decrease in bending moments for CCA with $\psi = \varphi'$. It is clear that the effects of these parameter changes are not additive: an assumption of superposition was shown to be highly misleading.

4.6 *A bug in CRISP*

During this work it was noted that contours of water pressure near the wall plotted by CRISP had the appearance shown in Figure 22. These imply very high

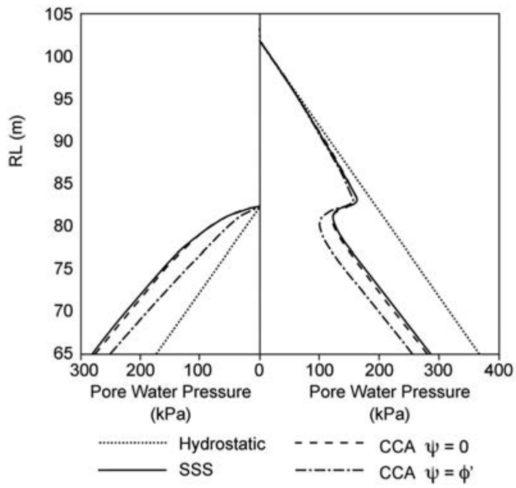

Figure 21. Computed water pressures for permeability profile B.

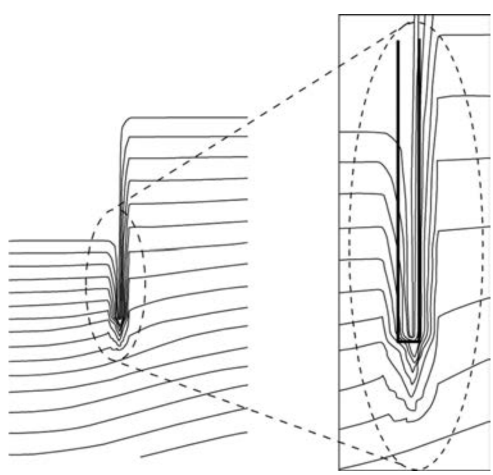

Figure 22. Impossible pore pressure contours from CRISP.

horizontal hydraulic gradients towards and away from the wall, both in the section above excavation of very low permeability and that below excavation of high permeability.

This situation is physically impossible and it transpired that it was caused by a bug in CRISP. It had the significant effect of reducing pore pressures in the layer adjacent to the wall and so increasing the available wall friction. The importance of inspecting computer output and questioning whether it is physically reasonable, is again emphasised, particularly in relation to water pressures.

4.7 *Teaching points*

Important points to note from this example are:

- When possible, simple calculations should be usued to check FE results. The h^2/c_v formula is frequently valuable.
- Users should inspect displacements, stresses and water pressures at all stages to understand the overall behaviour portrayed by an FE analysis, check for data errors and question whether the results are physically reasonable. Only then can the critical results, such as displacements and bending moments, be accepted.
- Dilation is a critically important parameter and must be understood by users of FE analysis.
- The effects of changing various parameters may not be additive in a simple way. Superposition should only be adopted when it is clear that the system is linear – often not the case in geotechnical engineering.

5 CONCLUDING REMARKS

On the basis of the examples considered, specific teaching points have been noted at the ends of the previous sections. The overarching points are:

- Engineers using computer analysis must not allow their thinking to be limited by available computer programs. They must ensure that all possible failure modes have been eliminated.
- Engineers must inspect computer results thoroughly, expecting to see them conforming to the basic principles of mechanics.
- Engineers who use FE analysis must have a sufficient grasp of soil behaviour, including dilation, to judge whether a particular model is adequate for their purposes.
- Engineers should be aware of the limiting strains of materials, as well as the strength limits.

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What topics should be taught in geo-engineering courses?

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Key skill sets for use in geotechnics – a contractor's view

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ABSTRACT: With pressure on student places at both first and second degree level, increased course costs and an industry desire to employ geo-engineering professionals who can 'hit the ground running', there has never been a greater need to ensure that the content of academic courses matches the needs of industry. Whilst working for a contractor was at one time seen as the stepping stone to consultancy, insofar as contracting afforded plenty of opportunity for hands on experience, the last two decades have seen the majority of students opting for immediate employment with consultancies. This has left a whole generation of geo-professionals with a varied, but in many cases incomplete, skills set and the effects have been felt throughout the geotechnical community within the UK. The reasons for this situation are complex, but largely result in a lack of communication between key individuals in industry and their counterparts within academia. There has also been a desire by many second degree (MSc) courses to cover as much of the geotechnical spectrum as possible, which has perhaps left some of the essential key fundamentals either not taught or at best not covered in sufficient detail. This paper provides a contractors view on what the key geotechnical elements are that will be needed by any graduate pursuing a career in geotechnics.

1 INTRODUCTION

There has been much debate and discussion over the past decade concerning the role of higher education (BSc and MSc) courses in relation to producing young geo-engineering professionals that have the right knowledge and skill sets for employment in the UK geotechnical industry.

This debate has often been polarised with the higher education institutions (HEI) presenting their views and often lamenting the lack of input and support from industry, whilst on the other hand industry has complained about the quality of both first degree (BSc) and second degree (MSc) students.

The ongoing debate between industry and academia has taken place against the back drop of reducing numbers of first and second degree courses. In particular the number of MSc courses in engineering geology or geotechnics has reduced from 10 courses to the current total of 6 over a five year period. Clearly all is not well!

Whilst providing a geotechnical contractor's view of the geo-engineering debate in the UK, this paper aims to provide a discussion piece with the hope of shaking the geo-engineering educational tree. What falls out of the tree needs to inform the link between industry and HEI's for the next decade and beyond.

2 HISTORICAL PERSPECTIVE

From the 1950's onwards the training (and also, by Inference, the learning) route for many graduate geo-engineering professionals was to obtain a first degree in engineering or earth sciences (geology) together with an MSc and then join a site investigation company. The MSc that they obtained was generally either in Soil Mechanics or Engineering Geology.

There were benefits and drawbacks to graduates joining site investigation companies direct from the world of higher education. On the positive side they were exposed to a large range of site investigation techniques and were required to make decisions on their own. Their exposure to the 'sharp end' of geotechnics generally resulted in them having a good appreciation of the ground and they had a firsthand understanding of how both soil and rock behaved in engineering terms.

The drawbacks to this type of employment were however that they were thrown in at the deep end and it was a case of sink or swim. There was often little structured mentoring and many young professionals tended to learn by their mistakes!

This introduction to the science of geotechnics did however tend to knock the rough edges of graduates and helped them to become relatively proficient within a short space of time. They gained confidence in dealing with the challenges thrown up by variable ground conditions and for many this knowledge was transferred to consultancies, which was often the preferred career move/progression after two to three years with a contractor.

In the late 1980's an increasing number of 'conventional' civil engineering consultancy firms, decided to develop their own geotechnical sections. This involved the employment of graduates who were badged as

Table 1. Main drivers for HEI's.

	Key Aspect	Main Points
External Drivers	Leitch Report (2006)	A skilled workforce was required at all levels. Shared responsibility for education: employers and government. Employers should contribute most to training that gives benefit.
	Browne Report (2010)	Cap on fees at £15000 per year, (government set this at £9000).
	Science, Technology, Engineering & Maths (STEM 2004–2014)	Identified skill shortages in Engineering. Noted that trends indicate future potential problems in engineering.
	Higher Education Funding Council for England 2012	Mainly undergraduate focussed, little on MSc courses. Limited discussion on Strategically Important Vulnerable subjects like engineering.
Internal Drivers	Employment skills	Greater emphasis on employability and transferable skills within courses at undergraduate and postgraduate level.
	Industry Support	More vocational courses supported by industry. New degree courses must show evidence of support from industry.
	Four year degree courses	MSci, MGeol and MEng etc seen as high risk. Little enthusiasm for new 4yr courses and some are closing.
	Funding post 2012	No plans to close 2012 MSc courses if recruitment remains positive. Significant rise in postgraduate tuition fees from 2012 onwards. Beyond 2013 future for courses is uncertain.
	Research Income	Universities moving toward greater research focus for staff Drive to increase research income and PhD recruitment.
Challenges	Support	Limited support from industry so far. Typically confined to prizes, site visit and student project involvement.
	Fee Rise	Well publicised rise in 2012 due to less central funding.
	Pay at Door	Students have to pay for Postgraduate courses on arrival. No government loans available for MSc courses.
	Recruitment	Recruitment beyond 2012 may be difficult due to new fee regime.
	2012	Problems will be felt in 2012 when fees increase.
	Research	Increased focus on research and PhD students (Research Excellence Framework (REF) 2013 onwards), rather than on MSc courses.

geotechnical experts even though many were civil engineers with no or very little formal geotechnical training. It is true that with time these constancies built up more expertise and by the mid 1990's were employing graduates with an MSc in a geotechnical related discipline.

For the last 15 years this has become the desired route for most UK graduates studying for an MSc in geo-engineering and now very few seek employment with site investigation companies, instead opting for the perceived 'glamour' of the consultancy world. The author would contend that this has been to the detriment of the industry as a whole.

3 DRIVERS FOR HEI AND INDUSTRY

It is worth considering both the drivers that HEI's believe shape the nature of geo-engineering courses and those that affect industry. The following table is a summary of a recent meeting held at the AGS (Association of Geotechnical Specialists) between university and industry representatives.

What stands out from the above table is the conflict that HEI's face in regard to balancing the types of courses offered, course funding and the need to attract research funding. This volatile mixture is tending to stifle any attempt at extending four year undergraduate courses and is even causing some second degree (MSc) courses to be closed.

On the other side of the equation, we have the needs and requirements of industry that are both potential recipients of graduates as well as a source of funding for HEI degree courses. The following table summarises the main drivers for industry.

For industry the above table illustrates that some of the internal and external drivers are interlinked and that the biggest challenge lies in the uncertainty of workload in the geo-engineering market place.

4 THE 'ROUNDED' GRADUATE EMPLOYEE

Regardless of a graduates initial type of employment (site investigation contractor, consultant or main building contractor) there are a number of key skills or attributes that prospective employers will wish to see. These skills form the basis of everything that is undertaken under the broad heading of geo-engineering and form the building blocks for more detailed design work which many graduate employees will become involved with as their career progresses.

Table 2. Main drivers for Industry.

	Key Aspect	Main Points
External Drivers	Client Requirements	Clients build relationships with employees who have specialisms. Expectations from clients that employees will be available.
	Company capability	Many companies operate in specialised areas that need specific graduates.
	Stakeholders	Shareholders and/or being part of a larger group can dictate areas of operation and hence types of employee needed.
	Global factors	New factors such as sustainability have to be accommodated in short space of time.
Internal Drivers	Work load & type of work	Bidding for certain types of work require employees with different skill sets.
	Basic skill requirements	All employees expected to have a basic level of understanding of geo-engineering fundamentals.
	Internal training	Larger consultancies and most contractors have in house training schemes that allow transition from university to industry.
	Market place position	Size and type of company often dictates what type of internal training is available and hence what type of graduate is employed.
	Geographic area of work	National regional and international company offices can employ different specialism's to suit the market.
Challenges	Economy	UK economy has suffered peaks and troughs for many years
	Training	Only companies of a certain size can afford internal training and have to rely on the 'finished produce' coming from university
	Competition	Increased number of smaller companies some employing overseas graduates, with low cost base
	Employee loyalty	Within last 10 years it has become common to keep moving job which has made companies reluctant to invest in employees.
	Image of geo-engineering	Geo-engineers have always been held in low regard even within an engineering industry in which engineers are not valued.
	Remuneration	Compared to mainland Europe, salary levels of geo-engineering employees remains low.

The basic key skills that the author believes every graduate employee should have are noted in Table 3. It could be argued that there are other key skills, but it is likely that in fact they will be subsets of those listed. Equally there will be those who will rightly perceive the ability to design as a key skill, but this can only successfully take place once the Basic Key Skills are in place.

The author contends that only once a graduate has understood the six key skills or building blocks of geo-engineering can they progress to the next stage of their development.

This next stage is course design work and involves using the key skills to generate design parameters.

All too often graduate employees find themselves in the position of having to undertake design work without understanding how different types of soil or rock will behave or how for instance different laboratory tests may be needed to derive design values for different material types.

Many graduate employees are really at home manipulating data in complicated design packages and yet they don't have a feel for whether the data they are inputting is likely to be meaningful and representative of the soil or rock in question. This is often because they haven't been taught how to start at first principles and get a proper feel for how material is likely to behave at both the material and mass scales.

This should not be construed as the employees fault, but rather a failing of the current system. In the limited time available on degree courses there is an overarching desire to ensure that the most difficult subject matter is covered since it is perceived quite rightly that this will not be 'taught' by industry.

5 HEI DEGREE COURSE STRUCTURE

So far this paper has looked at the drivers for both HEI's and industry, together with a proposal as to what essential key skills graduate employees should possess. The question then becomes what type of degree course(s) does industry want to see?

Currently a company employing a graduate in geosciences will typically get someone who has little mathematical/engineering skills, but who will have a complete grounding in looking at rocks and, to a lesser extent, soils. They are also likely to be good at visiting sites looking at the ground and identifying issues relating to the ground.

Conversely by employing a graduate with an engineering background, they will have an employee with all the right engineering tools to analyse data, but lacking in the knowledge of what soil and rock is and how it impacts on design.

In either case, for such graduates to be of use to a company specialising in geotechnics, considerable internal training would be required and even then some aspects of soil and rock mechanics would be lost on such employees.

Table 3. Key Skills as building blocks to development.

Basic Key Skill	Knowledge Needed	
SITE WALKOVER AND APPRAISAL	Identifying hazards and surface conditions First indication of likely ground conditions Observational Approach	PROGRESSION TO
GROUND INVESTIGATION DESIGN	Equipment and Sampling In situ Testing Match to required design parameters	
DESCRIPTION OF SOIL AND ROCK	Samples as well as on site exposures Engineering not geological behaviour Understanding mass and material scales	
LABORATORY TESTING	Scheduling of tests Sample types in relation to test types Interpretation of test results	
GEOTECHNCIAL PARAMETERS	Obtaining material data sets from all available data Deriving characteristic values Distinguishing unrepresentative values	
CONSTRUCTION SITE EXPOSURE	Look at ground works in situ Problem solving on site (design change) Foundation construction issues	
PROJECT DESIGN	Shallow and deep foundation design Retaining structures (including dams) Slope stability Tunnelling Application of finite element analysis Sustainability	

Traditionally this is where an MSc in engineering geology, soil mechanics or other related geo-engineering subject has stepped in to bridge the gap. As noted previously, however, even these courses haven't traditionally provided all the key skills needed by graduates when they enter employment.

Whilst perhaps going against the trend and funding opportunities for HEI's, the extended use of 4 year first degree courses could be considered, with the fourth year being optional for those graduates wanting to go on to specialise in the field of geo-engineering. This would however require students taking a traditional BEng degree to be afforded the opportunity to go on and take a fourth year specialising in earth science and similarly for students taking a BSc in earth sciences to have the opportunity to go on and take a fourth year specialising in design work with a civil engineering bias. The fourth year specialism could, however, be used to teach the key skills identified in table 3. Traditional MSc courses could then concentrate on the more technical aspects of design that many students will need in employment.

Alternatively the third year of such four year degree courses could be a year in industry, with the company in question filling in some of the key skill sets. This year in industry should be seen as a 'hands on' experience for the graduate during which time they are afforded the opportunity to see how geo-engineering is made to work on site.

Another option would be to run more courses aimed specifically at geo-engineering from the outset so that graduates spend 3 or perhaps 4 years on an engineering geology degree course leading to a BSc or MSci qualification. This would however require students to know more about geo-sciences at sixth form level prior to making their HEI selection.

6 INDUSTRY INPUT

It is clear that industry cannot afford to be a mere bystander in this debate and must get involved in helping HEI's to design degree courses that will meet their needs. It is not enough, however, for industry to demand degree courses to suit their requirements without giving anything in exchange. Gone are the days when industry can expect the giving of cash prizes, assistance with student projects and access to construction sites to be sufficient in contributing to the development of young geo-engineering professionals. Like it or not industry is going to have come up with both funding and more help from senior employees.

Realistically individual companies in the geo-engineering sector are not suddenly going to develop all-encompassing internal employee training schemes that will cover any shortfall in the content of degree courses and what is required by the employer. It will continue to fall to HEI's to provide the bulk of teaching for prospective employees.

Tangible help for industry could however come in one of several ways; some of these are listed below:

- Sponsorship of student through first/second degree
- Part sponsorship through year in industry type degree
- Offer of visiting lecturer personnel

Sponsorship of a student in any form would have to come with some strings attached. Most attractive to industry would be a guarantee that the graduate would be employed by the funding company for say a minimum of two years following graduation. If such degrees could also incorporate a year in industry with the sponsoring company, it is likely that any of the 'missing' key skills could be learnt by the graduate during their period in industry.

7 THE 'GRADUATE CONTRACT'

Whilst it is recognised that graduates will not wish to become tied to a single employer for a long period of time, industry will only make a significant financial contribution to a prospective employee if they can see something tangible in return. The author suggests that perhaps it is time for 'apprentice' type contracts to be considered by both graduates and industry alike. These contracts would tie the graduate to a specific company for a set period of time during which they would receive degree funding (either partial or full), followed by employment and further training by the company. At the end of the 'apprenticeship' period the graduate employee would have an obligation to remain in employment with the sponsoring company for a set length of time.

In return for offering such 'graduate contracts', industry could reasonably be expected to ask for more input to course content and structure, although it is recognised that an independent arbitrator would be required to ensure that a proper balance between education and industry was maintained.

Such a contract would benefit the HEI at which the student was studying, would benefit the student insofar as both funding and employment would be guaranteed and finally would help the sponsoring company to recruit geo-engineering employees with the right skill sets.

8 STUDENT MIGRATION EFFECTS

The comments presented in this opinion piece reflect both the author's experience of working in the UK as well as the current situation with HEI's. It is acknowledged, however, that the situation experienced in the UK may be part of a wider global phenomenon.

The situation with migration of students also needs to be recognised since this has had a marked effect on the overall numbers of participants on UK MSc degree courses. Over the 5 year period up to 2011, European Union and other overseas students accounted for approximately 30% of total MSc course numbers. Because of the enhanced levels of funding that such overseas students bring with them, this has undoubtedly helped to keep some courses open. In many cases however, course directors report that the overseas students often return to their home countries after graduation. Although this will undoubtedly benefit their country of origin, it does nothing to help the industry in the UK.

Many UK companies would welcome applications from overseas candidates who hold a good relevant MSc in geotechnics. Sadly and despite the fact the government recognizes geotechnics as a profession on its occupational skills shortage list, insufficient applicants are finding their way into industry.

All of this returns us to the starting point that says we need to put our own house in order here in the UK. Yes we need to continue to attract overseas students because of the diversity and different perspectives they bring, but we need to ensure that we have home grown geo-engineering graduates as well.

9 CONCLUSIONS

The geo-engineering market place (both HEI's and industry) has been subject to severe adverse economic factors over the past couple of years. These adverse factors are not likely to improve in the short term and arguably with the advent of higher course chargers by HEI's, may well get worse.

The debate over geo-engineering course content for degree subjects offered by HEI's that has raged for the last decade is undoubtedly coming to a head. The author would contend, however, that this is not a bad thing, but rather should provide the catalyst for everyone with a stake in geo-engineering to collaborate in finding sustainable solutions for the next decade and beyond.

More constructive meetings between HEI's and industry such as that organised by the AGS in October 2011 need to be planned with a structured content such that positive sets of proposals are produced. These meetings must aim to produce answers to the following key questions:

- What type and duration of degree courses do we want?
- Do such courses exist at present?
- Are degrees with industry placement the way forward?
- How many student places will industry fund?
- How many lecturers from industry can degree courses accommodate?

It is likely that further modification of both first degree and second degree course content will be needed, but this may only amount to minor tweaking.

The geo-engineering community (industry and HEI's) need to find a way that will ensure that all geo-engineering graduates can hit the ground running when they enter employment and will not end up after 5 or 10 years in employment, still unable to expound the key skills that underpin the industry.

If this means giving the geo-engineering tree of learning a good shake then so be it, there has never been a better or more pressing time to do so. However we must be prepared to catch the resulting fallout, sift it and keep best practice as the basis for the way forward.

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Will this be on the final exam? Learning objectives for an introductory geotechnical engineering course

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ABSTRACT: The paper describes a set of learning objectives incorporated into an introductory geotechnical engineering course. The objectives were developed using Bloom's Taxonomy and define what the students should know and be able to do upon completion of the course. Each objective begins with an action-oriented verb corresponding to one of six "levels of achievement" in the cognitive domain (i.e. knowledge, comprehension, application, analysis, evaluation, and synthesis). The paper includes a listing of objectives articulated for eight different learning modules. The paper also summarizes how the learning objectives were linked to lesson plans and assignments. Formative and summative assessments are used during the course to evaluate the achievement of student learning. Example assessment methods and results are presented in the paper along with the results of teaching evaluations, which indicate that students value this approach to course design and organization.

1 INTRODUCTION

Course outcomes, or learning objectives, define what the students should know and be able to do upon completion of a particular course topic or learning module. Articulating learning objectives upfront, as an initial step in the design of a course, can help an instructor focus on student learning as he/she develops lesson plans, decides on textbook readings, and prepares written assignments (Wankat & Oreovicz 1993). Sharing learning objectives with students helps to ensure that the class and instructor are on the same page relative to important topics. Further, educational research has shown that students are likely to learn more and better meet course expectations if they are introduced to learning objectives as part of a course outline or formal lesson (Stice 1976, Lowman 1995).

Learning objectives are commonly developed using Bloom's Taxonomy of Educational Objectives (Bloom 1956). In this case, each objective begins with a measurable, action-oriented verb corresponding to one of six "levels of achievement" in the cognitive domain (i.e. knowledge, comprehension, application, analysis, evaluation, and synthesis). Example action verbs are listed in Table 1 for each of the six achievement levels. These verbs can readily be observed and measured if incorporated into an assessment plan. In contrast, verbs such as "understand", "know", and "appreciate" are difficult to measure and should be avoided in the development of learning objectives.

Welch et al. (2005) note that, ideally, the synthesis and evaluation levels should be addressed in every course as a means of developing students' higher-order thinking skills. However, these authors also note that students must work their way up through the lower achievement levels if they are to successfully exhibit cognitive development at the upper levels.

Table 1. Action Verbs for Learning Objectives.

Achievement level	Example verbs
(1) Knowledge	define; describe; identify; list; name
(2) Comprehension	arrange; explain; paraphrase; summarize
(3) Apply	calculate; determine; implement; solve
(4) Analyze	compare; classify; organize; prioritize
(5) Synthesize	create; design; devise; construct; integrate
(6) Evaluate	appraise; critique, defend; judge; justify

The following paper articulates learning objectives for an introductory junior-level geotechnical engineering course. These learning objectives were developed using Bloom's Taxonomy. Background information is provided for the course (i.e. format, schedule, enrollment, course design, etc.). Then, learning objectives are presented for specific course learning modules. The basis for the selection of these objectives is briefly discussed.

Formative and summative assessments are used during the course to evaluate the achievement of the learning objectives. Example assessment methods and results are discussed in the paper. Also discussed are the results of recent teaching evaluations, which show that the students value this approach to course design and organization.

2 BACKGROUND

2.1 *Program, format, and enrollment*

The subject introductory geotechnical engineering course is offered at California Polytechnic State University, San Luis Obispo (Cal Poly) within the Civil Engineering Program. The course is taught at the 300-level, meaning enrollment consists primarily of junior-level (i.e. third-year) students. The academic year at Cal Poly is divided into four quarters, each eleven weeks long. Course instruction takes place over a ten week period; examinations are administered during the eleventh week of the term. The subject course is a 4-unit lecture course, which means it meets in a classroom for four hours each week. Typically, the university adopts a two day schedule for 4-unit course offerings, meaning the course meets for two hours each day following a Monday-Wednesday or Tuesday-Thursday calendar.

The geotechnical engineering course is included in the required Bachelor of Science degree curricula for both the civil and environmental engineering majors offered at the university. The course is currently taught five times each year with an average of 35 students enrolled in each section. The maximum enrollment within a section is forty students, and the ratio of civil to environmental engineering students within a typical course offering is four to one. It is noted that the civil engineering majors are required to enroll concurrently in a 3-hour geotechnical engineering laboratory course that meets once per week during the term. Experiments performed during this laboratory (typically six to eight in total) serve to complement the material covered in the subject "lecture" course. The separate laboratory course is not a focus of this paper.

2.2 *Course design*

The author has divided the geotechnical course into ten primary topics or "learning modules," which are listed in Table 2. The civil engineering faculty members at Cal Poly last reviewed the essential content of this course about five years ago and presented their findings in the form of a common syllabus. Essential course content is reflected in the topics listed in Table 2. A follow-on undergraduate elective course is available for students interested in learning more about geotechnical engineering and foundation design. Topics addressed under this course include bearing capacity theory, consolidation theory, settlement computation, shallow foundation design (geotechnical and structural aspects), and tools for field investigations. Separating these topics from an introductory geotechnical engineering course is uncommon. However, the civil engineering faculty members felt the time constraints of the quarter system at Cal Poly necessitated the development of two courses instead of one. It is noted that approximately 120 civil engineering students enroll in the follow-on elective course each year, which represents about 75 percent of the senior class.

Table 2. Primary Course Topics or "Learning Modules".

Topic #	Title
1	Introduction to Geotechnical Engineering
2	Terminology, Definitions, and Phase Relations
3	Geotechnical Site Characterization
4	Index Properties and Classification Tests
5	Soil Classification
6	Geostatic Stress Calculations and Earth Pressures
7	Earth Moving and Soil Compaction
8	Hydraulic Conductivity and Darcy's Law
9	Two-Dimensional Flow and Flow Nets
10	Soil Stiffness and Strength

The author presents terminology, definitions, concepts, theories, problem solving techniques, and other information related to the topics in Table 2 using in-class lessons, supplemental notes, and textbook readings. The in-class lessons involve considerable work on the chalkboard (or whiteboard) and include frequent student questioning (Estes et al. 2004). The supplemental notes include learning objectives, additional details on important concepts, problem solving tips, and examples prepared by the author. The students download these notes for free from the course website prior to the beginning of the term. These notes and the in-class lessons are supported with textbook readings assigned throughout the term. The author is currently using the textbook by Holtz et al. (2011) for this course.

Formal assignments for the course include homework, quizzes, and examinations. Separate homework assignments containing 10 to 15 problems each have been developed for the learning modules presented in Table 2; however, these assignments are not typically collected or graded. Rather, student performance is evaluated using daily quizzes and two examinations (a midterm and a final). During the last offering of the course, the grading breakdown was as follows: quizzes (40 percent); midterm (30 percent); and final (30 percent). A total of 19 quizzes were administered during the term.

The author prefers the use of daily quizzes for this course because: (1) students are encouraged to keep up with the course schedule, learning modules, and homework assignments; (2) the quiz problems provide additional practice opportunities for the students, which improves student learning and retention (Angelo, T.A. 1993); and (3) class performance on the quizzes allows the author to regularly assess student learning. In addition to daily quizzes, the author uses student questioning, in-class exercises, and informal classroom assessment techniques (Angelo & Cross 1993) as formative assessment tools.

3 LEARNING OBJECTIVES

In developing the course learning objectives, the author first identified essential knowledge and skills

Table 3. Learning Objectives: Terminology, Definitions, and Phase Relations.

Verb	Objective (# of Achievement Level)
Define…	important volume ratios, mass ratios, and densities. (1)
Prepare…	a properly formatted phase diagram for a given soil sample. (3)
Calculate…	void ratio, degree of saturation, water content, density, and unit weight from a given set of soil sample data. (3)
Describe…	how a Standard Penetration Test is performed and how an SPT N-value is determined. (2)
Interpret…	the data presented on a typical drill hole (i.e. boring) log. (2)

Table 4. Learning Objectives: Index Properties and Classification Tests.

Verb	Objective (# of Achievement Level)
Reduce…	sieve analysis tests data and plot a grain size distribution curve. (3)
Analyze…	a grain size distribution curve to determine the percent gravel, sand, and fines, important grain diameters, the coefficients C_u and C_c, and gradation. (4)
Explain…	why a hydrometer test may be performed on a soil sample. (2)
Summarize…	how the liquid limit, plastic limit, and plasticity index are found for a soil. (2)
Classify…	a fine-grained soil using Atterberg limits test data and the Casagrande Plasticity Chart. (3)
Evaluate…	the consistency of a soil. (4)
Explain…	how different index properties (e.g. gradation, particle shape, plasticity index, etc.) influence the engineering properties of soils. (2)

Table 5. Learning Objectives: Soil Classification.

Verb	Objective (# of Achievement Level)
Evaluate…	sieve analysis and Atterberg limits test results for the purpose of soil classification. (4)
Classify…	a soil according to the Unified Soil Classification System (USCS), which is summarized under ASTM D2487, by providing a group symbol and group name. (3)
Predict…	the engineering behavior of soils (relative to compressibility, strength, and hydraulic characteristics) based on classification results. (5)
Explain…	how the structure and fabric of fine-grained soil differs from that of coarse-grained or granular soil. (2)

for each of the course topics listed in Table 2. As part of this process, the author examined the common syllabus for the course (developed by the Civil Engineering Program), solicited input from faculty colleagues, reviewed "fair-game" topics defined for the geotechnical component of the Principles and Practice Professional Engineering (PE) Examination in Civil Engineering, and reflected on past experiences as a consultant and researcher in the profession. Draft lists of objectives were pared down to identify five to seven essential objectives for each course topic. These learning objectives are listed at the beginning of each learning module included in the supplemental notes, which are made available to the students at the beginning of the term. The instructor regularly refers to the learning objectives throughout the course to orient the students to the course material and review important concepts.

Essential (and rather broad) learning objectives have always been in place for the introductory geotechnical engineering course, having been developed by the geotechnical faculty members as part of past course development and program accreditation efforts. However, it was only more recently (about four to five years ago) that the author began linking more specific learning objectives to Bloom's Taxonomy and introducing these objectives directly into the course learning modules.

Table 3 lists the learning objectives defined for the learning module on "Terminology, Definitions, and Phase Relations." The action verb is identified for each objective along with an estimate of the level of achievement in the cognitive domain. The author established a goal of identifying an achievement level of at least 3, or "application," for each of the learning modules. This goal was considered appropriate, given the fact the junior-level geotechnical engineering course is introductory and more analysis-focused. This goal is reflected in the objectives shown in Table 3.

Tables 4, 5, and 6 present learning objectives for the learning modules titled "Index Properties and Classification Tests," "Soil Classification," and "Geostatic Stress Calculations and Earth Pressures," respectively. Achievement levels for the learning objectives presented in these tables vary between 2 and 5. Achievement level 5, or "synthesis," is noted for a learning objective in Table 5, which stipulates that students should be able to "predict the engineering behavior of soils based on classification results." Relative to this objective, students can be asked to review and reduce actual laboratory test results (with data outliers) and observations regarding a soil's index properties, classify the soil according to a given set of criteria, and relate this classification to different engineering properties based on an analysis of the given data and observations.

Tables 7, 8, 9, and 10 present learning objectives for the learning modules titled "Earth Moving and Soil Compaction," "Hydraulic Conductivity and Darcy's Law," "Two Dimensional Flow and Flow Nets," and "Soil Stiffness and Strength," respectively. Achievement levels for the objectives presented in these tables

Table 6. Learning Objectives: Geostatic Stress Calculations and Earth Pressures.

Verb	Objective (# of Achievement Level)
Explain…	the concept of effective stress. (2)
Calculate…	total vertical stress, pore-water pressure, and effective vertical stress at a point with in a soil mass. (3)
Summarize…	the different lateral earth pressure coefficients used in geostatic stress analyses. (2)
Calculate…	and assign the proper lateral earth pressure coefficient, depending upon the design situation. (4)
Calculate…	total horizontal stress, pore-water pressure, and effective horizontal stress at a point within a soil mass. (3)
Estimate…	the total lateral force on a cantilever retaining wall and locate its line of action. (4)

Table 7. Learning Objectives: Earth Moving and Soil Compaction.

Verb	Objective (# of Achievement Level)
Explain…	how Standard and Modified Proctor compaction tests are performed and define the term compactive effort. (2)
Construct…	a compaction curve and evaluate the maximum dry density (or unit weight), the optimum water content, and the zero-air-voids (ZAV) curve. (4)
Describe…	how compactive effort and molding water content affect a soil's maximum dry density, optimum water content, and engineering properties (i.e. soil strength, compressibility, and hydraulic characteristics). (2)
Summarize…	the process of compacting a soil in the field along with the different types of surface compaction techniques and equipment that are available in practice. (2)
Describe…	the typical quality control procedure used to monitor soil compaction during earth moving and grading projects. (2)
Interpret…	the results of a sand cone and nuclear density gauge field density tests. (4)

vary between 1 and 5. Achievement level 5, or "synthesis," is noted for a learning objective in Table 10, which stipulates that students should be able to "conduct a stability evaluation." Relative to this objective, students can be asked to define a geotechnical stability problem and any applied external forces, postulate a failure mechanism and develop a free-body diagram, characterize the properties of the soil and the available shear strength from available laboratory test results, determine applied shear stresses, compare applied shear stresses to available shear strength

Table 8. Learning Objectives: Hydraulic Conductivity and Darcy's Law.

Verb	Objective (# of Achievement Level)
Explain…	how hydraulic conductivity (k) is evaluated in the laboratory using constant head and falling head tests. (2)
Summarize…	typical hydraulic conductivity values and the parameters that influence hydraulic conductivity for a soil. (2)
Calculate…	total head, pressure head, elevation head, pore-water pressure, hydraulic gradient, flow rate, and seepage velocity for 1-D flow systems. (3)
Explain…	the phenomenon of soil liquefaction. (2)

Table 9. Learning Objectives: Two-Dimensional Flow and Flow Nets.

Verb	Objective (# of Achievement Level)
Define…	the terms "flow line" and "equipotential." (1)
Construct…	a flow net for a two-dimensional geotechnical cross-section assuming isotropic and homogeneous soil conditions. (3)
Interpret…	a flow net to estimate volume flow rate, exit gradient, factor of safety against a quick condition, pressure head, and uplift. (4)

Table 10. Learning Objectives: Soil Stiffness and Strength.

Verb	Objective (# of Achievement Level)
Define…	friction angle, cohesion, and the shear strength equation for soils. (1)
Explain…	the different factors that influence the frictional strength of a soil (i.e. friction angle, ϕ) and the cohesive strength of a soil (i.e. cohesion, c). (2)
Describe…	how direct shear and triaxial shear laboratory tests are performed. (2)
Reduce…	direct shear and triaxial shear laboratory test data and results to estimate friction angle and cohesion for a soil. (3)
Determine…	interface shear strength between a soil and a construction material. (4)
Evaluate…	settlement for a deposit of sand subject to a uniform surface loading. (4)
Conduct…	a stability evaluation for a geotechnical problem to estimate shear strength and factor of safety with respect to potential failure. (5)

(to characterize safety level), and formulate alternative solutions in cases where an adequate safety level is not realized.

Table 11 summarizes the breakdown of different achievement levels for the previously presented learning objectives. A total of 42 specific learning

Table 11. Tally of Objectives and Achievement Levels.

Achievement level	Number of objectives	Percentage of total
(1) Knowledge	3	7%
(2) Comprehension	17	40%
(3) Apply	10	24%
(4) Analyze	10	24%
(5) Synthesize	2	5%
(6) Evaluate	0	0%

objectives are addressed during the course. As evident, most of the learning objectives relate to the lower and intermediate achievements levels (i.e. comprehension through analysis), which is common for an introductory course such as this. Two learning objectives focused at the synthesis level were incorporated into the course in an effort to help develop the students' higher-order thinking skills.

4 ASSESSMENT

4.1 *Formative approaches*

The author uses a variety of formative assessments during the term to gauge student learning. Primary techniques include student questioning, in-class collaborative learning exercises, and quizzes. The benefits of posing questions to students in class have been discussed and reported by other researchers (Estes et al. 2004). The author develops a list of potential student questions prior to each lesson. These questions relate directly to the learning objectives summarized in Tables 3 through 10.

Regular (daily) quizzes represent the primary formative assessment tool used by the author to quantitatively measure student learning. These quizzes are typically administered during the final 5 to 10 minutes of a class period. The quizzes are related to specific learning objectives already addressed in class lessons and/or textbook readings. The quizzes are scored on a 5-point scale using a pre-defined grading rubric. Experience has shown that the author can typically grade a set of quizzes for a 35-person class in about 45 to 90 minutes, depending on the learning objective and achievement level addressed in the quiz problem. An example quiz question is shown in Figure 1.

Shown below is a soil profile. As indicated, the coarse sand layer is completely submerged under **x** feet of water. The sand is found to have a saturated unit weight of 120 pounds per cubic foot (pcf). What depth of water **x** (in feet) will lead to a pore-water pressure of 1,092 pounds per square foot (psf) at a depth of 11 feet below the surface of the coarse sand?

The quizzes are purposely designed to be short so that: (1) a limited amount of class time is used; (2) the problems are relatively easy to grade; and (3) the author can quickly turnaround feedback to the students. Prompt grading allows the students to evaluate their own progress relative to different objectives.

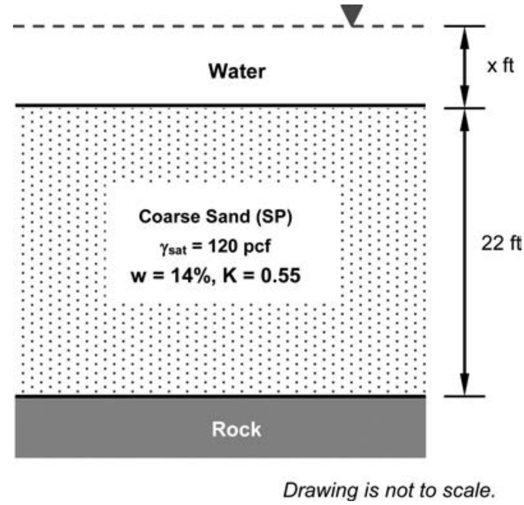

Figure 1. A typical quiz problem for the second learning objective presented in Table 6.

A quick turnaround of the assessment results also helps the author to measure the pulse of the class relative to individual learning objectives. A poor quiz grade for the class may indicate that the author needs to slow down and provide additional review for a particular subject. In addition, progress can be tracked for individual students, thus alerting the author early-on to individuals who possibly require some form of intervention (e.g. an encouraging e-mail, an office hour meeting, more detailed written feedback on a quiz, etc.). Overall, the author has found the daily quizzes to be extremely valuable tools as they provide "real-time" data on student learning relative to the objectives presented in Tables 3 through 10.

4.2 *Summative approaches*

The midterm and final examinations constitute the primary summative assessment approaches used by the author to evaluate student learning. The author currently maintains a modest database of questions that can be included on these examinations. The questions include multiple-choice, short answer, fill-in-the-blank, and true-false prompts and are written to address both concepts and problem solving.

For a typical examination, a student will have approximately 2 hours to complete 25 to 30 questions. Before the examination, as part of a short 5- to 10-minute review session embedded within a scheduled lesson plan, the author identifies which learning objectives are considered fair-game. The author then develops the examination with the goal of evenly distributing the questions among the specified learning modules and objectives. After grading, the students receive their examination scores only. Graded exams are not returned to the students, though a student may review his or her examination and ask questions during instructor office hours. Not returning graded midterm and final examinations has helped the author to preserve the integrity of above described database, which has limited the need to prepare and evaluate new examination problems.

Below is an example midterm examination question from the author's database. The question relates to the third learning objective presented in Table 3.

> *"A natural deposit of saturated stiff clay (CH) is found to have a total unit weight of 114.2 pounds per cubic foot. The void ratio of this soil is most nearly equal to: (a) 0.85; (b) 0.95; (c) 1.05; (d) 1.15; or (e) Cannot be estimated with the information provided."*

During the Spring Term of 2011, approximately 44 percent of the students taking the midterm examination answered the above problem correctly. Post-exam, the author noted specific student difficulties associated with this problem and implemented an improved approach to teaching this subject (and learning objective) during a subsequent offering of the course. During the Fall Term of 2011, approximately 61 percent of the students answered the question correctly, indicating at least some measure of improvement.

Below is a question taken from the exam problem database for the course final examination:

> *"A sandy clay ($\rho_s = 2.70\,Mg/m^3$) from the San Luis Obispo area was placed at a water content of 14 percent and compacted to a dry density of $1.66\,Mg/m^3$. Evaluate the in-place soil conditions. The as-compacted soil is most likely (a) dry of optimum, (b) wet of optimum, or (c) at optimum for the compactive effort actually employed in the field."*

During the Spring and Fall Terms in 2011, approximately 76 and 72 percent of the students, respectively, answered the above question correctly. The author did not change the learning objectives or his approach to teaching this subject, given the relatively strong class performance during each term. The author regularly conducts similar summative assessments to help improve both student learning and instructor effectiveness.

4.3 *Teaching evaluations*

Students at Cal Poly assess instructor effectiveness by completing a Student Opinion Form during the last week of the term, but before administration of the final examination. Three questions on this form relate directly to course design and teacher performance in the classroom. These questions are as follows: (Q1) How well prepared does the instructor seem to be in the subject matter; (Q2) Evaluate the instructor on his/her ability to convey the subject matter; and (Q3) Overall, I would rate this instructor. For each question, students are asked to mark one of the following replies: (A) Excellent; (B) Good; (C) Average; (D) Poor; or (E) Inadequate. Students also have the option to include their own comments. All student responses are kept anonymous. Responses are reported to the instructor only after final grades are posted for the course.

Table 12. Summary of Responses for Teaching Evaluations.

Term	Enrollment	Question	A	B	C	D	E
Spring 2011	25	Q1	20	0	0	0	0
		Q2	18	2	0	0	0
		Q3	17	2	0	0	0
Fall 2011	36	Q1	33	1	0	0	0
		Q2	29	5	0	0	0
		Q3	30	3	0	0	0
Fall 2011	39	Q1	32	1	0	0	0
		Q2	29	4	0	0	0
		Q3	29	4	0	0	0

The author was assessed for the introductory geotechnical engineering class three times during the past year. In each case, the Student Opinion Forms were distributed on the final day of class, after the author provided each student with a summary of their quiz score total and a brief status report on their course grade. Final examinations were administered a week later. Table 12 summarizes student responses to the three questions listed above. Note that enrollment numbers listed in the table for each class do not necessarily match the number of responses since some students did not attend the final class meeting or declined to answer a particular question.

Overall, the survey responses included in Table 12 are positive and exceed average responses reported for other full- and part-time faculty members in the Civil Engineering Program. Using a 4-point scale, cumulative average scores for the three survey questions are as follows: Q1 = 3.97, Q2 = 3.87, and Q3 = 3.89. In previous years before modifying his approach to using learning objectives, the author had typically received average survey scores ranging between approximately 3.40 and 3.60 for this course and the above defined questions.

The evidence in Table 12 points to an improvement in the author's teaching effectiveness coincident with the linking of learning objectives to Bloom's Taxonomy and the introduction of these objectives directly into the course learning modules. Informal classroom evidence leads the author to agree with this conclusion. Since incorporating more explicit learning objectives into this course, the author is generally more comfortable in front of the students and more organized in his approach to course design. The author has also seen improvement in instructor-student rapport, as expectations regarding student learning are now clearer and better defined.

Written student feedback on the Student Opinion Form corroborates the results summarized in Table 12 and the above opinions of the author. When completing their feedback surveys, students are able to provide their own written comments in response to a specific prompt on the opinion form. Below are selected student comments for the course offerings summarized in Table 12:

> *"Dr. Fiegel is one of the most organized professors I have had at Cal Poly."*
>
> *"Notes organized. Lecture easy to follow. Helpful professor, approachable."*
>
> *"Like the layout of the class…Notes and syllabus were good. Quizzes every class were annoying, but overall helped me to keep up with the material."*
>
> *"One of the best teaching styles/teacher I have ever encountered."*
>
> *"Dr. Fiegel is one of the best instructors I have had at Cal Poly. The note packet and lectures were excellent! Keep doing exactly what you are doing."*
>
> *"Very efficient use of lecture time."*
>
> *"Awesome, awesome teacher. So well organized, clearly explained every single thing we were supposed to know and had real world experience to relate things to. I wish all my teachers were as organized."*
>
> *"I really liked this class! Clear objectives, understandable lectures, and applicable homework!"*
>
> *"Very organized. Quizzes/midterm fair. Learned a lot."*

Overall, written student feedback for the geotechnical course has been overwhelmingly positive since the author began explicitly defining learning objectives. The students typically comment positively about: the high level of course organization; the fairness of the quizzes and midterm problems; and the usefulness of the supplemental note packet. All relate directly to the development and presentation of clearly defined objectives.

The author included the third comment listed above to illustrate that the course workload is sometimes a source of frustration. Each quarter, several students will bemoan the daily quiz requirement in their written instructor reviews. However, the author believes the value of daily quizzes as a formative assessment tool outweighs the potential negatives (i.e. increased instructor workload, reduced class time available for lessons, frustrated students, etc.). To help reduce student frustration, the author typically drops the bottom one or two quiz scores for each student prior to the computation of final grades.

5 CONCLUSIONS

The author highly recommends the incorporation of learning objectives into the design of any course. The learning objectives developed for the described introductory geotechnical engineering course have helped to improve course organization and more clearly define expectations regarding student learning. In addition, student learning continues to improve.

Having clear, well-defined, and measurable learning objectives simplifies the process of developing formative and summative assessment measures. The use of carefully designed formative assessment measures in this course (i.e. student questioning, in-class collaborative learning exercises, and daily quizzes) has helped the author to better track student learning and improve performance in the classroom. Student teaching evaluations and classroom observations by the author indicate that the use of learning objectives in a course can be very well received if carefully planned and addressed.

ACKNOWLEDGEMENTS

The author acknowledges the guidance and assistance provided by faculty colleague Jay S. DeNatale, who led the original design of the introductory geotechnical engineering course taught at Cal Poly. The author credits the mentors and master teachers of the American Society of Civil Engineers (ASCE) ExCEEd Teaching Workshop with helping him to improve in the areas of teaching effectiveness and course design.

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Geotechnical-structural integration in US foundation engineering curricula

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ABSTRACT: The degree of integration between the structural and geotechnical aspects of foundation engineering, as taught in US undergraduate civil engineering programs, is explored. Faculty surveys, reviews of textbooks, and reviews of curricula indicate little integration. Structural design of spread footings is frequently taught in reinforced concrete design courses, but almost completely independent of any geotechnical considerations. About half of introductory geotechnical engineering courses do not include any coverage of foundation analysis or design. Coverage of structural topics in foundation engineering texts has significantly decreased over the past 30 years. Surveys of practitioners indicate a greater emphasis on integration of geotechnical and structural aspects of foundation engineering than that perceived by faculty. The increased emphasis on Load and Resistance Factor Design in geotechnical engineering further underlines the importance of an integrated approach. Greater emphasis on this integration would produces future geotechnical engineers and structural engineers who are better equipped to optimise their foundation designs.

1 BACKGROUND

Foundation engineering is a cross-disciplinary topic that transcends geotechnical engineering, structural engineering, and construction engineering, so practising professionals should have competency in all three aspects. Nevertheless, the authors have observed an artificial separation between geotechnical/construction engineering and structural engineering, and this separation appears to be present both among foundation engineering practitioners and in academia. This lack of sufficient integration between geotechnical and structural engineering often leads to poor foundation design decisions.

For example, the interaction between geotechnical and structural design of spread footings is too often reduced to little more than communicating an allowable bearing pressure, as if this single parameter was sufficient. Foundation types are sometimes selected without sufficient attention to the various soil-structure interaction considerations, which sometimes results in a foundation system that is unnecessarily expensive.

As a result of these observations, the authors created an undergraduate foundation engineering course which integrates both the geotechnical and structural aspects of design. This course focuses on spread footings, and the expected outcomes include the ability to start with structural loads and subsurface exploration and characterisation data, and produce a complete foundation design including all structural details. In the authors' opinion, this type of integrative course, particularly at the undergraduate level, helps develop stronger design skills among civil engineering students. However, there was little or no information on how other academics and practitioners viewed this matter.

Therefore, the goal of the research presented in this paper was to determine the current state of foundation engineering education in the US as it relates to the integration of geotechnical and structural aspects of analysis and design. To accomplish this, the authors conducted a survey of geotechnical and structural faculty to determine the degree to which these topics are integrated in foundation engineering courses. A survey of foundation engineering practitioners was also conducted with two objectives: to determine their perceptions of the importance of various aspects of foundation design and to determine their satisfaction with recent civil engineering graduates. Finally, a review of the available library of foundation engineering and structural engineering textbooks was conducted to determine how geotechnical and structural design topics are presented.

2 SURVEY INSTRUMENTS

2.1 *General characteristics*

Two surveys were conducted online using a commercial survey provider. The surveys were conducted from July to August, 2011. Respondents were solicited via online professional networks such as the United States Universities Council on Geotechnical Education and Research, professional organizations such as

Table 1. Demographics of practitioners completing the survey.

Characteristic	Number responding	Percent responding
Engineering discipline		
Geotechnical	39	57%
Structural	22	32%
Construction	4	6%
Other	3	6%
Affiliation		
Private firm	60	87%
Public agency	9	13%
Geographic scope of firm/agency		
Local	12	17%
Regional	22	32%
National (US)	15	22%
International	20	29%
Service provided by firm/agency		
Engineering design	51	74%
Consulting	50	72%
Design/build	31	45%
Construction services	21	30%
Construction management	23	33%

ADSC: The International Association of Foundation Drilling and US civil engineering department chairs email list. There were no individual invitations for survey participants so it is not possible to determine the return rate of the surveys.

2.2 *Characteristics of practitioner respondents*

A total of 69 practitioners responded to the survey. The demographics of the practitioners responding are shown in Table 1. One of the goals of the survey was to get data from those describing themselves as both geotechnical and structural engineers. As seen in Table 1, geotechnical engineers are slightly over represented compared to structural engineers (57% geotechnical, 32% structural) but there is significant representation among both groups.

The respondents are heavily weighted to private firms (87%) compared to public agencies (12%) as shown in Table 1. Among the private firms there is a good diversity of geographic size of the firms as seen in Table 1. The data also show that firms/agencies represented by respondents most commonly provide design or consulting services (over 70%), but significant percentages of respondents report providing design/build or construction services (45% design/build, 30% construction). One third of respondents report providing construction management services.

The authors believe the sample group is sufficiently diverse and representative of the practicing foundation design community in the US, but no attempt was made to compare the demographics of the respondents to demographics of US engineering firms and agencies. The sample is significantly biased toward private firms versus public agencies and slightly biased toward geotechnical engineers versus structural engineers, but these biases in the data do not appear to significantly affect the conclusions reached in this paper.

Table 2. Demographics of institutions represented in the academic survey.

Characteristic	All ABET Schools*		Survey sample	
	number	percent	number	percent
Status				
Private	64	26%	23	24%
Public	185	74%	70	76%
Carnegie classification 2010†				
Bachelors	23	9%	9	10%
Masters	16	24%	22	23%
Doctorate	17	7%	4	4%
Research	149	60%	59	63%

*Data from ABET (2011).
†Data from Carnegie Foundation (2010).

Table 3. Demographics of faculty completing the survey.

Characteristic	Number responding	Percent responding
Engineering discipline		
Geotechnical	62	41%
Structural	74	49%
Multidisciplinary	16	11%
Academic area		
Geotechnical	75	49%
Structural	77	51%

2.3 *Characteristics of faculty respondents*

A total of 152 faculty members responded to the surveys. These respondents represented 99 institutions of which 94 were US institutions with 4-year ABET accredited civil engineering or civil engineering technology programs. The remaining 5 institutions were either outside the US or were 2-year community college programs and were excluded from the analysis presented in this paper. Including only US based ABET accredited 4-year programs reduced the total sample size to 147.

The demographics of the institutions included in the analysis compared to demographics of all US based ABET accredited 4-year civil engineering or civil engineering technology programs are shown in Table 2. In terms of public-private status, and Carnegie classification (Carnegie Foundation, 2010), the survey sample is representative of the total population.

The demographics of individuals responding are shown in Table 3. The balance between geotechnical and structural engineers in this survey was better than in the practitioner survey (41% geotechnical, 49% structural, 11% multidisciplinary) and the balance of academic areas in which the respondents reported teaching was nearly equal (51% structures, 49% geotechnics). No attempt was made to compare this data to the total population of all civil engineering faculty. The goal was to achieve a balance between faculty teaching structural courses versus geotechnical courses and this was achieved. The authors believe the survey sample is a satisfactory representation of the population.

3 UNDERGRADUATE FOUNDATION ENGINEERING CURRICULA

A brief review of the data from the faculty survey and a web-based review of BSCE curricula indicated nearly all institutions included design of spread footings in various places within their undergraduate curriculum, albeit often within elective courses. Deep foundations were always included in the graduate curricula and in some cases also in the undergraduate curricula. Since the design of spread footings is generally one of the first foundation systems covered in a design course and since it includes both geotechnical and structural engineering design aspects, the authors chose to focus on the design of spread footings to assess the coverage of geotechnical and structural aspects of foundation engineering in undergraduate curricula.

3.1 *Preparatory coursework for foundation engineering*

Important preparatory courses for foundation engineering include introductory geotechnical engineering (or soil mechanics), reinforced concrete design, and, to a lesser extent, structural steel design. Welker (2012) reports that 93% of US BSCE programs require an introductory geotechnical engineering course. A web-based review indicates all BSCE programs require at least one structural design course, but the students often have the option of selecting courses on certain materials (steel, concrete, etc). Informal discussions with civil engineering faculty at a number of US institutions indicate that all BSCE students who choose to focus on structural engineering and the vast majority of those who choose to focus on geotechnical engineering take both reinforced concrete design, and structural steel design courses.

Since introductory geotechnical engineering, reinforced concrete design, and structural steel design are taken by the vast major of students who are likely to become practicing foundation engineers, the faculty survey was used to determine what spread footing design topics were covered in these courses. Figure 1 shows those topics covered in introductory geotechnical engineering courses. Approximately half of the respondents report covering bearing capacity and/or settlement in this course. Equally important, nearly half of the respondents reported no coverage of footing design topics. A number of respondents reported in their comments that their introductory geotechnical engineering course covered geotechnical behaviour and analysis to the exclusion of design.

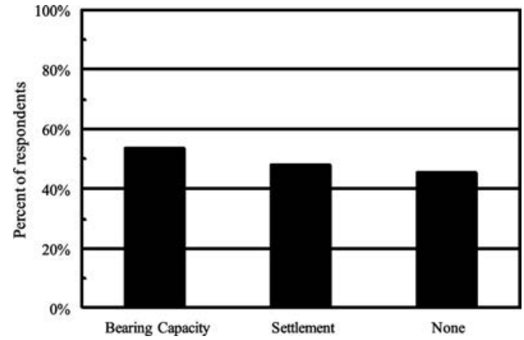

Figure 1. Footing design topics covered in introductory geo-technical engineering courses.

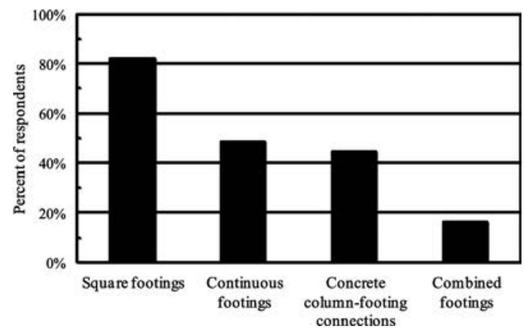

Figure 2. Footing design topics covered in reinforced concrete design courses.

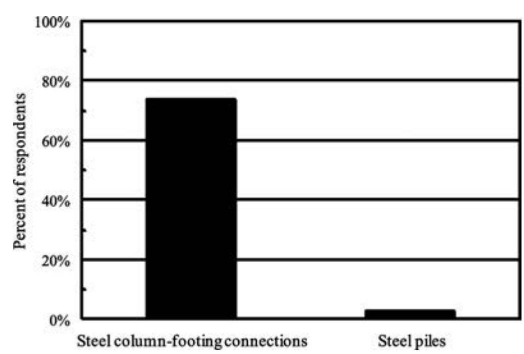

Figure 3. Footing design topics covered in structural steel courses.

Coverage of footing design topics in the structural engineering courses is shown in Figures 2 and 3. As shown in Figure 2, 82% of respondents report covering structural design of square footings. Significantly lower percentages report covering continuous footings, combined footings and column-footing connections. The data in Figure 3 indicate 74% cover steel column-footing connections, while only 3% cover the design of steel piles.

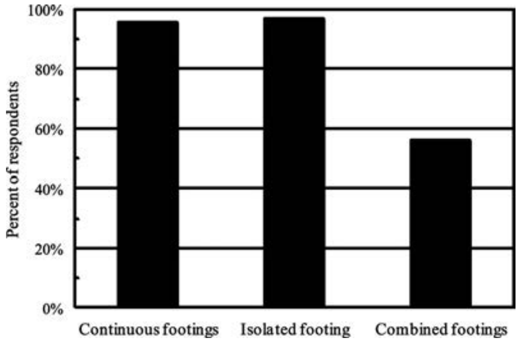

Figure 4. Footing foundation systems covered geotechnical engineering design courses.

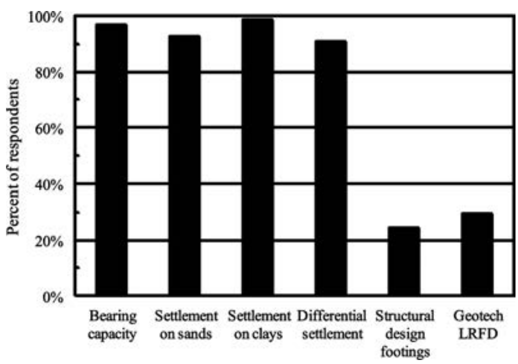

Figure 5. Topics covered in geotechnical engineering design courses.

3.2 *Foundation engineering design courses*

It is not surprising to find that a significant number of introductory geotechnical engineering courses focus exclusively on behaviour and analysis since this is the students' first course in geotechnics. In contrast the concrete and steel design courses follow one or two courses in structural analysis and are therefore able to focus directly on design.

Welker (2012) reports that 75% of programs offer a geotechnical engineering elective after the introductory course but only 37% of programs require a second geotechnical course. Data from this survey indicate that 6% of programs offer only an introductory geotechnical engineering course, 77% offer a second course, and 17% offer both a second and third geotechnical engineering course. Welker (2012) reports that in the majority of undergraduate programs, foundation engineering is the second geotechnical course offered. This survey indicates in 99% of the programs, the second course covers shallow foundation design. Figure 4 shows the shallow foundation systems covered in the second geotechnical engineering course and Figure 5 shows the topics covered in this course. Of particular note, Figure 5 shows that only 24% of programs cover structural design of shallow foundations in the geotechnical engineering elective course. By comparing responses of geotechnical and structural faculty

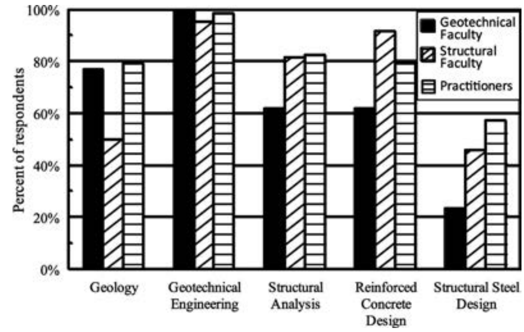

Figure 6. Importance of foundation engineering subjects as reported by geotechnical faculty, structural faculty, and practitioners.

at the same universities, the survey data indicate that 29% of programs which do not cover structural design of footings in their reinforced concrete class do cover it in their geotechnical design class.

Load and Resistance Factor Design (LRFD) is reportedly covered in 33% of programs (Fig. 5), but the survey did not distinguish between geotechnical and structural aspects of LRFD in this question. It is unlikely that the coverage of geotechnical LRFD design goes beyond a qualitative overview in those few courses which cover it, given the lack of textbook coverage of this subject as discussed later in this paper.

Two conclusions are apparent: First, most students are taught structural footing design either in their reinforced concrete or geotechnical design course. Second, the most common curriculum structure is to cover structural design of footings in the reinforced concrete course but not in the geotechnical design course.

4 FACULTY AND PRACTITIONERS' OPINIONS OF FOUNDATION ENGINEERING TOPICS

One objective of this study was to determine what, if any, differences existed between faculty and practitioners' opinions concerning the importance of certain subjects in foundation engineering. To accomplish this, respondents to both surveys were asked to rate the importance of several subjects potentially related to foundation engineering. The respondents were asked to rate the importance on a four point Likert scale (not very important, somewhat important, important, very important). In the following analyses the importance is reported as the percentage of respondents indicating a given topic was important or very important.

4.1 *Importance of component subjects*

Figure 6 compares the importance reported by geotechnical faculty, structural faculty and practitioners related to geotechnical and structural subjects. With the exception of geology, the opinions of structural faculty are more congruent with practitioners' opinions than are the opinions of geotechnical faculty. Another

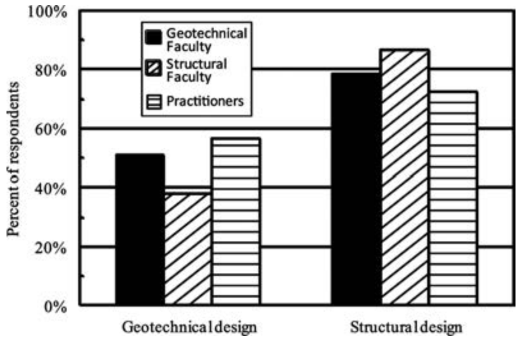

Figure 7. Importance of geotechnical and structural LRFD in foundation design as reported by geotechnical faculty, structural faculty, and practitioners.

possible interpretation of these data is that both academic disciplines undervalue the importance of the other disciplines, whereas practitioners place value on both.

4.2 *Importance of load and resistance factor design*

The importance LRFD in foundation design is increasing due to newer regulatory guidance such as Eurocode 7 and US Federal Highway Administration design criteria for transportation structures. One objective of this study was to compare how faculty and practitioners perceive the importance of LRFD given its increasing importance.

Figure 7 compares the importance of LRFD to foundation design reported by geotechnical faculty, structural faculty and practitioners. As shown in this figure, all three agree that LRFD in structural design is significantly more important than LRFD in geotechnical design. The structural engineering faculty attach significantly less importance to LRFD in geotechnical design compared to both geotechnical faculty and practitioners. Practitioners were asked the additional questions "For your firm or agency, how do you see the importance of LRFD methods, as applied to geotechnical foundation design, changing in the future?" Over 70% of practitioners responded that expected LRFD importance to significantly increase over the next ten years.

Practitioners' identification of the increasing importance of geotechnical LRFD methods and the faculty's underestimation of their importance are significant findings of the surveys. LRFD methods clearly separate strength limits from serviceability limits. This increases the importance of understanding soil-structure interaction which will, in turn, increase the need for interaction between structural and geotechnical disciplines.

5 EVALUATION OF TEXTBOOKS AND REFERENCE BOOKS

Foundation engineering and reinforced concrete design textbooks currently used in the United States were reviewed to evaluate their coverage of structural design of foundations. A similar review also was conducted on English language foundation engineering reference books and out-of-print textbooks.

5.1 *Reinforced concrete design textbooks*

Major US publishers currently offer nine reinforced concrete design books suitable for use as textbooks in civil engineering courses (Brzev and Pao, 2010; Fanella, 2011: Hassoun and Al-Manaseer, 2008; Limbrunner and Aghayere, 2010; McCormac and Brown, 2008; Nawy, 2009; Nilson, et al., 2009; Wang, et al., 2007; and Wight and MacGregor, 2012). All nine include an entire chapter on the structural design of foundations. In all cases the structural design of spread footings is covered in some detail. The structural design of deep foundations, mat foundations, pile caps, and other structural members is either not covered or only briefly mentioned. None discuss the geotechnical aspects in any detail, other than using an allowable bearing pressure to size the footings.

5.2 *Foundation engineering textbooks*

Major US publishers currently offer nine foundation engineering books suitable for use as textbooks in civil engineering courses (Bowles, 1996; Budhu, 2008; Cernica, 1995; Coduto, 2001; Das, 2011; Murthy, 2003; Rao, 2011; Reese, et al., 2006; and Salgado, 2008), and one additional book is self-published by the author (Candogan, 2009). All focus primarily on the geotechnical aspects, and cover them in detail. Only three of these books (Bowles, 1996; Coduto, 2001; Cernica, 1995) cover the structural design of spread footings, and each does in some detail. These three and Candogan, 2009 also include some coverage of the structural design of deep foundations, although to a lesser degree than for shallow foundations. The remaining books have no substantive discussion of the structural design aspects of foundation engineering.

Three other books (Teng, 1962: Leonards, 1962; and Peck, et al., 1974) were commonly used in the US as textbooks, but are now out of print. All three focused primarily on the geotechnical aspects, but two included significant coverage of the structural design of spread footings, one included a detailed discussion of the structural design of deep foundations, and one included a brief discussion of the structural design of deep foundations.

Bowles' textbook was originally published in 1968 and in use at the same time as the three out-of-print texts. Thus, during the 1970s and 1980s three of the four available foundation engineering texts (75%) included significant structural design content. Currently, only three of the nine available texts from publishers (33%) include significant structural design content and one of these three is the 1996 edition of Bowles' text. One could make the case that the coverage of structural foundation design foundation engineering texts has dramatically decreased in the past three decades. This increased specialisation at the sacrifice of topical breadth is not unusual in engineering education, but is nevertheless a troubling trend.

5.3 *Foundation engineering professional reference books*

All of the foundation engineering textbooks also are useful references for practicing engineers. In addition, eight other English language professional reference books, both in print and out of print (Brown, 2001; Curtin, et al, 2006; Das, 2009; Day, 2006; Fang, 1991; Gunaratne, 2006; Ng, et al, 2004; and Wyllie, 1999) were reviewed. Of these, only two included substantive coverage of the structural design of spread footings and only three included substantive coverage of the structural design of deep foundations.

5.4 *LRFD coverage in textbooks*

All of the reinforced concrete foundation design textbooks cover LRFD design extensively as that is the current design standard in the US. Only one of the textbooks reviewed (Coduto, 2001) has any cover of geotechnical LRFD design and the coverage in the text is limited to an overview of the approach. No geotechnical guidance suitable for design is provided.

There are four important observations from this review. Structural design of spread footings is a major topic in all of the major American reinforced concrete design textbooks, but the coverage is completely independent of any geotechnical considerations, other than the allowable bearing pressure. Only 33% of currently published American foundation engineering textbooks cover structural design of spread footings. Substantive coverage of structural design of deep foundations is available only in one foundation engineering textbook. Finally, only one foundation engineering text covers geotechnical LRFD, and even that coverage is in broad conceptual terms.

6 PRACTITIONERS' SATISFACTION WITH GRADUATES

In order to reach some understanding of how well academic curriculums are meeting the expectations of practitioners, the survey included questions related to practitioners' satisfaction with BSCE graduates hired within the last five years. Only firms or agencies reporting having hired a recent BSCE graduate during the past five years were asked to respond. The survey asked the practitioner both about the importance of certain foundation engineering topics (using the same four point scale described above) and their satisfaction with the performance of recent graduates. Satisfaction was rated on a four point Likert-like scale (very dissatisfied, dissatisfied, satisfied, very satisfied). The practitioners' ratings of importance and satisfaction were combined into a single measure by computing the gap between reported importance and reported satisfaction. The gap was computed by subtracting the satisfaction rating from the importance rating, since the importance rating always exceeded the satisfaction rating.

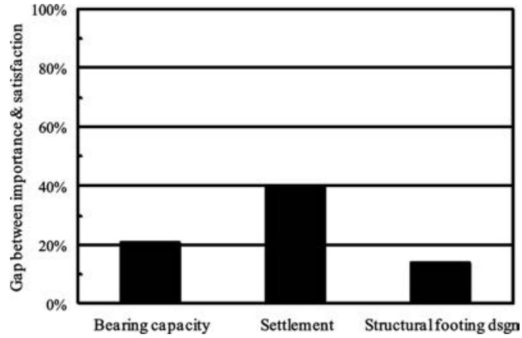

Figure 8. Gap analysis comparing practitioners' importance and satisfaction with footing design abilities of BSCE graduates hired within the past 5 years.

Figure 8 presents the gap analysis comparing practitioners' rated importance and satisfaction with recent BSCE graduates employed in the last five years. The data indicate practitioners are most satisfied with graduates' abilities in structural design of footings and significantly less satisfied with their abilities in bearing capacity and settlement computations.

The overall satisfaction with BSCE graduates' abilities in foundation engineering is quite low. However, this should be tempered by most practitioners' belief that an advanced degree is important for foundation engineers. When asked about the required level of academic training for foundations engineers, 83% replied that a master's degree was either advisable or essential. Still it is clear that there is plenty of room for improvement in the academic preparation of foundations engineers.

7 SUMMARY OF FINDINGS

7.1 *Undergraduate curricula*

Significant foundation engineering instruction is available to students interested in the subject. However, it is most commonly delivered in a stovepipe fashion with structural topics relegated to structural design courses and geotechnical topics relegated to geotechnical courses. Over 80% of the reinforced concrete design courses have significant coverage of the design of footings. Nearly half of the commonly required introductory geotechnical engineering courses cover some foundation engineering topics. Essentially all geotechnical design courses cover shallow foundation design, but less than 25% of these courses include structural foundation design. Both reinforced concrete design and geotechnical engineering design are most commonly elective courses, but are likely taken by students interested in foundation engineering.

This stovepipe mentality is also apparent in the importance geotechnical and structural faculty attach to the foundation design aspects of one another's disciplines. Geotechnical engineering faculty, in particular, attribute less importance to structural aspects of foundation design than do practitioners.

Structural aspects of LRFD are clearly covered in structural engineering courses. However, geotechnical LRFD subject are covered in less than one third of the geotechnical design courses and then most likely only as an overview without significant design content.

7.2 *Textbooks*

All current reinforced concrete textbooks thoroughly cover structural LRFD and devote an entire chapter to the structural design of foundations, but this is done in nearly complete isolation to geotechnical aspects of design. The coverage of structural design in foundation engineering textbooks has significantly decreased in the past two decades as older texts which frequently covered these topics are replaced by new texts which most often do not. None of the foundation engineering texts contain sufficient coverage of geotechnical LRFD topics.

7.3 *Practitioners satisfaction with graduates*

Foundation engineering practitioners are moderately satisfied with BSCE graduates hired in the past 5 years. They are significantly more satisfied with the graduates' abilities in structural design of foundations compared to their abilities in geotechnical design of foundations. The area with the least satisfaction is in settlement of footings. These finding are tempered by the fact that the vast majority of practitioners believe a master's degree is advisable or essential to foundation engineers.

8 CONCLUSIONS AND RECOMMENDATIONS

The geotechnical, structural, and construction aspects of foundation engineering practice are clearly intertwined, and the best foundation designs are achieved when all three aspects are fully considered. Most foundation engineering textbooks used in the United States 30 years ago included both the geotechnical and structural aspects, and presumably the corresponding courses also did so. However, most of today's textbooks focus almost exclusively on the geotechnical aspects, with only some attention to construction, and virtually none to structural aspects. The vast majority of undergraduate foundation engineering courses taught in the US today reflect this topical coverage.

The authors have observed that this artificial separation also carries over into practice, with insufficient communication and interaction between structural and geotechnical engineers. This often leads to less-than-optimal foundation designs.

This lack of integration will become more problematic as geotechnical LRFD methods become more widely used in practice. These methods force a clearer separation between strength requirements and serviceability requirements, which necessitates better interaction between the disciplines. The transfer of a single allowable bearing stress between the geotechnical and structural engineer has always represented an insufficient interaction. The adoption of geotechnical LRFD methods will make this blatantly apparent.

The authors believe the impending adoption of geotechnical LRFD methods in the US presents an opportunity to improve the quality of foundation engineering practice by forcing more effective interaction between geotechnical and structural engineering. The authors recommend implementing a greater integration between the structural and geotechnical aspects of foundation design, especially in undergraduate foundation engineering courses. This stronger emphasis should lead to better qualified graduates, who will then go on to implement stronger interactions among practitioners.

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Geotechnical engineering education – removing the barriers

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ABSTRACT: Degree programmes in civil engineering usually separate teaching of structural mechanics, hydraulics, soil mechanics. Educationally this carries three dangers. Firstly, the teaching diverges: common ground between the separate areas becomes difficult to identify. Secondly, it leaves the impression that the behaviour of soils is completely different from the behaviour of any other material that civil engineers will encounter. Thirdly, it ignores the fact that many of the challenges of geotechnical engineering arise from interaction – soil-structure interaction; erosion and scour. However, introductory soil mechanics can instead present soil as one of many civil engineering materials. In understanding stiffness and strength the key feature is that soil contains voids. A ‘critical state soil mechanics’ framework in which stresses and density are considered in parallel will be helpful.

1 INTRODUCTION

In typical undergraduate degree programmes in civil engineering, teaching of structural mechanics, hydraulics, soil mechanics is treated quite separately. There may be pragmatic reasons for this separation – academics have research specialities and like to teach only within those specialities; timetables have to be broken down into distinct units of convenient size for the purposes of delivery and assessment. However, educationally the marked subject division carries three dangers. Firstly, the teaching diverges: there is not often any attempt to identify common ground between the separate areas – and individual academics have their own particular notions of the best way to teach their subjects. Secondly, it rapidly generates a lasting impression that the behaviour of soils is *completely* different from the behaviour of any other material that civil engineers will encounter, and that soils are difficult materials: leading students to avoid, or to marginalise, an impossible subject. Thirdly, it leaves the impression that these several areas are indeed distinct whereas many of the design challenges of civil engineering (particularly geotechnical engineering) arise from interaction. Soil:structure interaction requires parallel understanding of the behaviour of both the structural and the geotechnical materials. Erosion and scour tend to be treated from the hydraulics angle of sediment transport.

It is suggested here that introductory soil mechanics can instead present soil as one of many civil engineering materials and use opportunities to indicate overlaps between subjects. In understanding stiffness and strength the key feature of soils, compared to (say) metals, is that soils contain voids, which permit significant changes in density. Thus a ‘critical state soil mechanics’ framework in which stresses and density are considered in parallel both provides a unifying description of soil behaviour and lays the groundwork for future development of models of soil response.

Some elements of a syllabus for introductory soil mechanics will be presented. This is obviously based on my experience teaching first year civil engineering undergraduates at the University of Bristol from which a recent book *Soil mechanics – a one-dimensional introduction* (Muir Wood 2009) emerged. Some of the material in this book goes rather further than a typical first year course might go, depending on the mathematical confidence of the students. However, although the restriction to a single dimension may appear rather constraining, there are a number of examples of more or less realistic geotechnical problems – including some rather simple analytical examples of soil:structure interaction – which are described by a single degree of freedom and which can be included to emphasise the importance of removing the boundary between these sections of the curriculum even at the earliest stages of a civil engineering degree programme. The inspiration for this approach to the teaching of soil mechanics came (at the suggestion of the late Ioannis Vardoulakis) from the book *A one-dimensional introduction to continuum mechanics* (Roberts 1994) which explores the common mathematical description of many physical phenomena such as traffic flow, waves, gas dynamics, stress analysis, fluid dynamics.

2 OPPORTUNITIES FOR OVERLAP

Students in the first year of the undergraduate programme come with a varied knowledge (and understanding) of mathematical and physical concepts. We need to introduce the concept of stress as areal intensity of force. This is likely to be unfamiliar although the idea of pressures in fluids may well have been encountered. Since we are restricting ourselves to a single dimension we do not need to become embroiled in resolution of stresses, principal stresses and so on. However, in the context of what comes later, the concept of a vertical gradient of stress in the ground as an integration of unit weight or density – or the summation of the effects of density and thickness for a series of finite overlying layers of soil – is a simple application. Gravity can be briefly discussed here – it is important that students appreciate the difference between mass and weight or force.

This is a convenient point at which to introduce the concept of water in the ground, water table, pressure and pressure measurement and some simple hydrostatics – buoyancy, Archimedes – and ideas of surface tension. This then leads to the logical partition of total stress (which is what we discover that we have been thinking about in applying considerations of equilibrium to the vertical profile of stress in the ground) between pore pressure and effective stress supported by the soil particles. I do not think it is necessary to dwell on putative proofs of the *Principle of Effective Stress*. It can be treated as a moderately well non-falsified conjecture which has demonstrated its worth over many decades. In early year teaching it is helpful to convey *certainties* even if we expect to encourage students to query them later on.

Having demonstrated a need for knowledge of density of soils – in order to calculate stresses in the ground – we now need to introduce density of soils as a variable. It is unfortunately unavoidable that we have to introduce a plethora of different ways of describing volumetric packing of soils. If it were possible to choose just one then specific volume v has a number of attractions (although the name invites confusion with specific surface). When the idea of volumetric strains is subsequently introduced, incremental volume changes have to be normalised with volume and it is more elegant to use v rather than $1+e(=v)$ (where v and e are specific volume and void ratio). Ideas of ratios of densities might actually be easier to convey than volume ratios and the definition $v=\rho_s/\rho_d$ (where ρ_s and ρ_d are the densities of the soil mineral and the dry soil with voids respectively) links the two approaches and clearly indicates that as the voids become progressively squashed the density of the soil mineral must be an asymptote for the density of the soil with its vanishing voids.

The idea of compaction can be introduced here as an application of these alternative descriptors of soil packing. It is interesting to note that, if specific volume rather than dry density is plotted as ordinate, then lines of constant saturation and constant air void ratio are straight (Fig 1).

The shape and size and differences in mechanical interaction of soil particles can be mentioned, primarily in order to convey the huge range of sizes that may

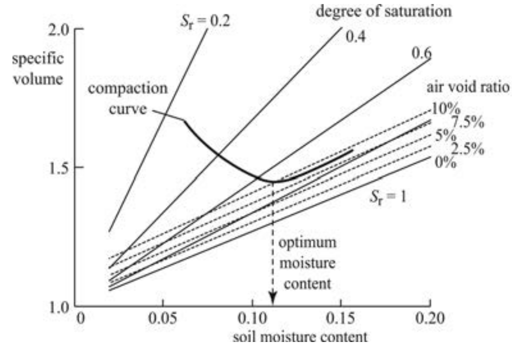

Figure 1. Compaction of soils plotted using specific volume v.

be present – which will have future implications. I see teaching of geology as distinct from teaching of soil mechanics (while allowing for any reasonable modest overlaps) but discussion of the origin of soils provides common ground.

For other civil engineering materials a key introductory mechanical property is *stiffness* – elasticity underpins much of the treatment of structural mechanics. Elasticity itself is not particularly applicable to soils but the concept of stiffness certainly is and, having introduced the idea of soil with compressible voids, we can conduct a thought experiment (arguing from physical instinct rather than from actual observation) to describe how we expect soil to behave when it is compressed one-dimensionally (Fig 2a). The soil is confined so we expect the stiffness to increase nonlinearly as the soil becomes more dense and the stress level rises. It is helpful then to describe this nonlinearity using a power law (Janbu 1963).

$$\frac{E_o}{\sigma_{ref}} = \chi\left(\frac{\sigma'_z}{\sigma_{ref}}\right)^{\alpha} \qquad (1)$$

linking incremental stiffness E_o and vertical effective stress σ'_z. This expression includes an exponent α and a modulus number χ (Fig 2c, d). The traditional linear semilogarithmic compression law for clays implies $\alpha=1$ and can be seen as a special case of the more general relationship.

Why is this helpful? The thought experiment emphasises in a simple way the nonlinearity that characterises soils. The power law allows more flexibility than an insistence on the semilogarithmic plotting. The charts provide some order of magnitude values. Having some understanding of this one-dimensional oedometric stiffness it is then possible to perform calculations of site settlement for simple situations involving soil placement or removal over large areas.

Seepage is an obvious topic for one-dimensional treatment – introduction of Bernoulli and the concept of total head for slowly flowing pore fluid; introduction of Poiseuille to justify an expected dependence of permeability on pore size; Reynolds' number as part of a discussion of the applicability of Darcy's

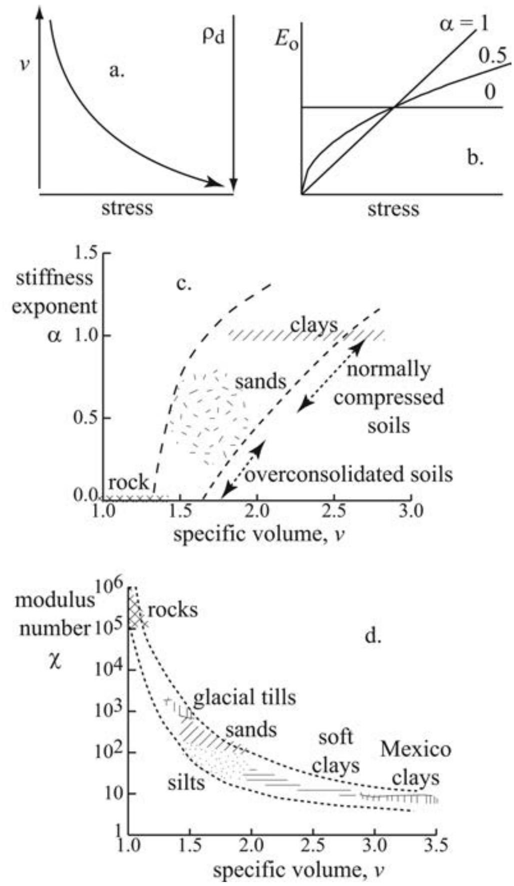

Figure 2. One-dimensional stiffness of soils.

law; permeability of layered soil as an illustration of parallel and series systems and analogies with flow of electricity or heat – thus emphasising the common analytical basis for all these apparently different flow problems. Even with only one dimension (or one spatial degree of freedom) there is quite a range of accessible seepage problems which can be tackled including axisymmetric flow to a point or line well.

With the low permeability of fine grained soils evident, the consequences of changing the stresses applied to a volume of soil which is able to deform only in one dimension – as in an oedometer – can be explored in three stages. First, the short and long term responses of clay are inevitably distinguished – the concepts of undrained and drained response automatically emerge – and calculations of long term settlement can be made for a site which is prepared by raising the ground level. Second and third, we can analyse the rate at which the transfer of total stress from pore pressure to effective stress occurs. The way in which this is done depends on the mathematical skills of the students. The simpler approach (second), which is nonetheless extremely instructive, is to use parabolic isochrones (Schofield & Wroth 1968) to study the

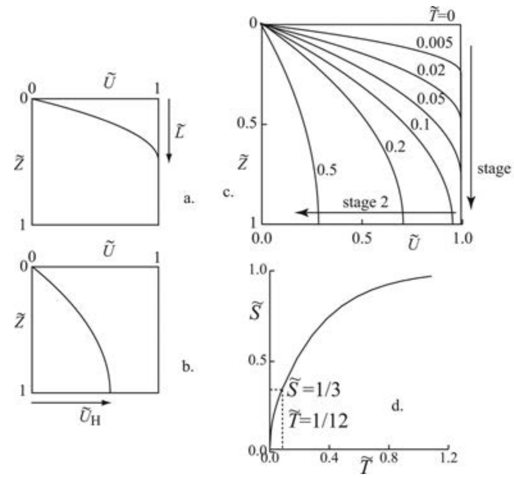

Figure 3. Consolidation of a soil layer: parabolic isochrones.

consolidation of an entire layer of clay as a complete *system*. The resulting controlling differential (diffusion) equation is of first order with a single variable and is straightforward to solve (Fig 3). The technique can be applied to various boundary conditions – the underpinning concept is simple: the rate of flow of water out of a clay layer must match the settlement of that layer consequential on the change of effective stress. If students have met the solution of partial differential equations then the third approach, direct solution of the governing equation written at the level of the infinitesimal soil element, can be applied. The analysis of the consolidation problem, whether using parabolic isochrones or the diffusion equation, provides an opportunity to work with dimensionless groups for time $\tilde{T}$, pore pressure ($\tilde{U}$), settlement ($\tilde{S}$) which can be tied in with other parallel exposure to dimensions and dimensional analysis (Palmer 2008). It is instructive to recognise, with either of these solution techniques, that the process of consolidation has two stages: first, a consolidation front travels steadily into the soil from the drainage boundary; then, once this front has traversed the entire thickness of the soil layer, there is a general exponential reduction of pore pressure with time, throughout the layer. Evidently the solution of the diffusion equation for this particular problem provides a reinforcing application of the mathematical technique.

3 STRENGTH AND MODELLING

Discussion of strength of soils as a one-dimensional concept seems to be beyond the realms of possibility. However, we can build up a model of strength of soils – using again our framework of critical state soil mechanics – from inspection of data from shear box tests. The use of this device as a source of data on strength and deformation of soils may seem eccentric.

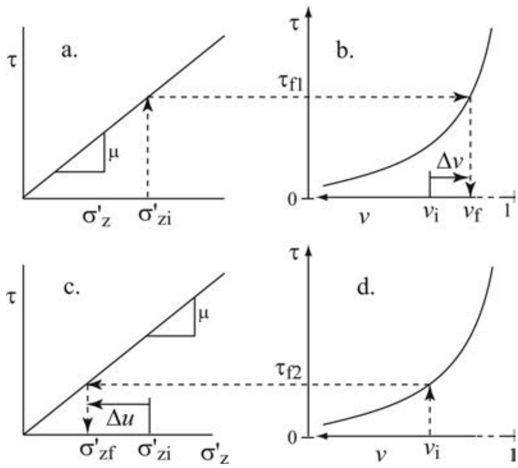

Figure 4. Drained and undrained strength.

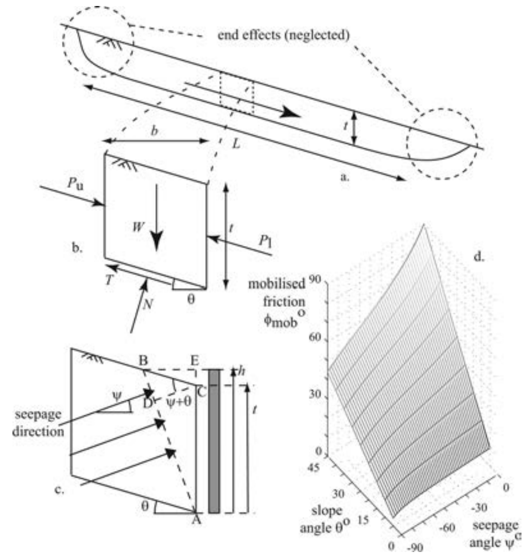

Figure 5. (a) Infinite slope; (b) typical element; (c) one-dimensional seepage; (d) mobilised friction.

However, it is a very useful simple pedagogic device which, being not completely enveloped in opaque metalwork, provides a very visual feel of the behaviour of soils, and particularly the property of dilatancy. It also reproduces the deformation and failure of soil around a failure plane or interface, and one can produce real examples of the relevance of such a mechanism of failure in shaft resistance of piles, and slope stability, for example. We have only to introduce the concept of a shear stress to represent this mobilised strength.

We require a pair of thought experiments: one of which suggests that it is reasonable to suppose that as we increase the stress level in a soil sample its strength will increase so that a frictional relationship between normal stress and shear stress will be appropriate (Fig 4a, c). The second suggests that the strength will increase as the density of the soil increases (Fig 4b, c). Immediately we have the critical state line before us as a description of strength in terms of effective stress and density (Fig 4) (Schofield & Wroth 1968, Muir Wood 2004). We can separate drained and undrained response, depending on whether the permeability of the soil allows volume (density) changes to occur during shearing. If volume changes can occur then the strength is controlled by the effective normal stress and the density has to adjust itself accordingly (Fig 4a, b). If volume changes cannot occur then the strength of the soil is controlled by the density and the normal effective stress has to adjust itself accordingly through the generation of pore pressure (Fig 4c, d).

With a frictional soil model we can look at the classic problem of the stability of an infinite slope in which failure is occurring on a shallow failure surface parallel to the free surface. Then the only degree of freedom left is the depth below the free surface of the slope – and we can combine this with our knowledge of one-dimensional seepage to show the interaction between the mobilised friction, the slope angle, and the direction of seepage (Fig 5).

If we want to extend these sketchy ideas into the description of a complete soil model (within the one-dimensional context) then our soil element of application is that seen in the simple shear apparatus – and this can be seen as similar to the conditions around the failure surface in the shear box. The simple shear element combines the one-dimensional constraint of the oedometer (so that earlier ideas of one-dimensional stiffness can be applied) with a shear deformation response described in terms only of the applied shear stress. Such a model is developed by Muir Wood (2009) and lends itself to exploration of other aspects of soil deformation and failure, such as the interaction of soils with plant roots, or the response of soils under undrained cyclic loading.

4 ONE-DIMENSIONAL ANALYSIS

In an introductory course on soil mechanics there is a limit to how far one can proceed. However, there are many more or less realistic problems which can be reduced to a single degree of spatial freedom: one-dimensional consolidation, flow of water towards a point sink or a line sink in a suitably infinite domain, stability of an infinite slope – these have already been mentioned. There are a number of examples of soil-structure interaction which can also be reduced to problems with a single degree of freedom. It is important to take whatever opportunities are provided by the skills and understanding that the students have developed to increase awareness of the interaction of soil and structural elements. It is not inevitable that the structural elements will always be significantly stiffer than the natural or man-made soils with which they interact (Muir Wood & Nash 2000, Muir Wood 2004).

Three somewhat realistic problems include a pile under axial loading; a beam on an elastic foundation;

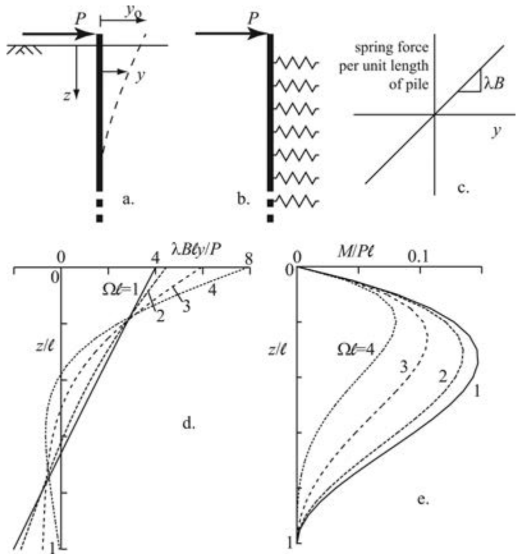

Figure 6. (a) Pile under lateral loading; (b), (c) soil modelled as horizontal springs; (d) normalised deflection; (e) normalised bending moment.

and a pile under lateral loading. A pile under axial loading can be considered as shedding its load to the surrounding soil through shaft friction and end bearing according to some notional elastic transfer models. A second order differential equation can be derived which relates pile settlement (or axial load) with depth below the ground surface. The response of the pile will be controlled by the ratio of the axial stiffness of the pile to the stiffness of the transfer of load from pile to soil.

The analysis of a beam on an elastic foundation is governed by exactly the same equation as the pile under lateral loading. The analysis of this problem requires the beam equation for the link between lateral loading and lateral deflection of an elastic beam – this is another topic for reinforcement through duplication. The beam equation is a fourth order ordinary differential equation so that a certain amount of mathematical confidence is required for its solution. These are again problems which lend themselves to dimensionless analysis – and, indeed, it is through reduction of the governing equations to their dimensionless form that the appreciation of the importance of *relative* stiffnesses of soil and structure can be obtained.

The beam equation for the deflection y of a laterally loaded pile of width B (Fig 6a), for which the soil provides a loading λy proportional to the lateral deflection (Fig 6b, c), is:

$$EI\frac{d^4y}{dz^4} = -\lambda By \quad (2)$$

where EI is the flexural rigidity of the pile and λ is a coefficient of subgrade reaction for the soil. The solution of this equation for a pile of length ℓ is written in terms of the dimensionless group $\Omega\ell$ where

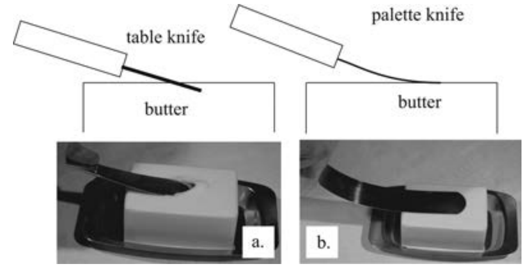

Figure 7. Demonstration of 'soil'-'structure' interaction: pack of butter indented using (a) stiff knife, (b) flexible knife.

$\Omega^4 = \lambda B/4EI$. The controlling group is $\lambda B\ell^4/EI$, combining mechanical properties of both materials (λ and E) and geometrical properties of the pile (I, ℓ and B). The normalised form of equation (2) is:

$$\frac{d^4\tilde{y}}{d\tilde{z}^4} = -4(\Omega\ell)^4\tilde{y} \quad (3)$$

emphasising the sole parametric dependence on $\Omega\ell$. The lateral deflection y is presented in dimensionless form as $\lambda B\ell y/P$; the bending moment M in the pile is normalised as $M/P\ell$; depth z below ground level is normalised with the length of the pile (z/ℓ). The importance of these particular groupings of parameters could have been deduced from dimensional analysis of the problem (Palmer 2008). For a low value of $\Omega\ell$ the pile behaves rigidly (Fig 6d); for a high value of $\Omega\ell$ the pile is flexible and the deflection at the toe may be negligible. But 'flexibility' can be interpreted as either a low pile stiffness E or a long pile length ℓ or a high soil stiffness λ or a combination of all three. No one descriptor of the pile or soil is adequate on its own to characterise the system response.

If nerves fail in the solution of differential equations then there are simple physical demonstration experiments that can be used to illustrate the importance of relative rather than absolute individual values of stiffness (Fig 7) but the analytical results may be more convincing and applicable.

5 DISCUSSION

A researcher in soil mechanics over many years might gloomily consider what if anything of the research output of the past half century has been reckoned sufficiently important to have been universally absorbed into the undergraduate curriculum. An optimistic view that 'critical state soil mechanics' could be a candidate for this accolade has to be rapidly discarded as soon as one conducts an informal survey of text books or syllabi. And by 'critical state soil mechanics' I mean simply the presentation of soil behaviour in terms of effective stresses *and* density. That seems to be the least we might hope to inject into all undergraduate teaching in order to provide a rational basis for many other more complex (and more controversial) topics.

When it comes to the development and implementation of constitutive models to be used in numerical analysis of geotechnical prototypes, almost all the successful models incorporate the concept of asymptotic critical states. The route by which they are attained varies. Armed only with an understanding of the interaction of effective stress and density (Fig 4) many qualitative and quantitative statements can be made about expected pore pressure change and volumetric change and short term and long term strength (Muir Wood 1990). These statements, which do not depend on any particular constitutive model nevertheless give a basis for judging rapidly the plausibility of results that emerge from the computer. Step Zero of numerical modelling is to write down the answer before you start the modelling – if you have no idea what the answer should be you will have no way of judging whether or not the computer is on the right track. A framework for modelling can support this preliminary step.

Boundaries are dangerous from all sorts of points of view. The frontier zone may be neglected because of uncertainties about the boundary location. The boundary may seem so impenetrable that those on each side are confident that their own territory is completely self-sufficient and has no need of the adjacent region. Physical failures occur when there is a failure to appreciate the existence of relevant unknown knowledge. At least in our teaching we should endeavour to break through the boundaries – by on the one hand being prepared to teach across the boundary and create overlapping territory (condominium) and on the other hand developing examples and activities which draw attention to issues which can only be understood through this boundary knowledge. Soil-structure interaction is one such issue.

Considering the overall soil mechanics content of typical civil engineering degree programmes, there are several areas in which the one-dimensional basis needs to be extended. The concepts required for two-dimensional analysis of seepage are already present in the one-dimensional treatment. Resolution of stress (and its application in earth pressure calculation) requires the concept of Mohr's circle. Structural teaching often concentrates on eigen values whereas soil mechanics applications benefit from the geometrical presentation. This is an area where reinforcement can be provided from contrasting approaches. Ideas of frictional strength (and development of simple soil models) can be extended from the one-dimensional introduction. The contention is that, with a thorough one-dimensional grounding in the underlying concepts, the subsequent move to two and three dimensions will be less threatening.

6 CONCLUSIONS

Four proposals have been introduced. There is no particular evidence in support of the benefit to be gained from any of them: they have emerged from several decades of teaching (and thinking about teaching) geotechnical subjects.

First, the potential exists to include introductory soil mechanics teaching at an early stage of an undergraduate curriculum in civil engineering, making use of every opportunity to reinforce understanding of topics that have been or are being met in other courses. So we have introduced overlap topics including stress, gravity, hydrostatics, hydrodynamics, stiffness, solution of partial differential equations, bending of elastic beams, dimensional analysis. These all provide opportunities for reinforcement – perhaps through explicit collaboration with colleagues or perhaps through deliberate espousal of different approaches.

Second, there is an importance of working with (effective) stresses and *density* in describing soil response: the possibility of changes in density during deformation is the key difference between soils and other materials, but this also feeds directly into discussion of short term and long term (undrained and drained) response. Provided the importance of density change is conveyed and understood, there is much common ground between the terms used for describing the behaviour of soils and other materials. This can be seen as the gentle (subliminal) introduction of a little of the framework of critical state soil mechanics at an early stage of the degree programme.

Third, it is important to introduce explicit examples of soil-structure interaction wherever possible in every year of the degree programme. This will usually imply understanding of soil stiffness and concepts of *relative* soil and structural stiffness which are often overlooked or not thought of as relevant by those with an exclusively structural approach.

Fourth, a one-dimensional or single degree of freedom approach to the mechanics of soils is remarkably rich in the range of concepts and applications to which it provides access. Simple thought experiments can be logically described and interpreted and used as the basis for more elaborate development or modification in later years.

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Shaking the Foundations of Geo-engineering Education – McCabe, Pantazidou & Phillips (eds)

Geo-engineering: A co-production of applied earth sciences and civil engineering – 2nd phase

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

1 INTRODUCTION

In 2006, the shift from the five-year programmes to the three- and two-year BSc and MSc programmes respectively has been seized upon as an opportunity to create a MSc in Geo-engineering under the auspices of both Applied Earth Sciences and Civil Engineering. The MSc built upon expertise in engineering geology and geotechnical engineering in view of new societal and technological developments (Ngan-Tillard et al., 2008a). Its programme comprised a total of 120 ECTS. Its 20 ECTS core, common to all geo-engineering students, included subjects that were deemed to be essential for a geo-engineer.

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

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

Geology, Geomechanics, Geotechnical Engineering and Underground Space Technology. Next to them, hybrid profiles can be defined.

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

2 NEW STRUCTURE FOR THE MSC IN GEO-ENGINEERING

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

2.1 *Convergence courses*

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

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

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

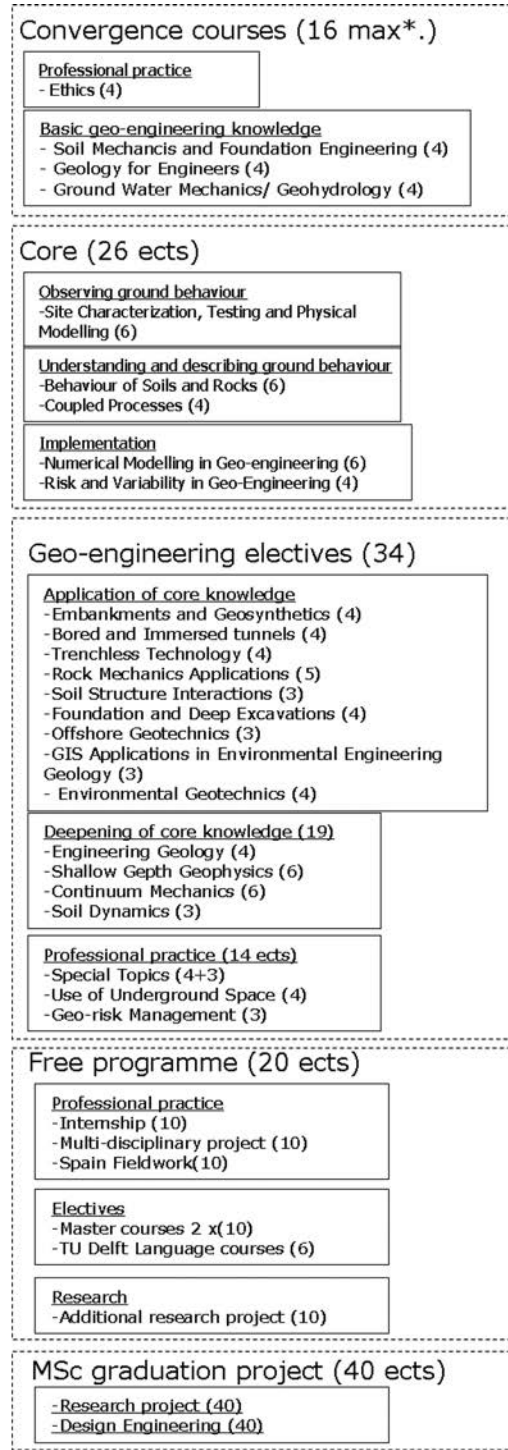

Figure 1. Detailed structure of the MSc programme. The weight of the different programme components and courses is indicated between brackets. *The convergence courses are taken at the expense of the geo-engineering electives.

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

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

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

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

2.2 *The core*

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

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

2.3 *The pool of geo-engineering electives*

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

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

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

2.4 *The free programme (20 ECTS)*

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

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

2.5 *The MSc graduation thesis*

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

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

Conditions to start the MSc graduation work are stricter than in the past to limit the number of students leaving the university after their graduation work without a diploma. Supervision by a multidisciplinary examination committee encourages creativity. Publication of final works in conference proceedings and journals is encouraged. A number of prizes are given by the University and Professional Associations to reward the best MSc graduation theses in civil engineering and geosciences.

3 A FEW HIGHLIGHTS ON THE PROGRAMME

3.1 *Physical modelling*

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

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

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

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

3.2 *Coupled processes in the subsurface*

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

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

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

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

3.3 *Exposure to non technical issues*

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

3.4 *Field exposure*

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

3.5 *Exposure to engineering geology*

Thanks to the new structure, the exposure of civil engineering students to Engineering Geology has increased. The number of participants to Engineering Geology courses has more than tripled. Engineering Geology is present in the Core, as in the 2006 programme, in the Site characterisation, testing and physical modelling course. Engineering geology knowledge is also needed in the new core course on Risk and

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

3.6 *Multi-disciplinarity and flexibility*

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

4 EVALUATION OF THE NEW PROGRAMME

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

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

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

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

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

5 FUTURE PROGRAMME DEVELOPMENTS

5.1 *Internal co-operation*

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

5.2 *International cooperation*

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

5.3 *Re-organisation of the BSc programmes*

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

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

6 CONCLUSION

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

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

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

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Shaking the Foundations of Geo-engineering Education – McCabe, Pantazidou & Phillips (eds)

Rethinking aspects of theory and tradition in soil mechanics teaching

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ABSTRACT: Some basic aspects of theory and tradition in soil mechanics teaching are examined and shown to be deficient. The first is the absence of material on residual soils despite the fact that at least half the world's surface consists of residual soils. The second aspect is the continued use of the e-log(p) plot for representing soil compressibility. This plot leads to routine misinterpretation of the compressibility of both sedimentary and residual soils. The third aspect is the water table and the seepage state above and below it. The water table is not a boundary below which seepage occurs and above which there is no seepage or pore pressure. The fourth aspect is the critical height of vertical cuts in clay. Equations for critical height are presented as though they can be used in practice. This is quite wrong, and a serious matter involving life and death.

1 INTRODUCTION

By way of introduction the following comments are made on university teaching, before moving on to the specific issues addressed in this paper:

(a) There is too much emphasis on methods and too little on concepts and principles. Graduates generally have a fairly good grasp on methods, but a weak understanding of the concepts and assumptions behind these methods This reflects both the natural inclinations of engineers, and the fact that much engineering teaching, especially with large classes, is more akin to "production line knowledge transfer" than true education. This issue has been addressed elsewhere, for example Streveler et al. (2008).

(b) The order in which material is presented in soil mechanics courses is often unsatisfactory. The first lecture should be on the principle of effective stress to stimulate the thinking and interest of students, followed by worked examples using the principle. Clay mineralogy, phase relationships, or classification tests, can be slotted in later in the course.

(c) Universities need to be clear on what they aim to achieve in their courses. "Geotechnical Engineering" and "Soil Mechanics" should not be confused. Soil mechanics is a theoretical discipline, while geotechnical engineering is a practical undertaking, more akin to a profession; it involves many components, including soil mechanics, geology, observation, experience, and a large measure of judgement. The role of universities should be to teach soil mechanics, and to be sure that what they teach is relevant to geotechnical engineering.

The issues addressed in this paper are those the author considers important and which space allows. Others that are of significance include:

(1) determination of the coefficient of consolidation from standard oedometer tests on residual soils. In these soils the rate of pore pressure dissipation is often too rapid for sensible time versus deformation data to be obtained.

(2) the rate of consolidation of small surface foundations on clay. Consolidation in this case is certainly not two dimensional, yet text books or courses seldom address this issue. Graduates tend to apply one dimensional theory to this situation and continue the practice throughout their careers.

(3) the Laplace equation, the Terzaghi consolidation equation, and the general transient seepage equation used in groundwater studies should all be linked, or derived together, to show their common basis and their connections.

(4) the stability situations, namely soil bearing capacity, earth pressure, and slope stability, should also be linked together to bring out their common basis, as well as their differences, especially with respect to the way the safety factor is applied.

2 RESIDUAL SOIL COVERAGE

Half the world's surface consists of residual soils, and yet soil mechanics text books and courses rarely even mention these soils, let alone give adequate coverage of their properties. There was some excuse for this in the past, since soil mechanics grew up in northern Europe and America where sedimentary soils predominate, but surely the time has come when the properties

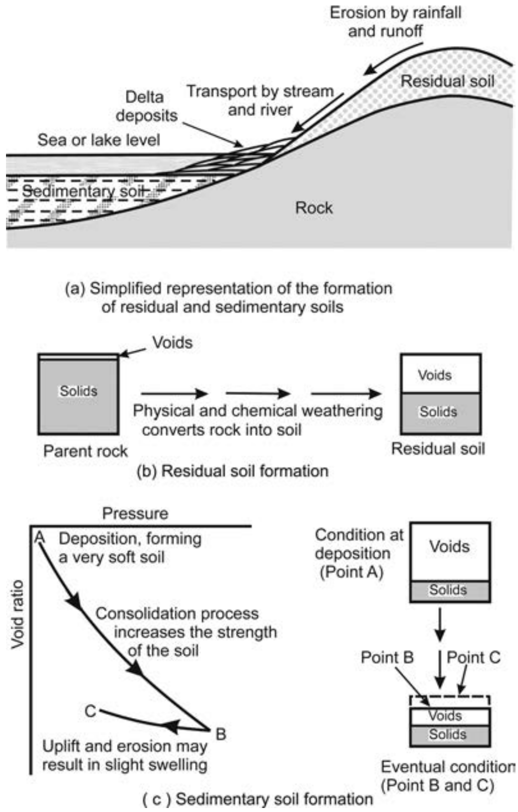

Figure 1. Sedimentary and residual soil formation.

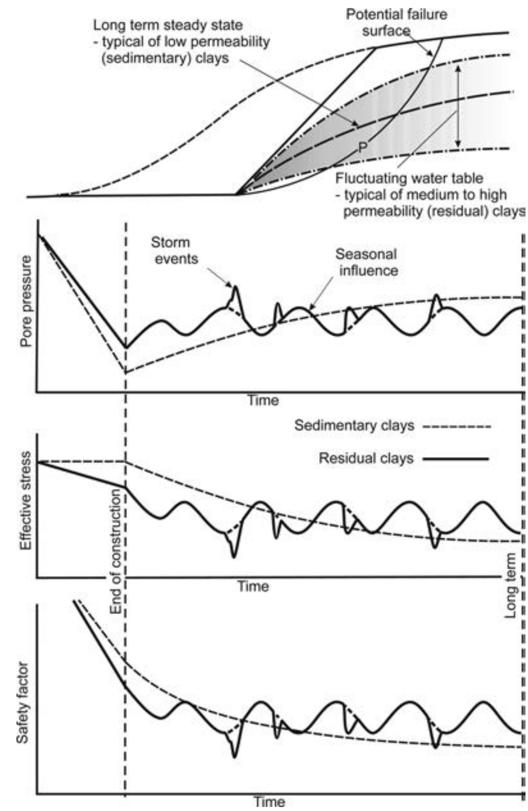

Figure 2. Short and long term stability of cut slopes.

of residual soils should be just as much a part of main stream soil mechanics as sedimentary soils.

In today's globalised world, geotechnical engineers can expect to encounter residual soils sometime during their working life, especially since the most rapidly developing countries today are those in which residual soils predominate. It is surely a cause for concern that in many such countries, soil mechanics courses do not cover residual soils at all, even though the universities in which these courses are taught are surrounded by residual soils on all sides, as far as the eye can see.

Figure 1 illustrates the very minimum that students should be made aware of, namely that the processes forming residual soils are very different to those forming sedimentary soils. Important factors follow from this:

(a) The transport and sedimentation processes of sedimentary soils give them a degree of uniformity and predictability that is missing from residual soils
(b) Stress history and concepts of normal and overconsolidation are irrelevant to residual soils, and there is no such thing as a virgin consolidation line for a residual soil.

Various other important differences follow from their formation method, one of which is that the permeability of residual soils is generally much higher than that of sedimentary soils. This has implications for various aspects of their behaviour, such as the short term and long term stability of excavated cuts.

Figure 2 shows the likely behaviour of residual soils compared with the well known representation for sedimentary soils. It is unlikely that residual soil behaviour will be undrained during construction, as water will flow towards the excavation as it deepens. In addition, there will not be a long term steady state situation, only a transient state reflecting seasonal and storm events. Thus, the challenge for the geotechnical engineer in assessing the long term stability of cuts in clay is very different for the two soils. With sedimentary soils, the challenge is to estimate the long term steady state seepage pattern, while with residual soils it is to estimate the worst possible pore pressure state resulting from a combination of seasonal and storm influences.

3 THE e-log(p) PLOT

The e-log(p) plot is a source of routine misinterpretation of compression behaviour, and it is extraordinary that it is still in (almost) universal use. If there is one "foundation" of soil mechanics that needs shaking virtually to destruction this is it. The author has promoted the use of a linear plot for many years based on experience with residual soils, only to discover relatively recently that Professor Janbu of Norway has

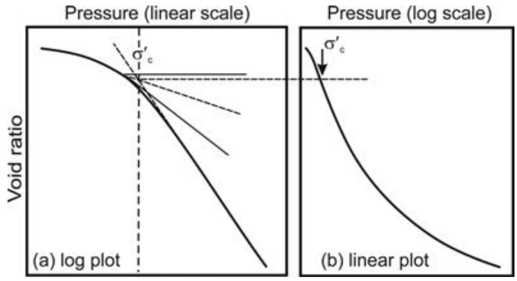

Figure 3. Conventional (log) representation of soil compression behaviour and a linear plot of the same curve.

been doing the same for considerably longer based on his experience with sedimentary soils.

> *"It is very surprising, to say the least, to observe all the efforts still made internationally in studying remoulded clays. If the aim of such research is practical application, it is obviously a total waste of money".*
>
> *"— it remains a mystery why the international profession still uses the awkward e-log p plots, and the incomplete and useless coefficient C_c which is not even determined from the measured data, but from a constructed line outside the measurements —*" Janbu (1998)

Figure 3 shows the standard representation of the compressibility of clay and the method for determining the pre-consolidation pressure, and the same graph re-drawn using a linear scale.

It is immediately apparent that the linear graph shows no evidence of a pre-consolidation pressure; the value inferred from the log plot is purely a result of the way the data are presented. As far as the author is aware, all presentations in text books illustrating pre-consolidation pressures suffer from the same defect as Figure 3.

There are countless examples in the literature of oedometer test graphs from which pre-consolidation or yield pressures have been determined that are completely absent when the data are re-plotted on linear scales. Examples are given in Figures 4 and 5. Figure 4 shows an example from a residual soil found in the southern part of the USA, known as Piedmont soil. Values of pre-consolidation pressure and over-consolidation ratios (OCRs) determined from the log plot are shown in the figure. The data have been re-plotted using a linear scale for pressure; these linear plots show no evidence of yield or pre-consolidation pressures.

For the plot in Figure 4 (and in some subsequent figures), using a linear scale, the compression is shown as strain in percent, rather than void ratio. This is done as it gives an immediate indication of compressibility and enables valid comparisons to be made between the compressibility of different samples or soils. A direct comparison of this sort is not possible using void ratio.

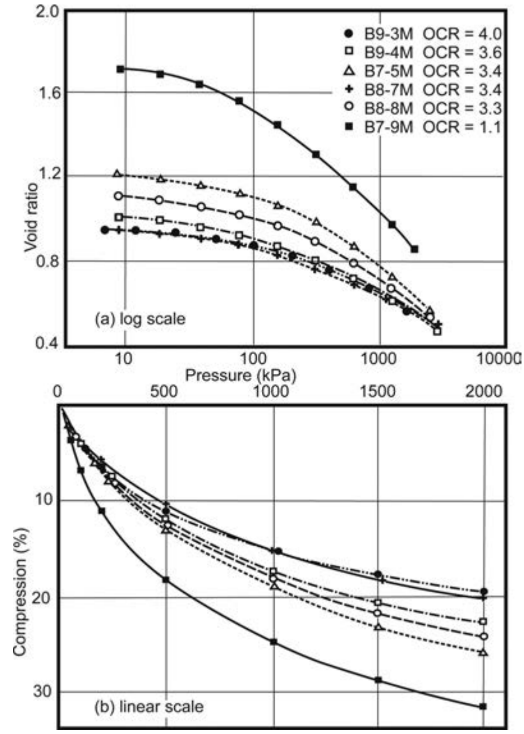

Figure 4. Compressibility of Piedmont residual soil (after Wesley 2000).

From what was said earlier, it is quite inappropriate to be seeking pre-consolidation pressures in residual soils, since their formation does not involve a consolidation process. If residual soils indicate a decrease in stiffness at a particular stress level, this should be termed a yield pressure. Many residual soils do not show a yield pressure at all, but there are plenty that do. Some residual soils derived from the same parent material can even show both types of behaviour, as is illustrated in Figure 5.

The compression curves in Figure 5 are from three samples of volcanic ash clay, again plotted using both scales. This figure also illustrates clearly another defect of the log plot, namely that it conveys the impression that the compression behaviour of all soils is similar. On the log plot the behaviour of the three samples looks similar, with each giving some evidence of a yield pressure. However, the linear plot shows that their behaviour is quite different. Only Sample A shows a clear yield pressure. Sample B shows linear behaviour, and Sample C shows steadily increasing stiffness.

Because of the defects of the e-log(p) graph, as illustrated in the above figures, a more realistic portrayal of soil behaviour is that shown in Figure 6.

This portrayal is intended for the stress range of interest in geotechnical engineering and is appropriate for both sedimentary and residual soils. In both groups, some soils show clear yield pressures, some

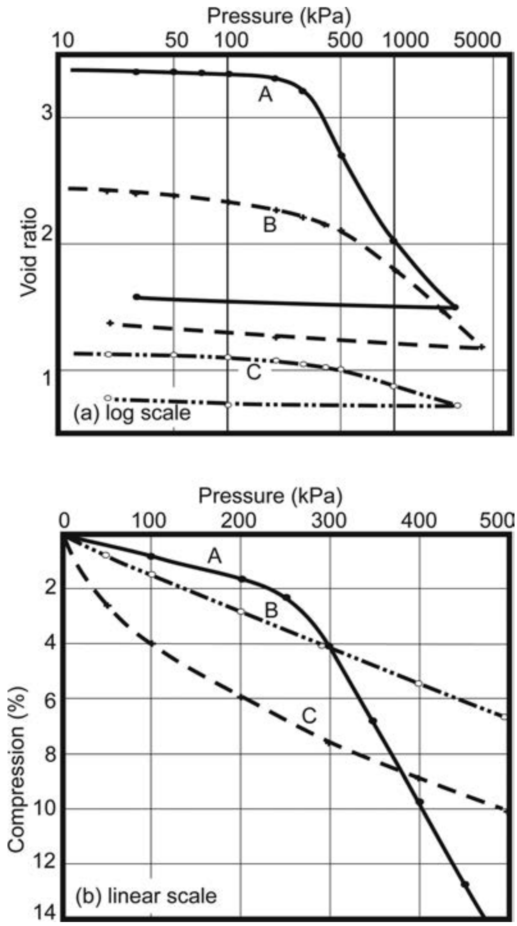

Figure 5. Oedometer tests on three samples of volcanic ash clay (after Wesley 2009).

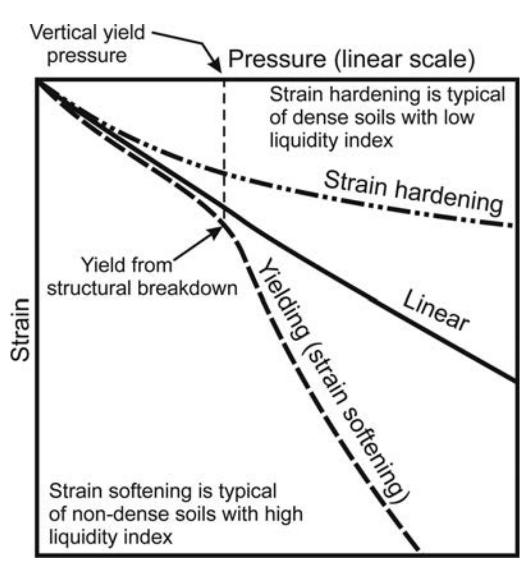

Figure 6. A realistic portrayal of soil compressibility (after Wesley 2010).

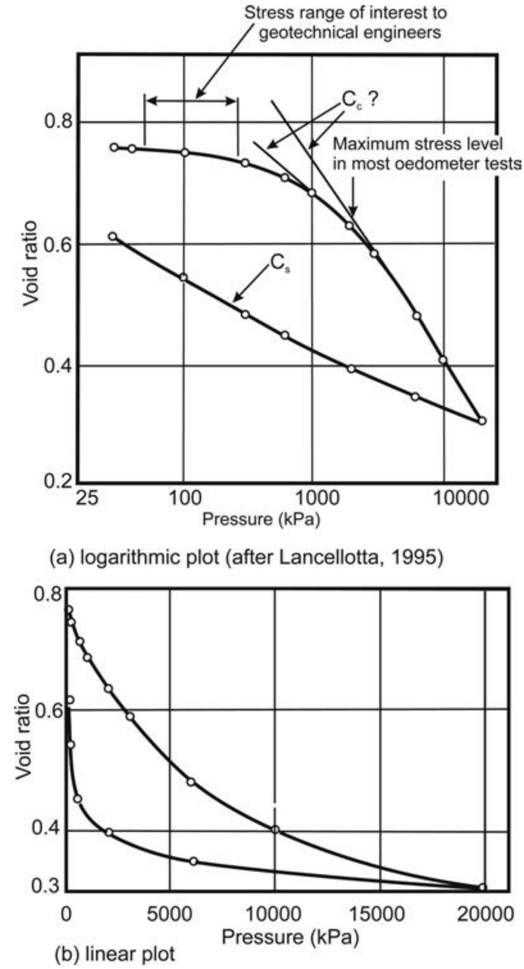

Figure 7. An oedometer test on an over-consolidated clay.

show approximately linear behaviour, and some show strain hardening.

To explain the above behaviour it is important to recognise that compression (or compaction) of a soil has two distinct effects, as follows:

1. Densification: Compression "densifies" the soil by pressing the particles closer together. This generally means a greater number of contact points between particles and a consequent decrease in compressibility.
2. Structure Destruction: Compression also tends to destroy any natural structure found in the undisturbed soil, which weakens and softens the soil.

The resulting compression curve will reflect the relative importance of these two effects. If the influence of densification is stronger than destruction of structure the soil will show strain hardening and vice versa.

Figure 7 illustrates a further defect of the log plot, namely the uncertainty and irrelevance of the parameters associated with it. The figure shows an oedometer test on an over-consolidated clay taken to a high stress level. The log plot seems to suggest a pre-consolidation pressure a little greater than 1000 kPa, but the linear plot shows no evidence of this. The graph suggests a linear section at higher stress levels, and the slope of this section should presumably represent the compression index C_c. However, most oedometer tests are only taken to a stress level between 1000 kPa and 2000 kPa.

A tangent to the curve at these stress levels would produce quite different values of C_c. Except for soft normally consolidated clay, the compression index is both of uncertain value and irrelevant to engineering situations. The meaning of C_c for a residual soil has not been seriously addressed. As originally conceived C_c was the slope of the virgin consolidation line. No such line exists for a residual soil, and C_c seems to be taken as the slope of the tangent to the end of an e-log(p) graph. As such it is of arbitrary value and of no practical use.

The value of the swell index is equally problematic, since the original loading line is clearly not parallel to the final unloading line. The slope of the initial loading line is much flatter than the rebound line. Neither of the conventional log parameters, C_c and C_s determined in the traditional manner has any relevance to a settlement estimate for a building foundation. The part of the curve relevant to such an estimate is likely to be between about 25 kPa and 300 kPa.

4 THE WATER TABLE AND SEEPAGE STATE

Much of the action of interest to geotechnical engineers actually takes place above the water table, especially in residual soils, and yet surprisingly little attention is paid to this regime in university courses, or in text books. Students should be made aware of the very different situation with clay to that with sand. The static situation is illustrated in Figure 8. The important point is that in wet or temperate climates clay remains fully saturated for many metres or tens of metres above the water table, and that it only becomes unsaturated as the result of evaporation at the ground surface, and not because water drains out of the soil under gravity forces.

With coarse grained materials, the situation is very different. In this case, water drains out of the voids under simple gravity forces. As drainage takes place air enters the void space formerly occupied by water, and the soil becomes unsaturated or partially saturated.

The water table (or phreatic surface) is not a boundary separating zones where seepage and pore pressures exist from those where they don't exist; it is simply a line of zero pore pressure.

The conventional portrayal of the seepage pattern in a clay slope may be valid for some slopes, but certainly not all. This point is illustrated in Figure 9, which shows two possible seepage conditions for the same measured water table. The upper graph shows the conventional portrayal, which implies that seepage into

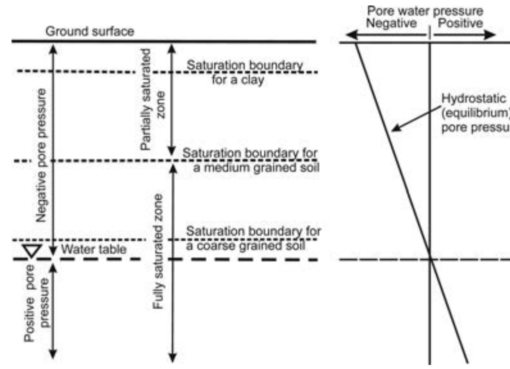

Figure 8. Water table and pore pressure state in the ground.

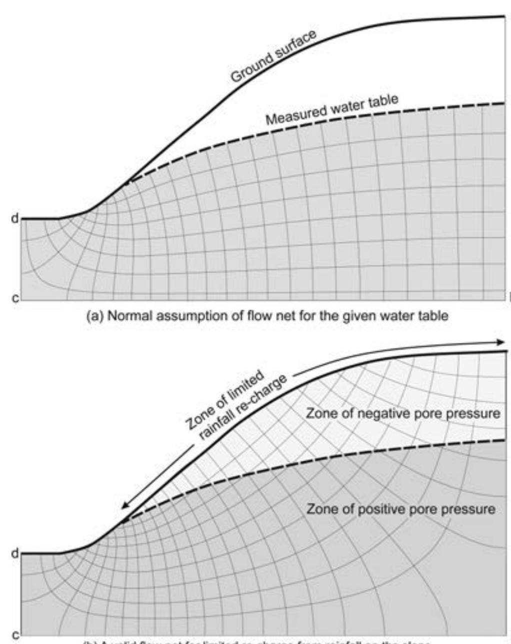

Figure 9. Possible seepage states for the same water table.

the slope only comes from an adjacent catchment. This is somewhat odd, as the rainfall most likely to affect the seepage state in the slope is rain falling directly on the slope itself.

The lower figure illustrates the situation for a symmetrical, double sided hill. In this situation the only source of water to the slope is from direct rainfall, and the seepage pattern is then quite different. The flow net in the lower figure has been obtained using the programme SEEP/W. To obtain a phreatic surface below the ground surface the boundary condition at the surface can either be a negative pore pressure (not realistic in practice) or a rainfall intensity less than the maximum capacity that the ground can accept.

5 STABILITY OF TRENCHES AND VERTICAL CLAY BANKS

Terzaghi once warned against over-reliance on theory with the following statement:

> "*However, as soon as we pass from steel and concrete to earth, the omnipotence of theory ceases to exist. In the first place, the earth in its natural state is never uniform. Second, its properties are too complicated for rigorous theoretical treatment. Finally, even an approximate mathematical solution of some of the most common problems is extremely difficult*" (Terzaghi 1936).

An example of over-reliance on theory is the way in which the maximum height of vertical banks or cuts in clay is described in soil mechanics courses or text books. The formulae normally presented, without warning about their practical relevance, are:

In terms or effective stress:

$$H_c = \frac{4c'}{\gamma\sqrt{K_a}} \tag{1}$$

where K_a is the active pressure coefficient.

For undrained conditions:

$$H_c = \frac{(3.8\,to\,4)\,S_u}{\gamma} \tag{2}$$

where S_u is the undrained shear strength.In the author's experience, the following parameters are typical of many residual clays;

Unit weight – $16\,kN/m^3$, $c' = 15\,kPa$, $\phi' = 35°$ Undrained shear strength = 100 kPa.

Using the formula above the depths obtained are illustrated in Figure 10. Undrained analysis gives $H_c = 24$ or 25 m. This is a nonsensical estimate, as it is quite impossible to imagine a clay bank of this height remaining stable even for a few seconds. Using the formula in terms of effective stress gives $H_c = 7.2$ m, which is still unrealistic. The values using a safety factor of 3 are also shown, and are still hardly realistic.

There is probably no issue in soil mechanics where theory is less useful than this question of vertical bank stability. Many lives have been tragically lost because of the collapse of vertical banks, especially those forming the sides of trenches in which workers are laying pipes or cables. Such collapses have occurred in situations where the above formula would suggest the banks would be stable. Teachers of soil mechanics should make it clear to students that the formulae above are of theoretical interest only. Statements found in text books such as "*for vertical cuts the best solution, and the one that is commonly used in design*" *is*: $H_c = 3.8S_u/\gamma$, are a recipe for tragedies.

Fortunately, agencies that regulate work-place safety have a better understanding of the behaviour of vertical cuts in clay than many authors of text books, and indeed of many geotechnical engineers.

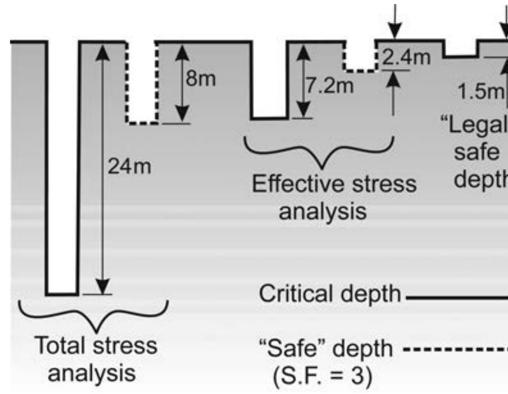

Figure 10. Heights or depths of vertical cuts in clay.

Such agencies normally place a limit of 1.5 m (some use 1.2 m) on the height of vertical banks or depth of trenches where workmen are employed.

This issue of the stability of vertical banks in clay appears to be a prime example of theory being given an omnipotence that is totally unwarranted. It is an interesting and somewhat worrying example, as the problem appears to lie as much with the theory itself as with the vagaries of nature. The author does not have a satisfactory explanation for the divergence between theory and observed behaviour in this case. One possible explanation is the complete absence in the above equations of pore water pressure. There is no doubt that some collapses of vertical clay banks are triggered by rainfall, but it is equally true that even without rainfall, clay banks do not remain vertical for long.

The issue is perhaps also an example of the failure of geotechnical engineers, or text book writers, to observe the behaviour of soils in practice. It is very difficult to find a vertical clay bank anywhere, even with a height of only a few metres. However, high banks of 60° to 75° are not difficult to find, so there seems to be a significant change in the behaviour of steep banks as their inclination is reduced from vertical to about 70°. It may be that a zone of horizontal tension is created in the upper part of steep slopes and this leads to the development of vertical cracks that play a role in initiating the failures.

6 CONCLUSION

Several "foundations" of conventional soil mechanics teaching have been examined, including the e-log(p) graph, the seepage pattern commonly assumed to apply in natural hill slopes, and the formulae for the critical height of vertical clay banks. Quite gentle shaking shows that these are not nearly as technically sound as they are commonly assumed to be.

These examples will hopefully encourage those teaching soil mechanics to address not only the questions of curriculum content and techniques for teaching the content, but also whether various commonly accepted components of the curriculum are in fact based on firm foundations.

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The use of case histories in geo-engineering education

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The use of case histories to encourage reflection by civil engineering design students

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ABSTRACT: The paper considers the use of case histories to promote reflective learning in a final year Geotechnical Engineering elective module. Reflection in action is promoted as a means of simulating the working environment and of encouraging student engagement with advanced topics. An example is presented in which students were provided with a site investigation report and were required to estimate the bearing capacity and in-service settlement of three shallow footings on sand. The student's predictions were compared to the measured footing response and the effects of mean stress level and non-linear soil stiffness were investigated in the context of a real-world design problem.

1 INTRODUCTION

The paper describes the design and implementation of a master's level elective module in civil engineering entitled Soil-Structure Interaction. The course was designed to incorporate the best features of Enquiry Based Learning (EBL), Boud (1985) and Kolmos et al. (2007) with the background technical content delivered through formal lectures. The class is scheduled 50% in a formal lecture space and 50% in the civil engineering project rooms located in the University College Dublin (UCD) Newstead building. The learning outcomes state that students should (i) be proficient in the design of foundation systems for unusual structures, (ii) choose suitable models and input parameters and (iii) be capable of incorporating improved models developed in the latest state of the art research in order to improve predictive reliability. It develops on theories of soil mechanics learned in core modules of 3rd year soil mechanics and the general design skills developed for civil engineers in 4th year design in Soils.

A key element is the use of worked examples to illustrate the use of design approaches and case studies (workshops) to verify the accuracy and identify the critical parameters to be chosen by the designer. The problems are based on full-scale experiments and case histories and after grading student predictions, a review session is held in which the students can compare the answers they predicted to the actual results. In each workshop the students begin by applying some of the conventional design approaches used in industry. The input parameters for these models are somewhat subjective and they gain experience in both choosing these and then seeing what effect their choice had on the accuracy of their predictions. By comparing predicted and actual responses the use of improved models of soil behavior being developed by current research are introduced in context.

2 ENCOURAGING REFLECTION

2.1 *Defining reflection*

Refection in education can be defined in many ways. In this paper the design of a module which aims to provide students with a means of reflecting on the practice of geotechnical engineering is described. The philosophical basis for this notion was first suggested by Dewey (1922) who contrasted the inertia associated with education, wherein the knowledge transmitted is the known orthodoxy, to the dynamic developments taking place at the time in the development of steel cantilevered bridges. He suggested that custom (orthodoxy) unmodified by thought, would not have produced these developments in practice. Schon (1983, 1987) suggests that in practice, Engineers reflect in action, using skills which cannot be taught in the classroom or laboratory but in the design studio. This support of social constructivist theory is dependent on some core principles being available to the student, and strongly suggests that a mixture of pragmatism (state of the art) and constructivism present appropriate models for engineering education.

2.2 *Enquiry Based Learning*

Enquiry Based Learning (EBL) is becoming a very popular form of undergraduate teaching (Boud 1985, Savin-Baden 2000, Kolmos et al. 2007). EBL provides an opportunity to develop many of the graduate attributes (outcomes) required by employers and accreditation bodies, these include; teamwork, problem-solving and leadership skills, within a framework where the student accepts control of what needs to be learned and how it should be learned. EBL provides opportunities for deep learning and introduces the students to resources and skills necessary for lifelong learning. Well designed courses satisfy many of the objectives (learning outcomes) specified by accreditation bodies. However, in engineering, where the accumulation of core principles is hierarchical, missing essential concepts may result in a failure to learn. Whilst the development of meta-cognitive skills will result from EBL, the risk of missing vital concepts and theories suggests that EBL should be used as partial solution to develop professional problem solving skills through the application rather than the acquisition of knowledge.

2.3 *Issues affecting geotechnical engineering*

Atkinson (2002) notes that in the relatively recent past civil engineering graduates learned the theories of soil mechanics at University and joined firms as trainees. Working under licensed agreement, this on the job training prepared the graduate for chartered membership. However, in recent years there has been a move from industry to try to move this training into the University, such that graduates have the capability to earn money from their first day of employment. He argues (somewhat compellingly) that Universities should teach theories and that practice is learned in the work place. However, experience of using real-life design problems in the class room undoubtedly raise student interest. Because of the recent expansion of undergraduate courses in Ireland from four to five years, an opportunity exists to integrate some design work which reinforces the core theories. We must however recognise that the primary role of the University is to produce critical thinkers and any such move should to ensure that relevant theories are embedded in student learning through appropriate teaching methods spread across the curriculum. Any move to move towards vocational training would be a shift away from the principles of Dewey (1922) who considered the issue of education as a means of training faculties or acquiring skills. Whilst recognising the importance of training in certain professions, he cautions that the method of achieving any such training should be through the growth and development of the individual, rather than by the training of some specific reflex action akin to the physical training undertaken by a gymnast or swimmer. Instead he argues that the purpose should be that the process of education will develop the capacity for further education.

3 MODULE ON SOIL-STRUCTURE INTERACTION

3.1 *Background*

As an example of an attempt to promote reflection-in-action in a traditional classroom setting a module in Soil-Structure Interaction (SSI) was developed for the new Masters programme in Civil Engineering at University College Dublin (Gavin 2011). The course which ran for the first time in January 2010, considers the interaction of structures with the ground. It is an optional module with a current enrolment of 35, 4th and 5th year students.

Each week there is one 3 hour class. The first 1 to 1.5 hours is a formal lecture. The remainder of the class is a workshop session. The majority of these sessions involve the students (working in groups of 2–3) undertaking a design assignment (for example estimating the load at which a foundation will fail, or the settlement of a structure). The problems are largely based on full-scale experiments from the literature.

The problems are chosen to demonstrate some weakness in the current theories (that are conventionally taught at undergraduate level and contained in most reference texts), for example the use of conventional earth-pressure approaches to estimate the shaft capacity of driven piles. Having demonstrated potential deficiencies or problems with the application of these methods, the use of improved models developed as a result of up to the minute research is presented. Whilst these address some of the deficits evident in existing theories, the limitations of the new models are also illustrated and discussed. The real objective in introducing these techniques is not as new improved models per-se rather to illustrate that the state of the art is constantly evolving. An important outcome is to encourage students to develop a scientific scepticism of some of the accepted knowledge. In this way it is hoped that they might be more open to question this and develop alternative, hopefully improved solutions.

3.2 *Example problem*

An example problem aimed at promoting reflection-in-action is described in this section. The students who will have learned traditional bearing capacity approaches for shallow foundation design and simple settlement analyses in basic soil mechanics courses are given a problem on the design of shallow foundations on sand. They are presented with an overview of the soil stratigraphy for a site, which comprises a 7.5 m layer of sand overlying clay. The water table is at 4.9 m below ground level (bgl.). field and laboratory test data including Standard Penetration Test (SPT) N values, Cone Penetration Test (CPT) q_c values (see Figures 1 and 2) and laboratory test data is provided.

The students, working in pairs are asked to:

(i) Calculate the ultimate bearing resistance of a 1.5 m, 2.5 m and 3 m wide foundation founded at 0.75 m bgl.
(ii) Estimate the settlement of the footings at the working load, and
(iii) Estimate the mobilised resistance when the footing settlement is 25 mm.

The students submit their predictions and in the class the following week, their predictions are

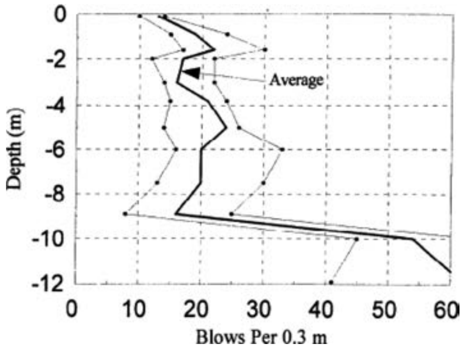

Figure 1. SPT Profile at site (after Briaud and Gibbens 1999).

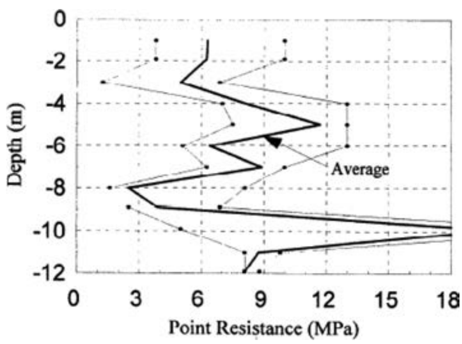

Figure 2. CPT q_c profile at site (after Briaud and Gibbens 1999).

compared to the actual foundation response thus providing the opportunity for meaningful reflection.

3.3 *Predicted response*

As noted, in introductory soil mechanics courses the students will have performed text book problems on applying the traditional bearing capacity approaches for estimating the ultimate bearing resistance of foundations and simple linear elastic approaches for estimating footing settlement, including the widely used equation:

$$\text{Settlement} = s = (\pi/4)qB\,(1-\upsilon^2)/E'_s \qquad (1)$$

The main input parameters needed for them to apply these familiar models to this problem are therefore the soils friction angle (ϕ') for the bearing capacity equation and the secant elastic stiffness (E'_s) for settlement estimation. The first lecture on the soil-structure interaction course concentrates on how to choose soil properties from site investigation data. Using this knowledge students estimate constant volume and peak friction angles based on material properties, relative density and the mean stress level applicable to the bearing capacity problem. They usually estimate the secant stiffness using some correlation with in-situ test data e.g. SPT N of CPT q_c. One of the first challenges they face in choosing design values for their parameters is considering the zone of influence of the foundations and dealing with the inherent variability in the measured data. To help in this process graduate demonstrators are provided to give guidance when requested.

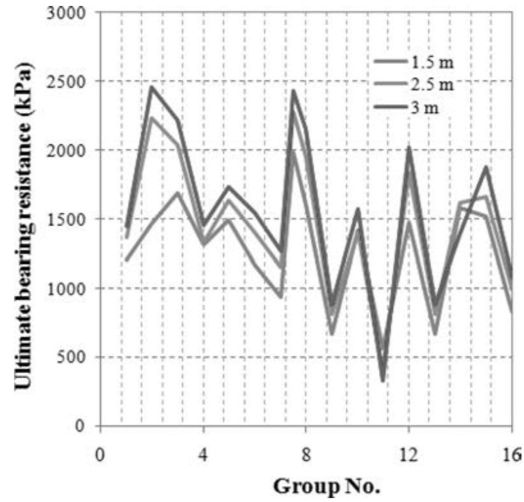

Figure 3. Estimates of the ultimate bearing resistance of shallow foundations on sand.

Eighteen groups undertook predictions in the first year the module was offered. The range of predictions of the ultimate bearing capacity for the three foundation widths considered is shown in Figure 3.

The following points are noteworthy:

(i) Although all groups used the same bearing capacity, shape factors etc, provided in a review sheet, their predictions for the ultimate bearing resistance (q_{ult}) were characterised by large scatter. In the absence of error in the calculations, this scatter is largely due to variability in the choice of ϕ' used in the calculation. This is as a result of assumptions made in the zone of influence (i.e. some groups used the same ϕ' value in all calculations) or variations in the level of dilation induced increase in ϕ' which were included. For example the predicted q_{ult} ranged from 380 kPa to 2475 kPa for the 3 m wide footing.

(ii) The predicted ultimate resistance increased as the footing width increased – one exception being the estimate by Group No. 11 of the q_{ult} value of the 3 m wide footing. This calculated value contained an error.

The estimates of settlement at working stress level are shown in Figure 4. All groups estimated the footing settlement using Eqn. 1 with some also using Burland and Burbridge's (1985) method as an alternative. The predictions are again characterised by large scatter with estimates of the initial settlement of the 1 m wide footing ranging from 5 mm to 25 mm, and for the 3 m wide footing from 10 mm to 62 mm. Part

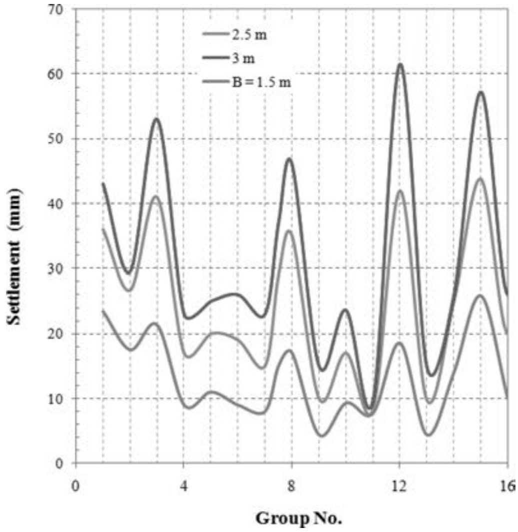

Figure 4. Estimates of settlement at working stress level.

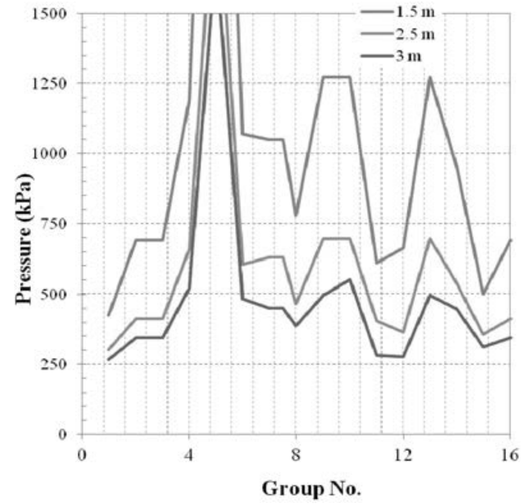

Figure 5. Estimates of mobilised pressure at a footing settlement of 25 mm.

of the reason for this scatter was a result of the definition of working stress, which groups took to be their q_{ult} value reduced by a factor of 3. Of the other input parameters used in the settlement model used by all groups, the same Poisson's ratio and shape factor were adopted by most groups. In practice the most uncertain parameter in this expression is the secant modulus, E'_s all groups used correlations between E'_s and SPT N or CPT q_c (of the form shown in Eqn 2), however, these simple correlations vary with the stress history of the deposit. Some groups assumed that the sand layer was over-consolidated and therefore assigned a much higher E'_s for the sand.

$$E'_s \approx 2500\ N_{60} \text{ or } 5\ q_c \text{ (kPa)} \tag{2a}$$

(in aged over-consolidated natural cohesionless soils)

$$E'_s \approx 750\ N_{60} \text{ or } 2\ q_c \text{ (kPa)} \tag{2b}$$

(normally consolidated, unaged soils)

In the final part of the problem, the students were asked to estimate the applied pressure mobilised for the three footing when the settlement was 25 mm. These estimates were readily obtained by rewriting Eqn. 1 for a fixed footing settlement of 25 mm. The estimates shown in Figure 5 exhibit the lowest variability between groups. With the exception of Group 5 who made an error in their calculations as their predicted mobilised pressure exceeded their estimate of q_{ult}, the ratio between the lowest and highest predictions was ≈2.5.

As the only variable input parameter in this calculation was E'_s and groups tended to favour the use of CPT data, is clear that groups who assumed the material to be over-consolidated assumed $E'_s = 5q_c$, whilst other used $E'_s = 2q_c$, thus explaining the relatively narrow range of predictions.

3.4 *Comparison of measured and predicted response*

The pressure-settlement response measured during load tests on the three foundations are shown in Figure 6a. The bearing resistance mobilised by footings was in the range 1100 kPa to 1400 kPa. The smallest footing (1.5 m diameter) developed the highest resistance and stiffest pressure-settlement response. Briaud (2007) compared measurements made at this site with a database of other footing tests and noted that when the footing settlement was normalised by the footing width, and the applied pressure was normalised by strength measurements from in-situ tests (i.e. the limit pressure measured in a pressuremeter test) a unique load settlement curve resulted.

Gavin et al. (2009) used the CPT q_c as the in-situ test for normalisation and produced the normalised pressure-settlement response for the test site shown in Figure 6b. They proposed the use of a definition of ultimate resistance which corresponds to the mobilised resistance at a normalised settlement of 10% of the footing width. They compared the footing tests shown in Figure 6b with a wider database of tests performed on model and full-scale foundation tested in a range of sand densities and found that the resistance mobilised at 10% settlement ($q_{0.1}$) could be conservatively estimated using the expression:

$$q_{0.1} = 0.2\ q_c \tag{3}$$

Using Eqn. 3 to provide an estimate of the *measured* ultimate resistance based on average CPT q_c within a zone of influence of the foundation results in q_{ult} values of 1400 kPa for the 1.5 m footing (which is in agreement with the measured values in Figure 5), 1375 kPa for the 2.5 m and 1560 kPa for the 3 m wide footing.

Comparing these to the values predicted using the traditional bearing capacity approach in Figure 3

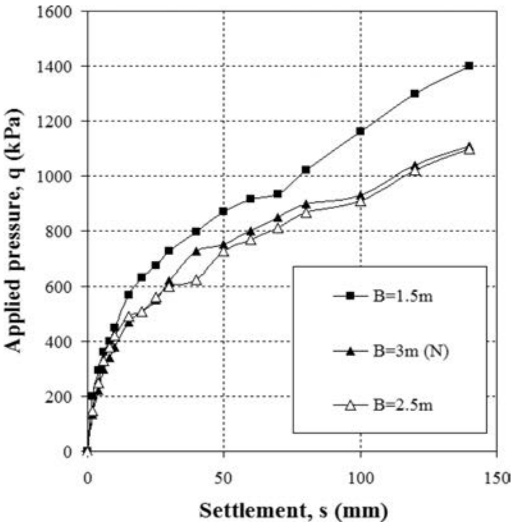

Figure 6a. Measured pressure-settlement response of footings.

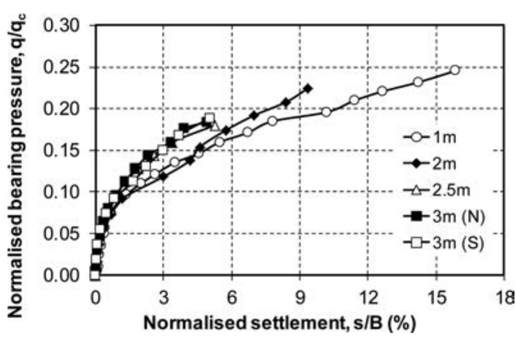

Figure 6b. Normalised pressure-settlement response of footings.

shows the *measured* values to be broadly compatible with the average values predicted, with ratios of predicted to measured q_{ult} being 0.93, 1.09 and 1.03 for the 1.5 m, 2,5 m and 3.0 m wide footings respectively. The traditional bearing capacity approach slightly underestiated the resistance of the smallest footing and slightly over-estimated the resistance of the larger footings. This trend arises because the mean stress level in the lightly over-consolidated sand deposit considered is relatively constant over the zone of influence considered for the three footings. The trend for the bearing capacity equation to predict increasing resistance for increased vertical effective stress, footing width and footing depth is of concern in deposits where the soil strength does not vary with depth.

The close agreement between the normalised footing response (at a footing displacement of 10% at this and other sites) and the bearing pressure which is predicted using Eqn. 3, suggests a simple correlation between in-situ test results is a good alternative to traditional bearing capacity approaches in the design

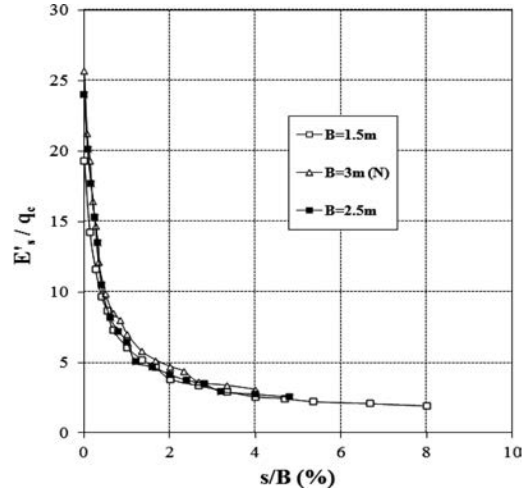

Figure 7. Normalised stiffness response of footings.

of shallow foundation. During the review session reference is made to the work of Briaud (2007) which questions the applicability of bearing capacity theory for soils where the soil strength does not increase with depth.

It was already noted that variability evident in the students' predictions for part (ii) of the problem, the footing settlement at working stress level (See Figure 3) were affected in part by their by their estimates of the ultimate bearing resistance. The groups used Eqn. 2 to derive stiffness values of between $2q_c$ and $5q_c$. These constant stiffness values were then used in part (iii) to calculate the bearing pressure when the footing settlement was 25 mm (See Figure 5). The bearing pressure mobilised at this displacement was between 550 kPa (for the 2.5 m wide footing) and 650 kPa for the (1.5 m wide footing). Predictions for the 2.5 m wide footing varied from 300 to 700 kPa, with an average of 518 kPa being just slightly lower than the measured value. For the 1.5 m wide footing, the predicted bearing pressure varied from 425 to 1275 kPa with an average of 890 kPa, i.e. a 37% over-estimate. This indicates that the soil stiffness was over-estimated for the smallest footing.

The adoption of a constant stiffness value results in a family of pressure-settlement prediction profiles (for varying footing widths) which are linear. This obviously does not agree with the highly non-linear measured footing response evident in Figure 5. The actual variation of stiffness normalised by the CPT q_c value is shown in Figure 7. From this figure it is clear that the E'_s value of $5q_c$ is applicable for one unique normalised settlement (strain) level of approximately s/B = 1.5%, while the E'_s value of $2q_c$ applies only at very large normalised settlement levels (>6%). For a fixed footing settlement of 25 mm and varying footing widths of 1.5 m, 2.5 m and 3 m, a variable stiffness must be chosen if using a simple settlement model such as Eqn 1. For the 3 m wide footing, the normalised settlement is 0.83% (i.e. 25 mm/3 m) and from Figure 6 an E'_s value of $7.5q_c$ could be adopted. For the 1.5 m wide footing the normalised settlement is 1.66% (25 mm/1.5 m) and from Figure 6 it is clear that the mobilised E′s is $<5q_c$. This simple exercise highlights the importance of considering the non-linear stiffness response of soils, and illustrates how, through the judicious choice of stiffness values, complex soil behaviour can be modelled using relatively simple techniques including Eqns 1 and 3.

4 CONCLUSIONS

The paper presents an example of the use of a case study from the literature in an effort to promote reflective learning in a final year course in geotechnical engineering. Simple design problems are presented to the students in a format similar to how they would be encountered in industry. In the first session students chose soil parameters from site investigation reports and applied standard design models to estimate footing resistance and settlement. In a follow-up session predictions were compared to actual footing response and trends such as (i) the effect of mean stress level on the mobilized bearing resistance and (ii) the non-linear stiffness response of soils are introduced in the context of real world design problems. In later problems the students used the non-linear stiffness models in preference to simple linear-elastic approaches as they recognised their advantage.

The introduction of weekly case study problems encouraged student engagement with the topics covered and promoted self-learning. As a result the workshop and tutorial sessions provided an enjoyable educational environmental where detailed discussion on the practical application of soil mechanics principles tool place, promoting learning for students, post-grad demonstrators and staff members alike.

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Teaching the importance of engineering geology using case histories

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ABSTRACT: Geotechnical case histories have been traditionally published in geotechnical conferences and journals as a way to share knowledge and experiences between academics and practitioners. This paper presents our recent experience with the use of failure case histories in graduate coursework as a teaching tool to make students develop an intrinsic understanding and recognition of the importance of geology in civil engineering, and to motivate students into the subject of Engineering Geology. Two tunnelling case histories with a deficient initial characterization of geology are discussed: one involving a tunnel failure in an urban environment, and another one involving extremely difficult tunnelling conditions that produced huge time and cost overruns. Our experience shows that case histories are an effective tool for effective teaching and learning in civil engineering curricula.

1 INTRODUCTION

Geology and engineering geology are important aspects of civil engineering design and construction. In that sense, for instance, Burland (2007) states that the most important decisions in a construction project are always founded on a good geological profile, and that most errors originate from a deficient knowledge of the characteristics of the ground. Unfortunately, however, it is common that not enough attention is paid to the importance of geology in engineering curricula. For instance, students are often only concerned with 'the parameter' (i.e., 'the number') that they need for their computational or analytical model, and it is common that there is not an adequate consideration of the specific characteristics of the soil or rock where the project is located. This is illustrated in Figure 1, where different areas of 'expertise' for students and practitioners with different training are shown.

Such 'lack of interest' for geology not only happens among civil engineering students who, in Peck's words, are unfortunately "led to believe that theory and laboratory testing constitute the whole of soil mechanics" (DiBiagio and Flaate, 2000) but also in practice, as in "too many cases in the past geology has been neglected" (Legget, 1979). For that reason, we believe that geotechnical teachers have an important challenge to demonstrate to their students the importance of engineering geology for the success of a specific project. The aim should be teaching methodologies that *motivate* the student in relation to the importance of geology in civil engineering. Ideally, we would aim to develop "intrinsic" motivation or, in Newstead and Hoskins (2003) terminology, motivation for "personal development", since we feel that such type of motivation is more likely to remain with time during their career.

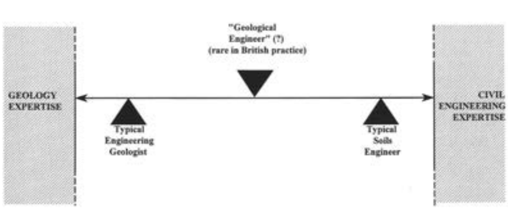


Figure 1. Areas of expertise based on training (Fookes, 1997).

We study the use of geotechnical engineering *case histories* in graduate coursework to develop such intrinsic understanding and recognition of the importance of engineering geology. Case histories can "make a rich learning experience" (Beaty, 2003) and they are, of course, often used in teaching as 'informal' discussion or examples, or as an introduction to a new topic. However, despite the inclusion of specific coursework into some geotechnical programs (see e.g., the "Case Histories in Geology Engineering" coursework in the MSc program at Imperial College London), their use as a "systematic" teaching methodology, from "identifiable needs" such as the appreciation of the importance of geology to "predictable outcomes", and with a planning sequence that incorporates a feedback loop (D'Andrea, 2003) is probably not so common in civil engineering programs.

For that reason, case histories and case studies can be employed to increase the student's 'experience toolbox'. Such case histories should not be limited to a simple problem statement, but they should incorporate deeper geotechnical aspects such as the analysis of the origin of the geotechnical problems, their evolution during construction and, if available, the adopted solutions. Access to such information is made easier by the involvement of the teacher in the project. In that case, one of the objectives of the lectures would be to "transfer" the teacher's own experience (Isaac, 1982). This is in agreement with Bonifazi (2003), who also indicates that study programs should include time for presentation of selected cases, specially those in which the teacher has participated.

Despite the primary interest of case histories in which the teacher has had a close involvement, however, there are situations (due, for instance, to lack of experience in young lecturers or to the specific interest of a project that is well presented in the literature) in which it is advisable to resort to published case histories. Case histories have been traditionally presented in congresses, conferences, and professional meetings such as, for instance, the *International Conference on Case Histories in Geotechnical Engineering* Series. Geotechnical journals also publish case histories on a routine basis, and an international journal entirely devoted to case histories has been recently launched (see the *International Journal of Geoengineering Case Histories* at http://casehistories.geoengineer.org).

In this paper we present our experience with the use of case histories to illustrate the importance of geology for civil engineering and, in particular, for tunnelling projects. More specifically, we present our experiences with the use of case histories as a teaching tool in a 3 ECTS module entitled "Reliability of geotechnical designs" in the MSc program of "Structures, Foundations, and Materials" at the Technical University of Madrid (UPM). The aim is to make students realize that engineering geology is crucial for the identification of failure modes in reliability analyses so that, no matter how advanced or sophisticated our calculation models are, "… if at the very start the geological structure of the site is misinterpreted, then any subsequent […] calculation may be so much labor in vain" (Glossop, 1968).

As we will show, case histories represent a viable approach for teaching and learning the importance of engineering geology. We start with a brief description of the importance of case histories in common geotechnical practice, and we continue with a discussion of two case histories in which geology had an important influence on tunnel behaviour and that were employed in the coursework mentioned above. Finally, the learning outcomes achieved and the results of a survey conducted among the students are discussed.

2 CASE HISTORIES AND ENGINEERING JUDGEMENT

As indicated by Burland (1987), geotechnical materials are completely different to those employed in other fields of civil engineering. For instance, concrete or steel are *manufactured* and *designed* with production specifications and property requirements. On the contrary, Terzaghi (as quoted by Goodman (1999)), warned us that "soils are made by nature and not by man, and the products of nature are always complex", and that "natural soil is never uniform", with its properties changing "from point to point while our knowledge of its properties are limited to those few spots at which the samples have been collected". Furthermore, this has consequences on our computed results, since "in soil mechanics the accuracy of computed results never exceeds that of a crude estimate, and the principal function of theory consists in teaching us what and how to observe in the field".

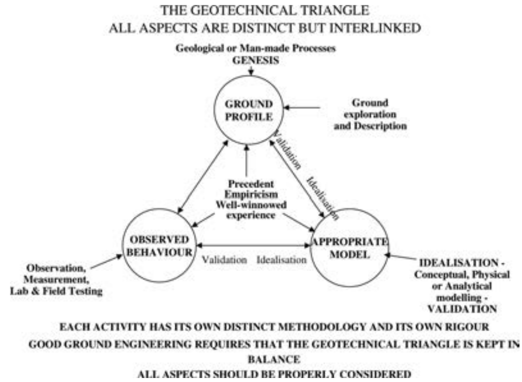


Figure 2. The geotechnical triangle (Burland, 2007).

The discussion above emphasizes the importance of geological and geotechnical investigations, with the objective of defining, *for that specific project*, what materials are going to be found, what are their inherent properties, and how they are going to respond in that particular case. Obtaining such information, however, is not always feasible, and the geotechnical design has to rely to some extent on *experience* and *engineering judgement*, so that, as stated by Peck "the successful practice of engineering requires a high degree of engineering judgement" (see DiBiagio and Flaate, 2000).

One further example of the importance of experience in geotechnical practice is illustrated by Burland's "Geotechnical Triangle" (Burland, 2007). As shown in Figure 2, there are three crucial aspects that need to be considered *in a balanced manner* for a good geotechnical design: the "Ground Profile"; the "Observed behaviour"; and an "Appropriate model". Note that *experience* plays a crucial role in the design process—'in the center' of the triangle—, so that judgment should be based on "precedent empiricism" and "well-winnowed experience".

We must note, however, that such experience and engineering judgement are not inherent to humans (i.e., we are not born with them); therefore, *we need to develop them*. One way is, of course, by 'passive' learning during our professional practice. Unfortunately, "one engineer in one lifetime can hardly be exposed to enough experience to develop all the judgment needed" (Peck, 2004). In addition, in relation to case histories related to 'failures', it is always a good idea to *learn with the mistakes of others*.

For those reasons, we can also use case histories to help develop engineering judgment during a student's education, so that the paradigm of teaching and learning 'from experience' from case histories and case records appears as a viable method for undergraduate and, perhaps more importantly, for graduate teaching. In fact, this approach has been previously employed in the classroom and discussed in meetings of Teachers of geotechnical subjects (see e.g., the work of Lings discussed in the MTGS meeting series as reported in http://www.dur.ac.uk/d.g.toll/mtgs/mtgs91.html.)

3 DESCRIPTION OF THE COURSE

The case histories presented in this work have been employed as a teaching tool in an 'optative' graduate course, entitled "Reliability of geotechnical designs" (offered at UPM) Because it is an 'optative' subject, the number of students is usually small; in previous years it has ranged between 6 and 15 students.

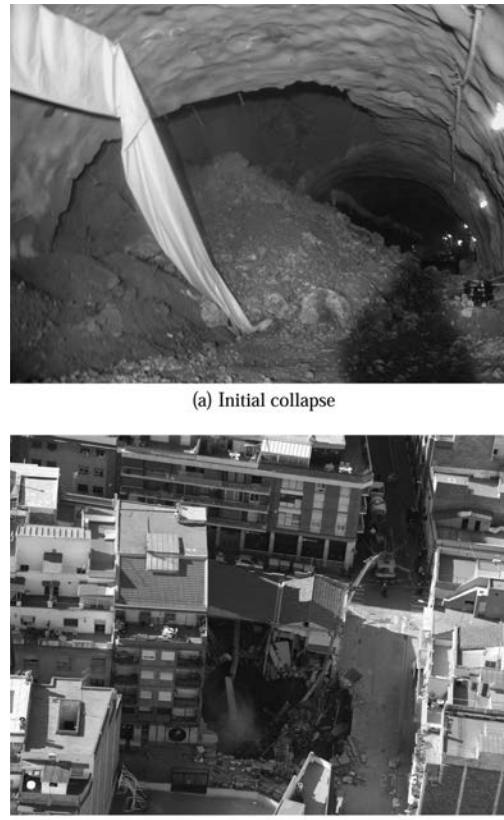
The course has a total amount of 3 ECTS. The instructor's presentations related to the case histories discussed herein take a total of approximately 1,5 contact hours. Students are further requested to work independently on the Yacambú-Quíbor case history (see below), to review the paper and to write a short essay with a summary and with their personal opinions and thoughts about it. This is estimated to take, approximately, an additional 4 hours of the student's time. Furthermore, in this course, the case histories discussed herein also serve as an 'example' from which students can build to broaden the scope of discussion. In particular, students are asked to work independently to prepare and deliver a short presentation (of approximately 10–15 minutes) in relation to other geotechnical 'failure' case histories, where the term 'failure' is employed in a broad sense, to indicate "cases in which performance was not 'as expected' during design".

As general objectives of the "Geotechnical Reliability" course, we have: (i) to familiarize the student with the important aspects of geological and geotechnical characterization under conditions of uncertainty; (ii) to quantify the effects of such uncertainty on the 'success' of geotechnical designs (i.e., failure probability); (iii) to calibrate geotechnical models and parameters given performance observations in a context of uncertainty; and (iv) to incorporate such uncertain inputs and observations into decision making and risk analyses.

4 LEARNING THE IMPORTANCE OF GEOLOGY THROUGH CASE HISTORIES

4.1 *El Carmel tunnel*

El Carmel tunnel collapse in Barcelona occurred in early 2005, and had huge economical and political consequences. The collapse started as a relatively small sized failure that, despite efforts for stabilization, progressed upwards destroying and heavily damaging some buildings at the surface. Figure 3(a) shows a photograph from the inside of the tunnel taken shortly after the initial failure; and Figure 3(b) illustrates the consequences of the collapse on the surface.



(a) Initial collapse

(b) Surface collapse

Figure 3. El Carmel tunnel collapse.

The tunnel had a cross section of (approx.) 100 m^2 and was being constructed with the NATM tunnelling method in a Carboniferous sandstone and microconglomerate formation that was overlaid by (unconformable) Quaternary materials and anthropic fills. Its alignment was quasi-parallel to one closeby station that, despite its significantly larger cross section, had been previously constructed without non-standard difficulties. The auxiliary tunnel was mainly designed using geological information related to the design and construction of the station and, unfortunately, very limited geological information about the new auxiliary tunnel location was available.

After the collapse, a forensic team with members from the Technical Universities of Madrid and Catalonia (UPM and UPC) was set up to investigate the causes of the collapse. (The first author was involved in the work of the UPM team.) The details of the analysis, that included geological and geotechnical investigations (boreholes, geophysics, an exploration

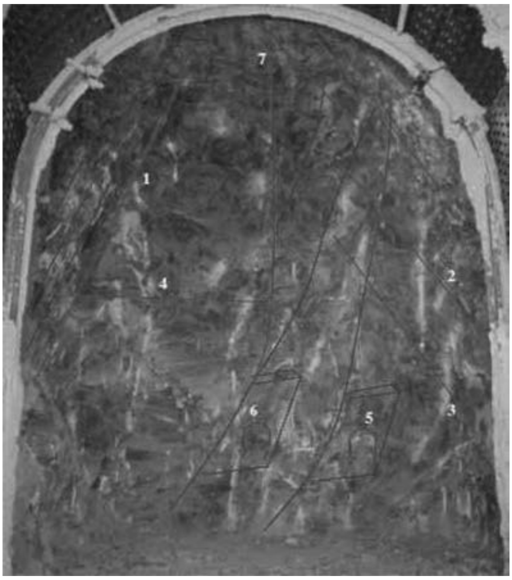


Figure 4. Aspect of the fault zone as observed in the exploratory adit.

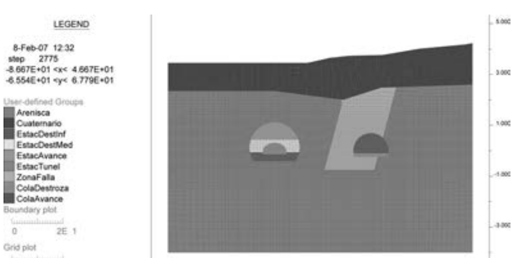


Figure 5. Representative cross section at the location of failure (Jimenez et al., 2008).

adit, in-situ and laboratory tests, etc.), will be presented elsewhere but, in summary, the conclusions were that (in addition to other construction and organizational factors) the presence of *an unanticipated fault zone was the main cause for the collapse*. Figure 4 shows a photograph of the fault zone as intersected by the exploratory adit; whereas Figure 5 shows a cross-section (representative of the position where the collapse started) of the FLAC model developed for the numerical analysis and that illustrates the positions of the auxiliary tunnel, of the tube station, and of the fault-zone.

4.2 *Yacambú-Quíbor tunnel*

The Yacambú-Quíbor tunnel in Venezuela illustrates how a case history from the literature can be employed to emphasize the importance of geology in underground constructions. It is a 23.3 km long hydraulic tunnel with (approx.) 4 m average internal diameter and a rock cover of up to 1270 m that has been considered by many as "the most difficult tunnel in the world"

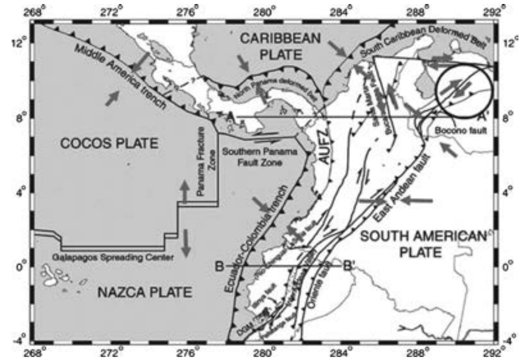


Figure 6. Tectonic regime in the NW South America and Panama. (After Trenon (2002) and Diederichs (2008) and as presented by Hoek and Guevara (2009)). NOTE: The project region appears in a circle in the upper-right corner.

(Hoek, 2001). The tunnel has been recently completed after 32 years (Hoek and Guevara, 2009).

Hoek and Guevara (2009) further discussed the history of the project and the relationship of some of the geotechnical difficulties to unanticipated rock conditions due to a poor understanding of the geology of the area. The discussion below is mainly based on this reference although there were, of course, other non-technical problems (financial, contractual, political) that are not discussed herein. As described by Hoek and Guevara (2009) (see Fig. 6) this area is "one of the most tectonically complex" regions on Earth. In the project region "strike-slip and transpressional faults react to accommodate the mismatch in movement of the surrounding plates" so that, as a consequence, the properties of the phyllitic rock mass range from "strong and reasonably massive" (in the dam area that was the main source of information during site characterization; see below) to "severely tectonically deformed graphitic phyllite" (in which most of the tunnel excavation took place).

The initial characterization of the rock mass was mainly based on the observations during walk-over surveys, exploration adits and a very limited amount of core drilling. In addition, most of the investigations were carried out near Yacambú dam site (at one extreme of the tunnel), where the silicified phyllite rock mass was of relatively good quality. Therefore, the TBM machines were designed for such rock of reasonable quality, although a large percentage of the tunnel length had to be excavated in a much weaker graphitic phyllite where significant squeezing problems were encountered in several other locations (Hoek, 2001). (Figure 7 shows an example of large convergences at the tunnel during repair works in 2006.) As in the case before, it seems clear that an incomplete characterization of the geology lead to unanticipated conditions that were, in addition to lack of knowledge that existed at the time to deal with such heavy squeezing, the reason behind the problems described.

Figure 7. Large convergences at Yacambú-Quíbor tunnel. (Courtesy of Ing. V. Camejo.)

5 OUTCOMES ACHIEVED

To analyze the effectiveness of the case history approach presented herein on the students' learning process, the evolution of students' opinions were studied by means of surveys conducted at the classroom. In such surveys, students were asked about the level of "importance" (in a numerical scale from 0 to 10) that they granted to several aspects related to tunnel design and construction. The specific questions of the survey were related to the following aspects: (i) *Geological* characterization (faults, stress state, etc.) (ii) *Geotechnical* characterization (cohesion, friction angle, deformability, etc.) (iii) construction method (TBM, NATM, etc.) (iv) personnel's experience and quality of construction; and (v) computational models and tools.

Surveys were conducted to find the students' opinions both *before* and *after* the coursework, which allowed us to identify changes of the students' perceived importance in relation to different aspects. In that sense, for instance, student surveys showed that these case-histories had contributed to their appreciation of the importance of geology in civil engineering so that "geological characterization" passed from being considered among the "most important" aspects of tunnelling for roughly 45% of the students before the coursework to approximately 90% of the students after the case histories coursework was completed.

As specific learning outcomes that could be linked to working with these case histories, after a motivated student completes this coursework, he/she would be able to *recall* two important cases of tunnelling in difficult ground conditions and to to *define* sources of geological uncertainties in geotechnical engineering ("knowledge"-related learning outcomes); and, in addition, will *recognize* (and appreciate) the importance of engineering geology for risk analysis and risk mitigation in the context of civil engineering ("comprehension"-related); and to *demonstrate* and *illustrate* several likely failure modes in geotechnical designs ("application"-related).

Note, however, that these outcomes are at the bottom of Bloom's hierarchical level (Bloom et al., 1956), hence indicating relatively low complexity and demand outcomes or a "surface" approach to learning (D'Andrea, 2003). Note however, that they go beyond confirming what is already known about case histories (i.e., that the provide "knowledge"-related outcomes, with students 'remembering' and 'liking' case history information), as we have additional outcomes related to a deeper appreciation of the importance of engineering geology for safe and successful engineering practice ("comprehension" and "application"-related outcomes).

In addition, and although we have not yet implemented this in our course, we argue that when case histories are sufficient in number —hence suggesting a wider 'experience'—, and when they are 'founded' on a good understanding of the underlying mechanisms (see below), the could also help develop 'higher' learning outcomes, such as "analysis"-related outcomes (e.g., to *distinguish* a 'flawed' site characterization program) "synthesis"-related outcomes (e.g., to *propose* a new site-characterization or modification for its improvement); or "evaluation"-related outcomes (e.g., to *criticize* the adequacy of numerical results or to *assess* the geological risk associated to lack of knowledge). A good approach for this would be to ask the students to complete a set of exercises and tasks that are related to the case history (Beaty, 2003) although, in such case, we should make a deliberate effort to make the case study a more substantial part of the course (Pantazidou, 2012). These activities constitute work in progress for us and the results will be presented elsewhere.

6 CONCLUDING REMARKS

We present our experience with the use of case histories to illustrate the importance of engineering geology to geotechnical graduate students. The main objective is to emphasize that a good geological characterization is crucial for the success of civil engineering projects and, in particular, for tunnelling projects; and also to illustrate that the identification of geotechnical failure modes is crucial for risk analysis and mitigation. To that end, we presented the case of an urban tunnel failure in Spain in which an unpredicted fault zone was the main cause for the occurred failure, and we also use an example case from the literature of a tunnel (the Yacambú-Quíbor tunnel in Venezuela) in which extreme difficulties were encountered due to an insufficient geological characterization. Furthermore, the case histories approach is employed as a basis for additional coursework in which the students are asked to prepare similar studies of geotechnical 'failures'.

As an additional note, we argue that case histories cannot be considered to be 'the solution' to all learning needs. One reason is that only low-level learning outcomes (in terms of Bloom's taxonomy) can be obtained unless a significant portion of the course is devoted to such case histories. In addition, case studies employed need to be relevant, as “experience does not always lead to learning” since reflection is a key aspect of learning through experience (Beaty, 2003), and experience (i.e., case histories) needs to be ‘founded’ on a good theoretical framework for understanding of the underlying mechanics. As Terzaghi warned, “no conclusion by analogy can be considered valid unless all the vital factors involved in the cases subject to comparison are practically identical”, so that [some] “engineers who are proud of their experience do not even suspect the conditions required for the validity of their mental operations” and, as a consequence, “practical experience can be very misleading unless it combines with it a fairly accurate conception of the mechanics of the phenomena under consideration” (Goodman, 1999).

Finally, we believe that this case-history approach incorporates other positive aspects that are related to problem-based learning (Overton, 2003) such as, for instance, an increase in motivation of students, and an encouragement of independent learning.

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Use of case studies in geotechnical courses: Learning outcomes and suitable cases

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ABSTRACT: The accepted wisdom in engineering education is that the use of case studies in instruction has a number of benefits, as argued in several publications. Less attention has been devoted to identifying the type of learning outcomes that can be achieved when using cases in instruction. This topic is addressed in this paper specifically for geotechnical engineering instruction. Particular emphasis is placed on the relationship between specific learning outcomes and the corresponding suitable types of case studies and case data. The difficulties in locating suitable case data are discussed and possible actions that could be undertaken by the geotechnical engineering community to overcome these difficulties are suggested.

1 INTRODUCTION

The use of case studies in engineering has been advocated at an educational policy level for at least half a century, judging by the funding by the US National Science Foundation of the Engineering Case Program originated at Stanford University in 1964 (http://www.cee.carleton.ca/ECL/about.html). Since then, demands on engineering education have increased in terms of transparency in goals and accountability for results achieved. These increased demands are also related to the progress of educational research into learning in general and into learning at university level in particular. Hence, we are now in a better position than 50 years ago to answer the question "exactly what can be achieved by using cases in engineering instruction?". This paper attempts to address this question for geotechnical engineering by determining possible learning outcomes. It then considers the characteristics of case studies required to achieve different learning outcomes, before turning to the practical matters of locating or creating suitable case material for desired learning outcomes.

2 LEARNING OUTCOMES

Today, designing courses and study programmes on the basis of learning outcomes and competences is widely regarded as a good practice (ASCE 2008) and is often required by accreditation agencies (ABET 2011). On a European level, the aim of creating a European Higher Education Area, as described in the Bologna Declaration (European Ministers of Education 1999), requires cooperation between education institutions and a system for mutual recognition of qualifications. This has been achieved through the establishment of the European Credit Transfer and Accumulation System (ECTS) and the requirement to provide detailed descriptions of courses and programmes in terms of learning outcomes. In some institutions, this requirement has led to the rephrasing of course syllabuses to create learning outcomes, e.g. "understanding topic X, understanding topic Y, etc." However, as Laurillard (2002) observes, "the point of having learning outcomes is to answer the question: how will you know if the students understand? What would count as evidence that they understand?" To this end, learning outcome statements are typically characterized by the use of active verbs expressing knowledge, comprehension, application, analysis, synthesis and evaluation. Jenkins & Unwin (1996) stress that the verb "do" is a key verb for stating learning outcomes and provide an extended list of active verbs suitable for each performance level, e.g. list (knowledge), classify (comprehension), interpret (application), compare (analysis), create (synthesis) and estimate (evaluation). Learning outcomes should be accompanied by assessment exercises capable of providing the evidence that outcomes have been achieved.

3 USING CASE STUDIES IN INSTRUCTION

3.1 *Project-based learning & case-based teaching*

Prince & Felder (2006) provide a comprehensive overview of inductive teaching and learning methods, whereby specific observations, case studies or problems are presented first, in order to place theory in its applied context, thus motivating subsequent theory instruction. For the remainder of this section, the terms used by Prince & Felder (2006) will be used, without making any sharp distinction between teaching (what teachers do) and learning (what students do). Nevertheless, the use of "learning" instead of "teaching" does imply that students have more autonomy and hence, more responsibility for the performance level they achieve. Prince & Felder (2006) is the perfect paper for a skeptical reader who asks: "OK, we have heard that inductive methods, such as case-based teaching, are supposed to be good, but what specific claims can be supported by (a) educational theory and (b), most importantly, empirical evidence?" According to Prince & Felder, the use of inductive methods is supported by several educational theories. Moving from the familiar specific to the abstract general is consistent with prevailing ideas on how learners build up their knowledge. In addition, if new knowledge is presented in the context of real situations, then this new information is more likely to be connected to existing cognitive structures and be retained. Moreover, the use of cases involving real problems has the potential to motivate the students. What is more, dealing with open-ended problems and the uncertainties of real problems has the potential to help students develop intellectually and abandon immature beliefs about the certainty of knowledge and there being only one correct answer which is provided by the instructor.

The key feature of project-based learning, according to Prince & Felder, is that the learning activity should lead to the production of a final product. In civil engineering, the final product often involves a design. A distinction must be made between project-based courses, where students mostly use projects to apply previously acquired knowledge, and project-based learning courses that use projects as an opportunity to introduce new knowledge. The evidence of the effectiveness of project-based learning compared to traditional instruction shows that students feel more motivated, and have a better understanding of issues of professional practice and of how to approach realistic problems. On the negative side, the comparison also shows that students taught on traditional courses may have a better understanding of engineering fundamentals, while students on project-based courses may be unhappy with the additional self-learning effort required by projects.

Case-based teaching is described by Prince & Felder as an instructional method whereby students analyze case studies that involve solving problems or making decisions. Often in engineering courses, the case is a failure and the problem to be solved involves diagnosis of the cause of failure. At the other end of the learner autonomy spectrum, the instructor may provide complete information on the problem and discuss how it was addressed, including the final outcome. Instruction with such cases cannot be considered as inductive nor suitable for learning outcomes at performance levels higher than application. On the contrary, when case specifics are given but the outcome is withheld, students can perform their own analysis and exercise decision-making skills. In other words, the same case can be used to achieve different learning outcomes, as shown by Papadimitriou (2011). Similar to project-based learning, empirical evidence shows that case-based teaching promotes transferable skills, such as reasoning and problem solving, but little or no evidence of increased subject-matter knowledge acquisition (Prince & Felder 2006). Yadav et al. (2010) arrived at the same conclusion using two carefully crafted case studies specifically constructed to improve conceptual understanding. Survey results indicated that, overall, students had a positive attitude towards the use of case studies. However, pre- and post-test results did not reveal any significant influence on conceptual understanding. From the above, it seems reasonable to posit that stating clear learning outcomes related to subject matter may improve the capacity of cases to promote knowledge acquisition.

3.2 *Case studies in geotechnical instruction*

Geotechnical engineering deals with a natural material. As a result, it is more difficult in geotechnical instruction to focus on the general and avoid addressing the particular, compared to in other engineering fields. In fact, experience is considered a constituent element of geotechnics (Burland 2008) and geotechnical design (Orr 2008).

Peck (2004) was very clear on the relationship between case studies and experience:

"Learning about the experience of others is where case histories play a vital role. Here is where one learns:

- *What worked and what did not,*
- *What was practical and what was not,*
- *What is appropriate to the present situation and what is not.*

Because practice changes with new procedures, new ideas and equipment, and even because of a new generation of engineers, yesterday's case histories may not be adequate to improve today's practices. Therefore, old, even classical case histories need to be supplemented by current ones."

The key role of case studies is highlighted in several recent seminal papers on geotechnical education, e.g. Jaksa (2008), Phillips (2008), Rogers (2008), Jaksa et al. (2009). Case histories allow students to appreciate the complexity and full context of a real design situation which involves the ground, the structure and the construction method. Case histories show the simplifications and assumptions that need to be made in practice. They also show the tests that are used to obtain the different soil parameter values and how the values of soil parameters values are selected in practice. The selection of case histories for a particular course should respect the competencies of the students on the course. Case histories should be presented in appropriate detail and with appropriate models for the particular level. Simple models and straightforward design situations are required for bachelor level while more advanced models and more complex design situations are appropriate for master level. These distinctions can be made in a most transparent manner by defining suitable learning outcomes, as discussed below.

4 SPECIFIC LEARNING OUTCOMES FOR SPECIFIC GEOTECHNICAL COURSES

Case studies are valuable aids to the instructor for a variety of general purposes. These purposes may be affective, i.e. to produce a particular effect such as to spice up lectures and motivate students to study the subject matter through using case studies of local interest or with a dramatic element, e.g. failures. Other general purposes may be cognitive, i.e. to show the contribution of a particular analysis to the complete set of calculations and to explain the construction issues associated with particular design decisions.

These general purposes, affective and cognitive, must be distinguished from the specific learning outcomes as defined in Section 2. Table 1 proposes a set of 10 broad outcomes covering a wide spectrum of performance levels for a study programme in geotechnical engineering. These outcomes are chosen to be complex enough, a characteristic that makes them prime candidates to be achieved through using case studies. Table 1 contains horizontal outcomes, i.e. they concern almost all geotechnical courses, and should further be specified in more detail for an individual course, e.g. see Kunberger (2012). The “safety elements” of outcome 7, which include choosing suitably cautious parameter values, applying partial/safety factors and making suitable geometric allowances (e.g. overdig allowances), exemplify the notion of a horizontal outcome, which is relevant to many geotechnical problems and courses. In relation to the 24 outcome types proposed by ASCE (2008), outcomes 1 to 8 are “technical”, whereas outcomes 9 and 10 are classified as “professional”.

Learning outcomes 1 to 4 are appropriate for all geotechnical courses, but particularly for introductory and undergraduate level courses, while learning outcomes 5 to 7 and, to a limited extent 8, are particularly appropriate for master-level courses. It is understood that learning outcomes 8 to 10 are only likely to be fully achieved after personal involvement in practice (ASCE 2008). However, it is important that all geotechnical students, including undergraduate and master level, are introduced to the complexities, professional responsibilities and ethical dilemmas that are involved in many geotechnical design situations. Case studies are ideally suited for introducing these concepts and achieving the required learning outcomes at different performance levels. Indeed, stating specific learning outcomes makes discrimination between performance levels possible. For example, without personal practical experience, it is difficult for a student to fully achieve the high level outcome 10 in Table 1 “*Appreciate* the ethical dilemmas in geotechnical practice”. Nevertheless, a lower performance level outcome is achievable, such as being able to “*Describe* the ethical dilemmas in geotechnical practice”.

Table 1. Learning outcomes achievable from geotechnical courses listed in increasing order of performance level.

No.	Definition of learning outcome
	Students have the ability to:
1.	Identify potential critical modes of failure
2.	Apply corresponding methods of analyses already covered in course (presupposes No 1)
3.	Select the appropriate type of soil parameter values for specific methods of analyses
4.	Appreciate the variability of experimental data
5.	Select appropriate calculation models for solving geotechnical problems
6.	Determine the soil profile and the specific soil parameter values to be used in geotechnical design (presupposes No 4)
7.	Choose appropriate safety elements (related to No 8, 9)
8.	Assess the complexity and uncertainties of a design situation
9.	Be aware of the professional responsibilities pertaining to geotechnical projects
10.	Appreciate the ethical dilemmas in geotechnical practice

Table 1 is intended to serve as an invitation to the wider geotechnical community to define key learning outcomes and suggest how these may be linked to appropriate courses. For example, soil parameter selection (outcome 6) may be more appropriate for a geotechnical design course rather than a soils laboratory course, where result evaluation often has as an end point the result itself and not its use for a particular design situation. On the other hand, if the goal is to evaluate data obtained from real soils, it is perhaps advisable that students first get some experience with high quality results from field research experiments (Gavin 2012). Then, students can progress to evaluating data from consulting projects, where it is possible that some data may be of such low quality that students have to judge that these data should be rejected, e.g. data obtained from severely disturbed samples (Lo Presti 2011).

5 EXAMPLES OF SUITABLE CASES FOR SPECIFIC LEARNING OUTCOMES

It follows from the above that part of the input required from the wider geotechnical community is, ideally, published case histories that are usable in class, accompanied by details of the desired learning outcomes and examples of the assessment exercises confirming that the outcomes were achieved. This section describes some indicative examples drawn from the personal experiences of the authors and from a workshop with the theme “Case histories in geotechnical instruction: Appropriate cases for each educational level”. The workshop took place during the XV European Conference on Soil Mechanics and Geotechnical Engineering (ECSMGE) in September 2011 in Athens, Greece, and was organized by the European Regional Technical Committee on Geotechnical Engineering Education (ERTC 16).

Due to the large size of the classes at undergraduate level, exceeding 100 until the recent financial crisis, the first author mainly uses published cases, such as the Transcoma grain elevator failure and liquefaction due to the Christchurch earthquake, for teaching. The aim of these case studies is to show different geotechnical failure mechanisms and the appropriate parameter values and analytical methods. Hence the focus is on achieving learning outcomes 1 to 3. At master level, where the class size is usually less than 20, the author gives students data from his consulting or research experience, for a design, e.g. students are given a number of borehole logs and asked to design a foundation. The aim of these case studies is so that students can appreciate the variability of geotechnical data and can select appropriate parameters and design methods. Hence the focus is on achieving learning outcomes 4 to 8.

The experience of the second author of this paper, whose expertise is environmental geotechnics, was chosen to highlight teaching needs inside and outside the instructor’s area of consulting expertise. In her course “Environmental Geotechnics”, the second author uses primarily case studies of contaminated site characterization and remediation from her own consulting experience. The cases serve the general purposes of motivating instruction and showing how topics taught in the course fit within a real project. In terms of specific learning outcomes, the use of cases contributes towards achieving the stated learning outcome “Students are able to take initiatives related to modelling, i.e. related to the formulation of a simplified problem that admits solution” (Pantazidou 2010). To this end, subsets of the case data are given to students who are asked to calculate input parameters and make decisions with regard$$ to possible simplifications, e.g. calculate hydraulic gradient by approximating groundwater flow as one-dimensional. The second author also teaches part of a slope stability course, for which she had to ask geotechnical colleagues who are consultants to share their records with her. Again she sought a case for the general purpose of demonstrating the contribution of a slope stability calculation to the entire project (design of a portal for a highway tunnel). In order to develop the case material for use in instruction and build the confidence to present the case without first-hand experience, she interviewed the project consultant, after reading the geotechnical investigation and geotechnical design reports. The educational case material produced includes a PowerPoint presentation and a bullet-like case narrative (in Greek). However, it is questionable whether this material can be used by another instructor. The transferability of case material is considered further in Section 7.

Two more instances of using cases in courses, which were presented in the education workshop of the Athens XV ECSMGE, are now discussed briefly. Lo Presti (2011), drawing on material from his own consulting experience, presented the case of a flood-plain bank that, over the years, developed several failure surfaces. The basic characteristic of this case exemplifies the idea of case-based teaching: some problem is presented (cracking) and the students have to diagnose its origin by thinking of and evaluating possible alternatives (a problem with the bank? a problem with its foundation material?). In order to evaluate alternatives, students perform slope stability calculations covered in previous courses. Apart from the application of slope stability methods, the learning outcomes of the course also include determining the soil profile and the soil parameters used in the calculations. The paper provides the key features of geotechnical investigation, while the entire data set is available on the internet (in Italian: www.ing.unipi.it/geotecnica). It remains to be seen if this material can be used by another instructor.

Bouazza (2011) presented details of an environmental geotechnics course designed in the tradition of project-based learning, whereby projects are used both to motivate learning and to give students opportunities to apply taught material. The teaching format alternates between traditional lectures on groundwater, solute transport, clay barriers, etc. and practicals dedicated to the project design. Bouazza has taught the course in this format since 1998, using every year a different project, mostly from his own consulting experience. The case study referred to in the paper was a landfill site, but there was minimal information on the case itself.

6 LOCATING SUITABLE CASES

As mentioned in Section 4, the goals of geotechnical instructors using case studies in their courses may be either affective or cognitive, or both. Locating published case studies to motivate instruction is relatively easy for two reasons. First, almost by definition, published case studies have some unusual characteristics that make them interesting and therefore publishable: they often refer to failures, sometimes dramatic, the investigations of which involve a level of soil characterization that is not customary at the pre-design, pre-construction stage. Second, when cases are used to motivate the presentation of theory, the instructor does not need all the existing documentation available: some key features of the case are adequate and these are typically presented in case study papers from the literature. Jaksa (2008) and Orr (2011) discuss possibilities for locating case studies, placing particular emphasis on geotechnical failures.

Orr (2011) also discusses the difficulties in locating suitable case studies for instructional use to achieve cognitive goals and specific learning outcomes. The characteristic that makes some case histories publishable is their complexity, and, as a result, these cases may be too complicated to be presented in detail in most geotechnical courses. In addition, many published case histories do not provide all the information required for the students to engage meaningfully, i.e. with some degree of responsibility and autonomy. Finally, and again related to the partial documentation of published case studies, it can be difficult for the instructor to present confidently in a classroom situation case histories in which there has been no personal involvement. As a result, when it comes to the use of case studies to achieve specific cognitive learning outcomes in geotechnical engineering, personal experience is perhaps the most common source of case histories, as shown in Section 5. The advantages of using case studies in which the instructor has been involved cannot be overstated (Orr 2011). Hence, the challenge for the geotechnical community is to make the personal communal, by facilitating the compilation of suitable case study material for use in instruction. To paraphrase Peck (2004), learning from the combined teaching and consulting experience of others is where case study material plays a vital role.

7 SUGGESTIONS FOR FUTURE WORK

Building a repository of case study material suitable for use in instruction (from now on referred to as, "educational case material") will be meaningful provided it satisfies three basic requirements. First, the educational case material should address clearly the stated needs of the user. To achieve this, compilers of case studies should clearly state the intended purpose of the case and the corresponding learning outcomes. This presupposes the development of a taxonomy for learning outcomes in geotechnical instruction, perhaps starting with a list such as that in Table 1. Second, the users should be able to search on-line for material suitable to their needs with relative ease. To fulfill this requirement, cases should be cross-referenced and searchable using both learning outcomes (e.g. determine soil parameters) and geotechnical topic (e.g. consolidation settlement). Third, the case material assembled should be deemed by the user to be complete. This is not a straightforward requirement to fulfill, since completeness is judged against the intended use of the case material. A general-purpose motivational case needs less documentation than a case allowing students to select appropriate calculation models for solving geotechnical problems. Moreover, completeness is judged against the scale of the case. It is unlikely that the repository will include cases able to support, on their own, a project-based course. Few people can afford to dedicate the time needed to transform personal consulting experience from a multifaceted project to transferable educational material. However, smaller-scale projects or parts of projects may offer suitable input to develop into educational case material.

Table 2. Case template with project information grouped in categories (Pantazidou et al. 2008).

[1]	Project introduction Type of project, location of project, photographs
[2]	Geological information Map with borehole locations, soil profile
[3]	Relevant analyses Characteristic cross-section(s), analysis types
[4]	Geotechnical investigation & evaluation of test results Soil tests performed and results, soil profile and soil parameters used in analysis
[5]	Construction – design considerations Constraints and data known prior to analysis
[6]	Geotechnical analyses performed Basic steps of each type of analysis + results
[7]	Key points/messages

Yadav et al. (2010) provide ideas for educational case material with their two examples of cases in the form of a narrative accompanied by drawings, which provide the pertinent information for students to start thinking "what is going on here"? These type of cases are the tradition in other disciplines, e.g. ethics, law, management, where a case is written up in a few pages, often with a quality justifying a purchase fee (e.g. http://www.ksgcase.harvard.edu/). Geotechnical engineering has the additional difficulty of requiring data in the form of site maps, borelogs, and other data obtained in the field. Nevertheless, it is feasible to limit the scope of a case study. For example, a failure helps focus a case on the data relevant to the cause of the failure.

One way to satisfy the requirements of easy perusal and completeness is by assembling educational case material with the aid of a template. One such template was suggested by Pantazidou et al. (2008), who argued that together with high-profile cases, there is a need to compile straightforward, undistinguished case studies suitable for undergraduate geotechnical instruction. The basic categories of the template are summarized in Table 2, whereas detailed information on each entry is given by Pantazidou et al. (2008). As an example of using the template, Pantazidou and co-workers provided detailed documentation of the case study of a reinforced earth wall (in English), which is available on the internet (http://users.ntua.gr/mpanta/TeachingEN.htm).

The idea of a template was discussed in the education workshop and the opinions were divided: a consultant offering case material for educational purposes was in a favour of a template, whereas an academic expressed the opinion that a template stifles creativity. On retrospect, it is realized that one template cannot fit all case studies. The template presented in Table 2 is suitable for students to work on a manageable design project and corresponds to a specific learning outcome: enabling undergraduate students to practice calculation methods on real cases instead of on idealized, textbook-type problems. Because a template makes it easy to both assemble and then review case material, it appears desirable to have available a few alternative templates and examples of educational case material assembled with each template.

8 CONCLUDING REMARKS

The use of case studies has been a staple component in geotechnical engineering education for decades, for a combination of affective and cognitive purposes. More recently, increased awareness of accountability requirements and the progress made in engineering education research have enabled geotechnical instructors to be more transparent in how they use case studies in instruction by defining specific learning outcomes. This paper proposed a set of learning outcomes for a geotechnical study programme.

Unlike other disciplines that also share an appreciation of the educational value of case studies, the geotechnical community has not developed a tradition of compiling suitable educational case material. In order to increase the repertoire of case studies available to geotechnical instructors for teaching, this paper suggests some actions to be undertaken by the geotechnical engineering community, including the development of alternative case templates and examples of educational case material.

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Laboratory work in geo-engineering

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The use of online resources to support laboratory classes in soil mechanics

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ABSTRACT: During the introductory soil mechanics course at the University of Sydney students undertake five 2 hour laboratory exercises (300 students in groups of 10). This paper presents and discusses the benefits of introducing two on-line resources that have been introduced to support the laboratory experience. The first is a set of on-line pre-lab tasks that have been used to prepare students for the laboratory experiences. These have resulted in more motivated and curious students who have engaged more wholeheartedly in the laboratory work. The paper discusses the features of the program that we believe have been important in making this initiative a success: getting the right balance of certain components, making the tasks relatively easy, making it count, and supporting the on-line work with paper-based materials and direct contact. The second is an on-line resource (WRiSE, Writing Reports in Science and Engineering) which has been developed to support the writing of laboratory reports in science and engineering at the University of Sydney. This award winning resource is freely available externally, and one of its modules is focused on the soil mechanics course. The presentation introduces the main features of the WRiSE site: report writing content; language support; presentation; student examples, and lecturer input, and discusses how it is used in the course. This resource has made a significant difference to the written reports. Finally how these resources are used to support the administration and processing of the large student cohort and how they are linked to the development of writing across the civil engineering program is discussed.

1 INTRODUCTION

It is widely accepted that students in civil engineering courses should have exposure to the laboratory, and one of the requirements for accreditation is that students should be able to plan, design and interpret experimental data. In geotechnical engineering the importance of familiarity with materials and routine procedures is also often stressed. For most civil engineering students the need for familiarity with standard geotechnical tests is debatable, and the primary objectives of the soil mechanics laboratories for these students are improved conceptual understanding and helping to make soil mechanics "real".

There has recently been considerable debate within the science and engineering communities about the effectiveness of laboratory instruction (Reid and Shah 2007, Adams 2009, Feisel and Rosa 2005). There is a general consensus that hands-on laboratory work is an essential component of undergraduate education in the sciences and engineering (Magin and Kanapathipillai 2000, Bhathal 2011) but more needs to be done to make laboratories more effective and better value for the costly equipment, dedicated technical staff, space and faculty time they require.

The educational literature stresses the importance of having clear justification and aims for the laboratory work. Reid and Shah (2007) suggest laboratory work should have 4 broad aims: skills related to learning the subject (soil mechanics), practical (professional) skills, scientific skills (observation, deduction, interpretation) and general skills (team working, reporting, problem solving).

What is common in all these discussions on the state of laboratory work in engineering and science, is that hands-on laboratories are essential, the objectives need to be ones that can only be met by hands-on activities, and there is a need to improve the effectiveness of the experience. The two main suggestions to improve the effectiveness are firstly to give students more involvement and responsibility in the design, planning and conduct of the experiments and secondly to make more effective use of students time in the laboratory by well planned pre and post laboratory exercises. The former approach has been used at the University of Sydney in an elective course with typically 50 students (Airey 2008) but its use with 300+ students would be difficult to manage. Thus the approach that we have been following has been to continue to refine and improve our existing laboratory exercises. For the last three years this has involved making use of on-line resources, and these developments are the subject of this paper.

1.1 *Pre-laboratory work*

Laboratory classes are costly and resource intensive and it is necessary to make effective use of the time spent in the laboratory. Traditionally, students were expected to prepare for laboratory sessions by reading through a paper-based document setting out theory, aims and procedure of the experiments. However, most students turned up to the laboratories ill-prepared, and simply followed the directions of the demonstrator. Often the laboratory session ran out of time without reaching meaningful conclusions, and little learning took place. To improve this situation it is important that students come to the laboratory well-prepared, which makes the role of the pre-laboratory work critical. The objectives of pre-laboratory material, as described in Reid and Shah (2007), can include:

1. Stimulating students to think through the laboratory work
2. Encouraging students to recall facts related to terminology, formulae, safety, etc.
3. Checking that experimental procedures have been read, and giving practice in the calculations required during the laboratory
4. Leading the student into thinking about concepts, encouraging revision of prior knowledge
5. Offering experiences in planning
6. Bridging the gap between laboratory and lecture, experiment and application.

Previous studies have reported that pre-laboratory exercises in Physics can improve student performance and improve student perceptions of the laboratory (Johnstone et al. 1998), however, the additional marking was seen as a potential disincentive (Reid and Shah, 2007). A number of studies have reported the use of computer based exercises to support the pre-laboratory work, particularly in Chemistry (e.g. McKelvey 2000) where it has been in use for over 10 years, and sophisticated online Dynamic Laboratory Manuals have been created incorporating video clips and interactive simulations (www.chemlabs.bris.ac.uk). There are also a number of uses of computer assisted pre-laboratory work in the biosciences (Adams 2009). One of these (Dantas and Kemm 2008) points out the importance of including assessment, as simply making e-resources available will not itself motivate students. The use of online pre-laboratory work has not been reported in the engineering education literature.

In this paper we will describe how we have implemented on-line pre-laboratory work in soil mechanics, and discuss our observations of the effectiveness of this approach.

1.2 *Post-laboratory report writing*

Communication skills, both oral and written, are highly valued in engineering graduates, are essential for career progression (Tenopir & King 2004, King 2008), and writing is also important for the development of scientific and technical thinking. With the increasing diversity in the higher education student cohort, deficiencies in students' writing competency have been noted, and universities and engineering faculty are under increasing pressure from the government, professional bodies and employers to address this issue (Commonwealth of Australia 2007, Nair & Patil 2008). For many engineering students, regardless of their background, report writing presents a challenge, and students need support and direction.

The approach in civil engineering at the University of Sydney has been to integrate writing tasks throughout the curriculum, and these include laboratory reports which are typically completed in the 3rd, 4th and 5th semesters of study. In the past, advice to students on content and presentation was provided in a series of paper documents. Students identified with particularly poor English skills were supported by the University's Learning Centre but the resources were insufficient to the need. It was clear to the Learning Centre staff that many students needed much more advice on language and presentation skills than could be provided individually and this led to the development of some online resources, and ultimately to the development of the WRiSE site, discussed in more detail below.

Online or eLearning approaches for improving engineering students report writing skills have not been reported widely. However, there is a wealth of information on successful approaches for improving engineering students' written communication in different higher education contexts. These approaches include collaboration with writing specialists, making assessment tasks and criteria more explicit, providing more realistic, work-related writing tasks, offering a draft/feedback cycle for submission of written assignments and clarifying learning outcomes for writing for engineering students (Boyd and Hassett 2000, Plumb and Scott 2002, Chirwa 2007, Yalvac et al. 2007, Flateby and Fehr 2008). These approaches draw on a number of pedagogical approaches such as situated learning or activity based learning, constructivist and knowledge transformation frameworks and genre based pedagogies (Walker 2000, Paretti 2008, Lord 2009).

Online environments offer students a flexible approach to learning as materials can be accessed at their own pace and according to their varied needs. Although a number of online programs support engineering students with advice and guidelines for report writing (e.g. Winckel et al. 2002) and some provide students with authentic examples and interactive exercises (Clerehan et al. 2003, Drury et al. 2005), they are not closely aligned with specific discipline course curricula and therefore remain largely generic in approach. This difficulty has been overcome in the approach described in this paper by embedding the report writing modules within the soil mechanics course material, and by designing the module from a student perspective with relevant and motivating content. The modules developed not only support students in understanding the structure and language, but also the process of writing their reports. In addition, learning activities to help students understand the concepts associated with the soil mechanics content of the report are included.

This paper will report on the approach and methodology used in the on-line modules, discuss the student responses, and comment on the value of the online tool.

2 COURSE STRUCTURE

This paper is concerned with a series of 5 laboratory exercises that are integrated within a semester long introductory course in soil mechanics, which for most students is taken in the second semester of their 2nd year of study. The course covers the topics of: definitions and terminology; effective stress; flow of water; settlement and consolidation; and soil strength. The course involves three hours of lectures and a 1 hour tutorial each week for 13 weeks, and five 2 hour laboratory sessions. For the laboratories, students are organized in groups of ten, although each laboratory is organized so that two sub-groups of 5 work fairly independently.

In 2011, nearly 300 students completed the laboratory work. This has been achieved by having 5 sessions a week and running each laboratory over a period of 6 weeks.

The five laboratory exercises are Classification, Compaction, Flow Nets (including permeability), Consolidation, and Shear Box.

The objectives of the laboratory work are to introduce students to soil as an engineering material (to make it real), particularly Compaction and Classification, which support the basic definitions, but importantly allow students to touch and visualize the materials. The later experiments are more sophisticated and their primary objectives are to aid in conceptual understanding. In all cases, students are introduced to the technical and procedural skills that provide a link to the professional practice of geotechnical engineering.

The following activities are completed in each of the 2 hour laboratories:

Classification: Liquid and Plastic Limits by Casagrande and Fall-Cone methods, Sieving and Hydrometer.
Compaction: 4 point Standard and Modified Compaction tests
Flow Net: Flow visualization for dam and drain models, Falling head permeameter test
Consolidation: Use of Oedometer, Construction of void ratio, effective stress relation, Time dependent consolidation for one increment, Hydraulic oedometer to show pore pressure changes
Shear Box: Six tests on dry sand, three normal stresses, two relative densities.

Moisture content analysis by oven drying (both conventional and microwave) is included in compaction, classification and consolidation.

As the students are not required to provide a write-up of each experiment, the necessary recording of data, calculations, interpretation and conclusions have to occur during the laboratory session. This is achieved with the aid of a laboratory manual to assist students in recording the necessary information and directing them to the necessary calculations. In the case of the consolidation and shear box experiments, data are entered into pre-prepared spreadsheets to assist with data manipulation.

The assessment weighting for the laboratory component of the course is 10%, and this is split 2% for the pre-laboratory exercises and 8% for the laboratory report. Attendance and satisfactory completion of the laboratory work are course requirements.

3 PRE-LABORATORY EXERCISES

The pre-laboratory exercises are provided to students online and have been designed to address most of the objectives suggested by Reid and Shah (2007) listed above. In addition we have included three on-line modules discussing safety in the laboratory and instituted an online safety quiz for which all students are required to obtain 100% before being allowed to undertake the practical exercises. It is intended that a typical student will spend 30–60 minutes doing each pre-lab.

There are seven on-line modules for each particular laboratory session (lab), and of these the first five are intended for use prior to the laboratory. The seven modules are as follows:

1. Introduction
2. Theory
3. Method
4. Movie
5. Pre-Lab Quiz
6. Report
7. Worksheet.

Prior to each lab, students are required to attempt the appropriate *Pre-Lab Quiz*. They are allowed 2 attempts with the highest score contributing 0.4% towards their assessment. The quiz is based on the *Theory* module and has 10 questions which may ask about theoretical concepts or numerical calculations based upon theoretical formulae. The questions are not difficult but do require some careful focus on the theory. Although called a “Quiz”, these are intended as learning tasks, not assessment tasks, and the questions are intended be within the capabilities of all students. To minimize student collaboration, each question is randomly drawn from a bank of similar questions, questions are randomly ordered and for multiple choice questions the choices are randomly presented so that effectively no two quizzes are the same. Marking of the quizzes is handled automatically in the learning management system (Blackboard) and the marks can be emailed to the laboratory supervisor so that it is known who has attempted the pre-lab work.

The *Theory* is supported by the *Introduction*, which is a very simple probing exercise designed to raise their level of curiosity about the lab, and by the *Movie* which is typically about 3–5 minutes and shows why and how the lab is done.

The *Method* and *Worksheet* are reproduced in hard copy and compiled with the safety rules to produce a

Laboratory Book which each student receives at their first laboratory class. The *Method* describes the steps that need to be followed during the lab and has tables for recording raw data and some basic calculations. The *Worksheet* is a 2-page interpretative exercise which the students must complete during the lab and is signed by the supervisor on completion. It typically asks students to draw graphs or make conclusions based upon the experimental data, to explain the meaning of some concepts, to compare experiment to theory, or to consider the experiment in a broader context. For most students the completion of the *Worksheet* is the end of their experiment.

However, 2 students in each group of ten must write a formal laboratory report (students are notified which lab they must write up at the start of the semester). The module *Report* outlines for each lab what are the report requirements for that lab and has links to various other documents and sites giving guidelines for writing lab reports (including the WRiSE site – See 6 below).

Students who do not attempt the pre-lab quiz *prior* to the lab receive assessment result of zero for that lab.

Five of the seven pre-lab modules are simple documents with images and links (written in MS Word with embedded hyperlinks and saved as web pages). The pre-lab quizzes were written using the University's On-Line Learning Software (*LMS BlackBoard*). The movies were compiled by 2 students for an undergraduate final year project, and were originally intended to be shown at the start of the laboratory sessions.

4 INTEGRATION OF ONLINE, HARD COPY AND PERSONAL CONTACT

The online material is supported by written lab materials (The Lab Book) and direct contact with the laboratory staff.

At their first lab session the students receive a short talk from the lab technical manager (mainly concerning safety and tardiness), and a short talk from the pre-lab designer explaining how the pre-lab program works, stressing the expectation of a professional approach to the laboratory and their report, and warning of the consequences of not doing what is required.

Students who do not attempt the pre-lab quiz prior to the laboratory, or who do not get more than 6/10 for a pre-lab quiz (information easily obtained from the LMS) are questioned individually during the laboratory and encouraged to take the pre-lab work more seriously. This approach has been very successful in obtaining near full compliance with completing the pre-lab quizzes.

5 LABORATORY CONTENT

The content of each laboratory and the tasks actually performed during the class have remained essentially unchanged despite the introduction of the online material. We are still using old equipment with weights on hangers, and dial gauges, the only exception being the hydraulic oedometer where a pore pressure transducer and associated voltmeter are used. Although the civil engineering laboratory exercises were suffering from an appearance of old-fashionedness, neglect and irrelevance, this was not in content, but in style and delivery. The soil mechanics laboratory exercises were designed over 30 years ago in a very different student environment, but are still relevant to today's laboratory objectives. We concur with the comment by Reid and Shah (2007) "to change the experience, you don't need to change the experiment, just what you do with it".

Minor changes to the laboratory content were made:

- to simplify some processes to ensure that the laboratory sessions could be completed in a compact 2 hours, and
- to provide computers in the laboratory with prepared spreadsheets to remove the onerous calculating and graphing which were always prone to errors and detracted from the learning purposes of the Consolidation and Shear box laboratories.

6 POST-LABORATORY

When the first author joined the University of Sydney, students were required to produce a write up for all five laboratories, and this was repeated in other courses which also had a laboratory component. One of the results of this was that students generally made little effort to produce a good report and copying from previous years was rife. The report writing was initially reduced to two of the exercises with the idea that students would receive feedback on the first to improve on the next. While this reduced plagiarism it did not entirely eliminate it, and the step was taken, also driven by increasing student numbers, to reduce the number of required reports to one. Feedback in this course would then be expected to be used in producing a laboratory report in a fluid mechanics course the following semester. It became evident during this process that the appropriate objective for the write up of the soil mechanics report was to learn the skills and process of presenting a professional style report. This built on writing tasks in earlier semesters (in other subjects), but involved a substantial advance in the presentation aspects. The structure of the laboratory write up in the fluids course in the next semester is similar. However, a heavier weighting is given to the data interpretation. The intention is to assist the students to develop their writing skills by raising the expectations from one semester to the next.

The current arrangement is that for each sub-group of 5 in the soil mechanics course, only one student will be responsible for the writing up of any laboratory session. The objective of the writing exercise is primarily to get the students to write a well-structured and professionally presented report, with appropriate language. To assist the report writing task an online module WRiSE (http://learningcentre.usyd.edu.au/wrise/home-B.html) has been created through collaboration with language and learning specialists and technical and eLearning specialists. Language and learning specialists have created learning materials to address the structure and language of a typical soil mechanics report based on their analysis of a corpus of student reports from previous years. Technical and eLearning specialists converted these learning materials into online modules. A student and the first author also provided audio interviews for the site. The student commented on the process of report writing and the difficulties he encountered and the lecturer explained his expectations of students' report writing, student difficulties and how to improve. The on-line module also contains a quiz to help with understanding the content of the laboratory exercise.

The WRiSE site contains 9 modules designed to support writing across science and engineering. The Civil engineering module is based on the requirements of the soil mechanics course. The design of each module is based on a model of learning which takes into consideration students prior writing experiences, their current perceptions and approaches and their interaction with the learning environment designed to support their written assignments (Prosser and Trigwell 1999, Laurillard 2002). The online approach to teaching writing is supported by a theory of language (Systemic Functional Linguistics after Halliday 1985, Martin 1992) and a genre based pedagogy which emphasises the influence of context and purpose on text structures (Cope and Kalantzis 1993, Martin 1999). This approach is widely used to teach writing at university, in both face-to-face and online situations (Jones 2004, Drury 2004).

Following genre based pedagogy, the online design makes explicit both the product and process of report writing through structured and scaffolded learning tasks embedded within the context of the course. This is captured in the *Help with Report Writing* section of the module which guides the user through the sections of a typical soil mechanics laboratory report. These include: the overall structure and purpose of a typical laboratory report; what kind of information belongs in different sections of a report; how to structure the information in each section in a logical way; and how to use scientific language in an appropriate way. This is achieved by providing students with interactive and animated explanations and exercises, with feedback, to make explicit the structure and language of each section of a typical laboratory report. Authentic student examples for each report section are highlighted and annotated as the basis for providing an explanation of the structural stages and language features. These examples have all been taken from the Flow Net laboratory exercise. This exercise was selected as it contains all the elements of a laboratory report, and the interpretation which requires comparison between theory and experiment has always been poorly attempted. As only one fifth of the students have to write up this report this might be expected to advantage these students, but this has not been evident in the marks.

Students can also undertake self-testing quizzes on entry to each section to find out what they already know about writing that particular section. At the same time, students can access a learning module to help them understand the content of the experiment they are writing about. This takes the form of a multiple choice quiz that is intended to assist students with their understanding of how to construct a flow net. In this way, both language and content are brought together.

7 DISCUSSION

The introduction of both the pre-laboratory work, and the support for the writing task, have both produced significant gains. Attempts to obtain student feedback have not been very effective, so it is difficult to quantitatively assess the impact on student learning and attitudes. Nevertheless, the outcomes measured in performance and attitude in the laboratories have changed dramatically for the better. The majority of the students turn up well-prepared for the laboratory classes, have a reasonable idea of what they are meant to be doing and why. The biggest difference is that all students are actively engaged and it is now rare to have a student wandering around the laboratory, talking to friends, and other unacceptable tendencies. Different students take to the pre-lab tasks with differing levels of commitment, but we have found that the pre-lab program has pushed up the level of well-prepared students from less than 1 in 5 to about 3 in 5. This creates a dominating group-dynamic which sweeps-up the less-committed students and leads to far greater individual completion rates for the laboratory worksheets, as opposed to just copying another students numbers. As noted above, all students have to complete the recording of data and the worksheet to be marked off as meeting the laboratory requirements.

The laboratory supervisors who had looked after the same laboratory exercises before the pre-lab program were strongly of the opinion that the laboratories were now much easier to run, and that students were more motivated and understood the laboratory much better. The greater student preparedness has meant that conversations between supervisors and students have been more sophisticated and this has enhanced the teaching and learning. Also, it has resulted in the exercises being properly completed within the scheduled 2 hours.

Completion of the pre-lab quiz was no guarantee that students had read all the pre-lab material, because the quiz was based mainly on the theory section. Nevertheless, it is considered that the benefit of at least getting the students to give some thought to the upcoming laboratory was of value.

A further benefit of the pre-lab work is that it enables students to tackle the laboratory well prepared even if the laboratory is scheduled either before or after the relevant course lectures. The laboratory exercises are generally scheduled to commence one week before the lectures on that topic, and finish four weeks after.

To assess the WRiSE site module, students were asked to complete questionnaires on their past writing experiences, the user friendliness of the module, their pathways and the sections they had accessed and their perceptions of how the module had improved their understanding and confidence. Unfortunately numbers completing and returning the questionnaire were small ($n = 17$ users, $n = 6$ non-users), but informal evaluations carried out during laboratory sessions indicated that the majority of students had in fact used the module and were overwhelmingly positive about it. Tracking data also support extensive use of the soil mechanics module. The majority of civil engineering student users agreed or strongly agreed about their improved understanding and confidence in both report writing and understanding of discipline content related to report writing.

Performance data also indicated that students who used the site gained higher average report marks (mean = 58.64) than those who did not (mean = 51.33). This trend was repeated across other science and engineering discipline areas and, on average, report marks of those who used the site were significantly higher than those who did not ($t(306) = -3.02$, $p = .01$). Since the user and non user groups displayed similar demographic and language characteristics and reported comparable past writing experiences, it can be concluded that the website helped students to improve their performance in report writing.

It was evident when marking the reports, from presentation and language, that some students had engaged with the report writing module and for these there were significant improvements in the reports compared with previous years when students received only general advice on report writing. However, there has not been a significant increase in the average mark, and this is because the marker expectations are now higher.

Despite these benefits and the evident success of the online learning environment in improving students' report writing, a number of issues remain. The majority of students who reported not using the website said they did not know about it and this was despite the fact that it was strongly promoted during lectures, and through links in the course website. It may be the case that students are overwhelmed by the variety and number of online resources available to them. We have noticed that when provided with simpler paper based instructions, even though these are excellent and contain all the necessary information, the students did not spend time engaging with the WRiSE site and the quality of the reports suffered. We have learnt from this the importance of providing a single and unambiguous set of instructions about the need to access the WRiSE material.

Also some students were either neutral or disagreed about the benefits of the module. Some of the open ended comments indicated areas of dissatisfaction or confusion '*quizzes were a waste of time'; the content should be much simpler*'; '*the module helped me improve my report writing but there were ambiguities with knowing what was expected*' and '*the site was particularly helpful for me as my report was on flow tanks, might not be so helpful for other areas'.* Students also wanted more practice, more examples and more feedback on their report writing and may not have engaged with the site due to the low weighting given to the report (8%).

In addition, implementation practices need to be proactive so that students are introduced to the learning materials in laboratory sessions or lectures and they do not merely remain as a link within a learning management system. At the start of the semester students claimed they were using the website when handing in their reports, but in fact, the early reports submitted did not show any improvement and it was only when this was pointed out and the importance and relevance of the learning module reiterated in a lecture that students used the website properly.

8 CONCLUSIONS

We present these conclusions largely as a matter of judgment based upon our direct observations and anecdotal evidence from students and laboratory staff.

The pre-lab program has re-energised the laboratory component of civil engineering. Students now see the lab program as an essential and interesting element of civil engineering. Laboratories are clearer for the students and easier to run for the supervisors.

The driving force of the entire program is personal contact with the students – the online pre-lab work is not a "*Set-and-forget*" solution for laboratory preparation.

The glue in the whole program is the consistency or dove-tailing of the various components: online, hard-copy and personal contact present a coherent, well-planned laboratory session for the student. This is also referred to as blended learning.

The main motivation for students is that each pre-lab quiz is worth 0.4% of their final assessment. This small amount is enough that nearly all students (>92%) do the pre-lab quizzes without any further prompting and more than half make a second attempt to improve their mark. This represents quite a lot of self-driven learning. Anecdotally we have noted that 0.4% is not enough motivation for students to cheat. Based on the students' responses, we believe that we have struck the right balance between marks earned and the time and difficulty required to complete the quizzes.

A secondary motivation is that the pre-lab modules are interesting, well-presented and colourful, with a good selection of supporting images and links to other sites for further exploration. They are also highly relevant to the laboratory exercises, a fact which students soon become aware of.

A third motivation is that students know they will be questioned face-to-face if they do not do the pre-lab work or if they perform badly on it. This is a simple but very successful technique and is particularly effective with students who have a predilection to "disappear in the crowd", which is particularly common among international students with cultural adjustment or language difficulties. It only needs to be done a few times before all students get the idea.

For the average student the pre-lab program provides the resources they need and want to get through the laboratory program. They know they have to do it, but they also know it will make the laboratory more interesting and relevant.

The online resource WRiSE has made a significant difference to the writing and presentation of student reports. The challenge is to get the students to use it. One possibility suggested by the success of the pre-lab work is to include a quiz within the WRiSE module that can count towards the course assessment. Alternatively we could include some of the activities from WRiSE in a tutorial session so that students could work through the language activities and apply them to a draft report.

The success of WRiSE has led to further support to develop an online writing centre to support engineering students with writing throughout their undergraduate years, and in particular with their writing of a major project report in their final year of study. The lack of development of writing skills in the early undergraduate years means that writing a large report is challenging both for the students and their lecturers who need to provide them with feedback and guidance. The use of online resources such as WRiSE assist in integrating writing skills into the curriculum so that students learn how to write as engineers and enables them to use writing to consolidate their engineering knowledge.

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Shaking the Foundations of Geo-engineering Education – McCabe, Pantazidou & Phillips (eds)

Soil mechanics laboratory classes as an integral part of the learning process

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ABSTRACT: Laboratory classes can be regarded as important to help students grasp the fundamentals of Soil Mechanics, but this is sometimes discarded as impractical or bound to be restricted to demos, especially in large classrooms. Demonstrations can, after all, be simply presented in the classroom, even by means of videos or YouTube clips. Notwithstanding the merit of such displays, the point is made in the paper that students can reach a better understanding of the fundamentals if they have a hands-on experience in the lab. Moreover, this experience can be designed so as to also foster development of soft skills which are valued competencies of the engineer of the 21st century. A tested method of doing so, even with large numbers of students, is described, as well as the involvement required from those students in terms of self-learning. Soil identification and classification is also learned by means of a carefully designed hands-on laboratory experiment that usually meets with joyful involvement by the students.

1 INTRODUCTION

Readers over 50 years old have probably witnessed different trends regarding laboratory classes over time. The author himself has had a rather limited exposure to the Soil Mechanics laboratory while an undergraduate at the Polytechnic School of the University of São Paulo. When he became a teaching assistant, a new professor had assumed the course and eliminated the laboratory classes altogether, on grounds of impracticability (for over 100 students) and potential better use of that time for lectures and exercises. Later on, again under a different professor, laboratory classes were reinstated, but rather as demonstrations with very little hands-on experimentation.

Distinguished members of our community have voiced many different views on the subject. Mitchell (1999) discussed the changes in the role of laboratory testing in education and practice, pointing out that *in situ* tests, numerical analyses, and prior experience and soil properties correlations had contributed to the reduced emphasis on laboratory testing. Graham, in his "forward to basics" plea (Graham and Sayão, 1999), advocates a reduction – but not elimination – in classification, compaction, and hands-on laboratory skills, among other topics.

The BOK2 (ASCE, 2008) report, on the other hand, lists "Experiments" as one of the 24 desirable competencies of Civil Engineers, to be developed by undergraduate curricula to level of achievement 4 of Bloom's taxonomy (Bloom et al, 1956). Level 4 (Analysis) refers to the "ability to break down material into its component parts, so that its organizational structure may be understood". JTC3 of FedIGS suggests, as a "starting point" (progress report, Turner and Rengers, 2010) that "Experiments" be split into two competencies: "Site investigations and 3D geo-engineering modelling (physical and numerical)", and "Natural materials science and testing". This latter competency is an expansion of "Materials science" in the BOK2 (ASCE, 2008) report.

At the same time, both reports (BOK2 and JTC-3), among many others, emphasize skills that cannot be overlooked in the education of engineers for the challenges of the 21st century, in particular communication, leadership, teamwork, and lifelong learning skills. Ionescu (2008) gives and example of improvement of soft skills by means of laboratory teamwork.

While being exposed to such ideas, the author was put in charge of a Soil Mechanics undergraduate course at the Polytechnic School of the University of São Paulo, and decided it was time to put those ideas to work in practice there.

During the Christmas vacation of 2011 a poll was conducted among students as to what they felt about the role of laboratory activities in their (just concluded) Soil Mechanics course. The poll took the form of an *enquête* in the very same Moodle interface the students had used during the semester. Unless otherwise noted, students have been asked to express their feelings on a scale of 0 to 4 (integers), 4 meaning, in accordance with the context of the question, the highest level of a feeling, the most favourable or desirable result, or full agreement with the statement, whereas 0 means the opposite. Participation was voluntary. Thirty students responded. Their answers are summarized in the following sections.

2 ABOUT THE DEGREE AND THE COURSE

The undergraduate Civil Engineering degree at the USP includes 4 required geo-courses from all students: Geology, Soil Mechanics, Earthworks, and Foundation Engineering. There is no specialization at the undergraduate level, thus all civil engineers that graduate from EPUSP have received essentially the same education (except for about 10% elective courses). Specialization occurs at the graduate (Master's) level, but it should be pointed out that such a degree is far from being valued as a pre-requisite for employment of civil engineers in Brazil.

The Soil Mechanics course covers essentially all the classical Soil Mechanics topics, from origin and nature of soils, index tests, classification, site investigation, compaction, stress distribution, seepage, consolidation, and strength. There is a general feeling that the Soil Mechanics-Earthworks-Foundation Engineering sequence must be re-organized, so as to allow more time for the fundamentals of Soil Mechanics, which should be distributed among two courses, interspersed with earthworks and foundation engineering applications. But this is a change that shall not take place before 2013.

For the past few years (and up to 2012) those Soil Mechanics topics have to be covered in 15 weeks of 200-minute per week classes (lecture + demonstrations + exercises), plus 8 weeks of 100-minute per week laboratory classes. Typically students have laboratory classes every other week. These classes had been used lately for demonstration purposes, with essentially no hands-on experimentation. Despite the recognition of the value of such demonstrations (Jaksa, 2008; Herle and Gesellmann, 2006) which, by the way, are also still in use in the course, it was believed that hands-on laboratory experimentation could lead to better understanding of the fundamentals, while developing a wider range of desirable competencies, as shall be discussed below. The course typically has an enrolment of about 150 students, distributed in 4 classrooms.

These are the boundary conditions for the experience conducted in the Soil Mechanics learning process.

3 GENERAL GUIDELINES FOR LABORATORY CLASSES

The changing role of laboratory testing was, of course, recognized: hands-on experience in laboratory testing is not essential per se for the education of 150 future civil engineers. It was decided to rely on hands-on laboratory testing as a powerful aid to the understanding of the fundamentals of Soil Mechanics: students do not run direct shear tests because all of them will need to know how to run shear tests to be successful in their professional lives; rather, they run direct shear tests as part of their learning process of soil strength. A demonstration (or a lecture, for that matter) is not as effective as hands-on testing to sediment those concepts, provided tests are run by teams that do not have too many members, that members are stimulated to take active part in the experimentation, and are previously instructed as to what to look for, both in the laboratory and after, when analysing the results for report preparation.

Each classroom (about 36 students) is divided into two halves, A and B, and each half is further subdivided into three teams, thus A1, A2, A3, B1, B2, B3. Teams A have laboratory classes on odd weeks, teams B on even weeks. Such an arrangement typically yields 6-member teams, which is not ideal, but still manageable. Some ways to ensure and foster individual participation are discussed in section 4.

Table 1. Experiments.

Experiment	Subject
C	Compaction (Proctor), unconfined compression, consolidation (one load increment)
P	Permeability (constant head), grain-size (sieve) analysis, Atterberg limits
R	Shear strength (direct shear test)

4 SCHEDULE OF EXPERIMENTS AND STUDENT PREPARATION

Table 1 shows the three "experiments" (frequently more than one test per session, as explained ahead) each team must accomplish.

For certain experiments (such as permeability and shear strength) the laboratory is not equipped to accommodate more than one test at a time. This fact implies that each of the three teams of students present in the laboratory at any time must be running a different experiment. For example: A1 running C, A2 running P, and A3 running R. These practical constraints forced the adoption of a schedule which required all teams to run at least one of the experiments before the subject matter involved had been covered in the lectures and exercises (Table 2). The decision to adopt such a schedule was not considered inappropriate because of two firm beliefs:

1) it is good to have the students take the initiative to learn some topics on their own; as a matter of fact; most recent studies on the future of engineering value the self-learning skills (BOK2 ASCE, 2008, Rengers and Turner, 2010);
2) no topic is completely learned upon first contact; it is a good idea to revisit certain themes at different times and circumstances, in order to review and sediment important concepts.

Figure 1 tries to somehow depict the actual degree of advance formal exposure of the student to the theme of each laboratory session: 0.0 means no exposure, thus self-learning required; 1.0 means no self-learning required.

Table 2. Semester schedule of laboratory activities.

Week	Teams	Activity	Details 1(1)	Details 2(2)
Week #1	All A's	Laboratory visit and familiarization		
Week #2	All B's	Laboratory visit and familiarization		
Week #3	A1	Experiment C	Normal	below w_{OPT}
	A2	Experiment P	e_{MIN}	
	A3	Experiment R	e_{MIN}	25,100,400
Week #4	B1	Experiment C	Modified	below w_{OPT}
	B2	Experiment P	e_{MIN}	
	B3	Experiment R	e_{MIN}	50,200,600
Week #5	A1	Experiment P	e_{MAX}	
	A2	Experiment R	e_{MAX}	25,100,400
	A3	Experiment C	Normal	above w_{OPT}
Week #6	B1	Experiment P	e_{MAX}	
	B2	Experiment R	e_{MAX}	50,200,600
	B3	Experiment C	Modified	above w_{OPT}
Week #7	A1	Experiment R	e_{INT}	25,100,400
	A2	Experiment C	Normal	near w_{OPT}
	A3	Experiment P	e_{INT}	
Week #8	B1	Experiment R	e_{INT}	50,200,600
	B2	Experiment C	Modified	near w_{OPT}
	B3	Experiment P	e_{INT}	
Week #9	All A's	Synthesis explanation		
Week #10	All B's	Synthesis explanation		
Week #11	All	Synthesis presentation, C+P		
Week #12	All	Synthesis presentation, P+R		
Week #13	All	Synthesis presentation, R+C		
Week #14	All A's	Identification and classification		
Week #15	All B's	Identification and classification		

(1)Normal or modified Proctor (compaction energy), void ratio (for permeability and strength tests)
(2)Moisture content (of compacted specimen for unconfined compression test), normal stresses (for strength test)

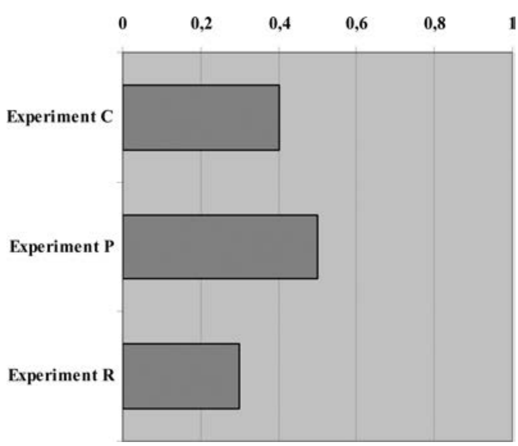


Figure 1. Your contact, in the laboratory, with the experiments indicated took place before (0) or after (1) the lectures and exercises on the subject?

Results in Figure 1 do not have a straightforward explanation, given that each laboratory session of a given team involves more than one experiment (Table 1). Considering only the Proctor compaction test, experiment C should yield a value of at least 0.9, given that compaction is taught at the very beginning of the course. If, however, only the consolidation test were taken into account, this number would be 0.0. Experiment P should, in fact, score slightly over 0.4, in view of the lecture schedule. The result for experiment R, however, is somewhat surprising, since **all teams** were formally lectured on soil strength **after** they had performed the shear strength test in the laboratory. A result close to 0.0 could therefore be expected. Previous exposure to the concept of friction and to strength criteria in other courses may explain the value of 0.3.

The decision to require a certain degree of self-learning has some important practical requisites and implications. The first requisite is that a good and objective textbook is needed, so that each team can be efficiently directed to the appropriate chapter or chapters in preparation to run the laboratory experiment. Fortunately such a textbook is available (Sousa Pinto, 2001). The second is that a guideline to each experiment must be made available well in advance, so that the team can prepare itself in due time. Current guidelines attempt to:

1) formulate the experiment(s) within the framework of geotechnical design and construction; it is important to know why the test is being run;
2) pose the most relevant questions, both conceptual and practical, and indicate where in the textbook the answers can be found;
3) describe the activities to be undertaken in the laboratory;
4) describe the template for report preparation.

Team leaders are advised to plan a team meeting in advance of the laboratory class, in order to discuss the guidelines, study together the required chapters of the textbook, and try to answer the questions. For better results, such meetings should ideally be officially scheduled, tutored (by teaching assistants, for example), and assigned credit points (such as ECTS credits) in accordance with the hours spent, much in the same way lectures and exercise classes are currently accounted for. According to the prevailing school policy, however, such activities are left to the discretion of the students themselves, frequently with less than satisfactory results. This situation will probably be changed in the curricular structure reform being planned for 2013.

On the day of the laboratory class the students are individually subjected to a 10-minute quiz covering the questions formulated in the guideline of that particular laboratory session. Quizzes are graded by a factor ranging from 0 to 1, which multiplies the grade to be attributed to the team laboratory report. This is, at this point, the way devised to foster individual participation.

The reaction of the students to the aforementioned aspects, namely self-learning and quizzes is depicted in Figures 2 to 4. In all cases a possible desirable result might follow a 45-degree line going from [0; outraged] to [4; stimulated], at least from the point of view of the educator. Actual results clearly indicate that students have mixed feelings, with more significant departures from "ideal" in the region of positive reactions. It is interesting to note that self learning causes more outrage and discomfort than 10-minute quizzes. Students were also polled on the relevance of those quizzes to foster preparation for conducting the experiment: the average answer was 2.2 on the same 0–4 scale, which suggests that formulation of those quizzes demands more attention in the future.

The author would, of course, be delighted to see his students more stimulated by the challenges set before them. Maybe these were not the most suitable challenges. Under the circumstances, however, self-learning in preparation for laboratory sessions was an inescapable requisite. Rejection levels, on the other hand, were by no means alarming, and indifference was low. All in all, the author believes that pedagogical benefits far exceed some discomfort or lack of motivation felt by students.

The template for report presentation stresses the requirement that reports should be limited to one A4 page. The reader should not be surprised if he recalls having heard of a similar requirement elsewhere; the idea is not original and he is referred to "The Infamous One-Page Summary" in "Ralph B. Peck, Educator and Engineer" (Dunnicliff and Peck-Young, 2006). This admittedly causes some stress, but the template goes into detail as far as the layout and required plots, the idea being that students need training in summarizing their main points in meaningful and well conceived plots and figures. Different alternatives have been tried, including extensive reports. They took too long to grade, in part, in these internet days, because most were stuffed with pointless descriptions and transcriptions generated by mere "cut and paste" activity. It

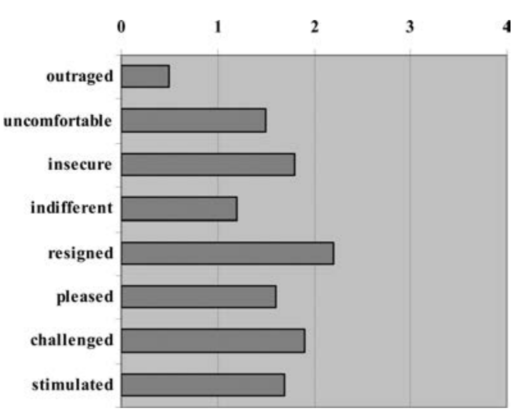


Figure 2. How did you feel about having do perform experiments without having first attended lectures and solved exercises on that specific subject?

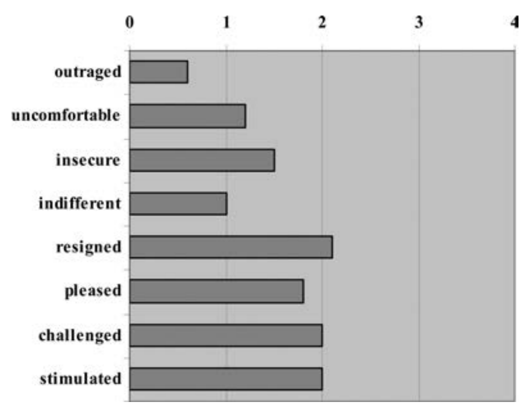


Figure 3. How did you feel about the self-learning requirement for some of the laboratory experiments?

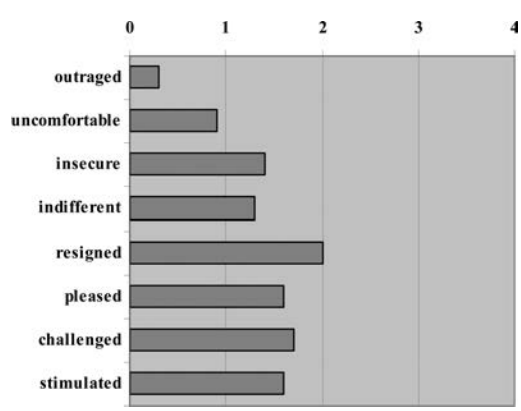


Figure 4. How did you feel about the quizzes applied before laboratory classes?

was then decided that the course educational contribution to the development of report writing skills should be restricted to a single aspect: making the essentials concisely meaningful to the reader in limited space.

Figure 5 clearly indicates a stronger rejection than other aspects of the laboratory activity (Figures 2 to 4), but no changes are planned: along their professional careers, those engineers will grow to appreciate the benefits of this exercise.

5 EXPERIMENTS PERFORMED

Given the tight schedule and the goal of using laboratory experimentation to better learn Soil Mechanics fundamentals, it has been necessary to limit the number of experiments, trying to select the most significant and most efficient for those purposes. Recall that each laboratory session lasts 100 minutes and takes place every other week for each team.

Experiment C consists of compaction of clayey silt at a single water content, subsequent unconfined compression of the compacted specimen, and application of one load increment to a different consolidating soft soil. Different teams are assigned different water contents and different compaction energies, according to Table 2, and the grade is partly related to the "distance" between the point obtained by the team and the "real" Proctor compaction curve, which is not known to students in advance. For a couple of years an attempt has been made to construct the compaction curve from the results obtained by different teams (2 points per team), but this test is prone to large uncertainties, mostly derived from improper energy application by different inexperienced students, and consequently those results tended to be less didactic than one would hope for; as a matter of fact, the shape of those Proctor curves departed so much from the usual that it was feared that they might have a negative effect on the learning process.

In the past an attempt was also made to construct a consolidation curve from increments applied by different teams. The experience was not successful, but it is believed that inadequate communication of the results was then the root of the problem. Nowadays all interaction of the course is made by means of a Moodle interface and students populate a database with the results of their experiments, so there is renewed hope of including consolidation – undoubtedly a most relevant topic – into the laboratory-based learning process. For time being (2011) each team has just been asked to apply one load increment (see Table 3 for scheduled sequence of load increments), and calculate the coefficient of consolidation for that increment. The good results of 2011 suggest that an attempt at construction of the full compression curve may be justified for 2012. Figure 6 summarizes student opinion about several aspects of Experiment C.

Experiment P consists of a permeability test (constant head) of a sand, grain size sieve analysis of that same soil, and Atterberg limits of the clayey silt used for Experiment C. Each team is required to prepare the

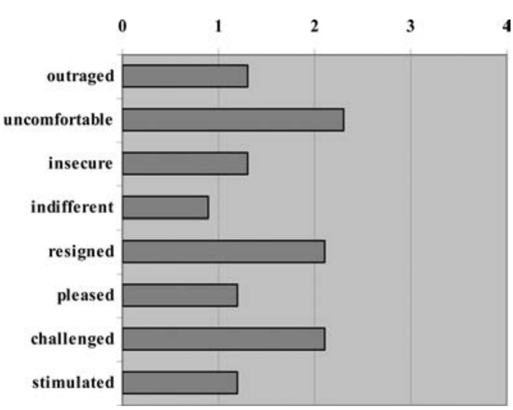
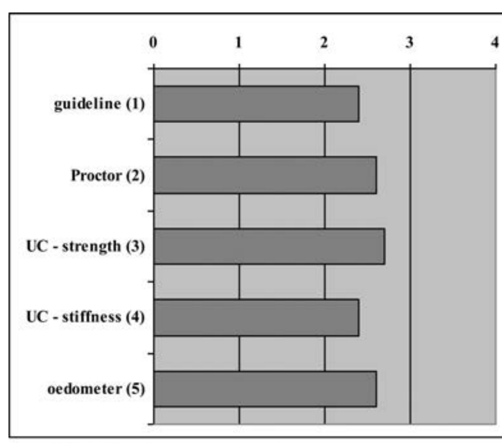


Figure 5. How did you feel about the need to present one-page reports?

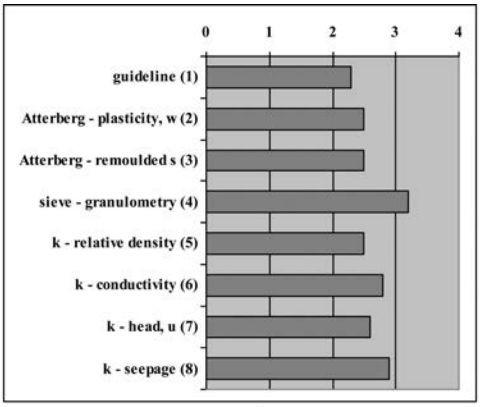


1. Guideline is clear and useful
2. Proctor compaction helped understand "compaction" and "water content"
3. Unconfined compression test helped understand "soil strength"
4. ... "soil stiffness"
5. Oedometer test helped understand "consolidation "

Figure 6. Please evaluate the various aspects of Experiment C, taking into account preparation, execution, and report writing.

Table 3. Schedule of load increments for oedometer test.

Teams in	Classroom 1	Classroom 2	Classroom 3	Classroom 4
LI from	high OCR	low OCR	approximately σ'_p	above σ'_p



1. Guideline is clear and useful
2. w_L and w_P helped understand "soil plasticity" and "water content"
3. ... I_C and its relationship to remoulded strength
4. sieve analysis helped understand the grain size distribution curve and its features
5. k test helped understand "relative density"
6. ... "hydraulic conductivity"
7. ... "hydraulic head" and "pore pressure"
8. ... "seepage"

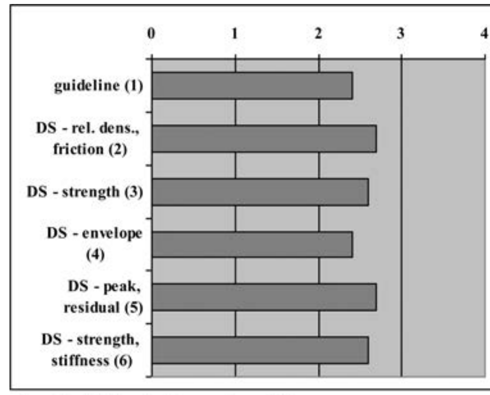
Figure 7. Please evaluate the various aspects of Experiment P, taking into account preparation, execution, and report writing.

specimen for the permeability test with a different relative density, as indicated in Table 2. Moreover, each of the four classrooms tests sand from a different origin. From a practical standpoint, students should check whether the tested sand is suitable as filter material for the compacted soil of Experiment C (grain size distribution of that soil made available in the guideline). Figure 7 summarizes student opinion about several aspects of Experiment P.

Experiment R is run on the same sand of Experiment P (one for each classroom), which is subjected to a direct shear test. Again, each team is required to prepare the specimen with a different initial relative density, as indicated in Table 2, where it is also shown that different teams use different normal stresses. Figure 8 summarizes student opinion about several aspects of Experiment R.

Figure 6 to 8 invite several comments. Students do not look especially satisfied with the guidelines, which might therefore deserve some improvement. The guideline for Experiment P is already of a significantly better quality than the other two, including more detailed explanations of each step of the testing procedures and photographs of the equipment. Nevertheless, student opinion about that guideline is not at all different from that about the other two; as a matter of fact, its average grade is 0.1 lower! Maybe a different type of improvement is needed, and alternatives are under investigation.

On average students felt that the experiments were about 65% effective (approximately 2.6/4) in helping



1. Guideline is clear and useful
2. direct shear helped recall concepts of I_D and "friction"
3. direct shear helped understand "strength criteria"
4. ... "Mohr-Coulomb strength envelope"
5. ... the difference between "peak" and "residual" strength
6. ... the relationship between "strength" and "stiffness"

Figure 8. Please evaluate the various aspects of Experiment R, taking into account preparation, execution, and report writing.

them better understand some key Soil Mechanics concepts. There is no similar effectiveness assessment for the demonstration-type laboratory classes previously adopted, thus one can only speculate that the current result validates the new approach. Experiment P scores slightly above the other two, which makes one wonder whether this result could be credited to the more elaborate guideline.

6 REPORT SUBMISSION AND RESULTS DATABASE

Each team is required to upload its one-page report to the Moodle interface before the next laboratory class (usually fourteen days after the day the experiment is run). In addition, the team leader is required to save all pertaining information in a Moodle database structured so as to facilitate the analysis and synthesis of the results.

The professor of each classroom grades the ensemble of three reports of each team on the basis of content, adherence to the template, and general format (legible and meaningful plots, etc.). Each student receives a mark that is the product of this team mark by the average of the personal factors obtained on 10-minute laboratory quizzes (see section 4). This compounded mark has a weight of 10% on the final student grade. It is believed that this percentage could be increased by 5% in the near future.

7 SYNTHESIS AND PRESENTATIONS

The so-called synthesis is perhaps the most important component of the proposed learning process. After all teams of all classrooms have saved their results in the Moodle database, each team is required to analyse all data available and prepare a presentation (no written report) which synthesizes the main conclusions about the influence of state and nature on the engineering behaviour of different soils.

Again, students receive a guideline for the synthesis of each experiment, so that they are made aware of what influencing factors and relationships they should be looking for. At that point in the semester the course has reached a stage when some of these relationships have already been discussed in lectures and exercises. Nevertheless, that synthesis is a challenging undertaking.

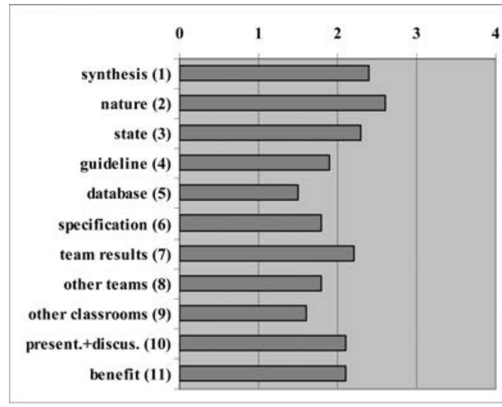
Three 100-minute sessions of synthesis presentations are organized with 4 presentations (and two experiments) per session (12 presentations per classroom), as indicated in Table 2. Each team makes two randomly selected presentations, in two of those three sessions, and teams A compete with teams B. Non-competing students vote for the most enlightening presentation (A or B) and this peer vote has a moderate influence on the grade attributed by the professor to the presentation. The purpose of this exercise is twofold: cement important concepts, influencing factors and relationships that govern soil behaviour, and train students at communication skills.

These presentations usually entice vivid discussions among students about the conclusions drawn and the quality of the data (obtained by themselves), during which the professor has the opportunity to review with the students the most important concepts, while discussing their relevance to practical applications, such as: influence of deviation from optimum water content on mechanical properties of compacted soils (and its relevance to embankment zoning, for example), influence of nature and origin of sands on the permeability and strength, influence of relative density of a sand on its permeability and strength, influence of the shape and position of grain size curve in its ability to act as a filter-drain to a soil, etc.

The students' opinions about the synthesis exercise are summarized in Figure 9. The idea met with moderate approval, although implementation needs to be perfected, especially with respect to the guidelines and the database. Perhaps this was one of the causes for the benefits to have been rated slightly below those derived from the individual experiments themselves (compare with Figures 6 to 8). Despite the fact that the poll involved all four classrooms, it is curious to note that, in terms of quality of results, the students rated their own classroom above the others, and their own team above the others in the classroom.

All teams are required to upload their presentations to the Moodle interface before the first presentation session (Week #11 in Table 2).

The professor of each classroom grades presentations on the basis of relevant (and visually enticing) content, ability to convey ideas by means of well designed graphs, and ability to discuss results in response to peers' and professors' questions. This mark is multiplied by a factor, either 0.9 or 1.0, depending on which of the two presentations (A or B) the non-competing peers preferred. For the purpose of assessing those factors, all students receive a guideline as to what type of "quality" they should be looking for in each presentation. The resulting mark is, by definition, the team mark. Finally, the members of each team gather to decide themselves on what should be the individual mark of each team member in this activity, under some restrictions; the most obvious restriction is that the team mark should be preserved as the average of individual marks. This compounded mark has a weight of 10% on the final student grade. It is believed that this percentage also could be increased by 5% in the near future.



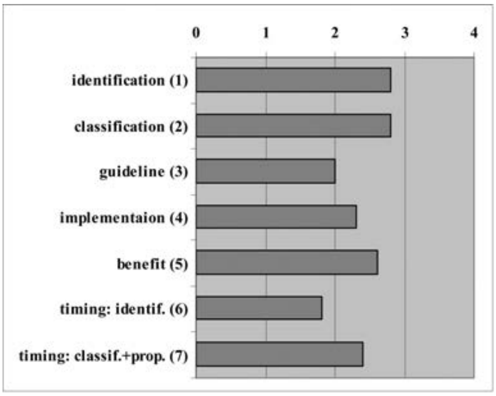
1. the general idea of syntheses
2. syntheses help elicit the influence of origin and nature on engineering properties
3. ... of state on engineering properties
4. guideline is clear and useful
5. saving results in a database
6. specification of results to be saved in database
7. quality of results presented by my team
8. ... by other teams in my classroom
9. ... by teams in other classrooms
10. classroom presentation and discussion of syntheses
11. educational benefit derived from the synthesis exercise

Figure 9. Please evaluate the various aspects of the synthesis exercise.

8 IDENTIFICATION, CLASSIFICATION, AND PROPERTY ESTIMATION EXERCISE

The laboratory activities are closed with an exercise in identification, classification, and engineering properties estimation (Table 2).

Identification and classification is usually taught at the very beginning of most Soil Mechanics courses, but it is believed that the subject becomes more relevant before the eyes of the students when they are faced with the real problem of estimating relevant soil properties on the basis of classification and a boring log, which is a common situation in practice. For this approach to be possible, it is essential that students



1. the idea of matching samples to folders (identification)
2. the idea of classification and property estimation
3. guideline is clear and useful
4. implementation of the exercise (folders, Moodle, etc.)
5. educational benefit derived from this exercise
6. best timing for identification exercise (0 = beginning of semester; 4 = end)
7. best timing for classification and properties estimation exercise (0 = beginning of semester; 4 = end)

Figure 10. Please evaluate the various aspects of the identification-classification-properties estimation exercise.

be exposed to the engineering properties of interest, say permeability, stiffness/compressibility, strength, **before** they can effectively tackle the problem of estimating soil properties by means of a boring log and soil classification.

Teams go to the laboratory where they find six soil samples (A to F) and six folders (1 to 6). Each folder contains results of index tests (grain size distribution, Atterberg limits, etc.) of one of the soil samples, as well as a boring log with SPT values of that soil. Teams are required to match folders to soil samples and to classify the soils using, for example, the Unified Classification System. They are then invited to advance estimates of engineering properties of interest, using correlations found in their textbook and other sources that they are referred to, all available from the Civil Engineering library. One of the aims of this exercise is to raise the students' awareness to the competency of being able to determine parameters for analyses, as emphasised, for example, by Atkinson (2008).

Currently this activity is not graded, although all students are required to participate. As a matter of fact, students tend to tackle with joy the fun-filled activity of matching soils and folders. Their opinion about this exercise is found in Figure 10.

Figure 10 indicates that this activity is one of the most popular among students in terms of relevance and perceived benefit. According to them, guideline and general implementation could be improved, and the identification exercise could be proposed somewhat earlier in the semester. The reason to have a single exercise that encompasses identification, classification, and property estimation is primarily motivational.

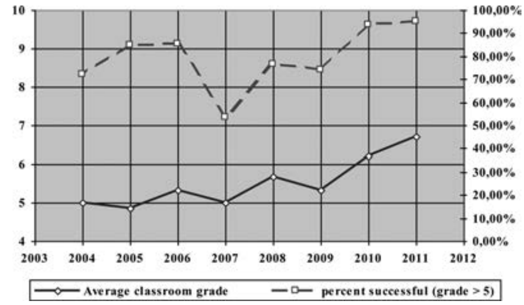


Figure 11. Evolution of average grade and percentage of successful students in the course.

Matching soils and folders could, in fact, be dealt with much sooner in the semester, and this alternative may be tested in the future.

9 EVALUATION OF THE RESULTS AND CONCLUSION

The degree of success of an experience like the one described can only be objectively judged by comparing how much the students learned under such conditions, as compared to the previous situation, all other factors being kept unchanged.

Figure 11 shows the evolution of average grades and of the percentage of students who were successful in the course, as the laboratory activities were being refined, while other activities (and grading system) remained essentially unchanged.

The question whether grades really reflect learning will be avoided here. Only time and professional performance may demonstrate whether these civil engineers did in fact receive a better Soil Mechanics education.

In addition, some major external changes took place, among the most important ones a quite welcome renewed interest in Civil Engineering, caused by the improvement in the economic situation of the country and long awaited new investments in infrastructure. Starting in 2008 a new admittance system was adopted by the school, so that students are now selected among candidates who have explicitly declared their interest in Civil Engineering, rather than in Engineering at large.

For the aforementioned reasons, as much as the author would like to credit the gradual improvement depicted in Figure 11 to the renewed laboratory activities, this cannot be objectively demonstrated.

Results of the poll are not brilliant, but it is believed that they do reflect the students' impressions, thus efforts are being made to meet some of their dissatisfaction: guidelines are begin scrutinised in search for possible improvements; database specification is being revised, so that students can deal more efficiently with the task of uploading the results of their laboratory experiments; minor changes in the current schedule of laboratory activities (Table 2) are also being considered.

The laboratory activities described represent a substantial amount of work on the part of students and professors alike. It is believed that if this ensemble of "laboratory learning resources" has its weight in the final student grade increased, this might foster the level of work that the students will be willing to undertake for them, possibly with some extra gains in learning.

The educator has, of course, a viewpoint that is significantly different from that of the student. One should not be expected to endorse all of the opinions of the other. Even if outcomes cannot be objectively validated yet, the proposed approach addresses many of the concerns of the BOK2 (ASCE, 2008) report and incorporates many of the objectives pointed out by Feisel and Rosa (2005) as fundamental objectives of engineering instructional laboratories. For these reasons, no change under consideration will be implemented if any doubts about its positive pedagogical impact persists.

ACKNOWLEDGEMENTS

The reported experience of close integration of laboratory sessions into the learning process of Soil Mechanics was enriched by the shared responsibility and enthusiasm of fellow professors teaching the other three classrooms. The author wishes to extend his gratitude to his colleagues Fernando Marinho, José Jorge Nader, Marcos Massao Futai, and Maurício Abramento. None of the objectives would have been attained if it were not for the effort of the laboratory staff, Joaquim Costa Jr. and Antonio Heitzmann, and many teaching assistants, especially Ms. Danielle Fernanda Morais de Melo.

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Interactive learning modules in geotechnical engineering

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ABSTRACT: Recent developments in e-learning authoring software, such as *Articulate Presenter* and *Adobe Captivate*, have greatly simplified the task of developing engaging and pedagogically effective interactive learning modules (ILMs). ILMs offer a number of benefits over traditional forms of instruction, such as increased student engagement and improved student experience by providing an appropriate learning context and an active learning environment. This is particularly relevant for the current student cohort of Generation Y learners who often prefer active learning environments. This paper explores the advantages and limitations of ILMs, presents examples of them in the civil and geotechnical engineering contexts and, based on the results of student surveys, examines their efficacy.

1 INTRODUCTION

Over the last decade or so online learning (also known as web-based learning) has become increasingly popular, with the vast majority of higher education institutions worldwide offering it in some form or other – from modules within courses (i.e. subjects), to complete courses, and entire programs (i.e. degrees). A relatively recent and important development in online learning is the use of online multimedia *Flash* presentations or interactive learning modules (ILMs). E-learning authoring software, such as *Articulate Presenter* (Articulate Global 2011a) and *Adobe Captivate* (Adobe Systems Inc. 2012a), has recently been developed which enables subject matter experts to generate e-learning objects relatively rapidly and easily from standard Microsoft *PowerPoint* files on their desktop. These software packages also allow for audio- and video-narrated content to be packaged with interactive and feedback mechanisms, such as *Adobe Flash* (Adobe Systems Inc. 2012b) interactions and quizzes (Carrington and Green 2007). This is particularly desirable given the relatively universal nature of *Flash* files, and provides a quick and efficient means of creating, delivering and managing educational material online.

ILMs provide a structured and active learning environment whereby students can learn by exploring and navigating through the content and can be assessed during the learning process, typically through the use of quizzes, which may be used for diagnostic, formative or summative assessment. Furthermore, students have the ability to revise material until it is understood, which is particularly useful for students whose first language is not the one used for instruction, as students can review the material as often as needed.

In addition, Maier (2008a, 2011) suggests that ILMs have several additional benefits for both students and teachers. With respect to the former:

- increased student engagement – the current group of students, usually referred to as Generation Y learners, often have significantly different expectations to previous student cohorts. They expect value for money and that higher education providers will accommodate pressures outside of study, such as paid employment and meeting family responsibilities, through the flexible delivery of teaching, services and advice (Bradley et al. 2008). Furthermore, several commentators suggest that they learn by doing rather than reading and listening to lectures, are adept with new technology, multi-task, expect more immediacy, have shorter attention spans and diminishing literacy skills (McNeely 2005, Roberts 2005, Windham 2005, Rogers 2007). E-learning and ILMs have been shown to enhance engagement and satisfaction of Generation Y learners, as will be discussed further below;
- improved learning outcomes;
- time flexibility – students can learn in their own time and at their own pace rather than needing to conform to a predetermined timetable; and
- location independence – students need not be on-campus to view the material. They might be at home, another campus, overseas or in a park.

With respect to teachers, Maier (2008a, 2011) suggests that ILMs also have several benefits:

- Reduced contact time – once the ILMs have been developed, less scheduled contact time is required to deliver the content included in the ILMs. Instead, the extremely valuable, face-to-face sessions can used in other ways (Maier 2008a, b), an example of which is discussed below in the context of just in-time teaching. It is worth noting that the time required to develop the ILMs themselves is not insignificant. The author has found that a one-hour lecture, in the form of a mature *PowerPoint* file, takes around 4 to 8 hours to convert to an ILM. Depending on the features included, the development will take longer;

- Less preparation time – again, once the ILMs have been developed, the face-to-face sessions require reduced preparation time;
- Fewer student queries – as the content is available online and the material can be reviewed according to the students' needs, Maier (2011) reports that queries have noticeably reduced;
- Teach at multiple campuses – again, as the content is available online, the material can be accessed at the host campus, as well as other campuses, including ones overseas;
- Tutor training – ILMs can be very helpful when training instructors, as the teacher can direct the tutors to the online content and the tutors can learn the material in the same way as the students. As a result, there is no need to arrange individual training sessions for the tutors;
- Provision of assumed knowledge – students who have not taken a particular prerequisite course and therefore lack the appropriate knowledge, can also be directed to the ILMs; and
- Course handover – when the course is transferred to a different teacher or coordinator, the ILMs greatly simplify this task.

One of the key features of ILMs is that engaging and pedagogically relevant assessment tasks and quizzes can be readily incorporated into the *Flash* presentations via products such as *Articulate Quizmaker* (Articulate Global 2011b), *Adobe Captivate* and *Raptivity* (Harbinger Knowledge Products 2012). *Raptivity* allows educators to create learning interactions such as games, simulations, brainteasers, interactive diagrams, virtual worlds relatively rapidly and simply. These interactions can then be embedded directly into online courses to improve learner engagement, similar to quizzes from *Articulate Quizmaker* and *Adobe Captivity*. It is useful to note that the software products described above are SCORM – (Sharable Content Object Reference Model – a collection of standards and specifications for web-based e-learning) and AICC – (Aviation Industry Computer-based training Committee) compliant, implying that they are compatible with most learning management systems (LMSs), such as *Blackboard* (Blackboard Inc. 2012) and *Moodle* (Moodle.org 2012), and the results of online assessments can be incorporated into the LMSs' grade books.

2 APPLICATIONS OF ILMS IN CIVIL ENGINEERING

Maier (2008b) has used *Articulate Presenter* and *Quizmaker* extensively in his Environmental and Water

Figure 1. Example of an *Articulate Presenter*-based ILM applied to water engineering showing opportunities for active navigation and exploration (Maier 2008b).

Figure 2. Example of an *Articulate Presenter*-based ILM incorporating an industry case study (Maier 2008b).

Engineering courses, an example of which is shown in Figure 1. It can be seen that students are actively able to navigate the module using the left-hand navigation bar and the pause/play/fast-forward/rewind controls at the bottom of the screen. In addition, students can actively learn by selecting various parts of each slide to expose additional information and resources such as photographs, illustrations, videos, sound bites and attachments including *Word* Documents, *Excel* spreadsheets, pdfs and so on.

Maier (2008b) has also promoted the use of ILMs to add real-world context to his courses by including case studies from guest lecturers from industry. The approach adopted by Maier is he requests the guest lecturer to prepare a 5 minute *PowerPoint* presentation on an agreed case study relevant to his course and also asks the guest lecturer to record narration of the *PowerPoint* presentation. The *PowerPoint* and associated audio file(s) are then emailed to Maier, who then transfers and synchronises them using the *Articulate Presenter* software. An example of such an ILM incorporating an industry case study is shown in Figure 2. In this way, Maier has been able to assemble a relatively large catalogue of relevant and engaging short, guest lecture presentations, which can be reused and which negates the need to organise and deliver face-to-face industry presentations each time the course is offered.

Maier (2008a) found that, of the 67 students surveyed, 88% thought that presentation of the course material in the form of ILMs was more enjoyable than using text-based resources and 84% felt that the ILMs were able to provide a more realistic context than the currently-available text-based resources. In addition, in response to the question "what the best aspects of using the online modules?" the following student responses were received: "*The online modules were really good and enjoyable and made it easy to learn the subject*"; "*The information was much easier to absorb with use of the modules*"; "*Modules helped to understand lecture material*"; "*The online modules were easy to follow and kept me much more interested than simply reading notes*"; "*It was made interactive*"; "*Interactive . . . videos in online modules made it easier to relate coursework to real life issues*"; "*It had more practicality than other courses and could be related to the real world*".

3 APPLICATIONS OF ILMS IN GEOTECHNICAL ENGINEERING

Recently, the author has used *Articulate Presenter* to develop pre-laboratory class learning modules, an example of which is shown in Figure 3. As class sizes have continued to increase, the laboratory component of the undergraduate geotechnical engineering program has presented difficulties as the result of limited equipment, technical and demonstrator resources, combined with class scheduling constraints. In order to address this, the author developed streamlined versions of the laboratory classes, whereby groups of students (typically 4 per group) participate in 45 minute focussed experiments. In order to enable these sessions to be as effective as possible, before each laboratory session, students are required to view the pre-lab ILMs, via the LMS. At the University of Adelaide, the LMS employs *Blackboard* and is known colloquially as MyUni. The ILMs incorporate audio narration and video footage of each of the experiments: sieve analysis, Atterberg limits, Proctor compaction, triaxial testing of clay, direct shear testing of sand, oedometer testing and seepage flow through a dam. Specific details of the laboratory experimental program are given in the companion paper (Jaksa et al. 2012).

As mentioned above, one of the most significant aspects of ILMs is that assessment can be embedded into them. These are important for a number of reasons. Firstly, sound e-learning design suggests that ILMs should include activities for students to do at regular intervals – generally no less frequent than 15 minutes apart. It is well understood, that students learn better by doing rather than passively listening. This is the nub of *active learning* (*cf* Felder & Silverman 1988, Prince 2004). Hence, e-learning designers are encouraged to include frequent activities and learning interactions such as quizzes, mini-games, simulations, brainteasers and interactive diagrams.

Figure 3. Example of a pre-laboratory *Articulate Presenter*-based ILM used in an Atterberg limits experiment.

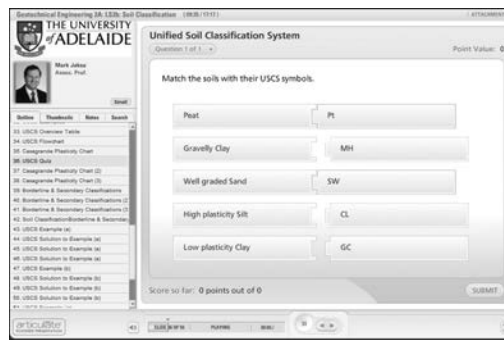

Figure 4. Example of a matching pairs quiz question embedded in an *Articulate Presenter*-based ILM.

Secondly, if assessment is embedded within the ILM, the instructor has the ability to use the assessment results to inform his or her instruction. Maier (2008b) further advocates the use of ILMs in the context of just in-time teaching (JiTT). Briefly, JiTT is a relatively recent constructivist approach, which combines the best features of traditional face-to-face instruction with e-learning (Novak & Patterson 2000). Maier (2008b) uses ILMs as a replacement for his traditional lectures, where the content is delivered. Instead, students access the ILMs via the LMS and go through them in their own time. Maier subsequently uses the results of the ILM-embedded quizzes to inform him about the various areas of the material that students are having difficulty understanding. The following face-to-face class then focuses on these areas of difficulty by means of additional instruction, examples and discussion. Hence, the teaching is just in-time, focussed and relevant. Further treatment of JiTT is given by Novak & Patterson (2000) and Jaksa et al. (2009).

As mentioned above, *Articulate Quizmaker* facilitates the development of quizzes within ILMs and a variety of templates are provided to enhance student engagement. An example of a matching pairs quiz question, in the context of unified soil classification, is shown in Figure 4 and a multiple choice question in Figure 5.

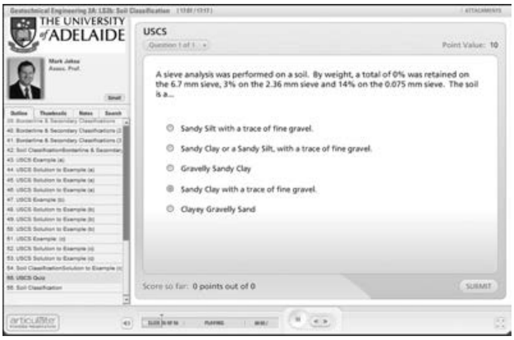

Figure 5. Example of a multiple choice quiz question embedded in an *Articulate Presenter*-based ILM.

A survey conducted by the author in 2010 of 124 Level 2 geotechnical engineering students and 39 Level 3 students found that 84% and 85%, respectively, felt that the ILMs assisted in the preparation of the laboratory classes and 73% and 82%, respectively, felt that the ILMs enhanced their learning.

4 LIMITATIONS

Whilst the ILMs present several significant opportunities, they should not be seen as a complete solution. The author uses them as an additional resource, not as a replacement for experienced educators or face-to-face classes. Whilst *Articulate Presenter* simplifies the task of converting a *PowerPoint* presentation into a *Flash* online module, as mentioned previously, considerable time is nevertheless required to develop the ILMs. Faculty may be daunted by the time commitment required to develop ILMs. Maier (2011) suggests that an effective approach is to develop the ILMs in stages. Firstly, one could audio record one's traditional face-to-face lectures and then, prior to the subsequent offering of the course, synchronise the *PowerPoint* slides to the recorded audio. At a later and convenient time, additional photographs, video footage and illustrations could be added, followed by more polished narration. Finally, again at a later time, quizzes could be added. In this way, a slick ILM could be developed in a series of stages, over a period of years, rather than seeking to develop the entire package at the one time.

A second issue with ILMs, and other e-learning technologies and deliverables for that matter, is their operational life. Computer software and operating systems are in a relatively constant state of flux. A current limitation of *Flash*-based, online deployments is that *Adobe Flash* is not supported by Apple mobile digital devices such as the iPad, iPod Touch and iPhone. In a recent response to this, Adobe have released a *Flash* to HTML5 convertor, currently named *Wallaby* (Adobe Systems Inc., 2012c), which may signal the eventual demise of *Flash* (Australian Personal Computer, 2011). Hence, an important question is "will the not insignificant time investment, of an educator in developing such resources, be wasted in a few years time when the operating system, software or deployment environment becomes obsolete?" However, this is a natural and inevitable part or 'cost' of technological progress.

Finally, ILMs offer no opportunity to answer automatically queries raised by students as they seek to learn and understand the material being studied. Hence, ILMs do not replace face-to-face sessions. Rather, they provide an opportunity to enhance them, through increased student engagement, and learning.

5 CONCLUSIONS

This paper has explored the use, benefits and limitations of interactive learning modules in geotechnical engineering. It has been shown that they have the potential to enhance student learning and engagement, particularly with the current cohort of students and this has been validated by student surveys. Commercial software, such as *Articulate Studio*, is readily available to assist subject matter experts in developing ILMs and, with such software, the task is relatively straightforward and time-efficient. The companion paper, Jaksa et al. (2012), presents a framework for improving geotechnical laboratory classes and ILMs feature prominently in the proposed approach.

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Shaking the Foundations of Geo-engineering Education – McCabe, Pantazidou & Phillips (eds)

Reinventing geotechnical engineering laboratory classes

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ABSTRACT: In his 1987 Nash Lecture, Prof. John Burland questioned the educational value of requiring undergraduate students to undertake routine laboratory testing, such as the triaxial, direct shear and oedometer tests. He stated that students are far from inspired by these. Other highly respected geotechnical engineering educators and researchers have expressed similar reservations about the current nature of geotechnical engineering laboratory classes. This paper re-examines the nature, structure and assessment of geotechnical laboratory experiments, explores their educational aims and proposes a framework whereby these classes can be more effective places of learning, be more engaging and more efficient. This last aspect is particularly challenging in recent times, as class sizes continue to grow to the point where educators are questioning the sustainability of resource-hungry and time-intensive laboratory classes.

1 INTRODUCTION

For quite some time, a number of eminent geotechnical engineering educators have questioned the value of undergraduate students conducting routine testing in the laboratory, such as the triaxial, direct shear and oedometer tests. Professor John Burland, in his 1987 Nash Lecture (Burland 1978) stated:

"*I have to admit to being somewhat ambivalent about undergraduate laboratory work.... I am at present of the opinion that routine laboratory testing, such as shear box, triaxial, and oedometer, is better demonstrated in class, perhaps by means of video recordings, using modern equipment and up-to-date testing procedures. The laboratory class would then be devoted to a few (perhaps two or three) experiments that are seen to be related to practical problems.*"

At the 1991 UK Meeting of Teachers of Geotechnical Subjects held at the University of Edinburgh, Orr (1992) reported "*Professor David Muir Wood ... considered the role of laboratory testing and whether the aim should be to impart knowledge, skills or understanding. Laboratory testing is time consuming and [class] time is limited. He had no sympathy for the view that the manual recording and processing of data was good for students. Time needs to be spent productively and experiments which merely confirm well understood facts should be removed. Routine tests should be demonstrated, maybe by video, using modern equipment and up-to-date procedures.*"

Poulos (1994) supported this view stating:

"*Many existing courses appear to involve a significant amount of laboratory testing which is carried out by the students. However, with the advent of modern technology, it would seem desirable that, in the laboratory component of the basic courses, less emphasis be placed on the testing procedures themselves, and more emphasis be placed on demonstration experiments and tests which enable comparisons to be made with theoretical analyses.*"

Atkinson (2011) also strongly advocates that routine laboratory testing by undergraduate students is of limited educational value and his views align with those expressed above.

Despite these strong and consistent opinions from eminent geotechnical educators for almost three decades – and with which we agree – the vast majority of geotechnical engineering undergraduate courses include routine laboratory testing. Furthermore, there is a great scarcity of information available in the literature to enlighten teachers in relation to the most effective approaches and pedagogies to adopt when incorporating laboratory experiments in undergraduate geotechnical engineering courses. Notable exceptions are Airey (2008) and Airey et al. (2012).

All would agree that an experience in the laboratory by geotechnical engineering students is an essential part of their education. However, how should the laboratory experience be structured and designed, to maximise learning and student engagement, and how much time should be spent in the laboratory and what is the optimal use of resources needed to achieve these objectives?

This paper presents a model that is currently under development by the authors as part of a learning and teaching research grant funded by the Australian Government. The broad aim of the project is to develop a framework and an associated suite of traditional and e-learning resources to enhance student learning and engagement in geotechnical engineering laboratory classes. As mentioned above, an additional and fundamental criterion is to ensure that the framework and developed resources are designed in such a way as to ensure that laboratory classes are as efficient and, hence sustainable, as possible, without compromising student engagement and the learning outcomes.

Prior to discussing the proposed model, it is worth first examining the learning objectives associated with geotechnical engineering laboratory classes.

2 EDUCATIONAL AIMS

Are geotechnical laboratory classes relevant in today's engineering education? If so, what is unique about the laboratory experience that cannot be achieved in any other manner?

The authors believe that geotechnical engineering laboratory classes are relevant and are needed because they:

- Reinforce concepts that are treated in lectures;
- Allow students to compare experimental results with theory and allow one to challenge the assumptions that underlie much of soil mechanics theory;
- Allow students to observe the engineering behaviour of soil (and rock) in standard procedures;
- Develop experimental skills;
- Provide a sensory experience of soils, particularly tactile, and allow students to identify, classify and distinguish between different soil and rock types;
- Allow students to relate the experiment and results to applications in the real world;
- Allow students to deal with uncertainty (experimental error) and ambiguity; and
- Facilitate the interpretation of test data, particularly for design purposes, and communication of the test results to various audiences.

3 PROBLEMS WITH THE STATUS QUO

As highlighted by Profs. Burland, Muir Wood, Poulos and Atkinson, students are often uninspired by routine geotechnical laboratory tests. A key aspect of this is associated with the behaviour of fine-grained soils, where the time taken to obtain results is often not insignificant. This is particularly the case for oedometer and consolidated undrained triaxial tests on clay. These tests are slow and very little happens or can be observed and students cannot be easily engaged in these tests. The ability to speed up time in virtual tests is an attractive alternative for these tests.

Other factors that conspire to diminish student learning and engagement and add to the burden of scheduling geotechnical engineering laboratory classes include:

- *Increased class sizes*: The move from elite to mass education in the higher education sector over the last few decades, in most parts of the world, has resulted in ever-increasing class sizes. In Australia, it is not uncommon for academics to be teaching a geotechnical engineering course to more than 200 students, and in some institutions, the number is more than double this. Given the inflexibility of the teaching semester – around 12 to 13 weeks in Australia, all of the laboratory classes need to be scheduled within this period. The large classes and limited time available inevitably lead to students having to work in groups, sometimes with as many as 8 members. As many of the experiments have limited physical tasks that have to be performed, many students, particularly the reserved ones, simply observe their peers perform these tasks and disengage from effective learning. This is similar to the situation described by Burland (1987) at the beginning of the paper.
- *Increased pressures on the curriculum*: Laboratory sessions can occupy a significant portion of a student's timetable. This scheduled time is under pressure from external demands to increase the teaching of sustainability, climate change, environmental studies and soft skills training, such as technical report writing and presentation skills. These time pressures are leading curriculum managers to push for the reduction or even the elimination of laboratories, which also physically occupy valuable university space.
- *Expensive equipment requiring specialised technical support*: Geotechnical laboratory equipment is expensive and requires skilled technical staff to operate and maintain. Appropriately skilled technicians can be difficult to find. Because of space and personnel constraints, students are often forced to work in groups that are too large for effective participation.

4 PROPOSED FRAMEWORK

In order to optimise the amount of time spent in the laboratory and to enhance student engagement, it is proposed to adopt a framework incorporating three components, which are shown diagrammatically in Figure 1. The components include an introductory module, the laboratory session itself and a post-laboratory module.

The proposed framework suggests the use of e-learning tools in the pre- and post-laboratory modules and a streamlined laboratory experience. The three components of the framework are explained more fully in the following sections.

5 INTRODUCTORY MODULE

The first component is intended to introduce the students to the laboratory class so that the subsequent laboratory session can be more focussed, engaging and streamlined. It is proposed that the Introductory Module will be developed in the form of an interactive learning module (ILM) adopting e-learning authoring software such as *Articulate Presenter* (Articulate Global 2011a) as detailed in the companion paper (Jaksa 2012). The Introductory Module should include a list of the desired learning outcomes, the real-world context and applications which the experiment is relevant to, the background theoretical framework applicable to the experiment, embedded assumptions and the equipment and procedure that will be used in the laboratory component. It is intended that the module will be multimedia rich and incorporate video footage, animations and narration, so that it can be appealing and engaging. An example of an *Articulate*-based ILM developed in the form of an Introductory Module for the oedometer test is shown in Figure 2.

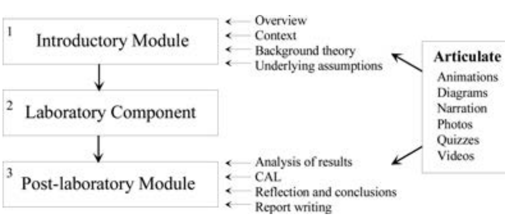

Figure 1. Proposed framework.

Importantly, the students' understanding of the concepts included in the module will be formatively assessed by means of quizzes embedded in the *Articulate* module. *Articulate Engage* (Articulate Global 2011b) will be used to develop these quizzes. It is not essential that the quizzes be used for formal assessment, rather as a tool to enhance the students' understanding. It is argued, however, by Airey et al. (2012) that some, albeit small, amount of summative assessment is critical to getting students to engage with the online modules.

The Introductory Module will be deployed to the universities' learning management system (LMS), such as *Blackboard* (Blackboard Inc. 2012) or *Moodle* (Moodle.org 2012), to enable students to access the material online, at a time to suit their convenience and at their own pace. The LMS will be able to track each student's access to the ILM and a condition of undertaking the laboratory component might (and ought to) be that they have taken the time to view the module and to answer the quiz questions. Whilst the introductory modules have yet to be developed, it is expected that, consistent with Airey et al. (2012), students will

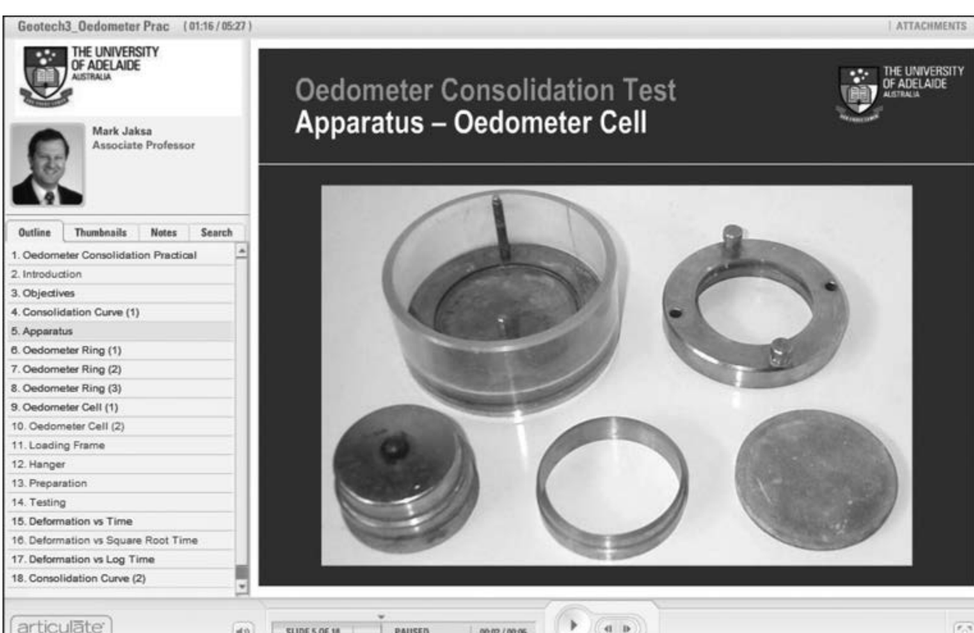

Figure 2. Example of an introductory module developed in *Articulate*.

need to achieve a threshold score with respect to the quizzes, before being permitted to take the laboratory component.

Preliminary versions of introductory modules, however, were developed and implemented at the University of Adelaide in 2010. As outlined by Jaksa (2012), a survey conducted by the first author of 124 Level 2 geotechnical engineering students and 39 Level 3 students found that 84% and 85%, respectively, felt that the introductory modules assisted in the preparation of the laboratory classes and 73% and 82%, respectively, felt that they enhanced their learning.

In addition, as outlined by Airey et al. (2012), introductory modules of a somewhat different nature were introduced at the University of Sydney in 2010 and this resulted in a stark improvement in the students' engagement with the laboratory classes. For example, students who used the online resources gained higher average report marks (mean = 58.64) than those who did not (mean = 51.33).

6 LABORATORY COMPONENT

As mentioned earlier, traditional geotechnical engineering laboratory classes often involve students working in groups – sometimes as large as 8 or more – on a particular experiment, usually in a 2 or 3 hour session. The second component of the framework adopts a more streamlined laboratory class which is more focussed, requires less technical support, both in terms of preparatory work and supervision during the sessions themselves, reduced student contact time, and less demand on scarce equipment and laboratory resources.

In order to understand better the proposed approach, the example of the oedometer test is again explored. Traditional practice is to structure the laboratory session so that a student group undertakes the experiment, in essence, several times to develop a consolidation curve. Each point on the curve is obtained by applying a load to a soil specimen and recording the settlement over a period of around 30 minutes. Many clays often require a much longer period of time to consolidate and specially selected or amended clay is needed to achieve primary consolidation within 30 minutes. Usually, 6 to 8 points are needed to generate a representative consolidation curve. Hence, the time needed in the laboratory can be quite extensive and the measurement process itself is extremely dull and tedious.

An alternative approach is to reduce the time spent in the laboratory to approximately 45 minutes. This is achieved by the students measuring one point on the consolidation curve, rather than the entire 6. The complete set of 6 points is obtained by subsequent student groups, who each apply a different load and, hence, obtain a different point on the curve. Therefore, over a 3-hour period, the entire consolidation curve is generated. Subsequently, the students can access the complete set of data, again via the LMS, so that they can perform the relevant analyses, evaluate the required properties and write up the report.

At the University of Sydney another approach is adopted where thinner specimens (12 mm) are used, thereby reducing the time of consolidation. In addition, the student group completes an entire test with assistance of lab staff who apply and record the first three load increments. Elsewhere, sandy clays are used to reduce the time of consolidation.

Due to the streamlined laboratory component students spend less time in the laboratory, hence there is less pressure on timetabling and students can therefore work in groups of fewer students – typically, 3 to 4. The net result is a more efficient and sustainable laboratory experience, which is more engaging, as students participate in smaller groups and are better prepared. As a consequence, improved learning outcomes are expected to be achieved.

The project will also explore other approaches for the streamlined laboratory sessions in order to recommend a range of alternatives for academics to adopt to suit their institutions' needs.

7 POST-LABORATORY MODULE

Similar to the Introductory Module, the Post-Laboratory Module will again incorporate ILMs developed using the e-learning authoring software *Articulate* and will include content on compiling and understanding the data obtained in the laboratory, explaining the necessary analyses in order to quantify the relevant soil properties, a comparison of these properties with other soil types, treatment of experimental errors, and the requirements of the report and guidance on report writing.

An important feature of this third module is the inclusion of computer assisted learning (CAL) objects. Using these, in a virtual laboratory context, students will explore the influence of varying a number of parameters associated with the experiment in order to appreciate their influence on the soil properties under examination. For example, in the oedometer test, the soil type, permeability, coefficient of consolidation and drainage characteristics (i.e. one- and two-way drainage) can be varied to examine their influence on the time of consolidation and settlement. As a consequence of the incorporation of CAL, technical resources and repetition in the laboratory are minimised. The *CATIGE* learning objects (Jaksa & Kuo 2009) will be used for this purpose, an example of which is shown in Figure 3. The *CATIGE* objects will be developed further, particularly to make them more visually appealing so that they appear more like the real laboratory experience. As highlighted by Chang et al. (2011), today's students are far more demanding than previous students in terms of their expectations of the quality of the graphics and navigation of e-learning software.

In order to 'close the learning loop', the students will reflect on the learning objectives introduced in

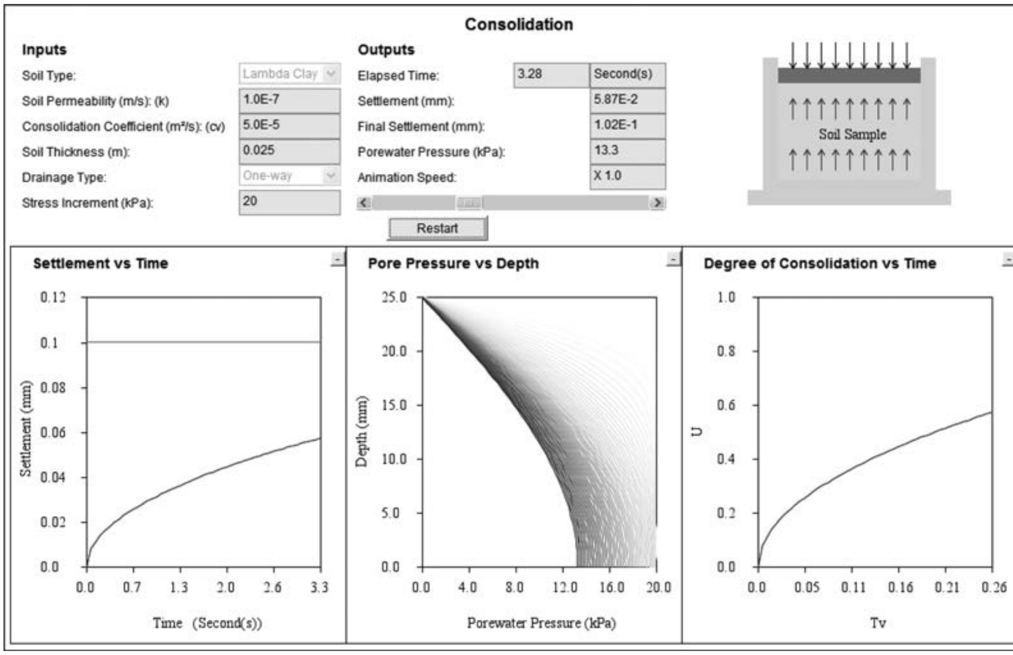

Figure 3. *CATIGE* – Consolidation object.

the first component and whether these have been achieved in the proposed framework by means of a quiz and survey. If the students' experience has been sub-optimal, they will be asked to provide feedback on how the experiment and its resources might be improved. This will provide a valuable ongoing resource for continued improvement.

8 PROPOSED EXPERIMENTS

The project proposes to develop traditional and e-learning resources for the following geotechnical engineering experiments:

- Soil classification – particle grain size distribution, hydrometer, Atterberg limits, field identification tests, linear shrinkage and moisture content test;
- Compaction – standard and modified tests;
- Direct shear test;
- Triaxial test – unconsolidated undrained (UU), consolidated undrained (CU);
- Oedometer test; and
- Seepage flow through an earth dam and beneath a retaining wall.

9 DISSEMINATION

A key aspect of the work outlined in this paper is to disseminate, as widely as possible, the resources that will be developed as part of this project, in order to facilitate its widest possible use. A web site is planned to be established as part of the work of TC306, the technical committee of the ISSMGE charged with geo-engineering education. Details of the TC306 web portal will be available via the ISSMGE web site and from the lead author. The resources will be freely available and will be developed in such a fashion as to provide as much flexibility as possible for academics to adapt the material to suit their needs.

In the interests of engaging as many academics as possible across the globe, comments and feedback on the proposed framework, experiments and resources are welcome. Interested readers are encouraged to participate and contribute to the project by sharing resources and by contacting the lead author (mark.jaksa@adelaide.edu.au).

10 CONCLUSIONS

The current nature of geotechnical engineering laboratory classes has been presented and several factors which diminish student learning and engagement have been explored. A framework has been proposed which incorporates three components – an introductory module, a streamlined laboratory experience and a post-laboratory module. The pre- and post-laboratory modules incorporate e-learning resources in the form of interactive learning modules with embedded quizzes and computer assisted learning objects to enhance student engagement and improve learning outcomes. An additional key criterion which is addressed by the framework is to ensure that laboratory classes remain viable and sustainable within an education sector with growing class sizes and greater efficiency demands. Initial work undertaken at the Universities of Adelaide and Sydney has demonstrated encouraging results, both in terms of improved learning and enhanced student engagement.

ACKNOWLEDGMENTS

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Shaking the Foundations of Geo-engineering Education – McCabe, Pantazidou & Phillips (eds)

Activities to enhance students' understanding of pore water pressure, seepage and total head

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ABSTRACT: When students start an undergraduate engineering course, many have a limited comprehension of water pressure, and find that understanding first hydrostatics and later the concepts of total head and seepage is extremely challenging. Yet this topic is very important in engineering practice, and misconceptions about the water regime often contribute to major failures in excavations and tunnels. This paper describes attempts at the University of Bristol to develop undergraduate civil engineering students' understanding of pore water pressure through classroom exercises and in the laboratory. In class students are encouraged to explore problems of one-dimensional seepage. Later, working in small groups, students observe flow through a dam built from sand in a seepage tank and compare their empirical flow-net with predictions using a finite element seepage analysis run for them in the laboratory. They measure the permeability of the same sand using a permeameter, which also demonstrates the link between seepage and non-hydrostatic pressure. Using this permeability they compare the predicted and measured discharge from the dam, before they observe failure of the downstream slope of the dam induced when the exit from the underlying drainage blanket is blocked. These activities develop their understanding of pore water pressure, seepage and total head so that many have confidence in their ability to predict and interpret groundwater observations by the time they graduate.

1 INTRODUCTION

Pore water pressure is central to soil behaviour, and a good understanding of it is essential for geotechnical professionals. On starting a civil engineering course, many undergraduate students have a limited comprehension of water pressure, probably because it does not form a significant part of the school physics syllabus. Most students can state that water pressure at a depth z in a water tank is equal to $\rho_w gz$ but then find that understanding and applying the laws of hydrostatics in a geotechnical context is tricky. Despite studying Bernoulli's equation in hydraulics courses, it gradually becomes clear that the concepts of total head and seepage are extremely challenging. The late Professor Peter Wroth identified groundwater and pore pressure as key concepts in civil engineering education, but despite the best efforts of educators, many students still graduate with a poor understanding of water in the ground.

This topic is of course very important in engineering practice. Many geotechnical professionals are uncertain how to interpret readings from piezometers in non-hydrostatic conditions. This becomes very important when interpreting conditions in an unstable slope or comparing assumed or predicted conditions in finite element analyses (e.g. using Plaxis) with the field conditions they are supposed to represent. Misconceptions about the water regime often contribute to major failures in slopes, excavations and tunnels.

Students learn in a variety of ways and at Bristol we have attempted to stimulate their curiosity both in class and in the laboratory. This paper describes some activities we use to challenge first and second year undergraduate civil engineers in large cohorts.

2 CLASSROOM EXERCISES

Students can generally calculate the water pressure at the bottom of a bucket full of water but they may be uncertain whether this is altered by filling the bucket with coarse gravel thereby displacing some of the water. Most can envisage threading a small tube (a simple piezometer) through the pore space down to the base of the bucket, and can then understand that the water pressure at the base of the tube is unchanged by the presence of the gravel. Students initially say that water flows along a pipe in response to a pressure difference but know intuitively that it is total head rather than pressure that drives seepage. When asked which way the water will move through a tube connecting two tanks and containing soil as shown in Figure 1, they are clear that it will flow from right to left, despite the pressure being greater at the left end. Similarly, calculation of the instantaneous pressure just beneath a porous bung in a U-tube as shown in Figure 2 is often difficult at first sight. The key to improving student's understanding of total head appears to develop their

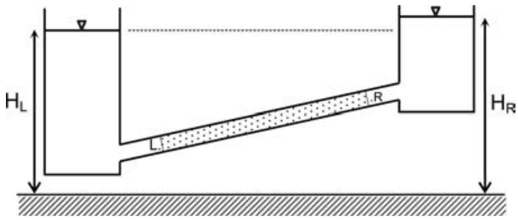


Figure 1. Simple demonstration of how it is total head rather than pressure that drives seepage through soils.

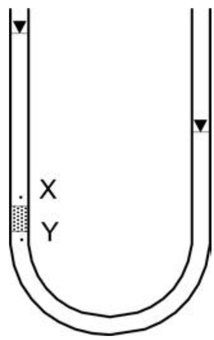


Figure 2. Problem to calculate the instantaneous pressures at points X and Y above and below a porous bung in a U-tube.

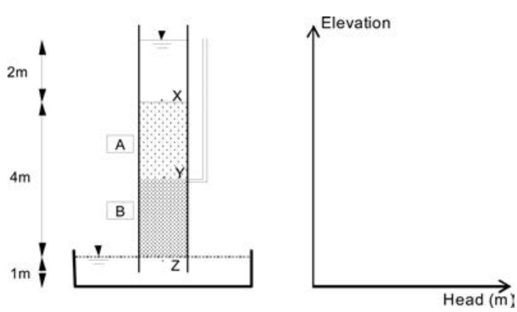
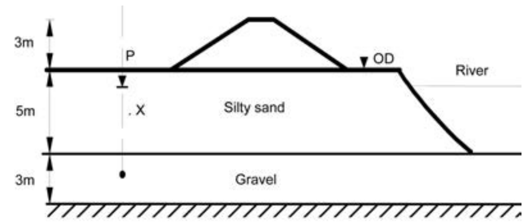


Figure 3. Problem to calculate and draw the variation of total head, pressure head and elevation head down the centre-line of a large tube containing two layers of sand A and B when i) $k_A = k_B$ and ii) $k_A = 2^*k_B$.

experience incrementally and to specifically challenge false preconceptions.

Many soil mechanics text books gloss over the conceptual difficulties of understanding total head, but the writer has found the chapter entitled *One-dimensional fluid flow* by Lambe and Whitman (1969) particularly helpful. A similar one-dimensional approach has been developed at Bristol and is described by Muir Wood (2009). Students may be encouraged to draw diagrams showing the variation of total head, pressure head and elevation head against elevation for problems such as that shown in Figure 3.

Students (and practising engineers) often have difficulty knowing how to start to analyse a full scale problem, and they need practice in recognising the parallels with simple conceptual models that they can



Note: Normal river level is 1 metre below ground level (i.e. at -1.0m OD) as shown. The gravel is hydraulically connected to the river so that the piezometer level at P always equals river level. Predict the conditions at point X when the river level is a) at -1m OD, b) at +0m OD, c) just below +3m OD, d) just above +3m OD and P is flooded to 3m depth, and e) when the river has dropped back to -1m OD leaving P still flooded.

Figure 4. Problem to predict the pore water pressure at point X halfway down the sand layer behind a flood embankment.

already analyse. A one-dimensional seepage problem that has proved useful in this respect is shown in Figure 4. Here the student is asked to predict the pore pressures in the ground behind the flood embankment as the river level fluctuates, before and after the ground is inundated by flooding. Recognising that this problem is analogous to those in Figures 2 and 3 is often the key to solving it.

3 LABORATORY EXERCISES

3.1 *Introduction*

Hands-on experiments in the laboratory are one of the best ways by which students may develop their understanding of total head. The writer has evolved a linked set of experiments that are carried out in a single three-hour laboratory class. Two groups of four or five second-year students undertake permeability measurement of a medium to coarse sand using a constant head permeameter, observe the seepage though a dam made from the same sand, compare the flow-net determined experimentally with that drawn with the aid of finite element software, and compare the observed seepage rate with that computed from the flow net. By the end of the class each group has undertaken similar tests and may then share the results.

3.2 *One-dimensional seepage*

Darcy's law may readily be demonstrated using a constant head permeameter (Figure 5). By arranging the apparatus so that seepage is upward, the transition to boiling may be observed and the hydraulic gradient at the onset of boiling determined. Knowing the dimensions of the sand column in the permeameter and its dry mass, the average void ratio may be found and the theoretical critical hydraulic gradient calculated. One student group measures the permeability of loose sand, the other of dense sand, so that the variation

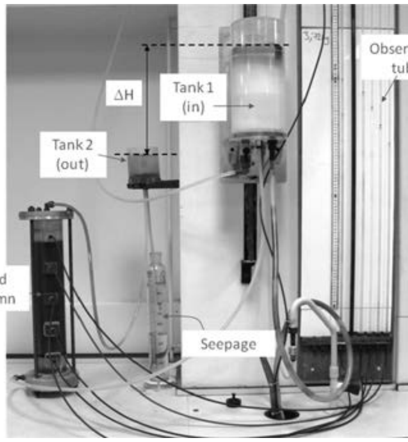


Figure 5. Constant head permeameter showing movable inlet and fixed outlet constant level tanks, and tapping points linked to observation tubes.

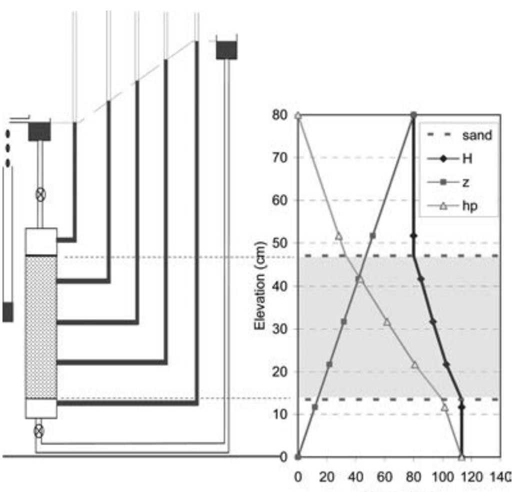


Figure 6. Diagram of permeameter showing the variation of total, pressure and elevation heads for one flow rate.

of coefficient of permeability with void ratio may be explored.

The permeameter is fitted with several tapping points which are used to observe the total head (or piezometric level). Students are asked to plot a graph showing the variation of total, pressure and elevation heads through the sand like that shown in Figure 6. For many students this is challenging and is a good opportunity to revisit the ideas developed in similar exercises undertaken in class (for example Figure 3).

When the sand has been boiled it is of course in a very loose state but it can be densified by vibration (using an electric engraving tool). Students are shown how even small vibrations result in the liquefaction of the sand as its surface settles and the sand densifies, and the parallels are drawn with liquefaction in earthquakes.

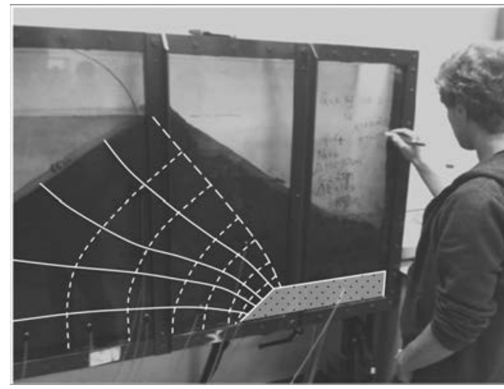


Figure 7. Flow through a model dam.

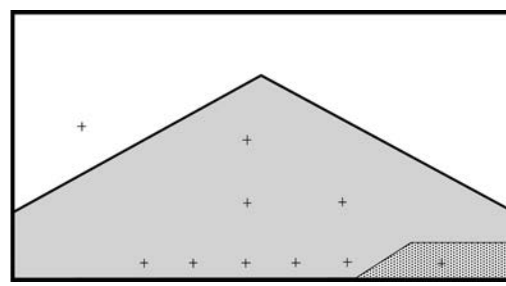


Figure 8. Scaled cross-section handout showing positions of tapping points.

3.3 *Two-dimensional seepage*

Most students are mystified when they have to sketch a flow net for the first time. The process appears to be completely subjective and the solution to be rather arbitrary. It does not help that the examples in many text books are poorly explained and frequently contain errors (as noted by Bromhead 2007).

One of the exercises that Bristol students undertake in class is to sketch a flow net for unconfined seepage through a dam, a problem that is also examined in the laboratory. Originally inspired by the description in *Two-dimensional fluid flow* in Lambe and Whitman (1969), the model dam is built in a tank 165 cm long by 25 cm wide. The perspex forming the front of the tank has been fitted with a number of tapping points, and the tank has an overflow at one end to control the upstream water level, and a basal drain at the other. Die is injected at several points just beneath the upstream slope, enabling the flow lines to be visualized and traced onto the side of the tank (see Figure 7 in which the photograph has been traced over). The seepage rate is measured by discharging water into a bucket for a known time, and the levels in the observation tubes are recorded. Each student is given a pre-drawn scaled cross-section (Figure 8) onto which the positions of the flow lines are carefully plotted. The piezometric levels at the tapping points (shown with +) are noted, marked on and are used to contour the total head to

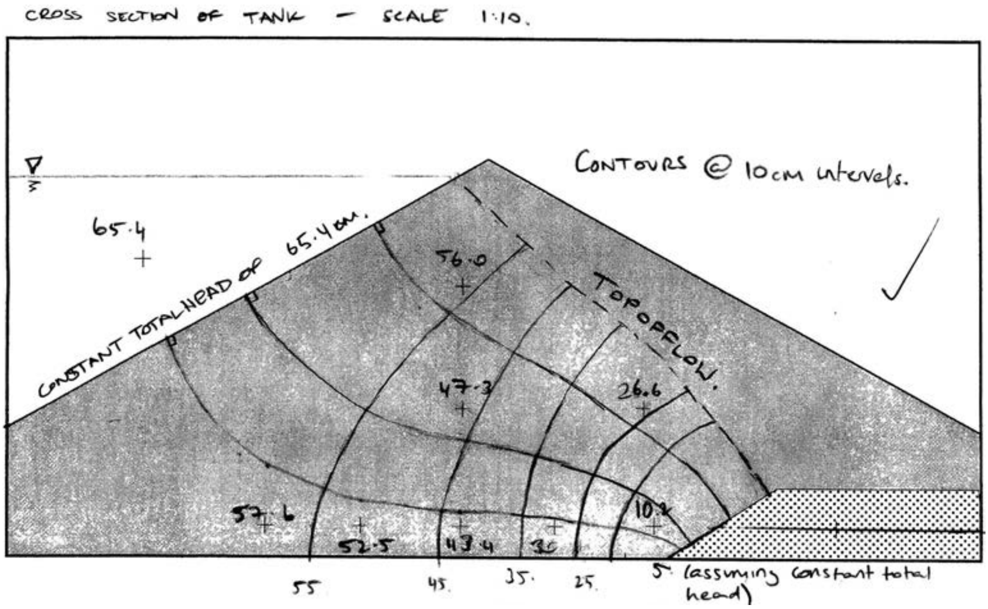


Figure 9. Flow net determined experimentally by students with total head contours at 10 cm intervals interpolated from values at tapping points plotted onto the scaled cross-section handout.

complete a flow net as shown in Figure 9. It is necessary to add a top flow line by inspection, along which the pore pressure is zero. Although there is some seepage through the zone above the top flow line it does not appear to influence the flow net.

The experimental flow net illustrates the concepts of orthogonal flow lines and equipotentials very well. Originally the chosen die injection points were equally spaced down the upstream slope of the dam and this tended to result in some flow fields being slightly rectangular rather than square (see Figure 9). The shape of the fields is also affected by variations of permeability resulting from uneven sand density obtained during construction of the dam. Currently we are experimenting with the die injection points to optimize the precise positions of the flow lines.

Students are also asked to generate a theoretical flow net for the same dam and to discuss the similarities and differences. In the past an electrical analogue model was used, but more recently the groundwater seepage analysis in the Plaxis 2D finite element package is demonstrated during the laboratory class – with the model prepared beforehand it takes only a few seconds to run (see Figure 10). Students are then provided with a handout of the same cross-section with the appropriate number of equipotentials, onto which they individually sketch flow-lines to complete the flow net (see imperfect example in Figure 11).

Using their theoretical flow net and experimentally determined coefficient of permeability students then compute the seepage rate from standard theory using:

$$q = k.\Delta H.\frac{N_f}{N_d}x$$

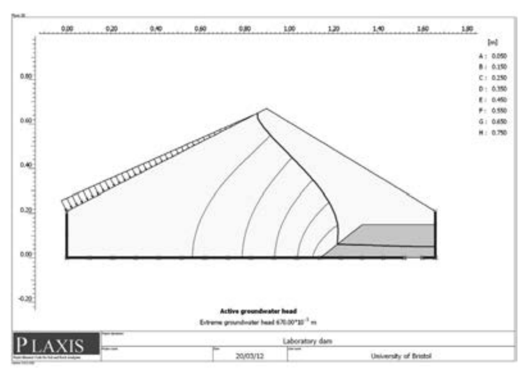


Figure 10. Output from demonstration of finite element seepage analysis.

Initially, when the experiments were first introduced there was not a very good agreement between the experimental and predicted seepage rates. This was thought to be because the sand in the dam was not homogeneous, and that the sand in the permeameter was of a slightly different grading. Taking care to ensure comparability, it is now found that predicted seepage rates using the two values of coefficient of permeability (loose and dense sand) bracket the experimental data satisfactorily, a finding that gives confidence in the validity of the analysis.

3.4 *Failure of dam*

It is found that the model dam is stable for long periods of time even if it has only minimal freeboard, although a gradual migration of sand into the gravel under-drain

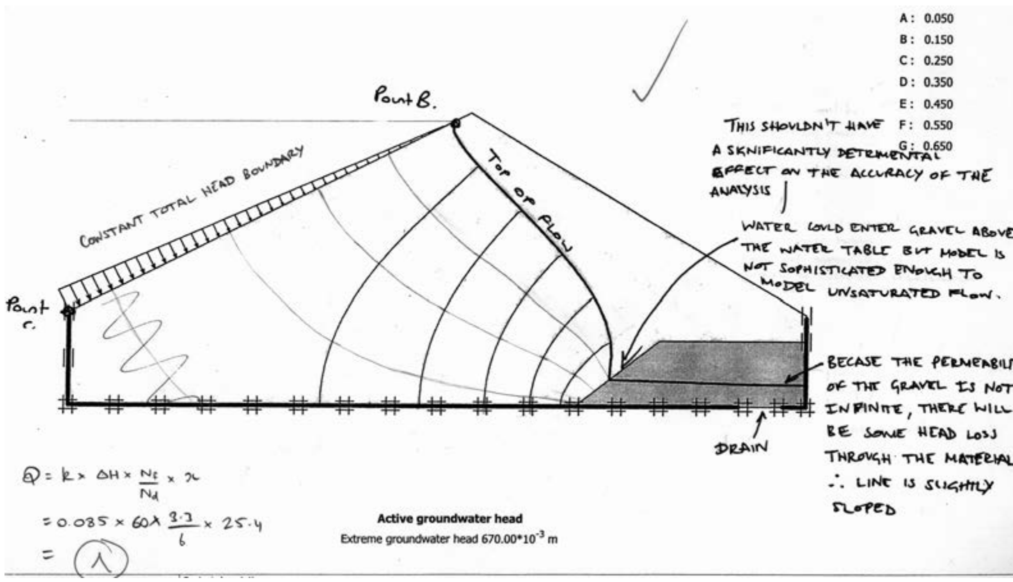


Figure 11. Handout from finite element seepage analysis with the theoretical flow net completed and annotated by a student.

may be observed. The detailed design of the filter could be improved, but the present arrangement is serendipitous as it prompts a discussion of internal erosion and the importance of careful filter design, and the possible consequences if the drainage system were to become blocked.

At the very end of the laboratory class the exit from the base of the tank is closed, and seepage is forced to exit from the downstream slope of the dam. Within a couple of minutes there is a shear failure of the downstream slope and the dam overtops in a dramatic manner. It may be remarked that such a failure results from the unsatisfactory design of the soil filter, and could not be predicted with any finite element analysis.

3.5 *Analysis and write-up*

Students routinely record experimental data and plot graphs in laboratory notebooks, and in this instance the completed flow net handouts are also glued in. The experimental work and most of the data analysis and flow net sketching are completed within the three hour laboratory class. Students are then asked to draw brief conclusions and to present their notebooks for marking three days later. If resources permitted, this group of exercises would be very suitable for writing up as a fuller report or technical note, an activity that would help to develop the student's writing skills.

4 DISCUSSION AND CONCLUSIONS

The study of soil mechanics requires commitment from the student with focused support from academic staff. Despite the considerable emphasis placed on developing students' understanding of pore water pressure, seepage and total head at Bristol, some students remain puzzled. For others the integrated approach described here is a helpful introduction to a difficult aspect of geotechnics on which they build further in later years, when for example they come to interpret piezometric data from a site with under-drainage as part of a design project.

Although demonstration of flow lines using a seepage tank is not uncommon (for example Marsland, 1953, Lambe and Whitman, 1969, Poulos, 1994, Jaksa, 2009, Marques, 2011), the writer believes there is great merit in the active learning involved in students undertaking this laboratory study for themselves. A similar but somewhat more extended project is reported by Marchese et al. (1999).

It is sometimes argued that skill in sketching a flownet is unnecessary. In the introduction to an interesting project on flow nets, Marstella (2010) considered that "*flow net analysis is a relatively disjointed and incomprehensive engineering tool that is not used extensively in industry*". The writer sympathises but disagrees. Whilst at university, students should be exposed to fundamental concepts that underpin engineering practice. Geotechnical specialists need to be fully confident in their understanding of pore water pressure, seepage and total head. While they are unlikely to solve many practical problems using hand-drawn flow nets alone, a flow net should always be sketched before the computer is switched on so that the boundary conditions and seepage pattern may be fully understood. The specialist is then in a position to check the output from a finite element analysis of seepage through a dam or into an excavation. Similarly before undertaking a limit equilibrium analysis of an unstable slope, the specialist needs to interpret the piezometric data so as to understand the hydrogeology.

A good understanding of pore water pressure, seepage and total head should be one of the *anchor points* for geotechnical engineers at all stages of their career (Burland, 1987). The educational approach described here is very traditional and requires good interaction between staff and students – something that is not easy to maintain as student-staff ratios increase inexorably.

Evaluating the success of this approach is difficult. In a recent survey of 19 final year students the majority said they were confident in their general understanding of total head although when faced with a problem like that in Figure 3, only one third could calculate the values correctly. Asked which activities most helped to develop their understanding of this topic the responses included "*Lectures and example classes have helped the core understanding, but experiments have helped to cement the learning*". and "*I believe that the only way to really get confident with the concepts has been to do numerous example sheets and exam questions. I also feel I have benefitted from the lab experiments, referring to my 2nd year lab book on a number of occasions. Having said this, the lecture notes (including worked examples) are also vital. In short, a combination of material and activities is necessary. In particular, I feel that the multiple exposures one gets to the same concepts are key – the ideas are new and take time to 'marinate'. My understanding was not a sudden eureka event, but more a gradual development as the material was revisited in different contexts*". and"*Laboratory experiments were essential. I still picture them in my mind every time I solve a problem about seepage. Flow net drawing sessions help a lot as well. Example sheets are also useful*".

Asked how students' understanding of these topics might be improved, the responses included "*Seepage and total head started to make sense for me when I was messing about with a siphon when making beer!*" and"*I would reiterate the need to cover the material multiple times*". and "*Simple: do a site visit. I have learned that site visits are real eye openers. If you took students to say an embankment dam or a cofferdam it would help visualise future questions they might be challenged with. On the site visit, make them calculate seepage through the dam, draw flow nets, point out the head difference between one side of the dam and the other*".

Clearly this is a topic that students learn incrementally in a variety of different ways. Students regularly give feedback that they like the integration between class and laboratory exercises, but it is clear from the survey and examination performance that many students still find the topic very challenging. For others, their curiosity about geotechnics has been engaged for ever.

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Fieldwork work in geo-engineering

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The BMG ignimbrite quarry: Case study of an undergraduate field exercise in engineering geology

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ABSTRACT: Field-based exercises are logistically difficult but essential elements in the teaching of engineering geology at any level. The degree of difficulty has increased in recent times by increasing student numbers, reduced teaching budgets and more stringently defined university policies. This paper presents a case study of a field exercise of a dacitic ignimbrite exposure in the abandoned BMG quarry near Raymond Terrace, Australia, which has been re-commissioned as a landfill. It describes how important phenomena such as columnar jointing can be used to interpret structural orientations of thick volcanic beds, which are subsequently confirmed by wider regional mapping. The interpreted structure is then used as a basis for assessing why the quarrying operations ceased, demonstrating how an understanding of engineering geology is critical for resource management in civil engineering. Discussion is provided on how the field studies have been adapted to cope with growing student cohorts of mixed background and issues that arise from visiting the same location every year. The importance of having a suitable site with cooperative owners/management is recognised.

1 INTRODUCTION

Perhaps more so than in any aspect of engineering study, field work is a key element in the teaching of engineering geology (Kern and Carpenter, 1984; Orion and Hoffstein, 1991; James and Clark, 1993). However, the approach to field trips must change as the needs of students and the operation environments of learning institutions change (Prather, 1989; Giles and Whitworth, 2006).

This paper presents the second year engineering geology excursion to the BMG dacitic ignimbrite quarry near Newcastle, NSW, Australia as a case study of a field trip that has been adapted to provide a positive learning experience in the modern Australian tertiary education environment.

2 ENGINEERING GEOLOGY AT THE UoN

The University of Newcastle (UoN) has Faculties of Engineering and the Built Environment, and Science and IT, which contain Disciplines of Civil, Surveying and Environmental Engineering, and Earth Science, respectively. Although mainstream geology is taught through the Discipline of Earth Science, there has not been a specialist engineering geologist in that Discipline for over 15 years. The teaching of engineering geology has fallen directly to the authors in the Discipline of Civil, Surveying and Environmental Engineering, who each, fortunately have qualifications in geology and experience in its application to engineering.

Engineering geology at the UoN is taught as half of the Geomechanics 1 course and it makes up only 1/64th of the entire civil engineering degree. The scope of the engineering geology part of Geomechanics 1 is to provide civil and environmental engineering students with a basic grounding in geology, in support of an understanding of its importance to geotechnical and geoenvironmental engineering. It covers the structure of the earth, geologic materials, the basic rock types and their formation, sedimentary and tectonic structures, weathering and basic mapping.

Historically, the engineering geology studies were supported by two field trips (one full day and one half day), but due to logistical difficulties arising from growth in student numbers without a matching increase in funding, this has been reduced to a half day excursion only, repeated on two occasions. This excursion forms the subject of this paper.

3 FACTORS AFFECTING EFFECTIVE FIELD TRIPS

Many factors influence the way in which field trips can be conducted to achieve effective outcomes. These are discussed here. These factors may be considered as "boundary conditions" in the formulation and configuration of field work exercises. Those identified below have all shaped the format for the case described in this study.

3.1 *Student numbers and teaching resources*

When a cohort of students is taken into the field, it is essential that each has the opportunity to hear and see what is being demonstrated and participate in exercises. It follows that situations of larger cohorts with fewer demonstrators lead to a degradation of the fieldwork experience for students.

3.2 *Availability of suitable and convenient destinations*

To illustrate geological principles to inexperienced students, it is important that the field expressions be clear and relatively uncomplicated by anomalies.

3.2.1 *Suitable sites*

Field trips are conducted to expose students to rocks in the context in which they occur (with all of their inherent variability, exceptions and anomalies), to teach observational and field skills and to illustrate concepts related to structure and conformity that cannot be demonstrated with hand specimens. A suitable excursion site must display the features of interest in such a way that they are readily related to the theory provided to the students. If the aim is to show how three exposures of the same bed can be used to formulate a three point problem, then the exposures need to be clearly recognizable as belonging to the same bed; if the aim is to observe mutually perpendicular jointing in undeformed sedimentary beds, then there should be few if any tectonic joints present to confuse the arrangement; etc.

Most importantly, it must be appreciated that what experienced geologists are willing to accept on the basis of incomplete and disparate exposures, may do more to perpetuate the mysteries of geology for a student than to clarify them.

3.2.2 *Convenient sites*

If one looks widely enough, one can find field locations to illustrate almost any geological concept, however one is very lucky if a suitable location is close enough to make the travel time a suitably small proportion of the total excursion time, and access to the site is unrestricted. If one is even luckier, the site owners are obliging enough to allow the site to be used. The BMG site is now owned by SITA Australia, who have been extremely generous and accommodating in allowing the excursion to proceed.

3.3 *University policy*

Many aspects of university policy directly affect the practicality and potential effectiveness of excursions. Some of these are discussed below.

3.3.1 *Policy in regard to student travel*

Because of the funding arrangements in Australian Universities, it is theoretically illegal to compel students to pay specific additional fees for excursion transport. Students may be asked to pay for their university-arranged transport costs, but only if they are given the opportunity to arrange their own alternative transport. This makes organization and cost-recovery budgeting of field trips difficult, since it is always difficult to predict in advance, how many students will choose to travel with the arranged transport and how many will choose to make their own way.

Students may be compelled to use university arranged transport, but only if the university bears the full cost.

3.3.2 *Policy in regard to attendance*

According to current UoN policy, a student cannot be made to attend a field trip (or failed because of non-attendance). Students can be prevented from passing a course, however, on the grounds that they did not complete an assessment item. Hence, attendance of an excursion can be made compulsory if the associated assessment item is deemed a compulsory requirement to pass the course. (Students unable to attend for good reasons are given an alternative literature-based exercise (essay) aimed at achieving related learning outcomes).

3.3.3 *Policy in regard to student feedback*

Policy at the UoN (and indeed good teaching and learning practice) requires that any assessment item be returned to students with a grade and useful feedback. In general, this amounts to giving the students the correct answers to the questions after they have been marked. Whilst there is no problem with this in conceptual courses, it is problematic for practical courses. For a site visit to a suitable and convenient location, there is a real danger that once the correct answers have been made available to students in a given year, then the same answers will be passed to successive cohorts of students in subsequent years to be resubmitted, undermining the value of the assessment item as a grading tool. It is generally not possible to continue to set new questions to test previously untested concepts, for the same geological site, and suitable and convenient sites are generally in limited supply.

3.3.4 *Policy in regard to student safety*

This important and necessary factor is not particularly significant in that the constraints it imposes are generally no more severe than those that would apply in research or practice. Fortunately, the UoN maintains a comprehensive insurance policy that covers students in most activities related to their enrolment, and so, safety related liabilities do not generally preclude field trips.

4 THE BMG QUARRY SITE

The Blue Metal Gravels quarry is located around 5 km north of the town of Raymond Terrace, which is around 21 km from the UoN. It can be reached by vehicle in around half an hour.

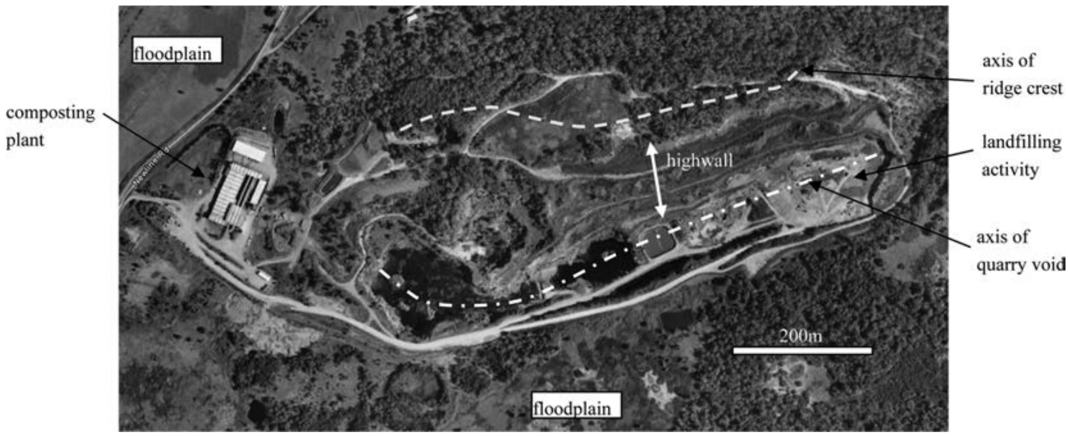

Figure 1. Overview of the BMG quarry site (from Google Earth, 2011).

4.1 *Geological setting of the BMG site*

The site comprises a sequence of beds from the Grahamstown Lake Formation of late Carboniferous/ early Permian age (Offler et al, 1974). The section exposed in the quarry consists of 3 beds: a very thick (>20 m) bed of conglomerate, overlain by a thin unit (~4 m) of shaley and pebbly tuff, and then by a thick (>20 m) layer of dacitic ignimbrite.

The conglomerate is a matrix-supported pebble-cobble conglomerate. Vertical jointing is very widely spaced (>10 m). The tuff layer comprises a thin lower layer of tuffaceous shale, displaying rhythmic bedding dramatically defined by red and green zeolites, and slump-induced folding and faulting. The upper part of the tuff is a disturbed and altered pebbly shale, recording a variety of textures and structures consistent with being buried by a flow of lava. The porphyritic dacite layer displays a poorly, but consistently developed columnar jointing, perpendicular to the bed surface. Columns vary from three to eight sided, from 0.3 m to 1.5 m across. A second set of shrinkage induced fractures breaks the columns inconsistently perpendicular to their axes.

The sequence of beds dips at 15 degrees to the southeast. Consequently, the axes of the dacite columns plunge at 75 degrees to the northwest.

4.2 *Physical setting of the BMG site*

The quarry is located on the southeast side of a strike ridge, where the dacite bed would have subcropped as a dip slope, prior to quarrying. The toe of the slope intersects the floodplain of the Williams river, where it is likely that the slope extends beneath an increasing thickness of saturated sediment, which is likely to exceed 20 m. The floodplain in this location has the characteristics of a wetland, and it extends across a width of 1.5 km, to suburban developments on the other side.

Quarrying at this site has focused only on the dacite, which has been worked over the 1 km long side of the ridge, in a series of stepped benches which extend up almost to the ridge crest. These constitute a highwall of around 50 m high. An additional thickness of dacite has been quarried from below floodplain level, to produce a pit of around 12 m deep, which maintains a depth of standing water due to seepage from the adjacent wetland (see Figure 1).

At the southwestern end, the ridge plunges, disappearing into an extension of the floodplain. To the northeast, the ridge weakens to a saddle, and the dacite dip slope is interrupted by an incised creek. From there, the line of the ridge is offset westward and the dacite bed is discontinuous.

4.3 *History of the BMG site*

Quarrying in the vicinity of the site began around 100 years ago, in an adjacent area where a shale bed was quarried. Subsequent to this, conglomerate was quarried in a different area, before quarrying of the dacite began in the 1950s. There is no evidence of the shale or conglomerate quarry areas in the area used for the excursion.

Quarrying of the dacite ceased in the 1980s. Following this, the site lay idle for around 10 years, before a composting and waste disposal facility was established. Since then, the site has received inert waste materials, which are gradually filling the abandoned quarry void. Prior to placement of waste, liners and leachate collection facilities are established in the base of the void, and an array of water sampling piezometers have been installed around the site.

The engineering geology excursion described here has been conducted every year since 1996.

5 FORMAT AND STRUCTURE OF THE BMG QUARRY SITE EXCURSION

5.1 *Aims*

The BMG quarry excursion was created to illustrate the following aspects of engineering geology:

- The mapping of a sequence of tilted beds

- Manifestations of weathering in a fractured volcanic rock mass
- Rock mass structures resulting from cooling-induced cracking in volcanic rocks
- Mechanical behaviours of excavated rock slopes
- The factors affecting quarry operations
- Estimation of quarry reserves from an understanding of the structure of geological units
- Geoenvironmental considerations in relation to waste disposal in abandoned quarries

5.2 *Course coordination*

The excursion is conducted in a 4 hour session, which is the largest that can be practically timetabled for a midweek session in the second year timetable. Four hours is sufficient to accommodate travel ($2 \times 1/2$ hour) and 3 hours on site.

When the BMG excursion was first conceived, it was designed for a cohort of students of between 70 and 80. Current cohorts have increased to around 140 students. Unfortunately, like in many other universities (Donovan, 2002), there has been little, if any, increase in the matching support, and in real terms, the support per student has decreased significantly. Accordingly, the approach to conducting the excursion has had to evolve.

Experience with this excursion has proven that the maximum number of students per group to enable students to see, hear, participate and be kept safe, is around 25. To accommodate larger numbers, multiple demonstrators leading separate groups are required. For numbers exceeding 100, conduct of the excursion becomes impractical, as 5 or 6 experienced demonstrators are required, and even if these could be arranged, it is not feasible for more than three groups to tour the site in a logical way in a three hour visit. To accommodate this, the excursion is now repeated on two occasions, with partial cohorts of students.

The success of this field trip relies upon the cooperation of the site owners. A reasonable condition imposed by the site owner is that the site should not be cluttered by a flood of private vehicles. As it is an operating industrial site, with frequent heavy vehicle movements, there are simply too many risks associated with the arrival of a large number of light vehicles. Hence, students are conveyed to site on pre-arranged coach buses. In response to university policy, an amount of the financial support for this course is allocated to the cost of hiring these.

To encourage full attendance, subject to the constraints of university policy, an assessment item is associated with the excursion. The assessment item is worth 10% of the Geomechanics 1 final grade. This value was chosen to make it large enough that students appreciate that it is a worthwhile component of the course. It is not necessarily a reflection of the importance of the excursion, but in a course which includes 6 assessment items (final exam, soil mechanics laboratories, geology practical quiz, assignments and a reading exercise), it represents an allocation that is consistent with both the importance and the amount of work involved.

Another consequence of increasing student numbers is an increase in the amount of marking that must be completed. To compensate for this, the assessment item is weighted heavily toward the graphical expression of what the students have observed. This will be discussed in a following section. Since students need (and deserve) feedback (Kent et al. 1997), and since it is difficult to vary the content of the assessment item from year to year, the assessment items are not returned to the students, but rather, students are provided with a feedback sheet that reports to them how well or how poorly they have answered a particular question. Students are invited to approach demonstrators or the course coordinator if they feel they need explanation of their shortcomings.

5.3 *Excursion format*

It is expected that most students will need assistance to interpret what they are seeing. However, rather than lecturing to them, the learning experience is structured as an interactive question session, where students are led, through a series of strategically arranged questions, to interpret the features of the site and draw conclusions. Any reluctance to answer on the part of the students is readily overcome by reminding students that the excursion will not conclude until all of the questions have been answered.

The following are the approximate sequence of questions used to elicit an understanding of the excursion site from the students.

Stop 1: somewhere at the western end of the quarry.

What colour is the rock in the quarry? (lead students to observe weathering and opening along joints).

What kind of rock is in the quarry? (make students aware of the nature of the fresh rock).

Is the structure of the rock the same on both sides of the quarry? (note the effect of angle of excavation).

What is the reason for the apparent difference/structure? (students recognize columns, their inclination and inferred bed orientation).

What is spacing and arrangement of fractures?

Stop 2: on access ramp

What are mechanisms of block instability on each side of the quarry? (identify sliding along column faces – SE; and toppling of column sections – NW, as shown in Figure 2).

What are reasons quarrying stopped? (look at material quality consequences of weathering).

Observe current activity: landfill management, contaminant management practice.

Stop 3: opposite highwall

Time to make sketches.

Note landfill liners, leachate ponds and piezometers/sampling standpipes.

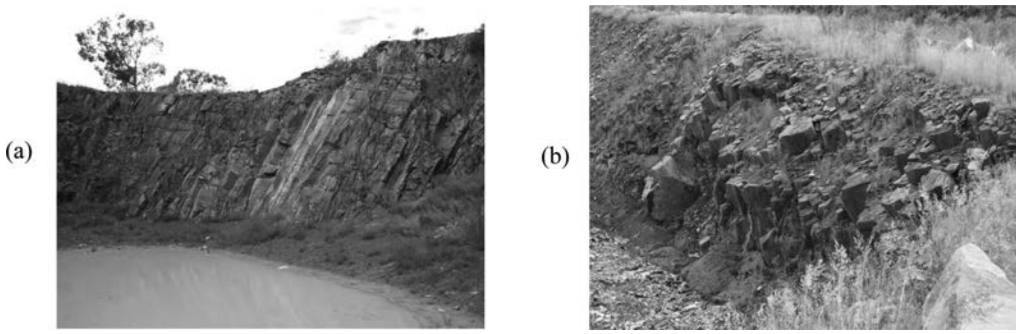

Figure 2. View of columnar rock mass expressions on the southeast (a) and northwest (b) sides of the quarry.

Stop 4: on shale/conglomerate outcrops

Where did the dacite go?

What is the geological arrangement (sequence of beds)?

Is it consistent with presumptions from the first stop (tilting layer of dacite?).

Describe shale and conglomerate in situ.

What is joint spacing in conglomerate (wide, implying very thick bed).

Observe contacts with shale: dacite and conglomerate.

What do you expect we should see as we climb the ridge? (shale on the exposed dip slope and conglomerate after reaching the crest of the ridge).

Stop 5: Highwall: good view of geological arrangement and surrounding district.

Why did quarrying stop? Note encroaching suburbia.

Why did quarrying stop? Note relative water levels of wetland and pit base and permeability of rocks (observe that total head difference drives flow).

Stop 6 (last) Highwall Failure.

What has happened: where is igneous rock, what is exposed?

Why did quarry stop? Where could they get more dacite from on this site?

Back to busses: note conglomerate underfoot along the crest of the ridge.

5.4 *Assessment item*

The assessment item comprises a series of short questions and two sketching exercises. As sketching of plans, cross sections and structures key communication skills in both engineering and earth science, these have been given prominence in the assessment process. There is also some efficiency in marking such tasks, so it has been a useful strategy to managing the increase in student numbers.

Originally, for the principal sketch, students were asked to draw a plan view map of the quarry site, based on their observations in traversing the perimeter of the void. However, with the emergence of Google Earth, students quickly found they could download a photographic image of the site and trace it, undermining the integrity of the task.

Hence, the sketch was changed to a cross section through the centre of the quarry, extending from the failure at the crest of the highwall, across the void, to the wetland. Students are expected to include profiles of the pre-quarrying surface, the existing quarried surface and the dipping rock units below the surface. The location of the section is chosen so that it is not possible to view it squarely from any specific location during the excursion. Rather, it can be viewed obliquely and partially from any number of locations. The students are encouraged to make a series of working sketches from each available vantage point, and then, to combine these in an interpretive cross section in their submission. If this is done successfully, it is possible to show the cause and arrangement of the highwall failure, which consisted of a wedge of dacite sliding on the tuff bed when the bench below was extended too far and it punched through the base of the dacite, into the weaker shale.

Initially, the sketching exercise was done poorly, as the students did not appreciate the importance of site sketches or the level of detail expected. To prepare students for the sketching exercise, they are now given a simpler sketching exercise in the geology practical class in the week prior to the excursion.

The primary written exercise is a discussion of the possible reasons that quarrying ceased at this site. These include difficulties with water management, encroachment of urban development, difficulties in meeting product quality specifications, and the more basic issue of a depleted resource. Each of these issues is teased out of the discussions at each stop around the excursion, as was described in the previous section.

6 OUTCOMES AND EFFECTIVENESS

Outcomes achieved by this excursion are:

- Students have seen how an understanding of localised rock mass structures (inclined columnar jointing) can be used to infer broader geological structures (tilted beds).

- Students have seen this inference confirmed by locating clearly expressed rock contacts in numerous locations.
- Students have observed the diverse textural variations that occur in a weathered, jointed, crystalline rock mass, from fresh to extremely weathered.
- Students have seen how geological mapping principles can be used to estimate location and distribution of geological units, and in turn, how this can be used for resource estimation
- From the overview from the top of the highwall, students have observed the relationship between the wetland and the deep void in fractured rock, and appreciated the consequences of rock mass permeability
- Students have considered the consequences of rock mass permeability and the proximity of the adjacent wetlands in the context of the site's new function as a landfill, and considered the measures being employed to manage the potential for groundwater contamination.
- Students are aware of the various technical, social and environmental issues that can potentially constrain developments involving excavations.

These outcomes span from the more traditional aspects of engineering geology to the more modern of geoenvironmental considerations, reflecting the changing needs of modern graduates (Giles and Whitworth, 2006).

The overall effectiveness of this excursion in the learning process is difficult to quantify. Whilst course outcomes are regularly assessed through student questionnaires, the standard question sets have varied significantly over time, and few are specifically directed at field work. Consistently, in the course surveys of 2006 and 2007, only 12% of students gave negative responses to the assertion that the fieldwork in the course "provided an effective learning experience" indicating that the majority of students see the value in this activity. In the survey of the course in 2009, 92% of students responded favorably to the assertion that "there have been sufficient references made to practice and real life" which can be mostly attributed to this excursion, as it is the most substantial practically-oriented activity in the course.

The likely degradations in the student experience that might occur from an increase in the cohort size have been effectively offset by running the excursion on two occasions, with manageable numbers in each.

Perhaps the most reassuring feedback comes from graduates who, after many years in the profession, express surprise about how useful their geological studies and associated field activities have been to them.

7 CONCLUDING COMMENTS

The excursion to the BMG quarry site is an important and valuable part of the Geomechanics 1 course. Engineering geology, without field trips, lacks context. Whilst many engineering students find such activities well outside their comfort zone, they respond positively to the additional stimulation that field teaching provides.

The format of the excursion has evolved to optimise its outcomes relative to its opportunities, and in many aspects it has adopted practices that lead to clear objectives and outcomes, in accordance with the principles identified by Lonergan, and Andresen (1988) for effective field trips.

With increasing student numbers, and ever-increasing policy restrictions, the conduct of undergraduate excursions is becoming onerous for the course coordinator. The conduct of successful excursions requires commitment from the course coordinator, the availably of suitably experienced assistant demonstrators and a generous and cooperative site owner. This course has been fortunate to have found all of these, and provided they prevail, it will continue to serve as a key element in the teaching of engineering principles at the University of Newcastle.

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The use of field visits in graduate geotechnical teaching

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ABSTRACT: Field trips are a good tool for effective geotechnical engineering teaching and learning at graduate level. This paper presents our recent experience with the planning of an "Applied Geology" MSc field trip to two tunnelling construction sites that involved TBM and NATM methods. In particular, this article presents some (personal) recommendations for the planning of field trips, it discusses the learning outcomes (including knowledge and subject-based, as well as other key and cognitive skills), and it argues that such well-planned field trips are useful because (i) they provide the students with hands-on experience about the unique technologies, the scale, and the inherent difficulties involved in this type of geotechnical project; (ii) they serve as a basis for discussion after student's presentations; (iii) they serve as a basis for a related design-based term-project using real parameters of geotechnical materials found at the site; and (iv) the new assessment methods that can be implemented after the field trip help to increase the motivation of students and encourage the students' interaction and teamwork.

1 INTRODUCTION

The teaching of soil mechanics and other civil engineering subjects has traditionally been (and still is) mainly conducted in the classroom. However, despite recent technological and audio-visual developments that allow more effective classroom teaching, there are still limitations to effectively illustrate the scale and complexity associated to real geotechnical projects.

For that reason, it is common that geological or geotechnical curricula include field work and site visits into their requirements. For instance, in the traditional Civil Engineering Curriculum of ETSI Caminos Madrid, students of the 'Applied Geology' course (in the 3rd year) would have a three-day field trip in which they visit several sites of engineering-geological interest; similarly, in later years, students would have a week-long field trip that is mainly focused on construction sites of large infrastructure projects related to the students' selected specialty (transportation, water resources, etc.). Similar arrangements can be found in the curricula of other programs elsewhere in Europe, the U.K. and the U.S.A. In fact, the first author has 'learnt' many of the ideas presented herein as a PhD student in UC Berkeley and in field trips with the Soils Mechanics and Engineering Geology MSc programs of Imperial College London.

In this paper, we share our recent experience with the organization of a graduate-level field trip for the 3 ECTS "Underground construction" module of the MSc program of "Applied Geology in Civil Engineering and Water Resources" offered by the University of Granada. The first author serves as Invited Lecturer for this module—he also teaches a similar course at the Technical University of Madrid (UPM); whereas the second author is the Course Director. In particular, we discuss a full-day field trip performed with MSc students to visit a tunnel construction project that involved TBM and conventional methods (NATM).

It is reasonable to assume that, as it happens in any other teaching activity (see e.g., Griffiths, 2003), successful teaching and learning by means of field trips "does not happen by chance". As we will show, and in agreement with Beaty (2003), field trips *should be planned* so that they become efficient tools in the context of the new educational paradigm of the European Higher Education Area (EHEA; see http://www.ehea.info/) and, in particular, in relation to the two main educational changes brought forward by the EHEA (i.e., to increase the interactivity between student and instructor and also to stimulate collaborative work in student groups; Michavila (2009).)

Additional positive outcomes result from such well-planned field trips, such as the possibility to have a hands-on experience with the unique technologies, scales and challenges related to a specific geotechnical project; to serve as a basis for discussion after student's presentations; and to serve as a basis for a related term-project that involves real parameters from geotechnical materials found at the site.

2 FIELD TRIP PLANNING FOR SUCCESSFUL TEACHING AND LEARNING

2.1 *Introduction*

The Underground Construction module covers several aspects related to tunnel design, such as engineering geology of underground excavations (see e.g., Goodman, 1993); construction methods (e.g., TBM vs. NATM); and methods for tunnel design (see e.g., Hoek and Brown, 1980; Panet, 1995).

Lectures are mainly delivered using computer-based presentations for the more 'geological' and 'construction-related' topics, and using blackboard derivations for (some of) the more 'mathematical' topics. Despite the use of photographs and diagrams in the presentation slides, however, it was found that students needed a closer grasp to reality, as it is sometimes difficult to illustrate, in the classroom or by independent readings, complex tunnelling operations, or to get a 'feeling' for the scale of real projects and for the difficulties associated to underground construction such as variability of geological conditions, lack of space for plant and equipment operations, reduced visibility and ventilation, difficulties associated to water flow into the tunnel, etc.

Although the details of TBM operations can be satisfactorily demonstrated using video simulations, the problem of illustrating project scale and the inherent difficulties associated to tunneling remains. (Although photographs and site videos can be helpful in some cases, light conditions are often challenging in real tunnels!) In addition, it is very difficult to reproduce the 'atmosphere' of a tunnel using only photographs and videos. Field trips can be employed as a teaching method to overcome such difficulties. For that reason, we organized a field trip to visit the construction works of two tunnels in the Murcia-Almería High-Speed Train project in South-Eastern Spain. In particular, we visited two tunnels (*Sorbas* and *El Almendral*) constructed in different geological formations and with different construction methods.

Sorbas tunnel was mainly excavated through sedimentary units of relatively good quality (conglomerates, sandstones, limestones and marls); although there were also some formations in which non-standard difficulties could be expected, such as gypsum-anhydrites and metamorphic rocks (slates, phyllites and schist) with intense tectonization due to reverse faulting. It has a length of about 7.4 km of which approximately 90% were to be excavated with a 10.08 m (external) diameter TBM; the remaining length—up to the location of the fault zone—was to be constructed using NATM.

El Almendral tunnel has a total length of 1.1 km, of which 786 m are constructed using mine-excavation and the rest using cut-and-cover, and a cross-section of approximately 100 m^2. It was constructed using 'conventional' (NATM) methods, and most of its length was to be excavated in a formation of black schist with varying degrees of fracturing.

Below, we present some additional points related to the planning of the field trip and to the possibilities for further work and for assessment that opened after the trip.

2.2 *Before the field trip*

Having an 'introductory' field trip at the early stages of a course or academic program can be a good way to motivate students and to build relationships ('ice-breaking' or team-building) among peers, hence facilitating future collaborative work (Beaty, 2003). This point is probably more relevant in one-year programs such as MSc's than in multi-year programs such as Bachelor degrees.

However, if acquisition of skills or knowledge is the main objective with this type of 'specialized' field trips, they are probably more effective if conducted once that students have received a good deal of exposure to the subject (say, after more than 50% of the contact hours have passed); the reason is that such previous exposure to the subject allows them to better understand what they see for a more productive visit. In addition, it is helpful that the students are given an introductory lecture and some background reading about the project and the site geology. Geological maps (Fig. 1), as well as photographs and diagrams of the project are useful to acquire an 'overall view' of the project at this stage; furthermore, providing simple 'fact-sheets' of the different geological formations involved, and that include their origin and description, as well as photographs and geotechnical properties. As an example, Figure 2 shows the corresponding 'fact-sheet' for the "Black Schist" formation in which a large proportion of *El Almendral* tunnel as well as the South portion of *Sorbas* tunnel were excavated. These 'fact-sheets' are helpful for a better understanding of the geology during the field trip and for the design projects that can/will be proposed for further work after the trip. For example, a design project could be the investigation of geological hazards and support design of the disassembly cavern constructed in the schist formation (Fig. 2) and that is shown in Figure 4, or the support design of the 'regular' tunnel in one of the formations for which there is geotechnical information (see Sect. 2.4).

This introductory lecture should be given *before the field trip* and, in addition to the technical content, it should (of course) include a safety briefing, and information about equipment and clothing requirements, as well as about 'logistics' (food stores and expected times for meals, restroom availability, etc.). In addition, to increase the motivation and the attention of the students during the trip, information about the assessment during and after the field trip should be provided at this stage. We feel that a total of 1–2 hours of student time (including the pre-trip lecture and readings) should be enough for preparation of this type of field trips.

2.3 *During the field trip*

It is highly advisable that the Technical Staff (Engineers, Geologists, etc.) involved in the tunnel design

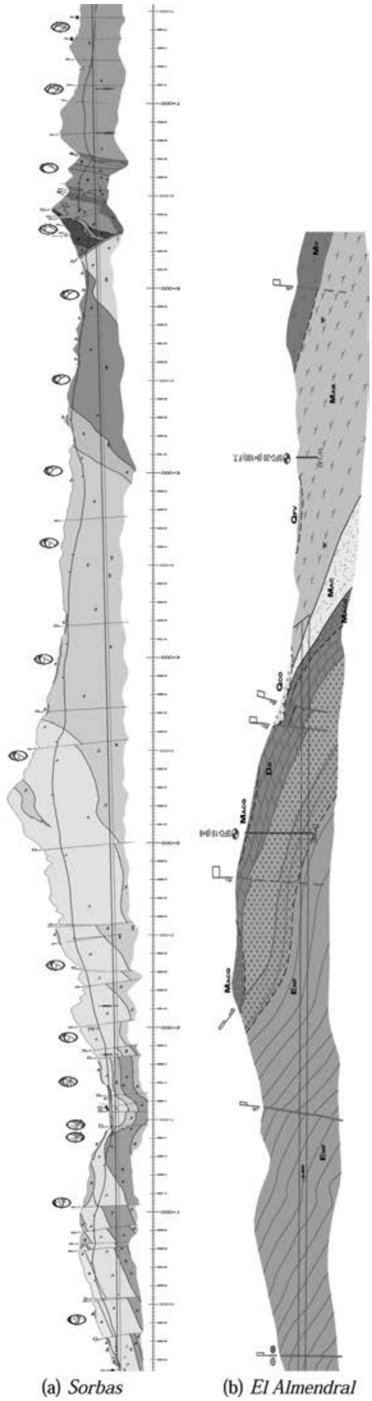

Figure 1. Example of geological maps for the tunnels (not to scale).

ENF

DESCRIPCIÓN GEOLÓGICA:

Los esquistos negros con cuarcitas pertenecen a Formación Montenegro. Dicho conjunto está formado fundamentalmente por una sucesión más o menos monótona de esquistos y esquistos grafitosos, con algunas intercalaciones cuarcíticas, y niveles o boudines de cuarzo.

En general, la formación ENF está constituida mayoritariamente por esquistos negros en porcentajes del 90% frente a los niveles cuarcíticos, siendo estos últimos representados por cuarcitas negras y por boudines o niveles de cuarzo lechoso, que se encuentran intercalados entre los esquistos.

Desde el punto de vista mineralógico los esquistos están constituidos mayoritariamente por porcentajes variables de cuarzo, minerales de las arcillas (sericita, moscovita, etc.), carbonatos, materia orgánica, opacos y óxidos de hierro.

FOTOGRAFÍA:

PARAMETROS GEOTÉCNICOS:

Parámetros de suelos

	Finos	LL	IP	Densidad Húm.	Parámetros de corte		Sulfatos	Materia orgánica
	%	%	-	kg/m³	φ'	c' (MPa)	%	%
Número ensayos	3	3	3	Bibliografía	1	1	3	2
Valor máximo	16,70	NP	NP	-	0,02	34,80	0,00	0,20
Valor medio	14,80	NP	NP	2200,00	0,02	34,80	0,00	0,10
Valor mínimo	12,40	NP	NP	-	0,02	34,80	0,00	0,00
Mediana	15,40	NP	NP	-	0,02	34,80	0,00	0,10

Parámetros de roca

	Densidad Apa.	RCS 35<β<50	RCS 35>β>50	RTB	PLT	E 35<β<50	E 35>β>50	v	mi	Veloc. Sísmica	CAI	Schimazek	DRI
	kg/m³	MPa	MPa	MPa	MPa	MPa	MPa	-	-	m/s	-	kN/m	-
Número ensayos	36	12	8	7	4	-	-	5	10	31	8	3	3
Valor máximo	2790,00	6,65	12,70	3,62	0,85	-	-	0,39	-	6145,00	1,60	0,391	77,33
Valor medio	2612,00	3,29	8,21	2,35	0,74	-	-	0,29	-	3026,00	0,80	0,17	72,56
Valor mínimo	2310,00	0,46	1,73	1,07	0,04	-	-	0,19	-	451,00	0,00	0,011	70,00
Mediana	2660,00	3,11	9,33	2,29	0,79	-	-	0,20	-	2641,00	-	-	-
Valor propuesto	2665,00	3,11	9,33	2,29	0,79	779*	2333*	0,3 (Bibliografía)	11,00	2641,00	1,60	0,39	72,56

*Datos procedentes del producto Módulos Reduction Factor (MR=250) y la RC

Figure 2. Example of 'fact-sheet' for the Black Schist formation in which the tunnels are excavated.

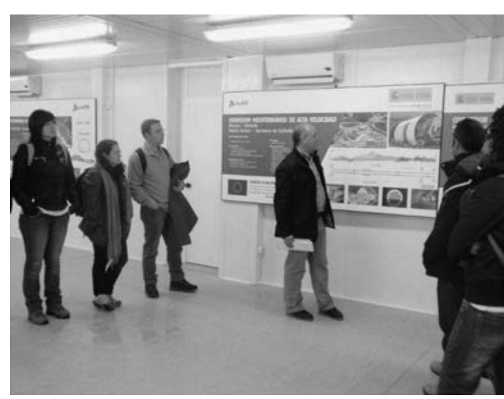

Figure 3. Illustration of initial introduction of the project conducted by the Technical Staff.

or construction (or both) join the group during the trip. This is because they are more familiar with the details of the design and, therefore, are better prepared to answer detailed questions; in addition, as discussed below, having a larger number of 'supervisors' tends to produce—if allowed by safety—the division of the group into smaller sub-groups, in which the students may feel more confidence to interact and to ask questions or to make comments.

After a reminder of safety requirements, the field trip can start with an introduction of the technical staff, followed by a brief presentation of the overall project and of its more important aspects. Poster-type panels can be helpful for that (see Fig. 3), but other 'technologies' such as computer-based presentations or paper handouts can also be employed. Depending

Figure 4. Illustration of disassembly operations of TBM inside the tunnel. The TBM cutting face is shown in the background; note the cavern excavated with dimensions slightly larger than the TBM diameter, and the auxiliary structure for the bridge crane.

on the amount of material, a total of 30–45 minutes is probably enough for this task.

Then, the actual visit to the site can commence. The planning of the actual visit and number of stops will, of course, depend on the characteristics of the site and on the travel time. In this case, for instance, the travel time of slightly more than 2 h was relatively long for a single-day field trip, since there are also safety limitations with the number of working hours for the driver. In our case, this reduced the possibilities for 'hands-on' experience (e.g., mapping of faces or outcrops or field testing), although that could be a very interesting exercise, if time allows, in this type of field trips.

As an example of our visit, Fig. 4 illustrates the visit to one particular location in *Sorbas* tunnel in which the TBM machine was being disassembled inside a cavern specifically constructed for such task, and once the TBM portion of the tunnel had been completed.

At each location, a brief introductory discussion should be delivered to the students, explaining what they are about to see and emphasizing its more important or interesting aspects. Due to background noise etc., and before proceeding to the next location, it is always a good idea to verify that everybody in the group understood the explanations. Students should be encouraged to take photographs and *carefully recorded notes*. A good incentive for that is to emphasize that field notebooks are "documents of record" that indicate a student's professional skills and, on that basis, to include their notebooks into the materials for assessment after the trip. If allowed by safety, they could be encouraged to 'explore' the site in small groups (that should be accompanied by a Instructor or by the tunnel's Technical Staff). As indicated above, this facilitates communication (if, for instance, the background noise is loud), and it also encourages student interaction and participation, as 'shy' students can feel more confident to make questions in a more relaxed and informal atmosphere.

2.4 *After the field trip*

The information and knowledge acquired during the field trip can be employed as a basis for at least two additional learning activities. The first is the preparation of 'short' group presentations by the students; the second is the preparation of a design project based on 'real data' obtained from the field trip information and, in particular, from the geotechnical characterization of the geological formations involved (Figs. 1 and 2).

To prepare their short presentations, students are divided into several groups, so that each group covers one different aspect of the visit. For instance, in our case, one group could cover *El Almendral* tunnel; another group the TBM portion of *Sorbas*; another group the cavern for disassembly of the TBM; etc. However, to help students maintain their attention levels during the field trip, it is probably a good idea that topics are not assigned to groups until the trip (or the day, for a multi-day field trip) has been completed. The presentations are better scheduled shortly after the field trip (if time allows, they can even be conducted on the same day), as the objective is that students still have a 'fresh memory' of what they saw (or of what they did not quite understand).

The presentation equipment does not need to be very advanced, and a simple large-piece of paper with color markers can be employed in multi-day field trips; for a single-day trip, in which the presentations can be conducted in the classroom the next day, more advanced technology, such as computer-based presentations, should be preferred, so that students can share the photographs that they took during the trip. However, even in that case, the productions of hand-diagrams should be encouraged, since the efforts to formalize ideas into simple and clear diagrams is a good learning exercise.

The presentation session should be organized so that *all students* make at least a portion of the presentation. It should also be employed by the Instructor to emphasize or clarify ideas, as well as to 'homogenize' the input received by the students. (Remember that they may have been split into subgroups during the visit and, for that reason, they may have been subjected to different information inputs.) To that end, the students should be encouraged to make comments or questions about the presentations of their fellow students, and they should also be aware that such interaction will be considered for the assessment of the field trip.

Furthermore, the site visit and the information obtained therein can be employed as a basis for a "design-project" in which the students can put in practice what they have learned in the module. The work can include, for instance, a description of the proposed project (that can be the same as or different from the real one), a description and characterization of the geological materials in one specific formation (for instance, the Black Schist formation presented in Fig. 2), and a selection of the tunnel excavation method and design of the support system for the tunnel length located within such formation.

3 LEARNING OUTCOMES

A field trip organized as discussed above combines several approaches to module design for effective teaching. For instance, following the classification proposed by D'Andrea (2003), it is *systematic*, since it "proceeds from identifiable needs" discussed in Section 2.1 to "predictable outcomes" that should be thought of when the trip is planned. Note, however, that some of the learning outcomes may derive from a *problem-based* approach (the final term-project) and, perhaps to a lesser extent, from an *experiential* approach in the form of individual observations (or 'feelings') by the student that may have not been generally discussed in class or during the field trip.

As specific learning outcomes, after the field trip and other activities (see Section 2.4) have been completed, able and motivated students should: *recall* different techniques for tunnel construction (e.g., TBM vs. NATM); *explain and describe* the functioning of a TBM and the construction sequence in a typical NATM tunnel; *use* actual geological and geotechnical data, as well as the convergence-confinement method, to compute the support needs of a tunnel; *analyse* likely difficulties associated to different geologies and construction methods; *design* a tunnel, *proposing* a specific excavation/construction method and a specific support; and, *assess* the validity of different tunnelling approaches and/or support proposals.

The sequence of learning outcomes listed above follows, in order of increased complexity or demand, the taxonomy of outcome levels proposed by Bloom et al. (1956), and it includes "knowledge and understanding" skills in addition to "cognitive" and "subject-specific" skills (following the "domains" of learning outcomes proposed by NCIHE (1997)). Also, there are additional positive learning outcomes related to other "key skills", such as communication skills (oral and written presentations) and numeracy (quantitative evaluations), among others.

Finally, as additional outcomes of the trip, we found that the new possibilities for assessment based on the field trip had a positive effect on the motivation of our graduate students, as previous research has found that the assessment system is "crucially important in student's motivation"; (for details, see e.g., Wakeford, 2003; Newstead and Hoskins, 2003), and the field trip was consistently identified by the students as the "most interesting" activity in an assessment conducted by the Instructor at the end of the module. In particular, surveys conducted at the classroom showed that they generally valued its practical aspects, as well as they opportunity that they had to directly observe, as applied in real construction practice, some of the different construction techniques that had been explained in class.

4 CONCLUDING REMARKS

Field trips are a good teaching tool for geotechnical engineering programs and, in many cases, it is very difficult to find good alternatives to them. This paper presents our recent experience with the organization and planning of a full-day field trip for the 3 ECTS "Underground Construction" module of an "Applied Geology" MSc program in Spain. Successful teaching and learning using field trips "does not happen by chance", and field trips *should be planned* towards a set of specified (and desired) "learning outcomes". The learning outcomes will be, of course, to some extent dependant on the availability of construction sites that can be visited and on their actual characteristics, although there is flexibility for the teacher to design the trip—and its 'pre' and 'post' activities—so that 'quasi-constant' teaching outcomes can be achieved.

This article presents some personal thoughts and recommendations for the planning of field trips, it discusses the learning outcomes achieved by our students, and it argues that such well-planned field trips are useful because (i) they provide the students with hands-on experience about the unique technologies, the scale, and the inherent difficulties involved in this type of geotechnical project; (ii) they serve as a basis for discussion after student's presentations; and (iii) they serve as a basis for a related design-based term-project. Finally, (iv) this type of field trips also helps to incorporate "secondary" learning objectives, such as 'interactivity' (between student-instructor but also among peers) and 'collaborative work' into the curricula (hence following the new European Higher Education paradigm), and the new assessment possibilities have further been found to increase the motivation of the students.

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Shaking the Foundations of Geo-engineering Education – McCabe, Pantazidou & Phillips (eds)
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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.

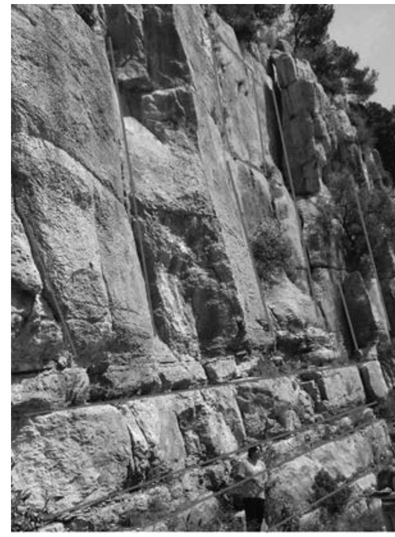

Figure 1. Collecting data for SSPC characterisation of the rock mass.

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.

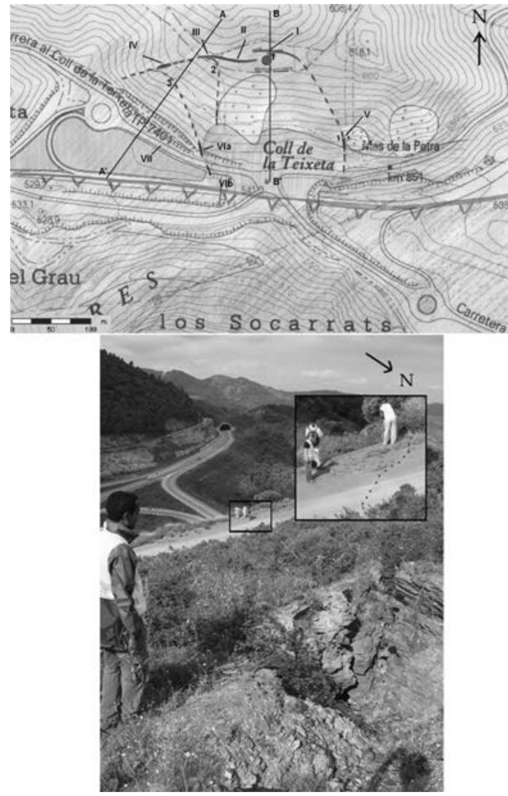

Figure 2. Tacking failure surfaces at Col de la Teixeta, Spain.
Legend: 1 to 3: sliding surfaces, I: Fault near windmill; II: Cavities along crack on top of hill; III: Large cavity within shale; IV–VII: evidence of cracks; A–A′ and B–B′: Cross sections.

2.3 *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).

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 geohazard 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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Computing and technology in geo-engineering

Shaking the Foundations of Geo-engineering Education – McCabe, Pantazidou & Phillips (eds)

Dunmore Bridge case study: An introduction to geotechnical engineering via finite element analysis

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ABSTRACT: This paper describes the development of a case study based upon the preliminary design of a working platform to support a 1200T crane during the replacement of bridge spans on the historic Dunmore Bridge (Woodville, NSW, Australia). The case study was developed to enrich the teaching of finite element methods to undergraduate students by exposing students to practical aspects of finite element modelling and the use of commercial finite element software. The nature of the project permitted geotechnical engineering topics to be incorporated into the case study and introduced students to CPT testing and interpretation, importance of working platforms and realistic soil profiles.

The Dunmore Bridge project was selected for the case study as it has many interesting aspects that are topical, interesting and motivational to the students. Historic records of the bridge construction are available and being a local bridge, the site can readily be visited by students. As the upgrade of the Dunmore Bridge is scheduled to occur within the next 18 months the project is topical and will be covered by the local media. The project is being recorded using time-lapse photography which will provide an additional multi-media resource for use in refinement of the case study. Feedback from students on the case study and how it helped motivate student learning was obtained via an anonymous online discussion forum.

Keywords: Finite element, geotechnical engineering, engineering education, case study

1 INTRODUCTION

The use of real world examples has been identified by engineering students as a key attribute of a good engineering lecturer (Collins, 2009). Case studies play an important role in engineering education by exposing students to real world examples (Raju and Sankar, 1999) and to situations and challenges that would not typically be encountered in classroom activities (Akili, 2007). In doing so, they provide relevance through the context of a real project, motivation for students to engage, interaction to enhance learning, integration of existing knowledge and the development of communication skills (Akili, 2007). They also provide a means for the development of key skills and attributes such as teamwork, communication and problem solving (Davis and Wilcock 2003). Case studies also improve the motivation and engagement of students in learning (Mustoe and Croft 1999).

In the teaching of geotechnical engineering, the use of case studies provides the means by which students can be exposed to the complexities of practical examples beyond the artificial world of infinite half spaces and homogenous and isotropic soil, typically used to drill undergraduate students in the fundamentals of soil behaviour. Indeed, the development of case studies in conjunction with adjunct faculty members or practising geotechnical engineers (Akili 2005) provides a means to bring the skills and perspective of engineering practice into the classroom and expose students to more of the practice of geotechnical engineering.

The use of real world examples, or at least more realistic problems, is becoming important in the teaching of finite element methods. Traditional finite element courses focus on the theory behind the methods which are often reinforced with computer programming to implement and apply the methods to simple problems. Indeed, this is the approach taken in many elementary text books of the methods (e.g. Smith and Griffiths, 2004). Such approaches, as recently advocated by Kosasih (2010) who used computer programming to compliment the use of commercial software packages, are still valuable, providing students with insight into finite element techniques. However, finite element courses, and their teaching, are being transformed by the availability of high powered commercial finite element software with easy to use graphical interfaces. The use of programming to develop a depth of understanding of finite element methods is being replaced with courses that teach the application of software with emphasis on finite element modeling.

Real world examples, or at least realistic examples, may also be introduced within a course through project or problem based learning methodologies. The use of problem based learning methodologies has also been adopted in the teaching of finite element methods. Zhuge and Mills (2009) redesigned a finite element course to utilize problem based learning methodologies in the context of structural engineering projects. Miner (2000) utilized a realistic project for the design of a bracket on an aircraft to educate mechanical engineering students.

In this paper we describe the development of a geotechnical engineering case study within an undergraduate course on finite element methods. In the context of the finite element course the primary objective of introducing a case study is to improve motivation of students and to better engage students in learning. The case study is intended to compliment the soil mechanics and geotechnical engineering strands of their degree by requiring students to employ knowledge from prior courses, gain an appreciation of the practice of geotechnical engineering and to prepare students for the capstone geotechnical engineering course. Motivated by Zhuge and Mills (2009), who restructured a similar course at the University of South Australia through the use of structural engineering examples, a case study has been developed based upon a geotechnical engineering project.

2 BACKGROUND

In the third year of the Civil engineering degree at the University of Newcastle students are required to undertake a course on finite element methods. The course focuses on the fundamentals of the finite element method including shape functions, numerical integration, linear algebra, formulation of elements (truss, beam and continuum), solution of large systems of equations and how these are used within the framework of displacement based finite element techniques. While students are not required to perform any computer programming, the course is presented in the context of how the methods are implemented in order to illustrate to students the power of the finite element method.

Feedback from students on the finite element course, through various student surveys, has generally indicated that some students struggle with the mathematics and formulations that form the basis of lectures. Suggestions offered by students in the survey, on how the course could be improved, often included better use of examples, such as:

> *"The course content can be very dry, providing more real life examples and case studies throughout would be appreciated."*

Other feedback from students, via surveys and casual conversations with the lecturer, reveals a perception that much of the course is of little relevance to some civil engineers, particularly to those students already planning a career outside of the design office. A consequence of this is that there appears to be an increasing focus by many students on learning how to answer assessment items, rather than gaining a deep understanding and appreciation of finite elements. Particularly alarming were comments by one student who wrote in an evaluation of the course:

> *"I would suggest more relevant examples based on the assignment content"* … *"Working through examples that are relevant to assessment items would be more appropriate to the learning process.…"*

This student has little motivation other than to pass the course and, as a result, has committed to superficial learning to achieve this. To motivate an increasing number of such students with similar perceptions, there is a need to challenge and motivate students, and to better engage students in higher levels of learning.

The courses in the geotechnical engineering strand of the Civil Engineering degree follow a traditional structure with the fundamentals of soil mechanics taught in the second and third years of the degree program. These are followed in the final year, by a geotechnical engineering course, undertaken by students in the first semester, followed by a capstone geotechnical design course in the second semester. Anecdotal evidence suggests that a there is an increasing number of students that struggle with the capstone course as it is the first time they are exposed to real-life, open-ended geotechnical engineering problems, based on actual soil conditions and site constraints.

The development of a case study for the finite element course provided an opportunity to introduce students to aspects of geotechnical engineering projects prior to them undertaking any courses in this area. As the geotechnical engineering content is not a core component of the course, it is introduced only in the context of describing the case study and developing the problem to be analysed by students using the finite element software. This also allows the information to be introduced quite informally, as more of a discussion with the class, and in doing so providing students with a break from the finite element content.

3 DUNMORE BRIDGE PROJECT

The historic Dunmore Bridge (Figure 1) crosses over the Patterson River at Woodville NSW, Australia. Constructed late in the 19th century, the bridge is of significant heritage value as it is one of three surviving overhead braced timber truss road bridges in NSW (NSW Office of Environment and Heritage, Heritage Database). An unusual feature of the bridge, and of further heritage significance, is a steel truss lifting span (17.8 m) that enabled river traffic to pass beneath the bridge. Known as an Allan truss bridge, its significance is described in various publications and reports of NSW Government departments (NSW

Figure 1. Dunmore Bridge at Woodville.

Roads and Traffic Authority, Office of Environment and Heritage) on timber bridges in NSW as

> *"Allan trusses were the first truly scientifically engineered timber truss bridges, and incorporate American design ideas for the first time. This is a reflection of the changing mindset of the NSW people, who were slowly accepting that American ideas could be as good as or better than European ones. The high quality and low cost of the Allan truss design entrenched the dominance of timber truss bridges for NSW roads for the next 30 years."*

Dunmore Bridge, which still carries traffic, features three timber Allan truss sections that span approximately 34 m each. Named after the designer, Percy Allan (a senior engineer in the Public Works Department) the Allan Truss bridges represented significant advancement on the previous McDonald truss design as Allan Truss bridges could carry 50% more load and, as it was constructed from mainly local materials, it was 20% cheaper to construct (MBK, 1998).

Planning for the upgrade of the Dunmore Bridge is underway with major site works expected to commence sometime in 2012. A significant component of the upgrade, which will increase the structural capacity of the bridge and reduce maintenance, involves the replacement the three Allan truss spans. To minimise the disruption to the community, it is proposed to only close the bridge to traffic for a period of up to 4 weeks. To prepare for this period of intense activity the new truss spans, each weighing approximately 125 tonnes, will be manufactured offsite and assembled on-site adjacent to the bridge. The replacement of the truss spans will then involve using a very large crane to remove each bridge span in a single lift, complete with the deck and other fittings. The replacement span would then be lifted by the crane from where it was assembled on the bank of the river into position on the bridge.

So that the construction works can be conducted from just one bank of the river, a preferred option for the removal of the existing structure and the erection of new bridge spans was the use of a Lampson LTL-1100 crawler crane, one of the largest cranes currently available on the east coast of Australia. The LTL-1100 consists of two crawler modules; the front crawler module supports the boom, with a counterweight carried by the rear module. The peak load to be carried by the crawler modules is approximately 1050 tonnes which, for the rear crawler unit, is mostly due to the 900 tonne counterweight required to lift the truss across the river at a lifting radius of approximately 80 m.

The Dunmore Bridge upgrade is a project with a lot of community interest. It is expected that the project will be covered widely by the local media, not only due to the interruptions it will cause to the local community during the works, but because of the historic nature of the bridge and the large scale of the works. The bridge works are being continuously recorded by a camera located on a nearby structure with the expectation that a time lapse movie will be produced showing the entire construction project. These aspects also make the project topical and interesting to undergraduate engineers, confirming it as an excellent project on which to base a case study that will engage and motivate students.

4 DUNMORE BRIDGE CASE STUDY

The case study described in this paper is based on the preliminary geotechnical design of a working platform on the banks of the Patterson River. The platform is to support a Lampson LTL-1100 crawler crane to be deployed for the upgrade of the Dunmore Bridge. The subsurface conditions at the site consist of deep layers of alluvial soils which are underlain by conglomerate rock at depths of up to 30 m.

The case study provides a basis for instructing students in the use of commercial finite element software for computer laboratories in a third year undergraduate course on finite element methods. The case study has two primary objectives; to provide a more realistic setting to instruct students in finite element modeling and to expose undergraduate students to the practice of geotechnical engineering.

Teaching of the course is conducted over a 12 week period with a typical week consisting of a one hour lecture followed by a one hour tutorial. In recent years

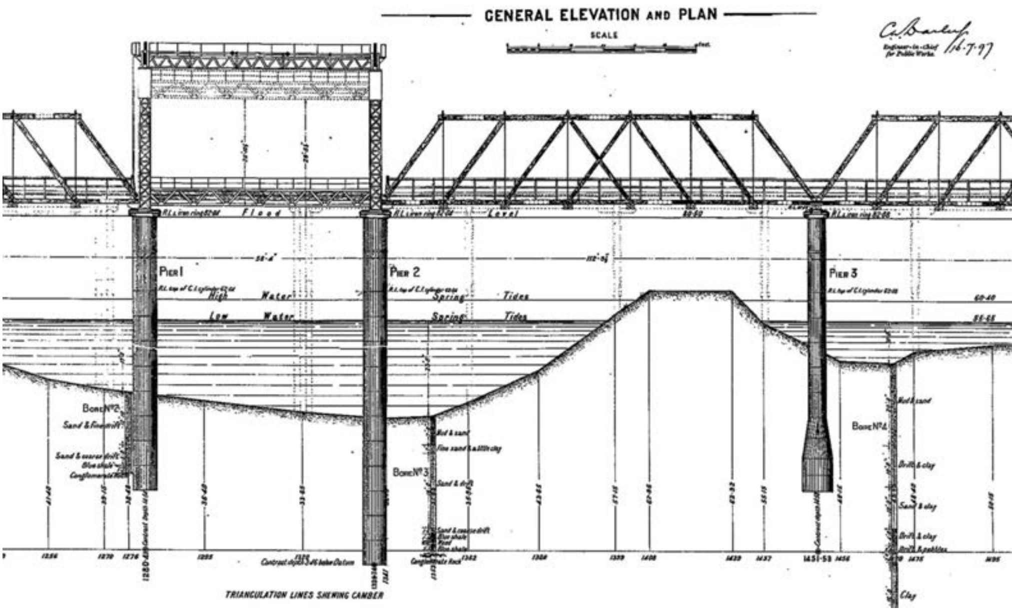

Figure 2. Extract from historic plans of Dunmore Bridge at Woodville.

computer laboratories were introduced to provide students with practical skills in the use of commercial finite element software. Due to resourcing issues, a total of only nine 1 hour computer laboratory classes can be scheduled. To accommodate this students are split into 3 groups with each group scheduled to attend a computer lab on a three-weekly roster.

The case study is introduced within lectures providing students with a break from the theoretical content of the course. Initially, the Dunmore Bridge project is described to students and the proposed construction methodology explained. The use of the large crane provides an opportunity to discuss with the class what problems might confront a large crane operating on alluvial soils adjacent to a river, the need for a working platform, and the importance of the design in achieving a safe platform. The message is delivered to students though images showing the consequences of failed working platforms. Resources that were readily available from the internet were used, including:

– Images in the presentation on Safe Working Platform by the Federation of Piling Specialists (UK) or Piling and Foundation Specialist Federation (Australia).
– Video of the Waikato Crane accident in which a crane toppled into a river due to failure of the working platform.
– Video of the collapse of a crawler crane, during construction of Brewer's Ball Park Stadium, Milwaukee in 1999.

In the second lecture the case study discussion guides students through the role of desktop studies, geotechnical site investigations and in situ testing. This begins by asking students how much we can discover about the geotechnical conditions at the site before doing any field investigation, or even visiting the site. This leads to a consideration of resources such as Google Earth, regional geology maps, reports from previous investigations on nearby, or even the same sites and books and papers on the local geology. In this case, historic drawings from the construction of the bridge were provided by the NSW Roads and Traffic Authority (RTA). These drawings, an extract of which is shown in Figure 2, include logs showing the soils encountered during the construction of the bridge and the depth at which rock was encountered at the site.

This second lecture also introduces students to various methods of site investigation used in the project. Particular emphasis is given to describing CPT testing and how the results of such tests are used by engineers to interpret the subsoil conditions at a site and to obtain parameters for modeling the soil. A CPT probe is handed around the class for students to gain a better appreciation of the methods.

The students then undertake the three computer laboratory classes, which are spaced three weeks apart. The purpose of the first computer class is for students to learn to use the Plaxis finite element software. Under the guidance of a tutor, students follow a simple tutorial provided with the software: there is no reference made to the case study. To become more familiar with the software and to prepare students for the next computer class, students are asked to follow through additional tutorials from the Plaxis manual in their own time.

In the remaining two computing classes, a finite element model to determine the stability of the crawler crane on the banks of the river is developed. This begins by providing students with a spreadsheet containing representative results from CPT testing at the site. Students are required to use a correlation to determine undrained shear strengths and then use these to develop a simple geotechnical model for the site which consists of up five to six geotechnical units with a problematic soft clay layer present near the water table.

Survey data for the site is also provided to students allowing them to build a simple two dimensional finite element model. This includes the addition of a layer of fill to provide a hardstand for the operation of the crane. A significant problem to be addressed by the students is the modeling of the crane loads and how to adequately represent them in a two dimensional finite element model.

Students then use this model to perform a finite element analysis to assess the stability of the natural site and the stability the crane situated adjacent to the river bank. For the natural site, a factor of safety above one is required to verify that the finite model adequately represents the current state of the site. In this case the stability of the crane will clearly be inadequate and measures to stabilize the river bank need to be explored. Unfortunately, insufficient time is available for students to perform any finite element modeling of structural elements such as sheet piling and anchors which could provide students with insight into the complexities of the finite element modeling of many geotechnical problems.

Modern graphical user interfaces enable powerful finite element software to be used by novice users. In teaching the case study it is emphasized to students the importance of understanding the fundamental behaviour of soils and other materials, the complexities of finite element methods and modeling, and in scrutinizing and verifying results. In particular, students are challenged to reflect on the behaviour of intermediate soils and how they might behave under short term loads.

5 STUDENT FEEDBACK

Feedback was sought from students on the use of the Dunmore Bridge case study as the basis for the computer laboratory classes. Initially students were asked to provide feedback via an online discussion board which permitted comments to be made anonymously. As the discussion board received no posts all students were emailed directly seeking their feedback. Responses were then received from only two students which is an extremely disappointing response from a class of over 90 students.

The comments received, however, generally valued the inclusion of the real world perspective.

> *"They were good as they related the course content to real stuff, which makes the theory seem more relevant."*
>
> *"I completed all three of the computer labs and found that they were beneficial. At first I struggled with the concepts but after practice got there in the end."*

Their comments also reflected the negative aspects of limited time available in the computer labs.

> *"I found the computer labs too short to actually learn what was going on, i.e. one hour isn't enough time to adapt to an entirely new program, whilst trying to understand the theory behind it."*
>
> *"I think one of the biggest problems was the time between the labs (especially when the third lab was postponed) meant that by the time we got into the lab I'd mostly forgotten how to use the program."*

One student also provided a useful suggestion:

> *"I think an actual demonstration of the tutorial (perhaps in the lecture) would be really good, as you could show the ability and concept without all the confusion of "how to run the program". I spent most of my time trying to figure out the layout of the program, and couldn't focus on the key content.*

A demonstration on the use of the Plaxis software will be included in future courses to prepare students for their first computer laboratory class and to accelerate their competency in the use of the software. No mention is made of any time devoted to the activity outside of the classes, as was instructed by the lecturer. This is supported by anecdotal evidence from the class tutors who reported little continuity between computer laboratories, as most students had not undertaken any practice in using the software.

Poor attendance was also an issue for the computing classes with approximately half the students choosing not to attend these classes. This is now a common phenomenon among engineering students (Fityus, 2012). The second student remarked:

> *"One thing that I did notice was that because these labs weren't compulsory or assessable, half of the students simply didn't bother with them. I understand that this is their loss, and I'm not really sure what you could do to combat this (I don't think making them assessable is a good idea, however maybe a mark for attendance or something)."*

The computer laboratory classes were originally introduced to so that students could gain experience in the use the Plaxis finite element software. The motivation for students to attend was to learn to use the software, which would be beneficial to them in the subsequent capstone geotechnical engineering design course. This was perhaps a naïve assumption and it reinforces that assessments are also necessary to motive students learning.

6 CONCLUSION

A case study based upon a real geotechnical engineering project has been introduced within an undergraduate course on finite element methods. The introduction of the case study had two main purposes: to motive and engage students in learning finite methods and to introduce students to geotechnical engineering practice through exposure to a real project. The case study was developed around the geotechnical design of a working platform for the upgrade of Dunmore Bridge. As a project that is currently underway in the local region, it is topical and features many interesting aspects such as the historic nature of the bridge, the proposed construction methods and the use of large cranes. It provided an opportunity to introduce students to a real geotechnical engineering project and aspects of geotechnical engineering practice such as the use of pre-existing site information, in situ testing, real soils and soil profiles, and the uncertainty arising from a high degree of variability to be managed by geotechnical engineers.

Although only a small amount of feedback was received from students on the inclusion of the case study, the authors believe that the use of a real engineering project improved the experience of students and served to better engage students. The case study provides a means of introducing multimedia content into lectures and also provides topical information which can be used to engage the class in a discussion and provide for student-centered learning.

Further development of the case study and computer laboratory classes is required, in particular, additional computer laboratory classes are needed to improve the frequency and number of computing hours that students have to explore the case study and apply finite element modeling. An assessment task also needs to be developed to ensure participation by the majority of students and to encourage students to perform the work expected of them in their own time.

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Integrating a major Excel exercise in an introductory soil mechanics course

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ABSTRACT: As part of the introductory soil mechanics course at the University of Sydney students undertake a major assignment using MS Excel. Although some variation is necessary from year to year to minimise plagiarism, the assignment is typically made of two parts. In the first part, students are to produce a spreadsheet that uses the finite difference method to solve 1-D consolidation problems, and is able to generate answers for a variety of initial and boundary conditions, and loading histories. In the second part of the assignment, students are to use the spreadsheet to answer a specific individual 1-D consolidation problem and produce a two-page report.

The students' prior knowledge of Excel is highly variable, and often rudimentary. To provide support for the students we have developed an on-line resource, the ExSite, as a teaching aid for students using Excel in science and engineering. Unlike other Excel support tools, it is focused on engineering and science type operations, and contains a series of structured learning modules and videos.

The paper discusses the rationale for the assignment, both in supporting learning in soil mechanics and in the development of IT skills, how the exercise works and is assessed, and the value of the on-line resource in supporting the students.

1 INTRODUCTION

Numeracy is one of the most fundamental generic skills of tertiary education. The ability to manipulate and tabulate data, communicate it in accessible forms to specialised or general audiences, develop mathematical abstractions of complex problems and solve the resulting equations, are fundamental skills expected of engineering graduates. To achieve this outcome most engineering programs include introductory computing courses that aim to teach basic programming skills, and provide experience with particular computing tools such as MATLAB, MS Excel, etc. Students are then *encouraged* to use these tools in subsequent courses, but they are often not *required* to do so and as a result little, if any, further teaching or learning of computing skills takes place. Lecturers often have little time to teach students how to use MS Excel and yet find the knowledge of many students is insufficient. Moore (2005) suggests that despite its widespread use in schools, students' knowledge of Excel is very shallow and their ability with the advanced tools needed for mathematical modeling is very limited. This situation is undoubtedly not helped by the lack of publications in the engineering education literature which provide guidance on how to teach MS Excel. Moore (2005) suggests that teaching and learning can be enhanced by the development of special learning and teaching resources that focus on engineering applications, as most books on MS Excel provide examples to aid learning which are not relevant. The book by Look (1994) on spreadsheet geomechanics is a notable exception, but unfortunately it is dated as the examples all make use of Lotus-123. In contrast to the lack of papers dealing with learning how to use Excel, there are hundreds of papers describing special spreadsheets that have been developed to assist student learning of concepts, but the role of students is primarily as a user of the tool developed by staff. This situation may reflect the fact that it is much easier to write about an interesting application than getting students to do it.

As discussed by others (e.g. Genik and Somerton, 2011) there is a need for courses that use and develop computing skills throughout an engineering degree program, particularly when these skills are used in context to solve more realistic engineering problems, for students to go beyond knowledge and comprehension to attain higher order skills of analysis, synthesis and evaluation.

Oke (2004) provided a review of the use of spreadsheets in engineering education and concluded that spreadsheet applications have contributed to greater understanding by students and researchers and, given their widespread use in practice, it is important that students are well trained in their use and application. In particular, Oke (2004) suggested that spreadsheet use should be encouraged, in individual or group projects, for students to learn how to employ basic analytical tools and procedures embedded in spreadsheet applications. This is partly because, compared to other computing tools, users need not be hampered by the difficulties of coding in a standard computer language, and can spend most of their energy instead on the problem itself, which leads to a more positive interaction with the computer. Spreadsheets also enable a clearer understanding of how models work, allowing modifications and improvements to be achieved, and can facilitate the deepening of students' understanding of models and modeling while using the language of engineering and technology directly. This is important to students who frequently request more exposure to the modeling of real engineering problems (Moore, 2005).

One aspect that Oke (2004) noted as needing attention was to improve students understanding of macros and the programming aspects of spreadsheets.

Spreadsheets are useful in geotechnical design as they enable easy comparison of the effects of different design options and parameters, they enable easy assessment of the sensitivity to design parameters and they provide flexibility in allowing model customisation (Look, 1994).

In this paper, we present and discuss an assignment aiming to (a) develop students' familiarity with spreadsheets; (b) enhance their ability to use them to solve engineering problems; and (c) apply them to solve 1-D consolidation problems and improve their understanding of soil mechanics. The students are only provided with about 30 minutes of instruction on how to use Excel and, for further support, are directed to an Excel teaching tool (The ExSite) which includes lessons (in the macro module) that have been developed in part to support this assignment. The ExSite includes 8 modules, as well as a number of video lessons which teach specific MS Excel capabilities by using them to solve science or engineering problems.

2 COURSE STRUCTURE

This paper is concerned with a major assignment that is integrated within a semester-long introductory course in soil mechanics, which for most students is taken in the second semester of their 2nd year of study. The course covers the topics of: definitions and terminology; effective stress; flow of water; settlement and consolidation; and soil strength. The course involves three hours of lectures and a 1 hour tutorial each week for 13 weeks, and five 2 hour laboratory sessions. One of the tutorial sessions is dedicated to assisting students with the Excel spreadsheets.

3 THE ASSIGNMENT

The assignment has two parts. In the first part, students are to produce a spreadsheet that uses the finite difference method to solve problems involving 1-D consolidation, and is able to generate answers for a variety of initial and boundary conditions, and loading histories. In the second part of the assignment, students are to use the spreadsheet to answer a specific individual 1-D consolidation problem, listed in the Appendix below. For part two students may use the spreadsheet they developed in part one, or make use of a second working spreadsheet that is made available after submission of part one. This is to ensure that students having difficulty with part one are not prevented from conducting part two. A report that is no more than two pages is required. It is required to contain a brief statement of the problem, present and discuss the key results, and make references to 1-D consolidation theory.

3.1 *1-D consolidation finite difference solution*

The equation of 1-D consolidation is:

$$c_v \frac{\partial^2 u}{\partial z^2} = \frac{\partial u}{\partial t} - \frac{\partial q}{\partial t}$$

where q is the change in total stress, due to applied loads, from the initial equilibrium situation when the excess pore pressures were zero.

A finite difference solution to this equation can be developed as described in several introductory soil mechanics texts (e.g. Budhu, 2000; Smith, 2006) which has the form:

$$u_B(t+\Delta t) = \Delta q_B + u_B(t) + \beta[u_A(t) + u_C(t) - 2u_B(t)]$$

where:

$$\beta = \frac{c_v \Delta t}{\Delta z^2}$$

and u_A, u_B, u_C are the excess pore pressures evaluated at grid points separated by depth Δz, Δq_B is the change in applied stress between time t and $(t + \Delta t)$.

This equation allows the solution at time $t + \Delta t$ to be evaluated if the excess pore pressure distribution is known at time t, subject to application of appropriate boundary conditions. Furthermore, the settlement can be calculated as follows:

$$\begin{aligned} S &= \int_0^H \varepsilon_v \, dz \\ &= \int_0^H m_v (q - u) dz \\ &= m_v q H - m_v \int_0^H u \, dz \end{aligned}$$

In the above equation, the integral of the excess pore pressure cannot be evaluated exactly because the excess pore pressures are only calculated at the grid points. However, the integral can be evaluated approximately using numerical techniques. The simplest approach, and that shown to the students, is to use the trapezoidal method:

Thus

$$\int_0^H u\,dz \approx \frac{1}{2}(u_0+u_1)\Delta z+\cdots+\frac{1}{2}(u_{n-1}+u_n)\Delta z$$

$$= \Delta z\left[\left(\frac{u_0+u_n}{2}\right)+u_2+\cdots+u_{n-1}\right]$$

where

$$u_i = u_i(\Delta z,t)$$

Hence the settlement can be evaluated simply from the excess pore pressures. This finite difference approach lends itself well to a spreadsheet solution as the same equation is required at every point in the solution grid, except at the boundaries.

The spreadsheet can be used to explore the effects of rate of loading and pre-loading, and the effects of changing boundary conditions (from drained to undrained) for a variety of consolidation problems.

3.2 *Assignment practicalities*

Because of the large number of students taking the course, part one of this assignment is intended to be completed in groups of five. The objective is to have a spreadsheet that can work correctly for the five individual problems described in the Appendix. The problems only differ in the boundary conditions and the load histories. Each group may submit a single spreadsheet or five individual spreadsheets, one for each problem. Each student in the group has to submit a report on a different question. This submission requirement is set to encourage students to work cooperatively in their groups. However, any student is allowed to complete the assignment individually on the understanding that they have to produce a spreadsheet that will work for all five problems to obtain full marks.

Part of the exercise is to develop a spreadsheet with user-friendly data entry. Because of the very large number of ways in which this can be done in MS Excel, it is practically impossible for students, or groups working independently, to generate the same spreadsheet. The students are advised that it is acceptable for every student in one group to have the same spreadsheet, but similar spreadsheets across more than one group will be considered to exceed the bounds of acceptable cooperation and will be assessed accordingly.

To assist the students in producing the 2 page report outstanding student submissions of the report from previous years are made available.

3.3 *Learning objectives*

Using Bloom's revised taxonomy (Anderson and Krathwohl, 2001), it is possible to classify learning, from the lowest to the highest levels of learning, as follows:

1. Remembering: recalling information,
2. Understanding: explaining ideas/concepts, interpreting, classifying,
3. Applying: applying knowledge appropriately to solve a problem, carrying out, implementing,
4. Analysing: break a problem into its components to explore understanding and relationships, comparing, organizing,
5. Evaluating: justifying decisions, checking, hypothesising, experimenting, judging,
6. Creating: generating new ideas or ways of viewing things, designing, constructing.

Even at the university level, most learning is found to be focused on the three lowest levels of learning. Consequently, another goal of the assignment was to bring the students to the three higher levels of learning. The programming aspects and use of macros are designed to assist the students with the application and also prompt them to engage with higher-level learning activities.

3.4 *Assessment*

The assignment is weighted as 20% of the course and is split 50:50 between the spreadsheet and the report. The following criteria are applied:

a) Spreadsheet

Full Mark (100%): General spreadsheet able to solve all problems with ability to cope with a range of boundary conditions and load histories as specified in self-explanatory input data. The spreadsheet will make good use of macros and some Visual Basic programming

High Distinction (HD): General spreadsheet able to solve all problems and handle a range of boundary conditions and load histories. The program will make use of macros, but may require some manual adjustment of the spreadsheet to cope with different boundary conditions and load histories.

Distinction (D): Spreadsheet able to solve all problems and handle the range of boundary conditions and load histories, but requiring manual adjustment of spreadsheet to cope with different boundary conditions and load histories. Some use of macros to automate the spreadsheet.

Credit (CR): Spreadsheet capable of being adapted to solve all problems and handle the range of boundary conditions and load histories. Some automation of spreadsheet included, but requiring manual adjustment of spreadsheet to cope with different boundary conditions and load histories.

Pass (P): Basic spreadsheet capable of solving 1-D consolidation problems. Each problem will require substantial modification of the spreadsheet to cope with different geometry, boundary conditions and load histories

Fail (F): No spreadsheet produced or spreadsheet still requiring substantial work to solve the problems.

b) Report

High Distinction (HD): A concise, well presented report including relevant graphs and discussion and showing a full understanding of the problem and analysis

Distinction (D): A good report including relevant graphs and discussion showing understanding of the problem and analysis

Credit (CR): A report including relevant graphs and discussion showing broad understanding of the problem and analysis but not of the detail

Pass (P): Poorly presented report but includes relevant graphs and discussion; well presented report with rudimentary level of understanding

Fail (F): Poor report containing irrelevant information and demonstrating no understanding of the problem or the results of the analysis

4 EXCEL SUPPORT

It is clear that there is a need to develop a more formal and systematic approach to MS Excel instruction and that the provision of assistance for students who wish to develop their skills in using spreadsheet software is important. Teaching staff often assume, erroneously, that students arrive in their classrooms already able to use spreadsheet software efficiently and effectively. At the same time, curricular constraints and the pressure to meet vocational and generic skills leave little time for adding major new materials to individual syllabi. Therefore, there is a strong case for a two-pronged, blended-learning approach to MS Excel teaching: creating virtual learning spaces for self-teaching and providing short and targeted MS Excel tuition from within existing units of study, especially those that already require the use of MS Excel by students, as well as those that teach computational skills. Such integration can only succeed if suitably modular material is available, for teaching, self-teaching and assessment. While many books on MS Excel have been published (e.g., Liengme, 2000; Bloch, 2003), no modular, easily-accessible system incorporating teaching, self-teaching and assessment material, and catering for a range of specific MS Excel skills, has been developed.

A new online tool, The ExSite, for teaching and learning MS Excel, was officially launched at the beginning of semester two, 2011. The tool is available exclusively to all University of Sydney students and staff with the aim of addressing the problem of disparities in student skills in MS Excel. A civil engineering team designed and developed the tool, over two years, under guidance from an advisory committee at the Faculties of Engineering and IT and Science and with assistance from e-learning. The project was funded by a large grant from the teaching development scheme at the University of Sydney.

The ExSite contains a set of discipline-specific teaching, self-directed learning and materials that can assist students develop the skills or groups of skills that they need to use MS Excel 2007 effectively. It uses discipline-specific, easily-understood examples drawn from the Faculties of Science, and the Faculty of Engineering and IT to assist students develop and enhance their spreadsheet skills. It can be utilised as a stand-alone, self-directed learning package or to support classroom-teaching. The ExSite is made of the following modules:

1. Entering texts, numbers and performing simple calculations;
2. Performing automated calculations;
3. Copying and pasting data;
4. Formatting cells and printing worksheets; and
5. Creating graphs;
6. Performing simple statistical analysis, forecasting and goal seek;
7. Performing matrix calculations;
8. Creating and using macro commands.

Each module includes general and discipline-specific text and video lessons.

In particular, undergraduate science and engineering students at the University of Sydney who are required to use MS Excel in their coursework or research, stand to benefit from it.

Students given the soil mechanics assignment under consideration in this paper were directed to the ExSite and asked to make use of it, under supervision in the classroom and in their own time.

5 DISCUSSION

The question of which computing package should be used in teaching has always been difficult to resolve. The goal is to select a tool which is easy to use, is appropriate for a wide range of computing tasks, and is used in practice. These three attributes are not generally shared by any one tool. In our school, the debate is currently between MATLAB and Excel. MATLAB is the primary tool used in the introductory programming course, and is used by several academic staff and postgraduates for advanced programming tasks. However, the civil engineering profession primarily uses MS Excel in combination with various specialised computational tools, in areas such as engineering design, laboratory analysis and statistics, to name only a few, and familiarity with spreadsheets is essential. To meet industry expectations, and to satisfy accreditation bodies, graduates need the skills to utilise the modern engineering computing tools necessary for engineering practice.

A recent analysis of numerical skills at the University of Sydney civil engineering curriculum revealed that MS Excel is by far the most employed data analysis software, and MS Excel is widely used as a data analysis and communication tool by students and lecturers in Engineering and Science. However, little or no formal teaching of MS Excel takes place. For engineering students, it is limited to the first 4 weeks of the introductory programming course.

Student motivation to develop their computing and spreadsheet skills varies widely. Moore (2005) reported a survey following the development of Excel support for environmental engineering students which revealed that 25% of students were not motivated to learn skills for themselves and believed they should be taught, while 25% were naturally curious and exposure to Excel led them to explore more features than needed. However, the majority would only learn when and as needed. Tools such as the ExSite are particularly valuable for this last group as they provide relevant and easily accessible information on the most important topics.

At completion of the soil mechanics course, students fill out a unit of study evaluation. In 2011, this was completed by 261 students (80% of the class) with an overall assessment of 3.82 on a 5 point Likert scale, that is the students agreed with the statement that they were satisfied with the course. The majority of the students made no comment on the computing assignment, 2% made positive comments and 9% negative comments. The negative comments were related to difficulties of group work, and unfair assessment, the need for more teaching related to macros, and not liking or seeing the relevance of the assignment. All the comments, both positive and negative, related to the Excel programming aspects of the assignment, which were generally done well (average mark was just below distinction), whereas the second, individual part of the assignment could not be completed by many students because their understanding of consolidation was poor and they could not appreciate when the spreadsheet output was faulty. It was evident from this exercise that students have little idea of how to produce a two page report to support an engineering argument. For example most students have never performed any parametric type study and are not aware that they can plot several curves on the one graph. The provision of reports from previous years has been found to be essential to provide guidance.

Obtaining feedback from students on the use of the ExSite has proven difficult, with students reluctant to complete an on-line survey despite prompting on several occasions. Of the 2% of students who responded with positive comments, all reported that the site was useful, particularly the Macro instruction module. From conversations with students it was evident that many had used the site and found it to be helpful.

To minimise issues with plagiarism the exercise is changed over a three to four year cycle. This has been achieved by changing the specific problems, and by providing a basic spreadsheet and requiring students to enhance the spreadsheet with easy to use input screens, improved output, and by adding further loading options. Occasionally the exercise has been changed to that of developing a spreadsheet to calculate 1-D settlement in layered soil profiles and using this to investigate the effects of sub-layer thickness.

We assessed 150 spreadsheets in 2011. To manage the assessment we did not check any of the code developed in detail. The assessment process involved first checking the spreadsheet for the specific problem it was meant to solve, to see if it worked correctly, and second by varying the input parameters to assess the robustness of the spreadsheet. The first step should have been straightforward, but often was not because the data entry requirements were unclear. The assessment highlighted an issue that occurs whenever undergraduates are asked to submit an assignment that involves writing computer code or using an existing computer program to obtain a solution. The issue is what mark should be assigned to an assignment if the solution produced is impossible, e.g. the settlement of the soil layer is greater than the thickness, H. One approach is to record zero marks because the solution is impossible and therefore has no merit. Alternatively one can allow for minor coding errors when for example everything is correct except for one line of code where the code has a "/" instead of a "*". As the students see it: "Come on, it's unfair for me to get zero just because of one mistake". We have tried to make an assessment of the number of coding errors and assess accordingly, and to then allow students to negotiate their mark if they believe we have been unfair.

Unfortunately, the calculation and submission of impossible solutions is not a rare event. This provides the stimulus to continually remind undergraduates to always firstly check whether the solutions generated from a computer program are possible and if so, secondly, perform ancillary calculations to assess whether they are probable.

6 CONCLUSIONS

Overall, our impressions of the exercise have been positive. Students have produced some extraordinary spreadsheets, often making use of features of Excel that we had not previously been aware of, and the majority of students increased their understanding of the capabilities of Excel even if individually they may have taken little part in the group work. Over the years of running this exercise, there have been numerous examples of students reporting the value of this Excel exercise during subsequent vacation work experience, and of how employers have valued the students' spreadsheet skills, in some cases even when students had failed the spreadsheet part of the assignment.

The outcomes in terms of the soil mechanics and their understanding of consolidation and its application have been mixed. While many students are able to produce a report showing a good understanding, there are too many students who report that the assignment is just too hard. How to identify and support these students is an ongoing challenge.

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APPENDIX

The Appendix provides the five specific problems that the spreadsheet needed to be able to provide solutions for.

1. During embankment construction on soft clay it is often necessary to build the embankment in stages to prevent premature failure, but it is also required that the construction time is minimised. Use the spreadsheet to explore the influence of the timing of the stages on the pore pressure distribution and the settlement variation with time. Assume that the clay layer is 5 m thick, $c_v = 5\,m^2/yr$, $m_v = 0.0003\,m^2/kN$ and drainage is 1-way. The final embankment height is to be 5 m, and is to be constructed from fill with $\gamma_{bulk} = 20\,kN/m^3$. Assume that a maximum of three stages are to be used.
2. A tailings disposal facility is provided with an underdrain to enhance consolidation and settlement. To reclaim the land it is proposed to place free draining material on top of the tailings at a rate of 1 m/yr (15 kPa/yr) for a period of 4 years. Use the spreadsheet to explore the consequences on the pore pressure distribution and settlement of the under-drain clogging up at various times after the land reclamation starts. The tailings deposit is 10 m thick and has $c_v = 2\,m^2/yr$ and $m_v = 0.0002\,m^2/kN$.
3. A sensitive structure applying 20 kPa to the ground is to be built on a site with a 5 m thick layer of soft clay. It is required that the settlement of the structure is less than 10 mm. Use the spreadsheet to explore the magnitude of the pre-load and the length of time that it must be applied if the structure must be constructed within 18 months of the application of the pre-load. Assume that the pre-load will be applied and removed rapidly. The clay layer has properties $c_v = 2\,m^2/yr$, $m_v = 0.0001\,m^2/kN$ and drainage is 1-way.
4. In an oedometer test with one-way drainage, the stress is increased rapidly by 50 kPa and then after some time reduced rapidly by 50 kPa. Use the spreadsheet to explore the influence of the time when the load is reduced on the pore pressure measured at the impermeable end and on the settlement, time response. The clay layer has properties $c_v = 0.8\,m^2/yr$, $m_v = 0.0003\,m^2/kN$ and the sample is 30 mm thick.
5. A wide road embankment is to be constructed over a site with a 6 m thick soft clay deposit, overlying a deep sand layer. To enable construction to be completed in 2 years and to minimize settlement of the road it is proposed to pre-load the soil. To avoid stability problems the pre-load is to be increased at a steady rate for 1 year, at which time the applied stress will be Q kPa. At that time some of the pre-load will be removed and the embankment stress will be thereafter held constant at 60 kPa. Road construction takes place 6 months after the pre-load is removed, and results in an increase of 20 kPa in the total stress. The stress, time history is shown in Figure 1.

   The embankment material is highly permeable, and the properties of the clay are $c_v = 4.5\,m^2/yr$, and $m_v = 0.001\,m^2/kN$.

   Assuming that consolidation and settlement are one-dimensional, use the numerical method to investigate the effect of the magnitude of the maximum pre-load stress, Q, on the excess pore pressures and the settlement, time response of the road.

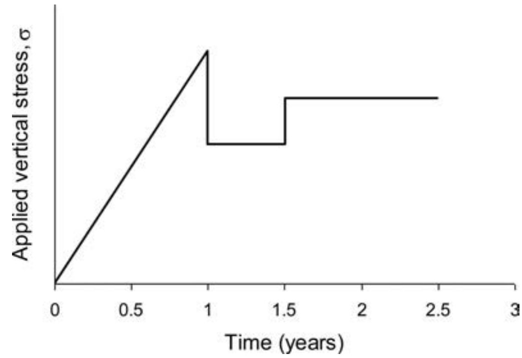

Figure 1.

Shaking the Foundations of Geo-engineering Education – McCabe, Pantazidou & Phillips (eds)

The use of electronic voting systems to enhance deep learning

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ABSTRACT: The present paper introduces a technology-enhanced teaching method that promotes deep learning. Four stages that correspond to four different student cohorts were used for its development and to analyse its effectiveness. The effectiveness of the method has been assessed in terms of examination results as well as results obtained from class response system software statistics. The evidence gathered indicates that the method developed is very effective and its implementation is straightforward. Furthermore, its success in achieving results seems to be independent of the skills and/or experience of the lecturer.

1 INTRODUCTION

Hand-held devices called Electronic Voting Systems (EVS), Class Response Systems (CRS) or simply clickers have become very popular in recent years and are used for teaching in almost every discipline. In their simplest form they are credit card sized instruments with buttons that students can press to select an option or answer from a multiple choice question that has been previously shown in the form of a presentation slide. Each clicker communicates via radio frequency (RF) or infrared (IR) to a receiver connected to the computer. Application specific software then processes the received signal and it is possible to provide statistics related to the response of the students. Commonly a bar chart indicating the percentage of responses corresponding to each of the possible answers is produced immediately after polling is finished. Students then have a form of immediate feedback that easily demonstrates where they are in relation to the rest of the class.

Recent advances in communication technology mean that transmission of alpha-numerical signals is already possible, even via mobile phones. However, to the knowledge of the author this option is not widely used in higher education due to cost and implementation issues. The discussion presented in this paper is therefore limited to the simplest and most economical version of CRS which allows selection from a list of answers of a multi-choice question prepared in advance.

Unlike an old-fashioned multiple-choice question exam, using CRS provides immediate feedback to students and as stated in various publications they have proven to encourage student engagement (e.g. Judson & Sawada 2002; Hall et al. 2005; Fies & Marshall 2006). Furthermore, positive student feedback in courses where CRS are used is commonly highlighted (e.g. Stowell & Nelson 2007, Kay & LeSage 2009). However, the fundamental deficiencies of a multiple-choice question exam are still present in any (basic) version of CRS. Namely, it is difficult to differentiate when a student has given a correct answer because he/she understood the question or if the answer chosen was guessed or randomly selected. The main problem in the use of CRS in higher education is then related to ensuring that they enhance deep learning (i.e. understanding) while discouraging surface learning approaches (i.e. memorising, fact acquisition, "bottle filling", etc).

Publications on CRS are abundant. Beatty and Gerace (2009) stated that existing literature tended to fall into three general (and often overlapping) categories: (i) introductions to technology; (ii) reports of individual efforts to teach with clickers and (iii) compilations of recommendations. They also stated that the discussion regarding the pedagogical use of EVS was limited and that how response systems can promote deep learning was an issue that was neglected in the existing published studies. This statement is still valid.

This paper starts by briefly discussing some of the existing CRS-based approaches and how they can be evaluated. The description of the new method, which is based on ideas from the existing approaches, is then followed by details of its development. Subsequently, an evaluation of the effectiveness of the proposed method is presented. This evaluation depends on final examination results, student feedback and CRS software output. The paper concludes with some discussion and conclusion remarks.

2 CRS-BASED APPROACHES AND THEIR EVALUATION

2.1 *Evaluation of teaching methods using CRS*

Existing research is in agreement that the success of any pedagogical approach when using CRS should be demonstrated by its effectiveness to foster deep learning (e.g. Roschelle et al. 2004). However it is also important to consider the ease of implementation.

In relation to the effectiveness of a pedagogical approach that uses class response systems, Fies & Marshall (2006) highlighted that missing from CRS research reports are tightly controlled comparisons in which the only difference is the use, or lack of use, of a CRS. The method of application for the use of CRS presented here follows such a research approach. Only one of the variables that are likely to affect the outcomes of this study was changed for each cohort. Hence, under ideal conditions and ignoring environmental factors and differences in the time of lecture delivery, it can be said that the effect of each of the variables can be isolated. Note however that is difficult to verify that all variables are independent of each other. As discussed later, even with these assumptions the addition of extra variables in the analysis seems to affect the performance/effect of the other ones.

An issue that seems to be neglected in most published studies is the ease of implementation of the proposed approaches for CRS use. As a minimum, three questions should be considered: (i) Can the approach be easily implemented by a person with limited teaching experience or lack of pedagogical knowledge? (ii) How is the time required for lecture preparation affected by the proposed approach? And (iii) How is lecture delivery affected by the method (also referring to class size and the need to distribute and collect handsets, or not, at the start and end of the lecture)? With regard to question (i) above, it should be emphasized that lack of experience or pedagogical knowledge are not desirable attributes for any teaching method. It is however advantageous to create teaching methods that can be used successfully by people even without such attributes. Clearly, the availability of experienced and knowledgeable staff can only add to the success of any method.

For the first time, the evaluation of the methods presented here assesses the effectiveness of various methods considering all these factors. Similarly, the new method proposed in Section 3 will also be assessed with reference to these different aspects.

2.2 *Existing approaches for CRS-based teaching*

Beatty & Gerace (2009) stated that they were aware of only three separate efforts to present and justify an explicit, coherent pedagogy for CRS-based teaching. These were: (i) Peer Instruction, (ii) Question-Driven Instruction and (iii) Technology-enhanced formative assessment. These methods are briefly described here because the new method described in section 3 takes some elements and ideas from them.

A CRS-based teaching approach not discussed by Beatty & Gerace (2009) that needs to be mentioned before those highlighted by them is that by Russell (2008). It is important because it is the only method found that specifically tackles the issue of determining when a multiple-choice question answered via a CRS has been completely understood or guessed. He suggested using sets of questions with contradictory paths which ultimately will help to reveal guessed answers. Such approach also emphasizes the potential of using CRS to adapt the contents of the lecture according to students' responses, an advantage that is also highlighted in other studies (e.g. Beatty & Gerace. 2009, Dufresne et al. 2000). Although this is a valid and certainly effective approach that fulfils that objective, it clearly requires excessive time for lecture preparation as each answer needs to be treated separately, deriving into numerous complicated alternative paths. Hence practical implementation is difficult, especially in those situations where the use of CRS-based teaching is intensive.

2.2.1 *Peer instruction*

This approach was proposed by Mazur (1997). The method suggests the use of multiple-choice conceptual questions at strategic junctures during the lecture. When a question is answered incorrectly by a high percentage of students, the class is asked to discuss the question amongst them and then answer again.

Quantitative evidence, primarily from pre/post testing (Hestenes et al. 1992) supports that the method improves student understanding (i.e. fosters deep learning). In terms of implementation, the approach seems straightforward and it is widely used at many higher education institutions, but requires lecturers with adequate skills and experience to effectively engage students in discussion. Note however that if a question is answered correctly by a high number of students, there is no reflection regarding the possibility of multiple guessed answers. Furthermore, a correct answer also excludes the need for discussion and peer instruction.

2.2.2 *Question-driven instruction*

This method, also referred to as the Assessing to Learn (A2L) approach was proposed by Dufresne et al. (2000). In this approach, a "question cycle" or iterative pattern is proposed. In that way the students read a question, think about it alone and/or discuss it in small groups, enter responses, then view the chart of response counts, present and discuss arguments for various choices, and then listen to an appropriate "closure" to the cycle.

An important difference between Peer Instruction and A2L is that Mazur's approach is intended for intermittent insertion within more traditional teaching methods. The A2L method is intended as the basic structure of class activity, other traditional teaching methods are only used when needed and motivated by the questions and discussion.

Leonard et al. (2001) demonstrated the effectiveness of A2L to foster deep learning but its implementation is not easy. It is not a traditional way of teaching and requires significant experience. Hence some of the evaluating parameters discussed in section 2.1 are not satisfied.

2.2.3 *Technology-enhanced formative assessment*

This method, also denoted as TEFA is based on the A2L approach and was proposed by Beatty & Gerace (2009). TEFA specifies an iterative cycle of question posing, student discussion prior to selection of answers, post-discussion based on the responses without revealing the correct one and finally, a summary, micro-lecture or closure is provided including meta-level communication. The content of the final closure is normally determined by the previous part of the cycle.

The method differs from others in various ways: (i) teaching is question-driven as for A2L but demands for questions to be challenging, multifaceted and disputable (i.e. no questions in the "you know it or not" style), (ii) opposite to Mazur's approach peer instruction is encouraged in all questions before and after the students have answered, and (iii) meta-level communication suggests a deviation from the question itself while focusing discussion about learning the content, commenting on the purpose, design, and unfolding of the course itself.

This method has been under development for almost 15 years. Beatty & Gerace (2009) state that it is consistent with established thinking in educational research and that it has also proved to be effective promoting deep learning. Note however, that its implementation is not easy. The creators of the method state that professional development programs are constantly conducted with the aim of helping teachers to master the approach. Furthermore, in an engineering context ignoring the development of "you know it or not" style questions is not straightforward. The nature of engineering subjects implies that if something is known the product will be successful and the structure will be safe, if something is not known failure and often catastrophic consequences could occur.

3 A NEW CRS-BASED TEACHING APPROACH FOR ENGINEERING SUBJECTS

The method proposed here has taken ideas from those approaches described in section 2. The method cannot be defended on the strength of experimental findings. Although the empirical evidence presented in sections 4.3 and 4.4 seems to demonstrate that it is successful, the amount of evidence is still limited. The method is presented for consideration as an easily reproducible and implementable method that hopefully can be used by most people with limited experience. It is hoped that the method is consistent with the perspectives of other researchers and users of CRS-based teaching. As in the case of TEFA, the method is based on established ideas in educational research.

The method, as in the case on Mazur's Peer Instruction, uses questions at strategic junctures of more traditional teaching methods. Hence, the difficulties associated with Question-Driven Instruction present in the A2L and TEFA approaches are avoided. The method however, takes important elements of these approaches and proposes a simple strategy to determine if a question has been understood or guessed, which in contrast to the approach by Russell (2008), has a straightforward implementation. Finally, meta-level communication as discussed by Beatty & Gerace (2009) is also used.

Some researchers suggest that CRS-based teaching is more effective when used as a small part of a lecture when the learning of key concepts is required (i.e. Draper & Brown 2004). The use of CRS should be limited to a single set limited number of questions, especially when experience on their use is limited. This is a suggestion but the success of the method is not expected to be dependent on such restrictions. It has been found from experience (details provided in section 4) that for each set of 5–7 questions the following steps should be carried out:

1. Use meta-level communication to introduce the purpose of the exercise, to explain what can and should be gained from it, and how the concepts learnt can be used when knowledge is finally obtained.
2. Present the question with the possible answers and poll the answers only after peer instruction amongst the students has occurred.
3. Reveal the right answer and show the statistics provided by the software.
4. Explicitly explain how each of the answers was obtained highlighting the mistakes in those that are not correct.
5. Provide a closure, clarification or meta-level comments if required and allow the students to ask more questions.
6. Proceed to the next question and follow steps 2 to 5.
7. Create a question that asks the students how many questions they answered correctly and show the statistics to the group.
8. Create a question that asks the students how many questions they guessed and show the statistics to the group.
9. Assess the outcome of the last two questions and determine how the lecture should proceed.

The use of meta-level communication in step 1 is intended to get the benefits of the TEFA approach. Therefore, as stated by Beatty & Gerace (2009), it should help the students to develop meta-cognitive skills and should help them in the learning process. Note, however, that for the new method proposed here this is done at the start of the questions and not at the end as in the TEFA approach.

Peer instruction in step 2 reaps the benefits to foster deep learning as suggested by Mazur (1997). It should motivate and engage the students with the subject.

Step 3 provides the usual CRS feedback for students and allows the students to identify their position in relation to the class. Note however that this only gives a measure of performance in a single question.

Step 4 is a very important one and generally allows emphasizing the causes and consequences of failure. This is very useful in engineering contexts. At this stage meta-level communication in addition to that presented in the following numeral is possible.

The two final questions referring to the number of correct answers and the number of questions guessed are very dependent on the honesty of the students, but they are very consistent and provide an easy way to verify if the whole exercise was productive, effective and if the topic was understood or if positive results were the results of multiple guessed answers. Furthermore, simple statistical analyses after the lecture allow determining if what the students stated in these questions coincides with their answers to previous questions. Honesty in the students' answers would reflect a match between the number of correct answers and the percentage of correct answers obtained in the previous sections. Although data regarding this comparison is not presented in this paper, it suggests that the student cohorts assessed in this study were honest. These two steps also show the students a much more complete picture of their understanding with respect to the rest of the class in comparison to what a bar chart from the results of a single question can offer them. Ultimately, the analyses provide enough information to determine how the following lecture should be approached and ensure that the fundamental concepts required are clear if necessary.

When formulating the new method a rigorous research approach was followed. In particular, the comments by Fies & Marshall (2006) regarding tight control on the evaluation of the effectiveness were considered. The final method as presented above is the result of using ideas by others researchers in an incremental fashion. Four stages of development were assessed, which correspond to experiences with four different student cohorts. The details of each of the development stages and the measures used to evaluate the success of the method are presented in the next section.

4 DEVELOPMENT AND EVALUATION OF THE METHOD

Four groups of students were used to develop the method. All groups were 3rd year undergraduate Civil Engineering students as part of a module in Geotechnical Engineering. The effectiveness of the method was evaluated in relation to the teaching and learning of bearing capacity.

In simple terms bearing capacity is the ability of the ground to support the loads transmitted to it from the structures built on it. Being able to calculate the bearing capacity of a certain soil under varying loading conditions is a key learning outcome in any geotechnical course. The nature of the subject and the existence of different geotechnical design codes worldwide require adequate knowledge of various definitions (types) of bearing pressure/capacity. While standard calculations of bearing capacity are given in gross terms, considering situations where the foundation depth is great it might be important to consider the value of bearing capacity in gross effective or net effective terms. The difference between these definitions are directly related to the definition of Terzaghi's principle of effective stress, a corner stone of soil mechanics which is also recognised to be a difficult concept to teach. Similarly, it is of the utmost importance to understand the difference between an allowable bearing capacity, an ultimate bearing capacity and a presumed bearing capacity, especially when referring to accepted values quoted in design codes. The corresponding definitions for these terms are not presented here but they can be found in most textbooks on soil mechanics and foundation engineering. The omission of such definitions should help to emphasize that the teaching method presented in this paper is equally valid for any topic, but it is expected that is particularly effective for engineering subjects.

4.1 *Details of module delivery*

Bearing capacity is only one of the topics in the module. For the four student groups all the topics of the module were delivered to them using a traditional teaching approach involving a combination of 12 two-hour lectures, 6 tutorial sessions including formative assessment, 3 laboratory sessions counting for 10% of the module marks, a piece of coursework counting for 20% of the module and a final exam providing the remaining 70% of the marks.

The first student group was taught with no use of CRS, while the other three groups included a lecture where a different CRS-based teaching approach was used to teach the different definitions of bearing capacity/pressure. Further details of the different methods used are provided in section 4.3. Although the number of students and time of delivery was different for each of the cohorts, the course contents, mode and pace of delivery remained unaffected. Evidence presented in section 4.4 as well as student feedback suggests that these differences did not affect the outcomes of this research.

4.2 *Method evaluation measures*

In section 2.1 it was indicated that CRS-based teaching should be evaluated in terms of its effectiveness to foster deep learning and also the ease of its implementation. The details provided in section 3 clearly demonstrate that the method is implemented easily. The use of CRS-based teaching is only present on a small section of the whole module delivery. The type of question needed in the method does not differ from that normally provided in any tutorial problem or exam question. Furthermore, the preparation of the CRS-based questions requires only little extra preparation in contrast to that usually required with other approaches such as those by Russell (2008), Dufresne et al. (2004) and Beatty & Gerace (2009), where the use of CRS is very intensive. Hence, significant staff experience in the use of the clickers for teaching is not required. The only difficulty that may arise in terms of implementation will occur if the number of students is large.

Note, however, that this is a logistical problem but it does not seem to affect the effectiveness of the method as highlighted in section 4.4.

In terms of effectiveness to foster deep learning, examination results and statistics provided by the CRS software were the main sources of information used to evaluate the benefits of the method. The final exam for the four student cohorts consisted of five questions. One of them was related to the topic of bearing capacity. The question consisted of a mix of calculation and theoretical/conceptual sections to ensure verification of understanding and to facilitate the detection of surface approaches to learning (i.e. memorised responses or mechanistic procedures to find an answer without considering its general context). Comments by various internal/external examiners during the exam moderation process have highlighted the good quality of the question and how it is industrially relevant and useful to evaluate the achievement of the learning outcome specified. The question is therefore transcribed below based on such comments and considering the main audience for this paper. Note, however, that the method proposed in this paper could be successfully used for any topic and discipline.

Exam question: *"The bearing capacity of a pad foundation can be calculated using the formula given by:*

$$q_f = cN_c s_c i_c + \gamma D N_q s_q i_q + 0.5\gamma B N\gamma s_\gamma i_\gamma$$

The derivation of this equation is based on the occurrence of a certain failure mechanism (i.e. general shear failure).

(a) Make a diagram of the general shear failure mechanism and refer to it to explain the meaning of the three terms in the equation above.

(b) "For geotechnical engineers the bearing capacity when a local shear or punching failure mechanism is likely to occur is not their biggest concern". Comment if you agree or disagree with this statement providing reasons for your answer.

(c) Ignoring depth factors determine the drained gross bearing capacity of a $2.5\,m \times 3.5\,m$ *pad foundation placed at a* $2\,m$ *depth. The soil found in situ is a firm, saturated clay (*$\gamma_{sat} = 21.5\,kN/m^3$*) layer extending to considerable depth with the following geotechnical properties:* $c' = 3\,kPa$ *and* $\phi = 27°$*.*

(d) Calculate the drained bearing capacity of a foundation as described in part (c) but considering (i) gross effective, (ii) net and (iii)net effective terms."

The nature of the question implies that plenty of formulae are required in order to calculate bearing capacity, shape and inclination factors. It was of course intended to avoid the encouragement of mechanistic procedures and encourage deep learning, so these formulae were provided on an additional sheet. It is worth mentioning, however, that definitions and formulae related with part (d) were obviously not included on this sheet as they correspond to fundamental principles that need to be conceptually understood and therefore evaluated. Furthermore, they are the basis of the CRS questions detailed in Section 4.3.2 which are also used to evaluate the effectiveness of the proposed methods.

In the UK, each cohort is usually provided with past exam papers of previous cohorts for study and revision previous to the exam. This was also done for the four groups analysed here. It is worth emphasising here that although the four cohorts did not answer the exam simultaneously as explained in Section 4.1, this did not mean (for example) that the 4th cohort had knowledge of the exams given to the three previous cohorts. This is an obvious measure that has to be taken to maintain the objectivity of the research approach. Since all the cohorts needed to be evaluated using the same exam questions, precautionary measures were taken to ensure that the students did not memorise the procedures or answers (i.e. an additional set of different review questions that asked the same subjects were provided). Additionally, in the final examination, the question on bearing capacity was identical for the four groups and only differed on the numerical values (i.e. parts c and d) and slight deviations in theoretical questions were also introduced where this was possible (i.e. parts a and b) without changing the learning outcomes that were assessed. Plagiarism was rigorously prevented and never detected. Furthermore, as highlighted above, none of the cohorts knew at any stage that their results were being compared to those of other cohorts and of course, they never had access to the exam questions of the previous cohorts. So the first measure of effectiveness of the method was the results (marks) obtained by the students on the question about bearing capacity.

It is also common practice to allow the students to choose 4 of the 5 questions to be solved. This approach was also taken for the four student groups. As a consequence, it is expected that students will choose to solve the questions they feel more confident with. That is because students are expected to intuitively answer those questions which they believe will help them to get the highest marks. Hence the percentage of attempts for the question can also be considered as a measure of effectiveness of the method described in section 3.

In relation to the CRS software statistics, the percentage of correct answers is a very intuitive and obvious manner to assess effectiveness. However, in this study, the responses provided by the students to the questions related to the number of correct answers and the number of guessed questions were also considered. It is believed that an increase in the number of correct answers accompanied by a decrease in the number of guessed answers is demonstration of improvement and effectiveness of the corresponding method.

4.3 *Development stages*

The development process involved four cohorts of students. Each of the cohorts corresponds to a certain development stage which in turn includes a particular enhancement which finally derived in the final method.

4.3.1 *Stage 1 – The control group (No CRS)*

In order to prove if the use of clickers is effective or not it is necessary to compare the results of a student group taught without using the system with another cohort using CRS under otherwise identical conditions. The control group for this stage (with no CRS-based teaching) consisted of 24 students.

For this group, each of the different definitions of bearing capacity to be taught were introduced to the students as part of a traditional lecture session. Each definition was defined appropriately in a single presentation slide followed by one or two more slides detailing a solved calculation example illustrating the principles behind each definition. After each example was presented the students were allowed to ask any questions or express any doubts or concerns. However, if there were no questions the lecture proceeded as normal. This is an approach very similar to that suggested by Mazur (1997), but with the absence of CRS. Since at this stage rapport between the lecturer and the students had already been established it was concluded that the concepts had been fully understood by the students if no doubts/concerns were raised after the concepts were introduced (as it happened in most of the definitions taught). Surprisingly, the examination results revealed the opposite.

Since CRS-based teaching was not used, the only comparable measures for the evaluation of effectiveness are related to students' results in the final examination. Results indicated that 66.7% of the students attempted the question on bearing capacity, making it the least attempted question. This compares to 91.7% of attempts for the most popular question. Those students who attempted to answer the question obtained an average mark of 38.0% with a standard deviation of 24.0%. Clearly, although the range of variation of results was significant, the achievement of learning outcomes is in general terms not satisfactory.

The lack of questions during lecture time and the exam results imply that although the students are able to follow and understand the principles explained as shown by the presented examples, they are not able to apply or extrapolate such concepts to different problems. Hence, using such an approach, the fostering of effective deep learning cannot be guaranteed. As a consequence, the use of alternative teaching methods as part of the more traditional lecture is justified.

4.3.2 *Stage 2 – The introduction of CRS*

The second student group consisted of 80 students and was taught under the same conditions of that at Stage 1. The only difference between the two cohorts was the use of CRS-based teaching in the lecture dedicated to the different definitions of bearing capacity. This meant that following the slides describing each definition, the calculation example was shown. Then, after time for questions and comments was given, a slide with a multiple choice question/problem to assess understanding was introduced and the clickers were used by the students. The problem asked was the following:

> *"The vertical load on a 4 m wide strip footing (including its self-weight) built on sand will be 400 kN/m^2. The footing base is 2.5 m below ground level and there is a static ground water table 1 m below ground level. The sand has a unit weight of 19 kN/m^3 when saturated and 16 kN/m^3 when dry. Calculate (a) the gross bearing pressure (q_{gross}), (b) the overburden pressure (p_0), (c) the net bearing pressure (q_{net}), (d) the gross effective bearing pressure (q'_{gross}) and (e) the net effective bearing pressure (q'_{net})".*

Hence, parts (a) to (e) in the problem above corresponded to a single multiple choice question to be solved using the clickers by the students. Solutions to these answers are not included here and neither are the possible answers for each of the questions. However, amongst the answers in the slide corresponding to each of these questions there was a correct one and various incorrect values that could be found if conceptual mistakes or common arithmetic errors were committed. The students were only asked for the correct answer and an appropriate (measured) amount of time for the solution of each question was provided. After the answers were polled the immediate feedback as provided by the CRS software showing the percentage of answers for each option was shown to them. Subsequently a few seconds were given for them to digest their own position in comparison to the rest of the class. Student feedback indicated that this stage was extremely valuable for the students to realise if they had actually understood the concept or not. So, it is clear that actually demanding the application of a concept in a different scenario to that used for its explanation is useful. Although the CRS are not an essential requirement to do this, they serve this purpose very well as they stimulate student engagement as demonstrated by various researchers (e.g. Draper & Brown 2004, Hall et al. 2005). However, as discussed before, this approach is not effective to differentiate which questions were understood completely or guessed even when the percentages of right answers are high. Hence, the simple approach described in steps 7–8 of section 3 was also introduced at this stage of the lecture. This could also be done independently of the CRS, but their use makes this process much easier, and makes the information available for further analyses after the lecture.

The exam results for this stage were very interesting. The percentage of attempts rose from 66.7% in Stage 1 to 80.0%. Similarly the mean value of the marks obtained also increased from 38.0% to 47.2% while the standard deviation remained almost constant at 23.6% (compared to 24% at Stage 1). Results were therefore encouraging; they indicated better student performance and higher student confidence. Student feedback related to the use of CRS was also positive. Furthermore, the constant standard deviation and the range of results seemed to indicate that the preventative measures taken in relation to past exam papers had been effective. Most importantly, all the results implied that the introduction of CRS-based teaching and the pedagogical principles described above had resulted in improved students' learning.

4.3.3 *Stage 3 – CRS and peer discussion*

The third group of students was comprised of 37 students. Following the same approach, teaching methods were exactly the same to those during Stage 2, and differed only on the introduction of peer discussion as suggested by Mazur (1997). In practical terms this meant that a period of time was introduced before polling of answers was accepted. During this time, students were asked to discuss amongst them about the answers and to argue and defend their positions within small groups before any answers were accepted by the CRS software. Hence, at least in theory, any changes in examination results could be attributed to the introduction of peer instruction only.

Interestingly, examinations results indicated a slight decrease in the percentage of attempts from 80.0% to 75.7%. Note however that such percentage is still high in comparison to that found during Stage 1 (66.7%). Similar observations could be made in terms of the marks obtained. The mean value was 46% (a slight reduction from 47.2%). On the other hand, the standard deviation was 24.4% (very similar to that in both Stage 1 and 2). Note that the number of students during Stage 2 was 80 compared to 37 during this stage. This seems to indicate that the results are not affected by changes in the size of the student group as discussed before. Also, it would not make sense to conclude, that in light of the results obtained, the introduction of peer instruction had no effect on the effectiveness of the method as this would contradict a significant body of evidence available (e.g. Hestenes et al. 1992, Mazur 1997). However, it can be said that peer instruction is perhaps the process that has the highest dependence on the experience of the lecturer. This also requires skill and although it can be confirmed that there was discussion amongst the students, perhaps more control and guidance was required from the lecturer at this stage to ensure its' effectiveness.

4.3.4 *Stage 4 – Final conception of the method*

The cohort at this stage consisted of 24 students. As before, the method of delivery remained identical with exception of a unique variable. In this case the variable of study was the effect caused by the addition of meta-level discussion. As described in section 3 this was made at the very beginning of the CRS-based teaching method instead of the approach of Beatty & Gerace (2009) that does so at the end of a question cycle. This was considered to be a risky decision because it was thought that telling the students that they were going to be asked, and how they were going to be assessed would put them behind the achievement of a short-term and perhaps forgettable outcome once it was finished. In the next section evidence will illustrate that perhaps there might be evidence of such phenomenon because the statitistics provided by the CRS software show significantly higher results in Stage 4 when compared to those than in the earlier stages. However, the examination results are surprising, very encouraging and suggest that the final structure and methodology of the CRS-based teaching proposed is very effective.

The percentage of attempts rose to 100%, making the bearing capacity question the most popular one in the exam for the first time. Similarly, the mean value of the results increased to 72.5% (from around 46% in Stages 2 and 3) with a much smaller standard deviation of 8.3% (in comparison to approximately 24% in the previous stages). The results are not only significantly higher, but they also demonstrate that the range of results is smaller, confirming that the learning outcome had been achieved by every student.

In spite of the results, there is not enough evidence to conclude that the success of the method is due to the introduction of meta-level discussion, even if this was the only variable that changed at this stage. The reason for that is thought to be that all variables might be influenced by each other. For example, meta-level discussion can give students a purpose, and in turn this will aid or encourage peer discussion. Hence, the results do indicate that the combination of methods in the final approach described in section 3 is very effective and does promote deep learning. As an added bonus, the teaching approach is very easy to implement. Hence, although more evidence is still required, the method is introduced as an easily implemented alternative with the likelihood of a good outcome, which also seems to be independent of the lecturer's skills and experience.

4.4 *Evaluation of CRS software statistics*

All the conclusions and statements provided so far were based on the results of final examination marks. It was of particular interest to analyse if the same conclusions could be derived when the CRS software statistics were studied. Figure 1 shows the percentages obtained by the students for the correct answer to 5 questions at the three stages when the corresponding

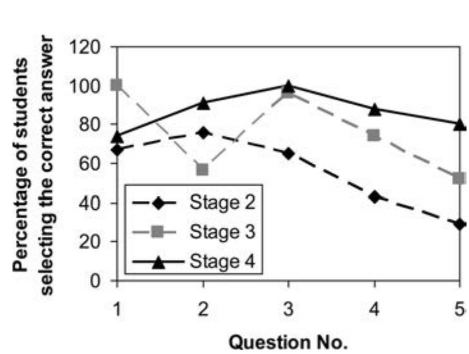

Figure 1. Percentage of students selecting the correct answer for five different questions at various stages of method development where CRS-based teaching was used.

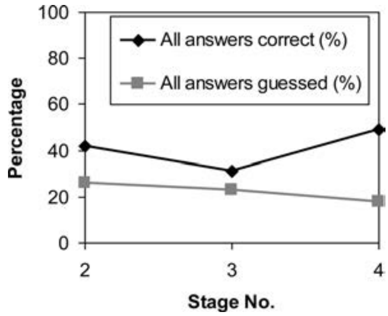

Figure 2. Analysis of verification questions to differentiate surface and deep approaches to learning.

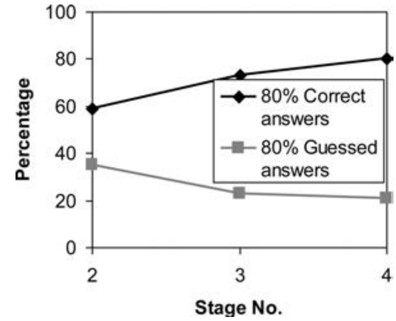

Figure 3. Aggregated CRS statistics considering percentage of students choosing 80% or more correct (or guessed) answers.

CRS-based teaching methods were used. It can be clearly seen, that excluding questions 1 and 2, the tendencies and conclusions derived from examination results are confirmed. That is, Stage 2 is the least effective, followed by subsequent increases on effectiveness for Stages 3 and 4 with Stage 4 being the most effective.

It is also interesting to see the results obtained from the verification questions (i.e. those to determine number of correct answers and number of questions guessed). Figure 2 illustrates the evolution of these parameters for each of the stages when CRS-based teaching was used. Note, however, that the figure illustrates the percentage of students that stated answering all questions correctly and the percentage of students confessing that they had to guess all the questions' answers. It can be seen that there is a slight decrease in the percentage corresponding to guessed answers as the method becomes more sophisticated (i.e. as the Stage No. increases). Similarly, there seems to be an overall increase in the percentage of students getting all the answers correct. This is relevant because examination results presented in the previous section seemed to suggest that there was no sign of improvement from Stage 2 to Stage 3 when peer instruction was introduced into the method. Figure 2 does confirm that peer instruction did have a positive effect demonstrated by the reduction in guessed questions, even though there is a slight reduction in the percentage of students getting all correct answers from stages 2 to 3.

As discussed in Section 4.3.4, the results in Figure 2, and in particular the radical increase in the number of correct answers from stage 3 to 4 might pose the question of the validity of deep learning. Such a change is of course a positive outcome for the method, but with the evidence available it is very difficult, if not impossible to determine whether these results are affected or not by surface learning approaches. Note, however, that exam results seem to support the conclusion that deep learning has been achieved, and hence that the method is successful.

In contrast to Figure 2, a continuous increase (for all stages) in the percentage of answers answered correctly is observed when the percentages are assessed in an aggregated manner. That is when the percentage related to getting some (but not all) of the answers correctly (or guessed) is also considered. Figure 3 shows the results considering the percentage of students that answered 80% or more of the questions correctly, together with the percentage of students that guessed 80% or more of the questions asked. When presented in this form, the results clearly show the benefits of the various additions introduced in the method at each of the development stages. There is an evident continuous increase in the correctness of the answers, accompanied by a continuous and clear decrease in the percentage of students that guessed most of the answers. It can be then concluded that although examination results do not show a significant improvement between Stages 2 and 3, the analysis of results from the CRS software indicate that indeed there is an improvement.

The results in Figures 2 and 3 also indicate that independently of the CRS-based method used, it is difficult to promote student engagement amongst those individuals that are not prepared or that do not intend to engage with the material. Nevertheless, it is encouraging to observe that there was a decrease as the approach became more developed. It is also believed that the results shown in Figures 1 to 3 and the examination results discussed in section 4.3 demonstrate with significant confidence that the new CRS-based teaching method is highly effective to foster deep learning.

5 DISCUSSION AND CONCLUSIONS

The present paper has used an incremental and rigorous research approach to develop and implement a CRS-based teaching method that promotes and enhances deep learning. Four stages that correspond to four different student cohorts were used for its development and to analyse its effectiveness. Each of the stages has attempted to look at effects caused by various approaches widely accepted in the educational literature. Amongst them, peer instruction, question-driven instruction and meta-level communication have been described, discussed and analysed where applicable.

The effectiveness of the method has been evaluated in terms of examination results as well as results obtained from CRS software statistics. It is recognised that the evidence gathered so far might be limited, but it does seem to demonstrate that the method is highly effective.

The main conclusions that can be inferred from the results and evidence presented include:

- The proposed approach is highly effective to promote deep learning, is easy to implement and it is based on educational ideas that are widely practised and strongly supported in the existing literature.
- The approach presented incorporates a very simple method that can be used to determine very easily to what extent the questions have been completely understood or its' answers guessed.
- There seemed to be a strong inter-dependency between the various approaches/methods that were incrementally added into the method. It was also observed that peer instruction requires a certain amount of experience to achieve conclusive results.
- It was demonstrated that although examination results alone seemed to indicate that there was no effect on the results caused by peer instruction, the CRS statistics demonstrated that such addition is indeed a very relevant part of the newly proposed method.
- It is difficult to verify if the different parts of the method are independent of each other, but it has been shown that as a complete unit, the proposed method works and enhances deep learning.
- Finally, it must be said that at various development stages it is difficult to determine whether the results obtained are influenced by unavoidable surface learning approaches adopted by some students. However, without stating that final examination results fully represent deep learning, it can be concluded that it is most likely that the results reported are the consequence of the encouragement of deep learning approaches. This is because all the necessary steps and measures to ensure that this is done have been considered for this research. These measures were detailed and described in the paper.

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Implementation of the use of computing and software in undergraduate Soil Mechanics courses

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ABSTRACT: To respond to the industry's increasing demands, it is generally accepted that Civil Engineering graduates and postgraduates should have broad technical knowledge, together with significant soft skills. In two courses on Soil Mechanics as part of the degree in Civil Engineering of University of Aveiro, Portugal, students undertake projects using general computing and specific geotechnical software that both enhance their technical learning and develop soft skills. Critical thinking is required for the validation of 'blackbox' numerical results by making comparisons with theoretical solutions, in reflection on the limitations of numerical tools, as well as for estimation of values for input parameters for analyses.

1 INTRODUCTION

1.1 *Scope*

To respond to the increasing demands of the industry, it is generally accepted that Civil Engineering graduates and postgraduates should be equipped with broad technical knowledge, together with significant generic competences and soft skills. Some examples are: efficient communication, orally and in writing; development of human relations, particularly the ability of working in team; ability to work with a computer, namely with text processors and spreadsheets. The ability of using computing and specific software can be included in both technical knowledge and soft skills.

To increase the employability of the Civil Engineering graduates and postgraduates at University of Aveiro (UA), Portugal, and to improve the quality of the program, the author implemented some non-traditional teaching and learning strategies in most of the courses under her coordination. Parallel, to assess the effect of such strategies on enhancing students learning, the author analysed its impact.

In two sequential courses on Soil Mechanics in the five year degree in Civil Engineering at UA, the students were confronted with the need to use computing and specific geotechnical software. The main goal was to help students develop soft skills and to become familiar with typical numerical tools currently used in Geotechnics. Such learning strategies were adopted using a cooperative learning system. More details on such system can be found in Pinho-Lopes et al. (2011) and in a companion paper Pinho-Lopes (2012).

1.2 *Use of computing and software in geoengineering*

Several authors have pointed out the importance of using computing and software in engineering practice and different perspectives of such use can be found in literature.

For example, Toll (2001) states that the information technology was becoming increasingly important in geotechnical engineering and computers were being used much more for non-computational purposes. This author points out several major areas of usage: geotechnical database systems, the use of artificial intelligence techniques, such as knowledge-based (expert) systems, and neural networks.

Rose (1978) said that it should be the duty of the university to teach how to use engineering computer packages intelligently, stating that *engineering design using computer packages* was a new technique to be learned, being a mixture of experimental planning, engineering logic and economics. The author points out that a computer package is also an excellent educational aid, allowing the student to get an engineering feel for a piece of equipment or system much quicker than by laboratory work or a series of hand calculations.

The use of software and computing has thus been increasing in engineering education as preparation for the professional atmosphere.

Jaksa et al. (2000) present computer aided learning (CAL) resources available in geotechnical engineering and engineering and environmental geology in undergraduate courses, which at that time were becoming more widespread and an accepted form of teaching.

According with Rothberg et al. (2006) engineering students in the UK like the use of CAL materials, but they still want notes to take away; they want to be supported in their use of software, especially when engineers' tools are used to demonstrate principles; timetabled support can work well as a catalyst to encourage self-study using the software.

Budge (2006) states that providing students with the chance to use a few of the tools they will use once they begin their careers as practicing engineers (e.g. finite element method commercial software) is a significant benefit to both the students and their employers.

Zoghi (1996) presents a case study where personal computers were integrated in the teaching of geotechnical engineering courses. The author refers to the use of spreadsheets as an alternative to a 'blackbox' approach, stating that for the design of foundations, such strategy leads to students gaining an insight into the material characteristics and the design implications by considering numerous 'what if' conditions. Zoghi (1996) also states that, during the several soil mechanics courses, a series of spreadsheet templates are generated by the students to incorporate the weight-volume relationships, compaction density curves, and soil classification characteristics. However, the majority of effort is expended on formulating spreadsheet routines for the permeability, compressibility, and shear strength characteristics. The same author states that, for instance, "a template is initially generated to compute and plot the vertical stress distributions due to overburden pressure as well as induced foundation loading. The concepts of effective stress, neutral stress and total stress are incorporated in this program. Once, the stress distribution is configured in a soil mass, the compressibility (or settlement) characteristics of soil are readily determined in a subsequent spread sheet template."

Carter et al. (2000) state the importance of validating computer simulations and geotechnical software, and suggest some methodologies for achieving this. Furthermore, they state that there is a strong need to define procedures and guidelines to arrive at reliable numerical methods and, more importantly, input parameters which represent accurately the strength and stiffness properties of the ground in situ.

Zoghi (1996) concludes that the use of microcomputer spreadsheets appears to be amenable to the solution of myriad of geotechnical problems. Due to the versatility that these tools offer and the fact that they furnish an interactive environment, the prospect of 'blackbox' approach may be eliminated. Thus, the students can enhance their knowledge of the material by primarily varying the input parameter values and instantly observe the outcome (Zoghi, 1996).

Therefore, introducing future engineers to this type of approach and encouraging a critical attitude towards the use and the results from computing and software is essential for achieving adequate preparation for the professional life.

2 CASE STUDY

2.1 *Civil Engineering programmes in Portugal*

Presently the Civil Engineering degree in UA is organised in two integrated cycles, corresponding to a program which lasts for five years. To clarify the meaning of such cycles it is important to mention that this organisation resulted from the Bologna process.

The most visible transformation from the Bologna Process in Portugal was the degree's reorganisation in three cycles:

- 1st cycle, three years (degree of 'licenciatura');
- 2nd cycle, two years (degree of 'mestrado');
- 3rd cycle, three to four years (degree of Ph.D.).

The engineers' professional organization in Portugal demands a minimum of 5 years scholarship for civil engineers to be responsible for all types of engineering projects. Thus, most civil engineering programs are organized in two integrated cycles (1st and 2nd cycle) leading directly to a M.Sc. degree.

Currently, at the University of Aveiro (UA) such a cycle has a duration of 10 semesters (300 ECTS), where ECTS stands for European Credit Transfer System. The concept of ECTS is based on a mutually agreed assumption that the annual workload of a student represents 60 credits. Student workload is estimated at being a value between 1500 and 1680 hours work per year. The value is based on a presumption that the average student works for 40 weeks per year with an average weekly workload of 40 hours. Thus, each ECTS credit unit represents 25 to 28 hours work. The workload includes, apart from class time, individual study time, preparation of reports, bibliographical research, preparation of examinations, etc. (UA, 2010).

2.2 *Soil Mechanics courses*

There are two Soil Mechanics courses in the Civil Engineering program at UA, Soil Mechanics I and II included in the 3rd year, 1st and 2nd semester, respectively. Therefore, they are included in the 1st cycle (undergraduate).

The aim of the Soil Mechanics I (SMI) course is the understanding of basic concepts and fundamental quantities of Soil Mechanics, so that later, they can be applied in the design of civil engineering structures. The course syllabus is grouped into four main chapters:

1. Physical properties and soil identification. Sedimentary and residual soils;
2. Stress state in soils. Capillarity;
3. Water in soils. Seepage;
4. Compressibility and consolidation of clay soils.

The Soil Mechanics II (SMII) course is focused mainly on the mechanical behaviour of soils (in particular its strength). Concepts, theories and methods generally used for the design of civil engineering structures are presented. Emphasis is placed on situations where the soils' strength conditions the stability. The field tests generally used to characterise the mechanical behaviour of soils are also presented. The course syllabus is grouped into four main chapters:

1. Introduction to shear strength of soils. Shear strength and stress-strain relationships in sands and in clays;
2. Lateral earth pressures; Earth retaining structures;
3. Stability of slopes and embankments;
4. Sampling and in situ tests.

In these courses, the stability analyses are carried out using both global safety factors and the partial safety factors approach from Eurocode 7 (EN 1997-1:2004).

The Soil Mechanics courses correspond to 6 ECTS each and typically have 60-90 students per school year. The weekly timetable of SMI consists in one Theoretical-Practical (TP) lesson with a limited number of students (up to 45), duration of two hours and includes a practical component, and one Practical (P) lesson with the duration of 2 hours and limited to 25 students. In the P lessons, the students use hand calculations to solve problems linked to the each aspect of the syllabus. The weekly timetable of SMII consists of two TP classes. Some type of hand calculations are done in the TP lessons, however, with this format it is more difficult to ensure individual support.

The Soil Mechanics I course is taught in the 1st cycle degree ('Licenciatura') in Civil Engineering Sciences. This course is also offered to the students of the 1st cycle degree 'Licenciatura' in Geological Engineering, in the same semester and year (20 to 25 students). This results in a variety of backgrounds, which conditions the teaching. The Soil Mechanics II course is also mandatory for the Civil Engineering students and optional for part of the Geological Engineering students. Typically there is one student per school year from such a programme.

Before the Soil Mechanics courses, the Civil Engineering students have contact with Geotechnics by attending two courses on geology: General Geology and Engineering Geology.

The cooperative teaching and learning model has been used in a more elaborated form in the SMI course. For the SMII course a 'lighter' version of such model has been adopted as the author has been teaching the course on her own.

2.3 *Cooperative learning model used*

This paper focuses on the use of computing and software in undergraduate Soil Mechanics courses as part of a cooperative learning model. In this section, such a model is briefly described. More details can be found in Pinho-Lopes et al. (2011) and Pinho-Lopes (2012).

The assessment system implemented was defined using suggestions by Felder & Brent (2007) and included two assessment elements: four team projects, developed during the semester, and one test. For the students who failed there was a second chance of passing – final exam, where the team projects' mark was still considered.

The team projects were compulsory for all students. During the semester, students prepared four projects (one for each chapter of the SMI course syllabus) and presented some of them orally to teachers and colleagues. The projects to be orally presented were chosen by the teachers, based on the necessity of clarifying possible confusing aspects revealed during their correction.

The projects were prepared in groups of four students with specific individual functions in each work and mandatory rotations. The four roles performed by each one were: laboratory/informatics technician, analyst, reporter and coordinator. This way, all students performed the four established functions (a different one in each project), representing the corresponding role-jigsaw project system.

The laboratory technician had to carry out laboratory tests to identify and characterise a soil sample (for the first and the fourth projects). The informatics technician had the responsibility to use numerical tools, such as finite element programmes (in the second and third projects). Such numerical tools are freeware versions, with student licenses, of commercial software currently used by engineers when studying geotechnical problems. The elaboration of spreadsheets and the analysis, interpretation and discussion of the results obtained were done by the analyst. The reporter assumed the preparation of the written part of the project, which included a short state of the art and a description of the work of his/her colleagues. Lastly, the coordinator had to organise the group, guaranteeing that all members followed the deadlines and exchanged information. In some school years, this role also included reading a scientific paper in English on the subject and preparing a summary of such information.

These roles had, as much as possible, a parallel to functions normally fulfilled by engineering professionals. Thus, the jigsaw project system was implemented, promoting positive interdependence between students. Areas of expertise were defined, corresponding to the several roles (literature review, theory, experiment, data analysis, etc.). At the beginning of the semester, the students assigned with a particular task were put together in expert groups and each group received specialised training, resources and checklists. Each team member had to make sure that his/her area of expertise was covered in the team project.

To get individual accountability, the test covered all subjects of the course syllabus and the individual mark on the project was obtained by applying a weight to the team project mark to consider the individual performance of the students. This weight was based on the students' self and peer assessment within the group (according to Felder & Brent, 2007).

All the information was available for the students via the e-learning system at the UA, where group areas were created, allowing each group to save and exchange files, e-mails and short messages.

For the SMII course there are usually only two or three team projects and, therefore, the roles are not imposed. The whole team is responsible for all of the work. Individual accountability is also done.

3 USE OF COMPUTING AND SOFTWARE

3.1 *Team projects and functions*

As mentioned before, the team projects were prepared in groups of four students, with specific individual functions in each work and mandatory rotations. The four roles performed by each team member were: laboratory/informatics technician, analyst, reporter and coordinator. Most of the team members had to use computing or software when preparing a specific project.

The reporter prepared a file using a text processor, gathering the information provided by the other team members and with a short state of the art on the subject of the project. The coordinator had to produce a résumé using a text processor of the team organization and of a given scientific paper on the project subject. The analyst had to prepare a spreadsheet from scratch to obtain results using theoretical numerical solutions. The analysis, interpretation and discussion of the results obtained were also a responsibility of the analyst. The role of the fourth group member was either laboratory or informatics technician, depending on the project. When the team project involved carrying out laboratory tests, this team member also had to work the test results, using a spreadsheet. In the case where numerical analysis were to be done, this team member had to use commercial numerical software to carry out such analysis and to help the analyst to compare the results from such tool with the ones obtained using the theoretical numerical solutions.

3.2 *Projects – Soil Mechanics I*

According to Triten (2001), a good structure for cooperative learning assignments has been developed by Michaelsen, as he recommends that all cooperative learning assignments be characterised by "The Three S's":

1) Same problem;
2) Specific choice;
3) Simultaneous report.

This was the approach adopted in the case study described.

Allowing students to analyse different aspects of the same problem, each project includes different perspectives of the corresponding part of the syllabus. Thus, on each project it is necessary to prepare a short state of the art on the subject, to carry out laboratory tests or to perform numerical simulations, to do calculations using theoretical solutions and to compare and criticise the results obtained.

When possible, the same geotechnical problem is used throughout the semester, allowing students to analyse different perspectives of the same problem. In Figure 1, the problem used in the school year 2011/2012 is shown. Particular aspects of this problem were analysed in each project, with the necessary adaptations.

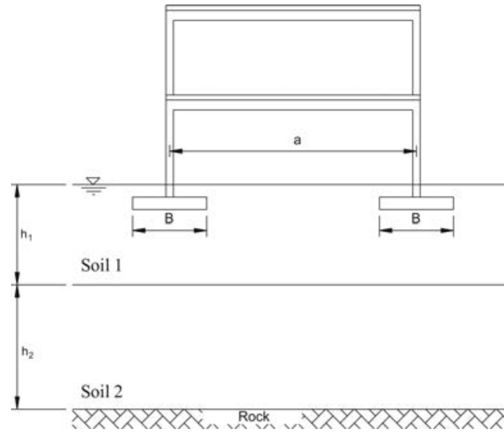

Figure 1. Problem used in the school year 2011/2012 in the Soil Mechanics I course.

For SMI, Project 1 includes carrying out identification and characterisation laboratory tests on soil samples and deriving the main physical properties of, for example, Soils 1 and 2 (Figure 1). The calculations are done using spreadsheets and include relationships between soil properties, in order to students to become more familiarised with them. Those results are also used to classify the soil samples using three different systems (Unified Classification system, AASHTO and LCPC-SETRA). Students have to prepare spreadsheets which, besides the calculation of the main physical properties, include, for example, the implementation of the plasticity chart of the Unified Classification system for soils.

Project 2 includes the determination of the stress state of a soil profile in different stages of construction (for example, in situ and after the construction of a given structure) and the representation of the variation of such stress states with depth and using Mohr circles and stress paths, for specified points within the profile. Different vertical sections are imposed for such calculations. The teams use spreadsheets to implement the theoretical equations for the determination of the stress states, which also involve the application of the equations valid for homogeneous, isotropic and semi-indefinite half-space. The elastic settlements of the soil mass are estimated. Simultaneously a finite element program is used to carry out the same calculations (Figure 2). During the preparation of the assignment the team has to make some engineering judgement, for example in the estimation of the Young modulus and Poisson coefficient of the soils involved. The team options have to be justified and, when necessary the quantities determined in the previous assignment can be adjusted or corrected. A critical analysis of the results and their relative values is expected.

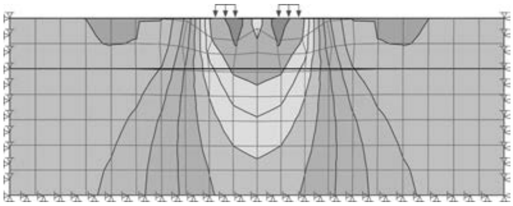

Figure 2. Vertical stress increment distribution obtained by a finite element method analysis.

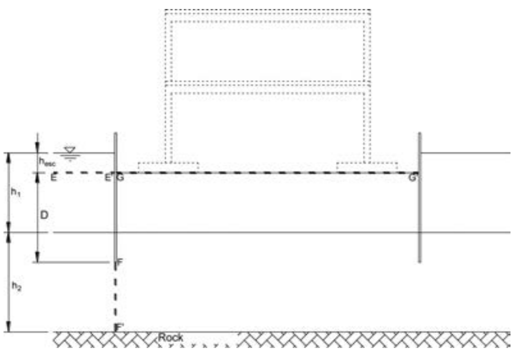

Figure 3. Project 3 base problem.

Project 3 involves seepage in soils. The structure of the project is similar to Project 2, for example, in this case simulating the excavation necessary to build the structure (Figure 3) and the seepage resulting from the pumping inside the excavation. For this project a finite element programme is used to determine the flownet in the soil and the water pressure distribution. The same flownet is also hand-drawn. The students have to use the flownets to determine the pore water pressures in the soil. The safety against hydraulic failure is analysed using the two types of results (from spreadsheets, using the hand-drawn flownet and from the numerical analysis). These results refer to particular imposed sections of the soil mass. A critical comparison and analysis of all the results has to be done. The soil permeability is estimated: for the granular soil, using semi-empirical equations (for example, Hazen equation); for the fine-grained soil the students use tables with indicative values and are invited to choose values, to justify their choice and to carry our parametric analysis, using ranges of values and comparing results.

In Project 4, the consolidation of fine soils is studied. As the oedometer tests are long and the number of test rigs available is limited, typically students use results from previously performed tests, without carrying them on their own. With those results a series of parameters has to be determined (compression index, swelling index, consolidation coefficient, overconsolidation ratio, etc.). The preparation of the spreadsheets includes the analytical and graphical determination, within the spreadsheet, of the mentioned quantities. Later, this information is used to study the consolidation process in a realistic (field) problem, by determining the consolidation settlement, the time necessary to attain a certain average degree of consolidation, the pore pressure distribution with depth in different moments, among others. These calculations are, once again, done using spreadsheets, where maximum automation is desired.

3.3 *Projects – Soil Mechanics II*

As mentioned before, in the Soil Mechanics II course in most school years a 'lighter' version of this system has been used.

Project 1 usually covers the syllabus chapter on the soil shear strength of both sands and clays. Usually the students are confronted with results from triaxial and/or direct shear tests and have to use spreadsheets to derive parameters from them (for example, cohesion and friction angle, peak and critical state values, Skempton parameter A_f, undrained shear strength, etc., depending on the type of soil and on the type of test). For a realistic field problem, the students have to determine the new stress state resulting from the construction works (sometimes including phasing) and to assess whether the stress states in the soil at given locations are permissible. Mohr circles, as well as stress paths, are also used to represent the stress state during the defined construction phases, for specified points within the soil profile. These calculations are done using both spreadsheets (for particular vertical sections) and numerical programs with the finite element method. A critical analysis and comparison of the results has to be done. A sense of the limitations of such tools, as well as their dependence on the quality of the input of the materials' properties is targeted.

Project 2 refers to the calculation of lateral earth pressures and the external stability of a retaining wall. Moreover, the students use spreadsheets to calculate the earth pressures and to the make external design of such walls. Such spreadsheets allow students to carry out simple parametric analysis to assess the influence of chosen parameters on the wall stability. Furthermore, the students are asked to carry out some scenario analysis where, for example, the width of a retaining wall is determined using the prepared spreadsheets in order to simultaneously satisfy all the external stability requirements while at the same time minimising the wall width.

Project 3 refers to slope stability and includes analysis of infinite slopes and of more general slopes. For infinite slopes, the stability is analysed for different scenarios (usually varying the seepage regime established) using both spreadsheets and numerical tools (Figure 4). Results are compared (an example is illustrated in Table 1) and discussed. Engineering judgement is stimulated, for example on the choice of the distance to the boundaries to be used in the numerical analysis. For the more general slopes, a similar stability analysis is carried out, using software and, for some specific failure surfaces, the same analysis is done using spreadsheets. The use of computer-aided design (CAD) is encouraged. This project includes

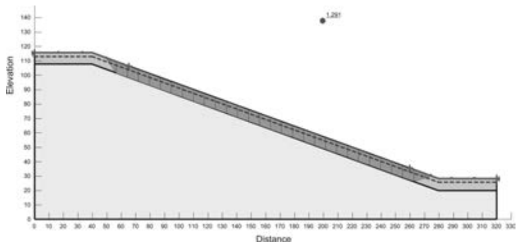

Figure 4. Slope stability result for an infinite slope with seepage parallel to the surface – students' solution.

Table 1. Summary of global factors determined for an infinite slope using spreadsheet and a numerical tool – students' solution.

Water level	Spreadsheet	Numerical tool
At soil surface	1.80	1.85
Parallel to soil surface	1.29	1.29
Very deep	1.04	0.99

using circular arc analysis. In the software the normal method of slices and methods of Bishop, Janbu and Morgenstern-Price are used and the results obtained are compared.

In some cases, Projects 2 and 3 are merged, where the stability of a slope which includes the analysed retaining wall is done as part of verifying its external stability.

3.4 *Progressive implementation*

This system has been implemented progressively. In fact, when the author started teaching these courses, limited material was available and the classes were quite small. When teaching the basic soil mechanics courses, besides presenting simple examples the author felt the need to confront students with realistic problems. The use of computing and software was the next natural step in order to allow working on field problems, to develop critical thinking and to increase the awareness of software limitations.

Thus, on first approach the use of spreadsheets was implemented. The students reaction was quite good, many of them stating that they finally had to learn how to use them.

Later, the use of typical numerical tools currently used in Geotechnics was implemented. To stimulate students and to allow them to work on their own, it was decided to use freeware versions, with student licenses, of commercial software currently used by engineers when studying geotechnical problems. Usually such software is in English which, for Portuguese students, can be an additional obstacle. Nevertheless it obliges the students to learn English technical language, which is a good and useful professional skill.

The students' reaction is distinct. While some of them are quite frightened by the need of using such software (particularly in English), others are quite enthusiastic about it. In some cases the fear is rapidly overcome by implementing classes where the students receive specialised training, resources and checklists. Video tutorials available at the software companies can also be quite useful.

The students are encouraged to use the spreadsheets they prepared and the software to derive solutions for the problems proposed in classes. In fact, when comparing the results obtained in the numerical analysis with the ones from textbooks or even with the problems solved in classes, students become more interested and involved in using computing and software and aware of its advantages, even during the time they spend at university.

The last addition to the teaching method was the laboratory testing, which in many institutions is the starting point. The Civil Engineering department in UA is quite a recent development (15 years old) and only after the laboratory had been adequately established and when Ph.D. students or laboratory technicians were available could this be implemented. The ideal situation would be that all the students would go to the laboratory and use all of the different software, however this could be difficult given existing conditions.

3.5 *Further details of project work*

It is important to note that, for both SMI and SMII, the projects were broadly the same for each team but with some significant differences.

Firstly, the soil samples tested were different. These samples were gathered, and sometimes manipulated in the laboratory, to ensure that all teams would analyse samples of a granular and of a fine-grained soil. Therefore, the amount of work and degree of difficulty of each team's problem was the same.

The use of different soil samples led to different geological profiles for each team and different decisions to be taken. In later projects, though the base problem was the same, different values for distances, soil properties and loads were also used, creating individualised situations.

Up to this point of their curricula the students have not encountered the finite element method. Sometimes this is a real obstacle for the use of software with such method. A simplistic explanation of such method was done, for example in order to allow the students to understand the need of manipulating the mesh, refining certain areas.

Comparing the results obtained from spreadsheets and from 'blackbox' software was quite useful in order to call students' attention some problems arising from the use of computing and software.

4 STUDENTS' REACTIONS

4.1 *Assessment of the system*

During the first application of the cooperative learning system in 2007/2008 and in the Soil Mechanics I course, the teachers felt the need to evaluate its success and impact on students' learning. In later years where the cooperative learning system has been used, a similar evaluation has been made.

Therefore, different and complementary strategies were used, namely: students' feedback during the semester; marks monitoring; and questionnaires at the end of the semester. These results are presented and discussed by Pinho-Lopes et al. (2011) and Pinho-Lopes (2012). The impact of computing and software has not been assessed separately. Nevertheless some of the students' opinions can be included here.

During the semester, the students were asked to give an informal opinion on the implemented evaluation system (orally and written, anonymously).

To better understand the efficacy of the implemented model, a statistical analysis of the number of students enrolled, which attended, evaluated and obtaining passing mark was done. The marks of the four team projects were analysed and some possible explanations for the results were put forward (Pinho-Lopes et al., 2011).

Questionnaires were prepared and were divided into two large blocks of questions: (1) course organisation and implementation; (2) functioning of the teams during the projects. For most of the questions, a five-point Likert scale was used.

4.2 *Results from the assessment*

From the students' feedback, the major difficulty associated with the use of computing and software was using and understanding the software. In fact, as mentioned before, for some of the students the language was a real problem. For others, with less aptitude for the use of computing, the necessity of using both computing and software was quite a challenge. In some cases, these difficulties were not completely overcome.

The specialised training on such issues helped. Students with the same role in a specific project got together to work out how to use the numerical tools and how to overcome the difficulties felt. A true specialists' team was formed.

The impact of the use of computing and software on the marks is not clear. In fact, the marks' monitoring revealed a very significant drop of the marks from the first project to the second one (for SMI). Another important difference was the marks obtained in Project 4. Some reasons can be pointed out to explain these differences, namely (Pinho-Lopes et al., 2011):

- The experimental nature of Project 1;
- More time available for preparing Projects 1 and 2 (due to less workload from other courses);
- Difficulties in using software packages for Projects 2 to 4;
- Need for more theoretical knowledge for the last projects;
- Fewer resistance from the students to the cooperative learning model in 2nd year of application (2008/2009);
- Increase of students' conflicts within some groups, hindering their performance. It should be noted that in some groups the opposite occurred – as the semester advanced the relational difficulties decreased.

The students that answered the questionnaire considered, almost unanimously, that the implemented learning model also led to the development of skills and knowledge other than the formal course content. There were questions meant to find out the students' difficulties during the elaboration of the projects and in fulfilling the different roles. Some questions were also introduced about the projects added value to the students' preparation for future engineering work. It was somehow consensual among students that this model has advantages in their preparation for 'real life' and for their future role as civil engineers.

4.3 *Impact of the teaching experience*

The impact of this teaching experience on the learning outcomes of the students can be quite varied. The author's experience and views are summarised.

The group projects improve the overall learning outcomes of fundamentals for most students. However, their magnitude depends on the students and on their attitude towards their degree. They practice concepts using different approaches and perspectives and some also use their own spreadsheets to check the solutions of the given problems. In some extreme cases, students tend to compartmentalise knowledge. Weaker students, who just want to do the minimum to pass, limit themselves to carrying out their own task in the project. In those cases, it is clear from the examinations in which project they coordinated the team.

Some students try to pass around spreadsheets. They ask for information particularly from colleagues from previous years. This cannot be avoided and students that do that are the most affected by such procedure. Their learning is compromised and they will not be as prepared as their colleagues. In some cases, the students confided in the author that they tried that as a first approach. However, to understand their colleagues work, to adapt the spreadsheet to the problem under study and to correct the mistakes they find is more difficult and time consuming than creating their own spreadsheet, thus most of them have abandoned such approach.

This teaching experience is also very demanding on the teacher. In fact, it caused a significant extra workload for the lecturers, which is difficult to quantify, as an accurate assessment of the impact of the method implemented on the workload of the lecturers was not done.

5 CONCLUSIONS

In this paper, a case study of the use of computing and software in two Soil Mechanics courses was described, which included a generalised use of spreadsheets, text processor and numerical programs, for example with the finite element method.

The use of such learning strategies was found to be adequate and led to enhancing students' learning, as well as acquisition of soft skills, necessary for any civil engineer professional.

The validation of numerical results through the application of theoretical solutions for the problems as well as the estimation of values for certain quantities was achieved. The development of critical thinking was targeted.

The author observed that some students tend to compartmentalise knowledge. In fact, for some students it is easily identifiable by the lecturer in which project these students coordinated the team. Thus, it is essential that all students participate in the practical lessons, where they use hand calculations to solve problems linked to the each aspect of the syllabus, so that they work on all aspects of the course. In the case study presented, for SMI this is relatively simple as it can be done in P lessons. For SMII, all the course lessons are TP, which creates an additional difficulty. Nevertheless, the lighter version of the learning model implemented enables partially overcoming such problem. As there are no established functions and the group has to organize its own work, some groups tend to solve all parts of the projects together, as a team, without dividing the work in several tasks.

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Learning issues related to basic concepts in geotechnics: A teacher's perspective

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ABSTRACT: Curricula were restructured in Croatia according to the Bologna process and implemented in 2005. The Faculty of Civil Engineering of the University of Zagreb has adopted a 3 + 2 system. Geotechnical courses are taught at both cycles, and the second cycle includes a two-year specialisation in geotechnical engineering. According to the experience gathered with four generations of graduate students in geotechnical engineering, it seems that students have difficulties with grasping basic geotechnical concepts. Simple numerical simulations are included in two courses with the intent to help students understand basic concepts and to prepare them for more complex numerical modelling. However, it seems that this objective has not been achieved. Possible reasons for this are presented in the paper from the teacher's perspective. Remedial measures are not easy to undertake, but they are necessary.

1 INTRODUCTION

In the fall semester of 2005, students enrolled at the first year of studies at Faculty of Civil Engineering of University of Zagreb according to the new undergraduate curriculum developed in line with the Bologna Declaration. The three-year undergraduate programme is common for all civil engineering students. It includes a course in Soil Mechanics. Graduate studies, also in line with the Bologna Declaration, are two years long, and students can choose between 7 offered specialisations, among which is the specialisation in geotechnical engineering (Szavits-Nossan 2008). The fourth generation of students is attending the first year of this specialisation.

Having gathered teaching experience with the new curricula, some observations can be made. As learning outcomes were defined at each cycle exit level, it was intended that first cycle graduates should be ready for employment, with some theoretical and some practical knowledge. Nevertheless, about 90% of first cycle graduates continue their education at the graduate level, and it can be observed that their knowledge of topics covered at the undergraduate level is poor. It mostly relates to theoretical background, which is, in any case, essential for practical purposes.

Geotechnical topics covered during the first cycle include soil formation, phase relationships, soil classification, principle of effective stress, seepage, consolidation, shear strength, drained and undrained conditions, essentials of Eurocode 7, retaining walls, shallow foundations, slope stability, and field investigations. There are three class hours of lectures and two class hours of exercises per week, within a semester consisting of 15 weeks. With this list of topics, basic soil mechanics principles escape students, who attend graduate geotechnical courses without understanding them. Namely, they have problems with seepage, stress and strain analysis, consolidation, and drained and undrained conditions. The aim of this paper is to illustrate an attempt to use simple numerical simulations in two graduate geotechnical courses to clarify basic soil mechanics concepts, and to prepare students for the more demanding subsequent course in numerical modelling. The author's experience with four generations of graduate students who attended these courses is presented and discussed. The results of this attempt are not satisfactory. Several aspects of this problem are discussed. On the one hand, new curricula brought about new problems in civil engineering education, and quality assurance measures are not fully implemented. On the other hand, students' attitudes towards learning, inherited from the previous system, and still pervasive, they mainly focus at just passing a course.

Although it might not altogether be an easy problem to solve, in view of the author, only an in-depth restructuring of new curricula, and revision of learning outcomes can improve the situation. The undergraduate Soil Mechanics course should provide students with fewer topics, enforce basic concepts, and ensure continuous student assessment during semester. In order to do this, major changes should be undertaken, which include the full implementation of quality assurance measures.

2 NEW CURRICULA AND QUALITY ASSURANCE

2.1 *New curricula and problems involved*

In 2003, the Croatian Parliament accepted the new Law on Research and Higher Education, according to which all institutions of higher education had to restructure their curricula following the Bologna process, and start with new programmes in the fall of 2005. Most technical faculties in Croatia introduced a $3+2$ system, where the first cycle graduates are awarded a Bachelor degree and the second cycle ones a Master degree. In the short period of two years left for creating new curricula, courses were mostly shuffled between different semesters. At the Faculty of Civil Engineering of the University of Zagreb, European Credit Transfer System (ECTS) points were allocated according to the weekly teaching load of lectures and exercises, and no assessment of the real student load per course was made.

The main problem with new curricula at the Faculty of Civil Engineering in Zagreb is that shuffling of courses, as well as undergraduate learning outcomes had drawbacks. Some basic courses were transferred to the graduate level, and some practical courses to the undergraduate level, with few changes in topics covered. Courses, such as Soil Mechanics, had to include topics relevant for employing Bachelors who would know how to design simple structures. This resulted in unbalanced curricula with unspecified learning outcomes for each course. At this point it seems that an in-depth revision of curricula is necessary, in line with good experiences in other European universities.

A comprehensive study of the design of civil engineering curricula at University College Dublin (UCD), for both cycles of a 3+2 Bologna-oriented programme, with the emphasis on the second cycle curriculum, was presented by Gavin (2010). In order to implement outcome-based education, the Master of Engineering (ME) curriculum at UCD consists of a series of core civil engineering design courses and a design project, a research oriented project, discipline specific elective courses, and non-discipline elective courses. Students also take courses in communication skills and ethical standards. The described curricula overcome the shortfall in important skills developed among university students. These skills include communication, decision-making, problem-solving, leadership, emotional intelligence and social ethics (Nair et al., 2009), required by industry. This is not the case with civil engineering curricula in Croatia, especially not at the graduate level, where specialisations seem to be too narrow, and students should be offered more elective courses to adapt to their different preferences. Besides, important skills such as the ones listed by Nair et al. (2009) are not being developed during the studies.

2.2 *Quality assurance and problems involved*

The European Association for Quality Assurance in Higher Education published Standards and Guidelines (ESG) for Quality Assurance in the European Higher Education Area. Among standards and guidelines are those for internal quality assurance within higher education institutions which should commit themselves explicitly to the development of a culture which recognises the importance of quality, and quality assurance, in their work (ENQA, 2009). At University of Zagreb, some quality assurance measures took place with introducing new curricula in 2005. It has, however, taken 6 years for the university to develop the policy and procedures for quality assurance, and these are yet to be developed at faculties. It remains to be seen how long it will take for implementing these procedures at faculties. As opposed to good practice in many European countries, the culture of quality assurance in Croatia is more formal than exercised.

For example, student feedback is an integral part of the continuous quality enhancement (Nair et al., 2011). Nair et al. (2011) comment that student surveys may not be effective without commitment of the university, faculty management and academic staff to act on the information provided by students in questionnaires. Another important aspect is that students must be informed of (and must also see the evidence of) such action, otherwise they would become cynical and not participate in future surveys. Monash University in Australia, taken as the case university in Nair et al. (2011), makes all evaluation reports public on their website.

Contrary to this positive practice and recommendations, student surveys at Faculty of Civil Engineering in Zagreb, at first accepted enthusiastically by students, proved not to be productive. The main reason for this is that survey results, except for statistics at the level of the whole institution, have been kept under the lid, so students have no information at all on their evaluations of teachers. They are, thus, less and less motivated to fill out the questionnaires. Another problem is that university and faculty managements do not take any productive steps toward poorly graded teachers, even though, formally, student survey results should affect their promotion.

Student surveys are also conducted after the end of each of the two cycles of studies. In these surveys students are asked questions on their satisfaction with different aspects of the study organisation and efficiency, ECTS points, faculty management, administration, library and computing facilities. Even though the results of these surveys, at least at the Faculty of Civil Engineering, show that major improvements of the system should be undertaken, not much has been done about students' opinions.

Besides the need to fully implement ESG measures, Agrawal & Khan (2008) report that to improve the quality of education, teachers are challenged to shift their focus from what they teach to what their students learn. Learning is addressed in the next Section.

3 LEARNING AND STUDENT ATTITUDES

Present theories of learning are founded on the premise of constructivism. Learning theories based on constructivism assume that learning is a cognitive process, a result of mental effort and activity. The constructivist approach to teaching encourages students to use critical thinking skills and to understand the causes and effects of ideas and action (Kolari et al., 2008). Kolari et al. (2008) state the definitions of two approaches to learning by Ramsden (1992). A deep-level approach to learning includes a meaningful construction of knowledge, understanding by focusing on what is significant, relating previous knowledge to new information, and organising content to get a holistic view of a subject. In the surface-level approach, the attention is on memorising facts and data, and reproducing them later apart from context, without relating them to anything, and without necessarily understanding. Ramsden (1992) considers that the choice of learning approach is both student-related and influenced by the learning environment. Discussing why the learning environment might not be designed so that students are motivated to assume a deep approach to learning, and devote more time and effort to out-of-class studying, Kolari et al. (2008) provide possible explanations: unrealistic curricula, course structures and workloads, information transmission as a teaching orientation, lack of commitment from both teachers and students, and an incorrect understanding of academic freedom. Some of these issues were addressed in the previous Section.

This Section focuses on attitudes of students at the Faculty of Civil Engineering in Zagreb, from the point of view of the author. According to results of assignments, tests and examinations administered by the author, and according to experience of other teachers, only about 10% top students make the effort to follow lectures thoroughly, to understand the principles and to apply them in exercises. They think and link what they have learned in different courses, thus applying the deep approach to learning. All others try to figure out what is essential to pass the course, and concentrate on reproducing results that are expected to get a passing grade. With a lack of written rules, they rely on the previous student generation rendition on requirements to pass the course. For example, students are used to the assumption that a soil is homogeneous and isotropic, when deriving a soil mechanics theory. If, however, they are asked to define a homogeneous and isotropic soil, they mostly fail to provide the correct answer. This particular majority student attitude might not be specific of Croatia, but it does have its roots deeply embedded in the whole Croatian educational system, starting from elementary school. Children are not encouraged to think and discuss in school, but rather to memorise class topics. Furthermore, students rely on the ‘solidarity’ of top students in sharing. Those who refuse to share, not only for assignments but also during written tests and examinations, are considered outcasts. It is not easy to deal with this approach to studying.

4 COMPUTER-AIDED LEARNING

Limniou & Smith (2010) report on an investigation conducted to get an insight into how teachers and students responded to the use of computer aided learning in engineering education and what their expectations were from online courses. It was more demanding for teachers than students to take part in this investigation. Students are accustomed to frequent communication through online discussion boards and they welcomed the participation of teachers in the quick individual feedback through emails. They appreciated more the use of websites for teaching than teachers did, but they still consider printed course material as relevant. Students also want to have all important information on a course on the website, but, interestingly, only 56% of them like online learning modules, as opposed to 75% of teachers. Rothberg et al. (2006) had reached similar conclusions from an extensive case study on computer aided learning in engineering. Students do like the use of computers in class. They want animations, simulations, images and videos, but they still want notes to take away. Thus, a blended approach of traditional teaching methods and new technology benefits proves to be the best for students and teachers.

For geotechnical education, Jaksa et al. (2000) provide an extensive list of stand-alone PC programs, such as CATIGE for Windows or SLOPE/W (student version), web-based resources, such as a collection of civil engineering projects in the Hong Kong region or geotechnical courseware, and CD-ROM resources with written materials, videos and photographs. This diversity of computer materials is helpful to attract student attention.

In this paper the emphasis is on the use of commercial computer software in two graduate geotechnical courses for simulating simple geotechnical problems to help students understand basic soil mechanics principles. Since the same software is used in the following semester for the course Numerical Modelling in Geotechnical Engineering, where complex geotechnical problems are solved, this is also a good introduction to this software.

A prerequisite for numerical modelling in geotechnical engineering is a good knowledge of soil mechanics and constitutive relationships. Additional prerequisites are the knowledge of the finite element method and meshing (if used), and of the strength of materials. Reese & Isenhower (2000) and Mesat & Riou (2000) comment on these issues. The first prerequisite was supposed to be covered by introducing simple numerical simulations in graduate courses Soil Mechanics II and Flow Processes in Soils and Rocks. Three modules of the software GeoStudio (full licence) are used. Module SIGMA/W is used for stress-strain analyses, SEEP/W for steady state and transient seepage problems, and SLOPE/W for slope stability analyses. The first two modules use the finite element method, and the third module uses the method of limit equilibrium. Experience from introducing these numerical simulations is presented in the next Section.

5 NUMERICAL SIMULATIONS

Whenever you use new computer software and look at the manual, there is a suggestion to start from simple problems. This especially holds true for geotechnical software, because water in soil makes effective stresses responsible for deformations. According to this suggestion, simple geotechnical problems are first solved to illustrate the principle of effective stress, steady state seepage through soil, undrained and drained conditions in triaxial testing, shear strength, dilatancy and soil consolidation. The complexity of problems increases during the semester, so flow of water through unsaturated soil and slope stability analysis above the phreatic surface are also covered.

Figures in this Section show these simple numerical simulations. However, simple problems may not always lead to straightforward understanding of physics behind numerical modelling. After students master the elementary commands of the software, which is user-friendly, their performance in class is less than satisfactory. All examples shown here are such that students can make their own hand calculations prior to numerical simulations. This is where they show that they mostly cannot provide correct results.

Figure 1 shows a soil model with the finite element mesh and the boundary conditions, prepared for the steady state seepage analysis with SEEP/W. At the upper boundary of the model the total head is 4 m, and at the lower boundary it is 1 m. Students are also shown that the same result can be obtained if boundary conditions are given by pressure heads. This exercise is also intended to explain the principle of effective stress, so the resulting total heads in all nodes are taken as initial conditions for the corresponding model in SIGMA/W (Figure 2). The straightforward distribution of total stress through the model is presented in Figure 3. Diagrams of the form such as the one in Figure 3 can be obtained for all relevant variables.

In this case the problem arises when students are asked to calculate total and effective stresses at the lower boundary of the model, before showing them computational results. They either forget the water on top of the soil for total stress, or miscalculate the pore water pressure at its bottom. The same occurs with other similar examples, even after they are shown the diagram in Figure 3.

The next example (Figure 4) shows the model for steady state seepage through layered soil. Boundary conditions are the same as in Figure 1. This example can serve to illustrate deriving the equivalent coefficient of permeability for a homogeneous soil of the same total height. Distributions of hydraulic gradients and Darcy velocities through the model, and fluxes through layers can be shown to students. Figure 5 shows lines of equal pressure heads and their uneven distribution, and the diagram of pore water pressure through the model is presented in Figure 6. Both these figures surprise students.

Simulations of triaxial tests are first made with the linear-elastic constitutive model. The effects of drained and undrained loading are explained by Mohr circles and stress paths, and Skempton parameters A and B are introduced. Even though students recognise that $B = 1$ corresponds to a fully saturated soil, and they can envisage the spring analogy for consolidation process when the piston is closed, they are not

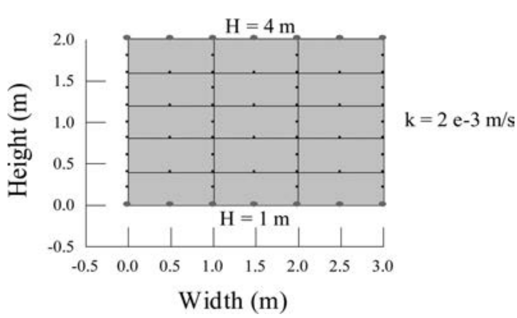

Figure 1. Model and boundary conditions for steady state seepage.

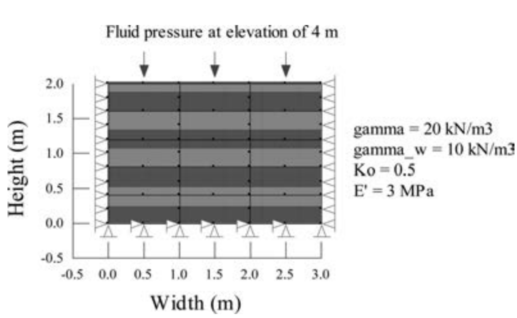

Figure 2. Model and boundary conditions for calculating total and effective stresses.

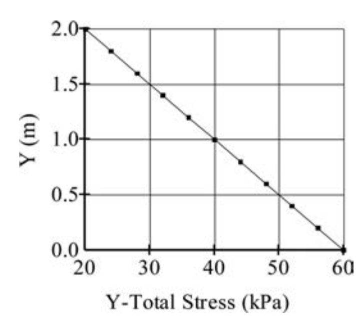

Figure 3. Vertical total stress through the model.

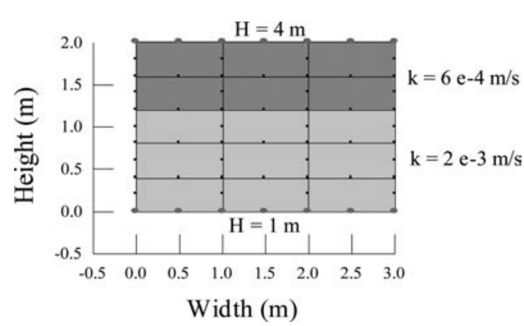

Figure 4. Model for steady state seepage through layered soil.

aware of all effects of triaxial undrained loading. Once they accept that undrained conditions correspond to no volume change, the change of pore water pressure and the corresponding change of effective stress in undrained shear appears to them as contradictory to the principle of effective stress. Figure 7 shows the soil model for triaxial undrained isotropic compression and Figure 8 shows the corresponding increase in pore water pressure. The excess pore water pressure is then allowed to dissipate, and total stresses from isotropic compression are taken as initial conditions for triaxial undrained shear (Figures 9 and 10).

The elastic-plastic constitutive model for triaxial simulations is introduced to illustrate the Mohr-Coulomb strength criterion and dilatancy. Figure 11 shows the soil model for the simulation of a displacement-controlled drained triaxial test, where total stresses from the previous isotropic compression are taken as initial conditions. A vertical displacement

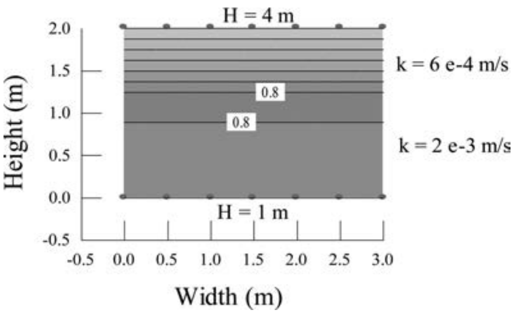

Figure 5. Lines of equal pressure heads (m).

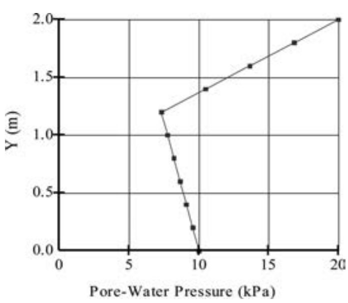

Figure 6. Pore water pressure through the model.

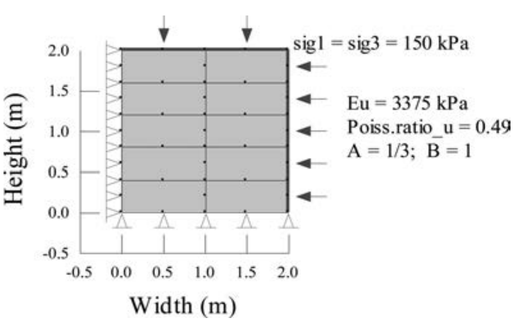

Figure 7. Simulation of triaxial undrained isotropic compression test.

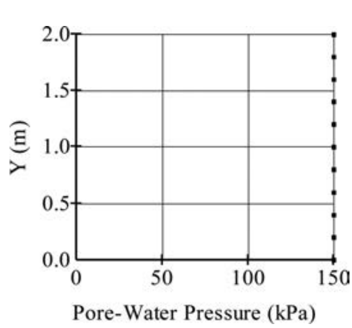

Figure 8. Excess pore water pressure through the model after isotropic compression.

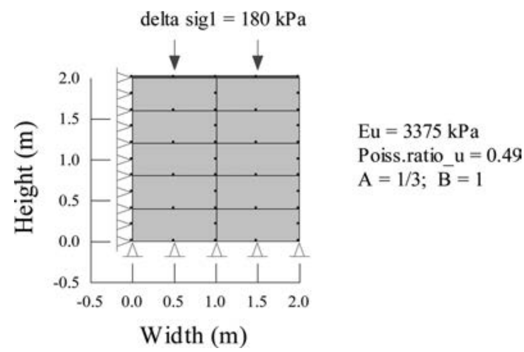

Figure 9. Simulation of triaxial undrained shear test.

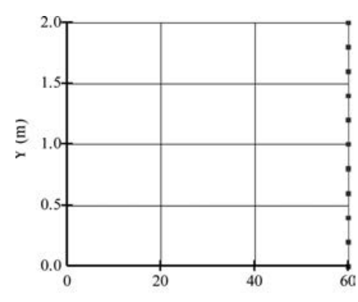

Figure 10. Excess pore water pressure through the model after shear.

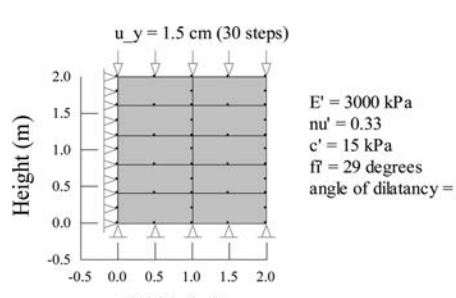

Figure 11. Model and boundary conditions for deformation-controlled drained triaxial test.

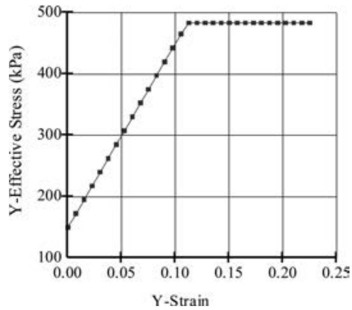

Figure 12. Elastic-plastic stress–strain relationship.

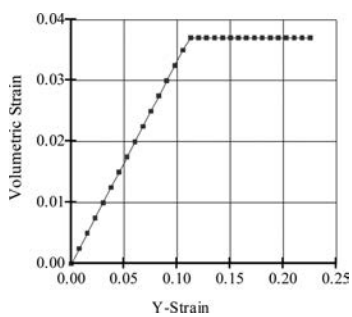

Figure 13. Volumetric strain (angle of dilatancy is zero).

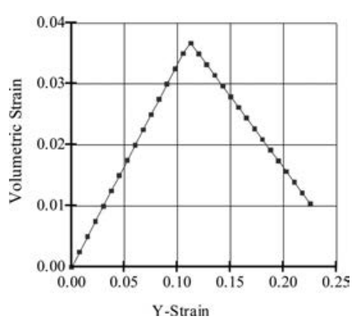

Figure 14. Volumetric strain (angle of dilatancy is 6°).

of 1.5 cm is imposed in 30 increments. The resulting elastic-plastic effective stress – strain relationship is shown in Figure 12. In this example, the angle of dilatancy is zero. Volumetric strains (Figure 13) show elastic and plastic behaviour. They are constant in the plastic zone. The same example is repeated with the angle of dilatancy of 6°. Volumetric strains (Figure 14) now decrease in the plastic zone, whereas the effective stress – strain relationship is the same as the one in Figure 12.

In this instance, it seems difficult for students to grasp plastic soil behaviour. The Mohr-Coulomb failure criterion, when looked at superficially, makes most students perceive the soil crumbles immediately after reaching the shear strength. When dilatancy is included, it is, thus, more difficult for them to foresee what is occurring within the soil.

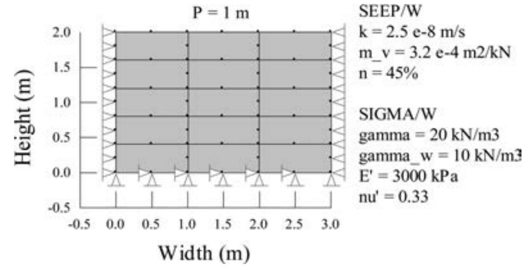

Figure 15. Model and boundary conditions for consolidation after lowering of water table (final state).

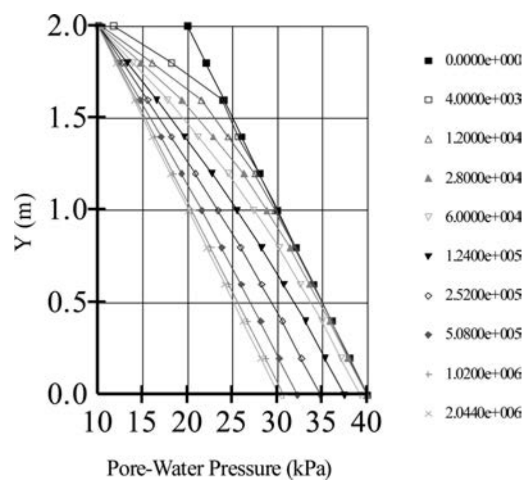

Figure 16. Isochrones through the model (time is in seconds).

The last example deals with consolidation. Even at the undergraduate level students have problems with understanding the relationship between loading a fully saturated fine-grained soil, the gradual transmission of excess pore water pressures to effective stresses and the consequent soil deformations. When they reach the graduate level, and should start thinking about what is happening in different situations involving the consolidation process, it becomes apparent the process itself is not clear to them.

A clay model is used for simulating consolidation. It is assumed that on top of the clay layer there is a layer of sand, 2 m thick, and the water table is originally on the surface of sand. The water table is then lowered in sand by 1 m. Initial conditions for this model are calculated first, with water table 2 m above the model surface, resulting in consequent stresses and pore water pressures. For the final condition, pressure head of 1 m is specified at the model top boundary (Figure 15). This problem requires the use of both SEEP/W and SIGMA/W modules for one-dimensional coupled consolidation.

Isochrones resulting from this analysis are shown in Figure 16. When given this example, only a few

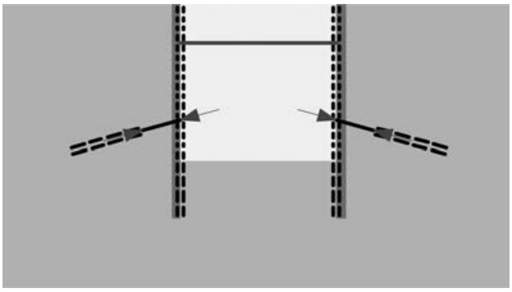

Figure 17. Example of an excavation with the diaphragm wall, strut and anchors.

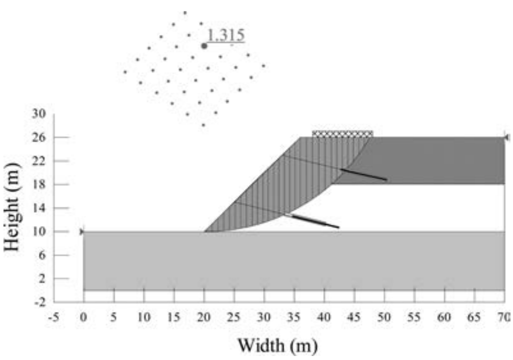

Figure 18. Example of stability analysis of a slope reinforced by anchors.

students reached the presented results. It is interesting to note that students were asked to draw by hand diagrams of the initial and final vertical effective stress distributions through the model, before computations, to help them understand the increase in effective stresses due to lowering of water table. Only those few students who performed correct computations provided the two diagrams.

Following courses in Soil Mechanics II, and Flow Processes in Soils and Rock, there is a graduate course in numerical modelling of more complex geotechnical problems to prepare students for solving these problems by computers when they are in practice. The emphasis in this course is on the true meaning of engineering judgement necessary to select input parameters and to review computation results with understanding. Some examples of problems solved during this course are presented in Figures 17 and 18. However, students are not ready to apply engineering judgement based on their previous knowledge, because their acquired knowledge is mostly poor.

6 CONCLUSIONS

Introducing new curricula according to the Bologna process and of quality assurance measures in Croatia has not brought about satisfactory results. In the opinion of the author, the reasons for this at the Faculty of Civil Engineering in Zagreb are: new curricula are unbalanced, which is especially important at the undergraduate level; courses, such as Soil Mechanics, are overloaded and not thought through; core civil engineering courses are not accompanied by those required by industry, such as courses in communication skills and ethical standards; graduate specialisations are too narrow, and they include compulsory courses which would much better be suited as electives; quality assurance measures are not fully implemented; most students have a surface-level approach to learning.

To illustrate unsatisfactory results of curricula at the Faculty of Civil Engineering, examples of simple numerical simulations are described in the paper. These simulations were intended to help students understand basic soil mechanics principles, and to prepare them for the more demanding course in numerical modelling. It was thought that new generations of students would positively respond to computer aided learning. However, most students show in class results which are not satisfactory, and the underlying principles still escape them. As stated above, it is not their fault alone.

This situation requires remedial measures. It is, however, easier to state the problem than it is to solve it. All issues listed above should be properly addressed by faculty and university managements. From the two-year experience in restructuring old curricula, it seems that the major issue is how to restructure new ones to have satisfactory courses with reasonable learning outcomes in line with the needs of the profession.

Finally, graduate students who mostly have not mastered topics covered in their undergraduate study are not ready to accept what is offered at the graduate level. This should be a warning sign for changes that need to be made to educate Masters of Civil Engineering who are well prepared for all the challenges of their future employment.

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Geo-engineering research and teaching experiences

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The LARAM School: teaching "LAndslide Risk Assessment and Mitigation" to PhD students

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ABSTRACT: The paper deals with the ongoing 6-year long experience (2006–2011) of the International School on "LAndslide Risk Assessment and Mitigation" (LARAM), which was founded by the University of Salerno (Italy) on April, 12th 2005 with the aim of offering a systematic and continuous forum among young researchers and renowned experts in the field of landslide risk. The main focus of LARAM has been a yearly residential Doctoral School, held in Italy and more recently in China, for PhD students working in the field of civil engineering, environmental engineering, engineering geology or related fields.

1 INTRODUCTION

Landslides are among the most destructive natural hazards, causing every year significant economic losses and casualties all over the world, as shown by the map of avalanches/landslides disasters (Figure 1) derived from the OFDA/CRED Disaster Database (EM-DAT).

This worldwide problem is regularly addressed by the scientific and technical community by means of a large number of regional and international initiatives (e.g., Symposia, Conferences, Projects) in which high level researchers and professionals exchange their experiences on many issues related to landslides. However, typical teaching programmes on this topic for young researchers (Table 1) are not as common and, when they are offered, they mostly occur as project-based short-term initiatives within projects (e.g., SAFELAND, MOUNTAIN RISKS, CHANGES) or thematic research networks and centres (e.g., ALERT, CISM). Furthermore, considering that these initiatives are essentially monodisciplinary, they are mostly aimed at participants coming from a specific field of expertise, and they do not offer a systematic and continuous forum on landslide risk to which young researchers can usefully refer.

The International School on "LAndslide Risk Assessment and Mitigation" (LARAM), founded by the University of Salerno on 12 April 2005, was envisioned to overcome the above limitations by offering a permanent venue for students having different backgrounds, young researchers and renowned experts to interact and exchange ideas in the field of landslide risk. The main objectives of LARAM are: to develop high educational interdisciplinary programs for assessing, forecasting and mitigating landslide risk over large areas; to promote the creation of vocational training programs "on the job" aimed at solving real landslide risk problems using the most advanced theories and methodologies in the fields of geotechnical engineering, geomechanics, geology, mathematical modelling, monitoring, GIS techniques, etc. These aims are achieved by means of yearly cycles of lectures, seminars, workshops and conferences.

Figure 1. Number of Avalanches/Landslides disasters by Country 1974–2003 (modified from http://www.emdat.be/maps-disaster-types.

Table 1. Typical features of educational initiatives for young researchers on landslides.

	Offer	Duration	Recurrent	Reach	Disciplines
Project	W, S	1–2 days	no	nat/int	mono/multi
Network	W, S, C	1–3 days	no	int	mono
Centre	S, C	3–5 days	no	nat/int	mono
University	S, C	3–6 months	yes	nat	mono
LARAM	C	1–2 weeks	yes	int	multi

W = Workshop, S = Seminar, C = Course
nat = National, int = International
mono = monodisciplinary, multi = multidisciplinary

2 TEACHING LANDSLIDE RISK

The most general formula which can be used to identify the risk associated to a natural phenomenon, R_t, was proposed by Varnes (1984):

$$R_t = ER_s = EHV \qquad (1)$$

where: R_t (Total risk) is defined as the expected number of lives lost, persons injured, damage to property, or disruption of economic activity due to a particular natural phenomenon; E (Elements at risk) means the population, properties, economic activities in a given area; R_s (Specific risk) is the expected degree of loss due to a particular natural phenomenon; H (Natural hazard) means the probability of occurrence within a specified period of time and within a given area of a potentially damaging phenomenon; V (Vulnerability) means the degree of loss to a given element or set of elements at risk resulting from the occurrence of a natural phenomenon of a given magnitude.

Despite the apparently simple formulation, this definition of risk has proved to be very useful and efficient since it clearly identifies the three components of the risk related to landslides. Of course, the adequate application of this formula requires at the same time the capacity to have a global perspective of the problem and several specific expertises in different fields, which range from geology to civil engineering, from social sciences to economics, among others. To this aim, it is necessary to have a clear procedure to follow in which both the aims and the most adequate methods to adopt are specified.

Once risk is estimated, further steps are necessary as the computed risk must be evaluated and, when necessary, risk mitigation options must be put in place. Recently, a comprehensive framework for landslide risk management has been proposed by Fell et al. (2005). The Authors define a process comprising three sequential and interrelated phases: risk analysis, risk assessment and risk management (Fig. 2). Within this framework, risk assessment takes the output from risk analysis and assesses these against judgements and risk acceptance criteria. The output from the assessment is then used to develop risk mitigation options, including accepting the risk, reducing the hazard or reducing the consequences. This last phase necessarily involves a number of different stakeholders including owners, residents, the affected public, regulatory authorities, geotechnical professionals and risk analysts.

It is clear that the global efficacy of the obtained results is strictly related to the effectiveness of each step and, above all, to the reliability of landslide risk analysis and zoning. This aspect is well addressed within the recent "Guidelines for landslide susceptibility, hazard and risk zoning for land use planning" (Fell et al. 2008). For instance, the purpose of the study (e.g. information, advisory, statutory, design) determines both the scale of the analysis (e.g. regional, local, site-specific) and the methods to be used for susceptibility, hazard and risk analysis and zoning.

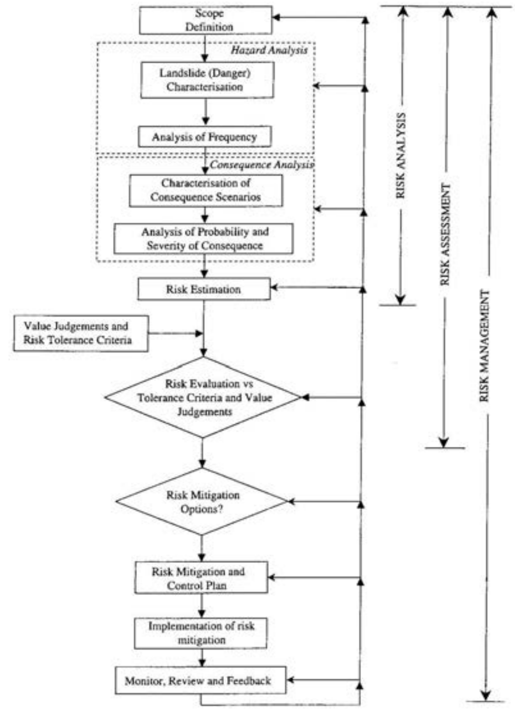

Figure 2. Flow chart for landslide risk management (from Fell et al. 2005).

On the basis of the previous considerations, it can be concluded that teaching the landslide formula, the landslide management framework and the methods for landslide zoning are not challenging tasks, in principle. However, it is not straightforward to find a small number of lecturers who are experts on so many wide-ranging technical areas. To overcome this difficulty and to effectively teach the concepts related to landslide risk, the LARAM School involved, since its beginning, a large group of outstanding international experts in many different fields. Thanks to this choice, the LARAM School is designed to transfer to selected students both a global overview of the risk management process and the most advanced and up-to-date topics and methods to be used for the evaluation of the factors defining landslide risk. Moreover, for every course, a strongly international and multidisciplinary class of PhD students has always been selected. This encourages the mutual exchange of different experiences and backgrounds, thus promoting a multidisciplinary teamwork approach to the study of landslide related problems.

3 THE LARAM SCHOOL EDUCATIONAL CASE STUDY

3.1 *Structure of the School*

The LARAM School's administrative bodies, which are appointed for three years at a time, are: the Director, the Board of Directors, the Scientific Committee, the Technical Committee and the Administrative Unit. The Director of the School is, since the foundation of the School, Prof. Leonardo Cascini, full Professor of Geotechnical Engineering at the Department of Civil Engineering of the University of Salerno. The Director presides over a Scientific Committee composed of about 20 experts in the field of Landslide Risk Management. Every year the Committee sets the criteria for the students' selection, defines the contents of the courses, chooses the lecturers, and evaluates the results of the School's programme. The Scientific Committee has always been very international (Tab. 2) with a majority of members having an engineering expertise. As for the Technical Committee, it is in charge of implementing the programme planned by the Scientific Committee, supervising the organisation and evaluation of the courses, defining and collecting the School's teaching material and managing the School's information system. The Authors of this paper have served as the Technical Committee's members since the foundation of the School.

The main yearly initiative of LARAM is the Doctoral School, which is held in Italy in the month of September. Every year 40 PhD students are selected to attend the School's residential courses, with 10 places reserved to Italian PhD students. The courses include formal lessons, tutorials and field training. Over the six years, the LARAM School's lectures have been attended by 238 students belonging to over 150 different European and extra-European Universities from many different Countries (Fig. 3).

Other significant initiatives organized by LARAM in these years were: a yearly Workshop, held in Italy in the same period as the School, dealing with specific landslide risk issues attended by researchers, professionals and authorities in charge of the territory governance in Italy and Europe; the participation in the SAFELAND project "Living with landslide risk in Europe", a European funded 3-year long cooperative project among researchers from 25 different Institutions, with the main task of disseminating the project results; the launch of a first LARAM-Asia Course in 2011, a teaching initiative outside Europe planned to extend the reach of the LARAM teaching approach to a continent heavily affected by landslides; a constantly updated web portal (http://www.laram.unisa.it), aimed at presenting information on the LARAM initiative as well as becoming a virtual community among LARAM alumni and lecturers.

Table 2. Members of the LARAM Scientific Committee.

Year	Italy	Europe	World	TOT
2006–2008	4	10	7	21
2008–2011	4	9	5	18

As for the SAFELAND initiative, it must be stressed that LARAM, besides being a key partner of the research Consortium, contributed significantly, through a strongly positive evaluation of its dissemination capabilities, to the winning bid of the Consortium to the FP7 research call of the European Union. This may be seen as an indirect confirmation of the potential of the LARAM educational initiative in this field. As for the LARAM-Asia initiative, this course is not meant to remain a solitary experience but rather a first step towards the diffusion of the LARAM teaching format in regions of the world where the risk related to landslides and its management are important.

Finally, the financial support to the LARAM School was provided, over the years, by different sources of funding. The main financial sponsors of the School have been, in order of importance: the local Authority in charge of the governance of the territory of the Amalfi coast "Comunità Montana Penisola Amalfitana," without which the LARAM School activities, probably, would not have started (about 67% of budget); the Campania Region (about 10% of budget); the SAFELAND project (about 10% of budget); the research network between the Universities of Salerno and Naples dealing with natural risks "CUGRI" (about 7% of budget); the University of Salerno (about 3%

Figure 3. Number of Universities per country providing PhD students participating to one of School's classes from 2006 to 2011.

Table 3. Number of lecturers at the LARAM School and the LARAM-Asia Course, by year and location.

Year	Italy	Europe	World
LARAM School 2006	3	8	3
LARAM School 2007	8	9	2
LARAM School 2008	4	7	3
LARAM School 2009	6	8	3
LARAM School 2010	7	8	4
LARAM School 2011	6	8	0
LARA-Asia Course	2	4	9

of budget); other sources (about 3% of budget). As for the LARAM expenses, they are related to: accommodation and lodging for the selected students, who enrol to the School at no cost (about 55% of budget); travel, accommodation and lodging for the lecturers, who do not get otherwise paid for their teaching activity (about 35% of budget); logistical and administrative costs (about 10% of budget).

3.2 *The programme of the School*

The LARAM course is structured to follow, as much as possible, the landslide risk framework presented by Fell et al. (2005). Therefore, every year the lecturers are chosen and the programme is set by paying a great attention to address both the most advanced theoretical issues as well as to present and discuss relevant landslide case studies coming from many different Countries. To this aim, the list of lecturers has always been strongly international (Tab. 3) and the different topics are organized in sessions reflecting the structure of the landslide risk management framework (Fig. 4).

As Fig. 4 shows, in the first 5 years the structure of the programme remained almost constant, i.e. two weeks of classes (75–80 hours among lectures, tutorials and technical visits) and the majority of lectures offered within the same main sessions. In this period, the only few fine-tuning improvements occurring were: the introduction, since the second year, of a short introductory session specifically devoted to outline the role of geology and geotechnics within landslide analysis; the discussion, since 2009, of the results of the cooperative European-wide project SAFELAND. The year 2011 differs significantly from the previous years because two LARAM teaching initiatives were offered: i) a one-week special edition of the LARAM School, mainly aimed at disseminating the results of the European project SAFELAND; ii) a new two-week course, held in China, which included a 3-day field trip. Globally, this means that the amount of lecture hours devoted to three important sessions of the programme (Intro to landslides, Safeland project, Field trip) significantly increased.

As it concerns the interdisciplinarity of the programme, all the topics of the landslide risk management framework are purposefully addressed through many short lectures delivered by many different lecturers (on average 16 lecturers per edition with 4 hours

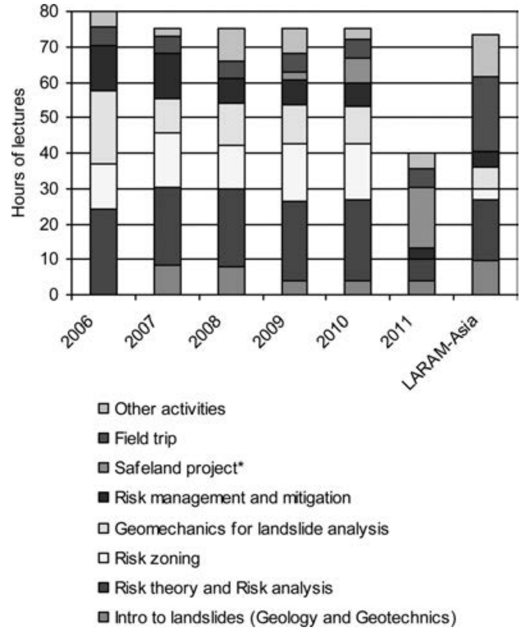

Figure 4. Topics addressed in the LARAM School lectures from 2006 to 2011 and in the LARAM-Asia Course.

of lessons, including tutorials, per lecturer). In such a way, each student, irrespective of his/her background and previous knowledge, gets "exposed" to state-of-the-art methods of analysis, experience and developments in all the areas of the landslide risk management framework, with lectures delivered by recognised experts in the fields. Another important benefit offered by such a programme is that it allows significant networking opportunities to the students at a very early stage of their career among themselves (i.e. the future landslide experts), as well as with the lecturers (i.e. the experts). In order to illustrate the LARAM programmes better, the following section provides details on contents and organisation of a typical LARAM course.

3.3 *An example: LARAM School 2008*

The LARAM School 2008 was held in Ravello, Italy, from 8th to 20th September. The LARAM class of 2008 was composed of 40 students enrolled in PhD programmes of 36 different European and non-European Universities, selected from a pool of 101 applications sent by PhD students coming from all over the World. The teaching group comprised 14 lecturers, coming from 11 different countries, for the most part also belonging to the LARAM School Scientific Committee. The programme of the School consisted of 60 hours of lectures, 10 hours of tutorials and 5 hours of field training. Particularly, the detailed programme of the Course (and hours of lectures) was:

INTRODUCTION. [1] Introduction to LARAM 2008 (0.5 h); [2] Introduction to landslides. (1 h).

SESSION I "Landslide analysis using approaches based on: Geology, Geotechnics and Geomechanics." [1] Landslide identification. Key geological, geomorphological and hydrogeological features of: landslides in soils, large landslides and rock slides (2 h); [2] The geotechnical slope model (1.5 h); [3] Basic geomechanics of landslides (3 h); [4] Tutorial (1.5 h).

SESSION II "Risk Theory and Risk Analysis for Landslides." [1] Landslide Risk Management concepts and framework and examples (2.5 h); [2] Deterministic and Probabilistic models for slope stability evaluation (2 h); [3] Introduction to modelling of catastrophic landslide events (2 h); [4] Empirical models for travel distance (1.5 h); [5] Application examples of probabilistic methods and semi quantitative methods for landslide hazard zonation (2 h); [6] Landslide Frequency Assessment (1.5 h); [7] Different components of vulnerability to landslides. Prevention and long term management of landslides (3.5 h); [8] Case Studies: coal waste dump risk assessment, example from motorway in La Reunion Island, Aknes Rock slope in Norway (2 h); [9] Application of QRA to other geotechnical problems – Internal erosion of dams, crater lake hazard (1.5 h); [10] Advanced numerical models: initiation of landslides, propagation of sediments/climate change effects (3.5 h).

FIELD TRIP "Technical visit." Field trip to an area affected by catastrophic landslides in 1998 and to the geotechnical laboratory facilities of the University of Salerno (5 h).

SESSION IV "Landslide susceptibility, hazard and risk zoning at different scales." [1] Input elements to zoning maps. Zoning scales, levels and methods. Basic methods and procedures for zoning at small and medium scales (<1:100,000–1:25,000). Tutorial on susceptibility, hazard and risk zoning at 1:25,000 scale. Statistical methods for susceptibility and hazard analyses (6 h). [2] Natural terrain zoning and management criteria – Hong Kong practice and experience. Qualitative risk rating for individual slopes/hillsides and global quantitative risk assessment. Site-specific quantitative risk assess-ment and risk management. Tutorial on quantitative risk assessment (6 h).

SESSION V "The role of sophisticated methods in landslide Risk analysis." [1] Introduction to advanced slope stability characterization (1 h); [2] Analysis of the stability of soil slopes with low slope angles as a result of latent instability (3 h); [3] Finite element modelling of landslides by taking into account an hydromechanical coupling and an instability criterion (3 h); [4] Flow-like mass movements in pyroclastic soils: triggering mechanisms and some remarks on propagation stage (1 h); [5] Thermo-hydro-mechanical couplings in slope stability: the case of rapid drawdown, thermal effects in landslides. Tutorial on rapid slides (4 h).

SESSION VI "Landslide risk management and mitigation." [1] Risk management on la Désirade Island and Pointe-Noire in Guadeloupe (3 h); [2] The role of control works in the risk mitigation framework (0.5 h); [3] Site investigation and field monitoring in the research of sliding mechanisms of residual and colluvial slopes in tropical areas. Principles of prevention and long-term management of landslides, efficiency of drainage works (1 h); [4] Remarks on Control works for Landslide Risk Reduction and some Case Histories (1 h); [5] Principles and design of control works against rockfalls and shallow slides: solution in urban areas – the example of Rio de Janeiro (1.5 h).

CONCLUDING SESSION (1 h).

Finally, in order to have significant feedback on the learning level of the students, the programme included tutorial activities and an end-of-course exam.

Example of tutorial activity

One of the tutorials offered in SESSION IV was aimed at addressing the issues related to landslide risk zoning at medium scale. The problem statement was the following: "A Regional Authority needs to set up a procedure for landslide hazard and risk zoning of its territory of about 12,000 km^2, based on maps available at 1:25,000 scale. The mapping must be completed within a few months using qualitative risk assessment criteria. An engineering consultant company will be hired to help define the zoning procedure. Four companies (i.e. 4 groups of 10 students) expressed an interested in performing this job. The competitive evaluation of the 4 companies (i.e. today's tutorial) consists in defining an adequate zoning method with reference to a sample area of about 18 km^2."

Each group of students (i.e. each virtual Company) was provided with the following maps of the sample area at 1:25,000 scale: i) topographic map; ii) landslide inventory map, including a 2-class descriptor of the state of activity of the phenomenon; iii) urban areas and infrastructure map; iv) elements at risk map; v) damage map; vi) consequences map. The students were also provided with the procedure used to define a "Consequence model" producing a 4-class qualitative consequence map on the basis of available thematic information. Each group was asked to work for 60' to define either a Susceptibility, or a Hazard or a Risk Model, following the example of the Consequence model provided. At the end of that time, a 30' plenary session was scheduled for 5' short presentations by the leaders of the 4 groups and a 10' final discussion on the criteria on which the models proposed by the different groups were based.

End-of-course exam

The end-of-course exam was offered, upon request, to students interested in being evaluated for accreditation purposes. To this aim, during the last days of the School, the interested students were asked to answer three out of five questions within a take-home style 48-hour long examination.

The questions on the LARAM 2008 exam were the following: [1] Using a summary of your PhD thesis, indicate how the lessons at LARAM School will improve the work that you are doing. [2] The frequency of debris flow in a site is about one event every four years. A city of 10,000 inhabitants is located in the deposition area. a) What kind of data would you look for in both hazard and risk analysis assessment? b) What kind of measures would you suggest to reduce the risk? [3] What are the advantages and disadvantages of assessing the performance and reliability of protection measures by drainage and anchors? [4] What is a suitable scale for assessing risk at the level of a commune or region? Which parameters or components should be taken into account and how do they influence the choice of the scale? [5] What does "landslides characterisation" mean? Why is it important for risk assessment?

Three students asked to take the facultative exam. The evaluation of the exam was in charge of the six members of the Scientific Committee involved as lectures in LARAM School 2008. After the end of the School, each exam was sent to the lecturers who were asked to review the students' answers and to evaluate them. Each exam was considered as passed if it received sufficient marks from at least 51% of the evaluators. All three students passed the exam. As for the marks, a scale expressing a percentage with respect to a 'full mark evaluation' (i.e. from 0 to 100%) was initially used and then converted into different nominal scales following the specific needs expressed by the different students. In particular: an "A to E scale" was used for a Norwegian student; a "1 to 5 scale" – being 1 the best grade and 5 the worst – was used for an Austrian student.

4 THE SCHOOL: SIX YEARS OF EXPERIENCE

A total of 238 PhD students attended the LARAM School in Italy from 2006 to 2011 (Fig. 3). As expected, most of the students were enrolled in PhD programmes offered by Italian and other European Universities. Yet a significant number of students coming from Canada, USA, Brazil, China and Russia was also observed.

The first LARAM-Asia course was attended by 37 students mostly coming from China or other Asian Countries, thus highlighting the strong regional attractiveness of this initiative, which reaches out to students unwilling or unable to apply to the Italian LARAM School.

The main statistics on the LARAM School Alumni, i.e. PhD students selected to participate to one of School's classes from 2006 to 2011, are reported in Figure 5. They indicate a clear majority of male over female students (140 vs 98), engineers over geologists or engineering geologists (131 vs 83), first and second year students over students approaching the end of their PhD programme (180 vs 68) and students younger than 30 years old over "older" students (172 vs 76). The comparison among these data and the corresponding statistics for the first LARAM-Asia Course (Fig. 6) shows, beside the already mentioned issue on the country of origin of the students, the following main differences: more geologists or engineering geologists than engineers (17 vs 12) and a more even distribution with respect to the PhD year.

To investigate how the students valued their LARAM experience, since the first year of the School, a questionnaire was set up with reference to both the didactic and logistic aspects of the School and handed out to the students at the end of each year's course. Figure 7 shows the results of questionnaires

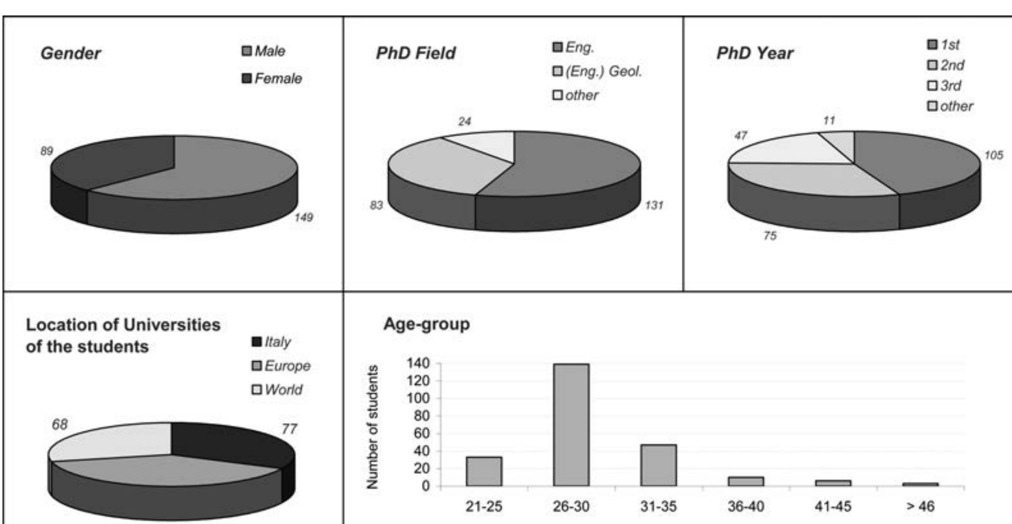

Figure 5. Statistics of the LARAM School Alumni, distribution by: (a) gender, (b) PhD Field, (c) PhD Year, (d) location of University, (e) age.

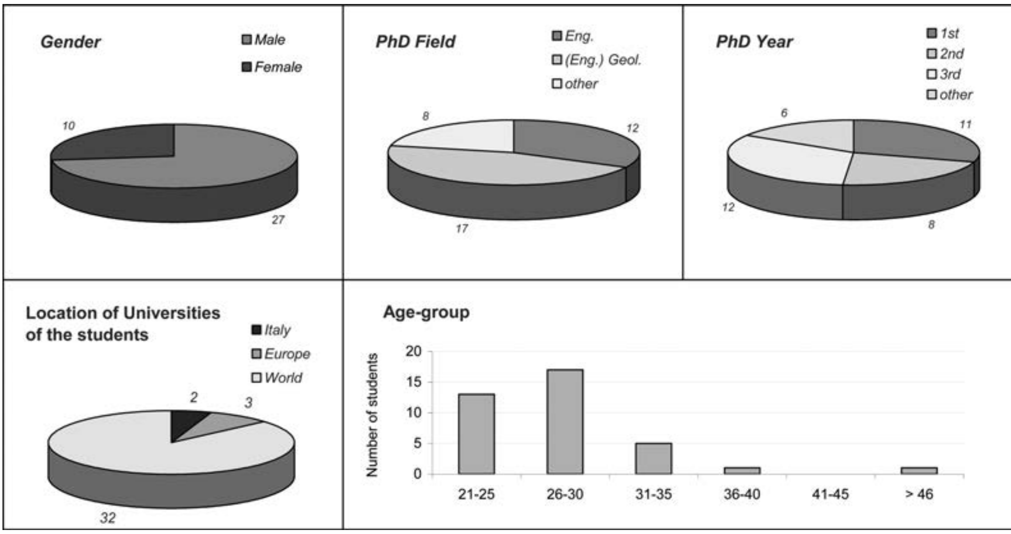

Figure 6. Statistics of the LARAM-Asia students, distribution by: (a) gender, (b) PhD Field, (c) PhD Year, (d) location of University, (e) age.

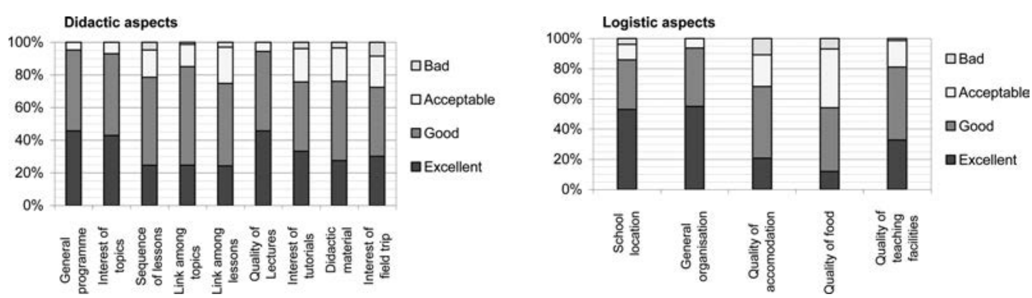

Figure 7. Results from questionnaires filled by the LARAM School students (2006–2011) at the end of each year.

filled by the all the 238 LARAM School Alumni. An extremely positive feedback was provided for the interest of topics and the general programme (about 95% of excellent/good answers), thus highlighting the seeking of knowledge on the part of PhD students in this field interest and the adequateness of the School programme for this purpose. Also the link among topics was judged positively (85% of excellent/good answers), which means that the basic goal of the LARAM mission, i.e. bridging the current gap between geotechnical engineering, geology and other fields in landslide risk theory, was achieved. However, an improvement on this issue is still desirable and possible, as the high quality of teachers is also recognised by the students (95% of excellent/good answers). A positive judgement (average of 75% of excellent/good answers) was given to other teaching issues: tutorials, field trip, didactic material and teaching facilities. Of course, the success of the School as a didactic experience also depends on logistic aspects. As for these issues, while School location and the general organization reached outstanding reviews (average of 90% of excellent/good answers), the quality of accommodation only reached 70% of positive answers and the "world-famous Italian food" ranked as the very last added value of the School (only 55% of excellent/good answers).

As for the effectiveness of the education provided by LARAM for the students attending the School and its relevance for the pursuit of their PhD degree, the Authors had positive feedback only from few of the 238 LARAM Alumni who passed an optional post-course exam. Regardless, the Authors believe that the real benefits of the participation of the PhD students to such an initiative will appear "more effective" to them only at later stage of their career, when they will be able to value the LARAM experience with respect to their research standing and other educational experiences.

5 CONCLUDING REMARKS

Landslide risk is becoming more and more a worldwide problem that requires adequate actions to be taken from both Authorities in charge of territory governance and the scientific community. The latter, in particularly, is called to give scientifically-based answers to the analysis, assessment and, more in general, management of landslide risk. This must be performed taking into account both the large variability of geo-environmental contexts as well as the different social expectations related to different socio-economical conditions. A particularly important issue in this process is the dissemination of proper procedures and methodologies, which need to be shared and validated by the international scientific community. To this aim, the LARAM School is working to become a permanent didactic institution through which young researchers meet and interact with renowned experts in the field of landslide risk.

The first six years of experience of the LARAM School seem to demonstrate that the path towards that challenging goal is promising. Over the years, the LARAM community has grown significantly both among students and landslide experts, thus underlining the effectiveness of the initiative. Such success is also demonstrated by the fact that other Countries, for instance China, have expressed the need to have residential courses within their Institutions. Of course, future developments of LARAM will depend on many other factors, such as, for instance, the demand of such expertise, the amount of PhD candidates working in the field of landslide risk and, of course, on the related actions promoted by LARAM.

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Moreover, the Authors wish to thank all the members of the Scientific Committee, who surely provided an outstanding contribution to the success of the School. The Authors also thank all the students that attended the School and, more in general, all the applicants, because they are the main reason why such an initiative exists.

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Challenges in teaching engineering to the next generation: Some data from a geo-engineering perspective

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ABSTRACT: This paper looks at the changing attitudes amongst undergraduate students toward learning in engineering, in the context of teaching in geomechanics. On the basis of experiences in courses teaching introductory soil mechanics and geology in second year, and applied, project-based design in final year, a number of observations are made. The data underpinning these observations includecourse results, student survey results and anecdotes of interactions with students. It considers changes in the expectations of students as a function of generational attitudes and government and university policy. The experiences described point to a trend of students choosing to skip classes, becoming reluctant to think in order to learn, and failing to appreciate how much time they need to devote to their studies in order to achieve the necessary learning outcomes. Results presented show that course failure rates correlate strongly with non-attendance of lectures, and it is concluded that solutions to this problem are far from straightforward.

1 INTRODUCTION

The world, and life as we know it, continues to change at an ever-increasing rate. Many aspects of our lives, such as how we live, how we work and how we relax, have seen profound evolutions over the past 30 years or so. Despite our basic physiology remaining relatively unchanged during this time, the way we learn seems to have changed, driven largely by behavioural adjustments in response to changes in society, its expectations and its opportunities.

Whilst the expected outcomes of a university education in engineering have not shifted significantly, the aptitude of students presenting to study engineering, the educational environment and societal context of students have all changed markedly. This has resulted in a quantum shift in the university experience for both students and educators, that has thrown up many challenges (Vest, 2012) which as yet, are mostly unresolved.

2 GEOTECHNICAL ENGINEERING AT THE UNIVERSITY OF NEWCASTLE

Geotechnical engineering at the University of Newcastle sits within the Discipline of Civil, Surveying and Environmental engineering. The civil engineering program is made up of thirty-two 10 unit courses, of which 4 are geotechnical courses, taken in years 2, 3 and 4. These are described, as follows.

Geomechanics 1: The Geomechanics 1 course is made up of two compulsory parts, delivered simultaneously throughout a single semester. The engineering geology part provides the students with all of the geological knowledge they will receive whilst studying this programme. The soil mechanics part of Geomechanics 1 introduces soils, their fundamental properties and classification and their deformation behaviour. Geomechanics 1 has a heavy workload: it is assessed on the basis of 4 soil mechanics exercises, 3 soil mechanics assignments, one excursion, a geology practical exam, a reading exercise and a final exam.

Geomechanics 2: The Geomechanics 2 course covers the strength/stability aspects of soil behavior. It introduces soil strength models, methods of strength measurement, bearing capacity, lateral earth pressure, retaining walls and slope stability. It has 3 laboratory exercises and a number of assignments.

Geotechnical Engineering: Geotechnical Engineering takes the concepts of Geomechanics 1 and 2 and applies them to site investigation and foundation design. It introduces methods of subsurface sampling, in situ testing, types of shallow foundations, pile design, and a brief introduction to geoenvironmental engineering.

Geotechnical Project: The Geotechnical Design Project is capstone course of the geotechnical strand, providing students with a real, multifaceted design problem. It is devised by an experienced geotechnical consultant, based on a real project and supported by real field and laboratory data. The students work, in groups of 4 toward a solution, which they must present as a consulting report. The assessment for this course is derived from 50% based on the individual students' efforts and 50% from the group effort, and it rewards conceptual understanding, aptness of the solution and the quality of the communication of the final outcomes.

The observations presented in this paper have been derived by the author from this involvement with Geomechanics 1 and Geotechnical Design Project courses over a period of more than 15 years.

3 PRIMARY FACTORS IN THE TEACHING AND LEARNING EXPERIENCE

The teaching and learning environment in Universities is controlled by a range of factors, including:

- Government tertiary education policy
- Institutional policy
- Educational policy in schools
- Societal norms and expectations
- Professional expectations

Whilst all of these are broad-ranging and distinct factors, aspects of one may have significant consequences for others in the university teaching and learning environment. Note that in the context of the present discussion, "teaching and learning environment" are taken to mean the broader environment that affects the student's learning experience. Directly, it includes the university, its staff, its teaching spaces, its policies and procedures and its IT systems. Indirectly, it includes society, its expectations, its opportunities, and its constraints.

3.1 *Australian government policy*

Over the past 10 to 20 years, the Australian tertiary education sector has seen significant and rapid change, driven by government policy. Most important amongst these were strategies to make the sector more cost effective, in response to assertions that increased funding cannot be readily justified (Marinova, 2006). The principal ways of achieving this were to increase the contribution to the costs of education borne by the student, and to exploit the quality and reputation of the Australian tertiary sector to raise income from full-fee-paying overseas students. DEEWR (2011) reports that this has been very successful, providing data to show that the overall government contribution to university education has decreased from 83% in 1987 to 42% in 2010. During this period, student contributions have risen from around 3% to 16%, and new income from overseas students of almost 18% has been achieved.

The incentive to universities to chase overseas student funding has largely been a simple financial one: reduced financial support from the government for universities to carry out their core business. The consequences of this, when translated into the institutions themselves, have been both direct and indirect. Directly, less funding has led to a need to either reduce costs, with consequent increases in student/staff ratios (Bradley et al, 2008), or increase income, through recruitment of overseas students, which has also lead to increased student/staff ratios. Less directly, the need to maximize student derived income has led to an increase in inter-institution competition for both domestic and overseas students, and an indirect increase in the cost and effort devoted to institutional marketing.

3.2 *Institutional policy*

In most cases, institutional policy formulation has been a direct reaction to government policy. Universities have striven to maximize both local and overseas enrolments in all disciplines. In real terms, universities only get ahead by doing this, if they keep staffing levels static. Increased marketing has been the principal tool for attracting more local and international students. However, to fill quotas of local students in an increasingly competitive market, universities have adopted policies of lower intake cutoff scores, more diverse entry paths and fewer academic prerequisites. As a result, student numbers in both Geomechanics 1 and Geotechnical Project have increased by around 50% over the past 10 years (Fig. 1). With increasing student cohorts in geomechanics courses come issues of teaching quality in field and laboratory exercises, which are hands-on and generally very teacher-student interactive. Without commensurate increases in experienced support staff, the practical learning experience is degraded.

A consequence of more aggressive marketing of universities is a greater emphasis on student satisfaction. Operational policies for encouraging improved student satisfaction incorporate increased scrutiny of course coordination and the perceived quality of

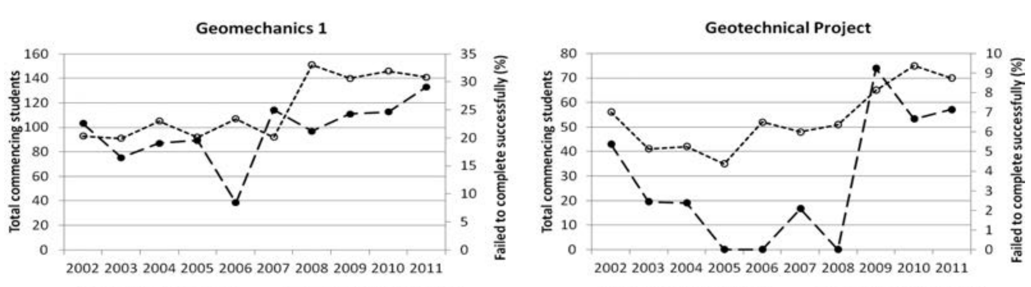

Figure 1. Student numbers and failed completion rates over the past 10 years for a) Geomechanics 1, and, b) Geotechnical project (Note that failed to complete data includes both failing final grades and students who abandoned the course).

teaching and course experiences, delivery of courses through more diverse and flexible modes, and a change in emphasis to assure students that their expectations and rights are important to the institution.

3.3 *Educational policy in Schools*

The preparedness of students entering university is a key factor in shaping the success of their university experience. In New South Wales, where the majority of the University of Newcastle's students come from, the leaving qualification is the Higher School Certificate (HSC), and it includes a score, out of 100, that describes a student's overall performance.

The range of around 85 courses available for inclusion in the HSC is very broad. Of these, there are 4 maths courses, 5 basic science courses and a course in Engineering Studies that are potentially suited to students wishing to become engineers. The remaining courses cover subjects of interest in broader society from retail and hospitality studies to dance life skills.

Student performance in each course is assessed using a standards-based reporting scale, on which the level of performance is judged according to predetermined benchmarks of understanding that might be displayed by a student (BOS, 2012). These differ for every course, but the relative depth of understanding they represent are set generically and equally for all courses. Most significantly, there is no recognition given to the level of intellectual challenge of different courses, so, any course studied has equal weighting in the calculation of an HSC score.

3.4 *Societal norms and expectations*

These have arguably undergone the greatest and most profound changes over the past 20 years, and in general terms, there are far too many to consider in any comprehensive way here. Hence, the present discussion will be limited to a few observations that are pertinent to the discussion which follows.

The following are some generalizations made in regard to the current generation of students:

- They see themselves as education customers.
- They have grown up with computers and the internet, and are undaunted by the learning curves associated with new technology.
- They have grown up with computer games and computer animated graphics are commonplace.
- Mobile phones/smart phones are essential personal items and additional accessories such as iPods, Tablets and Kindles, etc are commonplace.
- Students accept that their modern conveniences have a financial cost, and they are willing to work in paid jobs whilst studying to maintain them.
- Formalities in interpersonal interaction and communication have mostly been disregarded, and student-teacher interaction is casual.

In general, the world is now more "politically correct" than ever, and this has led to trends of student expectations, and institutional priorities, are more liberal than ever before.

3.5 *Professional expectations*

Expectations of the corporations and organizations employing graduates have not changed so rapidly, as they are controlled by people of older generations. If anything, there may be an expectation that, given the greater opportunity presented to the current generation of graduates, they might be somehow superior to their predecessors. Certainly, the basic knowledge and fundamental principles of most technical disciplines have not changed, and still as relevant. Also, problem solving and analytical skills are still required. However, the forefront of technology has advanced significantly, and there is an ever-increasing number of things to be familiar with.

4 OBSERVATIONS OF TEACHING AND LEARNING TRENDS AT THE UON

From 15 years of involvement with the Geomechanics 1 and Geotechnical Design courses, the following trends in the teaching and learning of civil engineering students in geomechanics have become apparent:

Students in engineering are increasingly less prepared for their studies. This occurs because of school education policy which does not discriminate between the value of courses on the basis of intellectual challenge, and university policy which does not enforce pre-requisites on the basis that it would discriminate on the basis of student choices rather than intellectual ability. Consequently, potential engineering students are being encouraged at school to study less challenging courses in place of maths and science, since this will improve their HSC score.

Students are increasingly choosing to "skip class". In the Geomechanics 1 class of 2011 (140 enrolments), 140 copies of the course outline were taken for distribution in the first lecture: 45 were not distributed, as students did not attend. In a survey conducted in week 10, the average attendance of lectures was only 60. Typical weekly tutorial attendance (optional) is around 50 at the beginning of the hour and reduces to around 25 by the end of the session. There is also an increase in requests for the lectures to be taped and made available on the internet.

Students are no longer willing to write notes in class. Instead, they, expect to have notes presented to them in a professionally prepared form. Even examples in the notes, worked through in class by writing in spaces provided, are insufficient for many students, who request written copies to be uploaded after the class in which the answers were provided.

Students are increasingly reluctant to consult text books. In providing students with prepared notes, there is an expectation that these should serve as an extended syllabus, and that students should read more widely from texts to clarify their understanding, on an as-needs basis. The expectation of students, however, is that the provided notes should be stand-alone, giving them all they will ever need to know about the subject matter.

Students no longer ask questions during lectures, and make little use of timetabled tutorial sessions.

Students are reluctant to solve questions without worked solutions. In Geomechanics 1, the students receive a list of tutorial problems weekly, with only numerical answers attached. Throughout the semester, there are repeated requests for full, worked solutions to the tutorial problems. When asked “why do you want them?” the students usually reply that they have insufficient time to work through all of the questions, and that having full worked solutions makes completing the tutorials more efficient.

Students increasingly expect precise marking rubrics for all assessment items. Also, they will analyse returned items against the rubric rigorously, when the items are returned, and challenge any perceived shortcoming in the assessment process.

Students are increasingly seeking greater flexibility in the timing of submissions and attendance. The two most common reasons given are that they must earn money to subsist, or that they are fulfilling an indispensible professional role in their workplace.

It should be noted that there are some aspects of student attitude that have not changed significantly, and most importantly, it seems that despite all of the changes noted above, students still enroll in courses with the sincere intention of learning enough to pass the course. For some students, the intention may be to learn just enough, though this is nothing new amongst students. Importantly, students still believe that it is important to have an amount of working knowledge in order to practice as an engineer. What is significant, however, is how the trends identified above are mostly working in opposition to the students desire to gain knowledge, and to the teacher’s responsibility to impart this knowledge. This is explored in the following section.

5 DISCUSSION

It is the opinion of the author that although most students enroll in their courses with every intention of learning what the teacher has set out to teach, many underestimate what it takes to fully appreciate the subject, and seem to undervalue and disregard the advice given at the beginning of the semester.

The reasons for this are complex, but two principle reasons are apparent: students’ priorities have shifted in response to societal changes, and their secondary school training is not imparting the learning and time-management skills necessary for studying engineering at university.

5.1 *Learning skills*

Students are being trained in their HSC studies in secondary school to expect a highly structured and predictable curriculum, which is designed to help them maximize their final HSC score. For their teachers, and the broader community, the focus is on achieving the highest HSC score they can. This leads to the selection of less appropriate courses to achieve higher marks, instead of the traditionally more difficult courses of math and science which better prepare students for geoengineering studies.

The current HSC system is designed to take a student to a superficial level of understanding, with very clearly defined expectations and outcomes. Students are encouraged to learn by completing questions from past exam papers, which are structured according to tightly constrained plans, so as to consistently conform to the expectations of students and their teachers. Past exam papers and solutions are widely available to all students on the internet. The expectation of students and their teachers is that if they have done all of past exam papers, then they have learned enough to achieve a high mark. This comes at the expense of deeper understanding and it trains students to study to pass an exam rather than to master a subject. These students arrive at university with this approach to learning, and many struggle to adjust to an environment where they are expected to understand broad theoretical concepts and apply them to open-ended, applied problems.

In Geomechanics 1, this leads them to a sense of insecurity when they are given tutorial material in soil mechanics without fully worked solutions. Many are either reluctant, unwilling or unable to read the course material and interpret it in order to solve the tutorial questions. It is commonplace to field questions about assignments from students who have not yet attempted any of the associated tutorial questions, and which have answers that are readily and directly found in their course notes.

In the Geotechnical Design Project, students struggle with the open-endedness of geotechnical design problems and that there can be many solutions with varying degrees of suitability to any particular design situation. Fortunately, by their final semester, most have come to appreciate the way engineers handle uncertainty in the design process, from their earlier studies in geomechanics and water engineering, although the leap of understanding required is daunting for many. Some students complete the course, comfortable with designing for natural variability, whilst others remain unconvinced.

5.2 *Evolving expectations*

Perhaps the most significant impediments to student learning arise from the expectations of students in modern society, and they manifest in the balance between what the students expect to receive, what they expect to have and what they expect to give.

As noted earlier, students are now well aware of their status as customers, and they expect that they should have some say in how the service they are buying is delivered. Sometimes what they want is inconsistent with what teachers think is best for them, and this leads to dissatisfaction. University policy, in response to government pressure to increase student numbers, has exacerbated this situation by creating a learning environment where student satisfaction is given far more attention than staff satisfaction or learning outcomes. Students are now surveyed intensively and staff are leveraged on the basis of the results, to do whatever it takes to make students happy with their experience.

What students are willing to give to gain an understanding of applied engineering is largely determined by how they allocate their time. What emerges from interacting with students in course coordination, is that the amount of time devoted to recreation and personal time has not changed significantly. However, there seems to have been a shift from time devoted to outside study to time spent in employment. Students are now more heavily committed to part time work, and in extreme cases, are trying to juggle full time work with full time study.

A primary factor in increasing work commitments is the need to fund a lifestyle in the technological age, which offers unprecedented opportunities for communication and information, but at a cost. It is now almost unheard-of that a student would not have the latest mobile phone and personal computer devices, with subscriptions that give them comprehensive access to the electronic services that most of society has. The costs of this are additional to the everyday costs (rent, car, food, clothes, sport and entertainment) that students of the past had to manage.

A secondary factor is the shortage of engineering professionals, causing companies turn to undergraduates to accommodate an increasing workload. There are now frequent requests from students for extensions of time and for rescheduling of laboratories etc. on the basis of work commitments. Many companies who employ undergraduates in professional capacities, through necessity, leverage a greater commitment from students than they can afford to give.

It seems that this trend is at the heart of declining class attendances. There is a tendency for students to plan their semesters by blocking-out class times in their schedules, and then filling the spaces in between with work commitments. Increasingly, additional self-directed study time is something that students expect will just happen in unspecified times between lectures and work. This behavior explains the gradual decline in attendance observed throughout a semester, where as a course proceeds, students begin to receive assessment tasks, and they feel compelled to skip class in order to work on them.

5.3 *Teaching considerations*

The focus so far has been on the changes which have occurred in the students' learning environment. The other, equally important side of this complicated equation is what is happening in the teaching environment.

In many cases, teaching staff have not sought to change their approach to teaching, finding it hard to justify changing what has worked effectively for previous generations. In other cases, teachers have embraced technological and pedagogical change and attempted to adapt and innovate in response to the challenges that have arisen. Innovations such as on-line course delivery (Kim and Bonk, 2006), videoed lectures (on demand) and virtual laboratory exercises have all been tried (Ertugrul, 2000), though there would seem to be no clear evidence that they have been more effective.

There is one school of argument that supports giving students what they want, because they have already learned at school how study in their own way, and traditional views on what makes effective study may not apply to them. It is difficult to accept however, that deeper levels of understanding can be gained from non-attendance of lectures and practice doing fully worked solutions (in place of taking more time to read the course material and assimilate it in order to be able to solve the problems from scratch).

One way to evaluate whether the change in student study patterns is having a detrimental effect is to look at the failure rates of students in courses. The graphs presented in Figure 1 show that, on average, failure rates in Geomechanics 1 have risen consistently over the past 10 years, whilst failure rates in Goetechnical project are changing less consistently, though higher now than ever before. Note that the higher rates of failure in Geotechnical Project may reflect both student behaviour in that course, and also student behavior in the earlier Geomechanics courses that feed into the design course.

Evidence has indicated that attendance of lectures is of benefits to students (Massingham and Herrington, 2006). To get a clearer indication of whether there is a correlation between non attendance and likelihood of course failure, a simple survey of attendance in the two Geomechanics 1 lectures was arbitrarily conducted in week 10 of semester in 2011. The students were not told that the surveys would be carried out, and the results of the survey were not analysed until the course marks were finalised. Figure 2 shows the frequency of final grades for students who attended

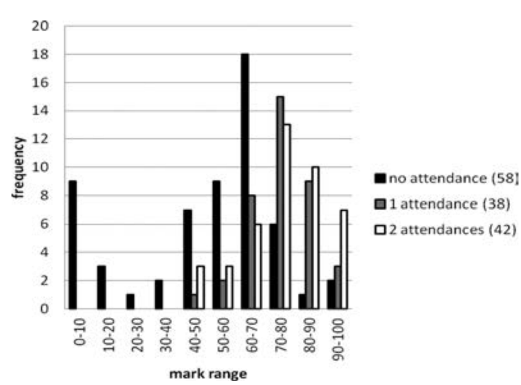

Figure 2. Frequency of final grades for Geomechanics 1 students who attended two lectures, one lecture or no lec-tures in week 10.

both, one or neither of the lectures in week 10. Figure 2 shows clearly that students who do not attend lectures are significantly more likely to fail to complete courses successfully, and feature less frequently amongst the higher grades achieved. Students who attended at least one class in the week of the survey achieved significantly better results, with attendance of both, correlating to slightly better grades and a greater proportion of the highest grades.

Interestingly, there were 2 students who did not attend class in week 10 who achieved marks greater than 90%, and students who attended both classes who failed, though relatively few and not by much.

6 CONCLUSIONS

Achieving good pass rates and satisfactory learning outcomes in geomechanics courses at the University of Newcastle has become increasingly difficult over the past 10 years. This is partly due to a combination of government and institutional policies aimed at increasing productivity in Australian universities, and to a shift in attitudes and study patterns amongst undergraduate engineering students.

Government policies to encourage universities to attract more students, and university policies to attract and admit more students, have seen significant increases in the numbers of less well prepared students undertaking engineering studies without a commensurate increase in teaching resources. At the same time, student commitment to study has reduced in response to increased commitment to part time work, leading to a trend of student non-attendance of classes and incomplete attempts of tutorial questions and assessment tasks.

Whilst it would be reassuring to find that students' study effectiveness has adapted along with their study patterns to achieve suitable learning outcomes with reduced investment of time, the evidence is to the contrary: it seems that failure to attend class correlates to a significantly greater frequency of failure. It would also be reassuring to believe that teachers can adopt more flexible and innovative delivery modes to complement the study-time constraints and modern lifestyles of "Gen Y" students (Mc Crindle, 2011), and enhance their learning efficiency, but it is the author's opinion that flexible delivery modes can only compensate so far.

The reality is that the knowledge base for geomechanics is only broadening, and there is an amount of knowledge that must be acquired in a professional degree program, which cannot be compromised if graduates are going to meet the expectations of employers. This leaves geo-engineering teachers with a challenge, for which this author has few answers.

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Shaking the Foundations of Geo-engineering Education – McCabe, Pantazidou & Phillips (eds)

Lecturers' perceptions of students' learning needs in geo-engineering in Spain

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ABSTRACT: Results from a study on university lecturers' approaches to teaching and lecturers' perceptions of students' learning needs in Spain are presented in this paper. A total of 27 lecturers of geotechnical engineering and engineering geology were selected for the study. Participants were asked to complete the Trigwell & Prosser's Approaches to Teaching Inventory and a second Inventory developed by the last author of this paper. The first inventory gave an indication of lecturers' approaches to teaching, whereas the second provided data on perceptions of students' learning needs. Results showed how a content-focused approach is favoured by 67% of participants. Time management, critical thinking, problem solving skills, ability to make sound judgments, and ability to apply knowledge in practice, were all identified as key students' learning needs; whereas ability to give oral presentations and research skills came last in the list. A number of comments regarding education of geotechnical engineers and engineering geologists in Spain are included in the paper.

1 INTRODUCTION

Changes to higher education introduced by the Bologna Process are affecting the way civil engineering in general, and geo-engineering in particular, is being taught in universities throughout Spain. The most significant change to date has been the substitution of the alternative three-year or five-year undergraduate degree for a four-year undergraduate course followed by an optional one or two-year postgraduate qualification.

Not only has the format of the degree changed, but also the number of institutions offering civil engineering courses in Spain has increased dramatically over the past few years. Whereas before only a reduced number of public universities offered the longer (and more exclusive) undergraduate degree, now there is an increasing number of institutions – both public and private – offering the old and about to start offering the new degrees.

The above changes call for a re-evaluation of the teaching and learning process with takes place in institutions offering civil engineering degrees in Spain.

Research in higher education on the topics of lecturers' approaches to teaching, their conception of teaching, and the relationship between these two areas, has highlighted differences between alternative approaches to teaching (Trigwell & Prosser 2004, Prosser & Trigwell 2006, Postareff et al. 2008). On the one hand, a learning-focused (or student-focused) approach views teaching as a way of facilitating students' learning process. The lecturer focuses on what the students are doing in the teaching-learning situation, and students are expected to construct their own body of knowledge and produce a new worldview independent of that of the lecturer. A content-focused (or teacher-focused) approach, on the other hand, is associated with a scenario in which the student is considered a passive recipient of information, transmitted from the teacher to the student. The focus of transmission is on facts and skills, and prior knowledge of the student is considered to be unimportant.

A distinction between approaches to teaching is important, since research has shown that each approach can have a distinct and marked effect on the way students see the learning process (Trigwell et al 1999, in Trigwell & Prosser 2004). A content-focused approach to teaching has been associated with a surface approach to learning (reproduction), whereas the use of a learning-focused approach to teaching has been shown to result in students adopting a deeper approach to learning (understanding).

Studies on teaching and learning within the context of civil engineering in Spain are scarce. Considering the recent changes to degree programs, this seems an appropriate time to explore the subject in some detail. In order to do so, the authors have carried out a pilot study on a sample of 27 university lecturers. Since the first two authors teach geotechnical engineering and engineering geology at undergraduate and postgraduate level, their interest lies within these two areas of knowledge. Therefore, only lecturers teaching in any of the above two disciplines were selected for the study.

The study aimed at providing preliminary answers to the following two questions, within the context of geotechnical engineering and engineering geology education: (i) what are the lecturers' approaches to teaching, and (ii) what are the students' learning needs from the lecturer's point of view. This paper reports on the methodology and the results derived from this study. The findings are expected to be of use not only to academics involved in the planning of courses in geotechnical engineering and engineering geology in Spain, but also to others outside the country which find themselves in a similar situation.

2 METHODOLOGY

2.1 *Participants*

A total of 27 lecturers of geotechnical engineering and engineering geology were selected for the study. It is acknowledged that this constitutes a very small sample; however, one must consider (i) the limited number of individuals lecturing in any of these two disciplines in Spain, and (ii) the inherent difficulties in conducting such a study (despite best intentions, academics tend to be rather busy people with little time to spare to fill in questionnaires). Except for one, all participants lecture at the Universidad Politécnica de Valencia (UPV). The last participant teaches at the Universidad Politécnica de Cartagena (UPCT). It is noted that the term "Universidad Politécnica" is given to those institutions specializing in technical degrees (there are four such institutions in Spain).

Regarding the sample's composition, there was a good spread in academic category and teaching experience, although there was a majority of male respondents. All different academic categories recognised within the university system in Spain were well represented. In terms of teaching experience, six of the respondents had been teaching for more than 21 years, eleven between 11 and 20 years, seven been 5 and 10 years, and only three had been teaching for less than 5 years. Out of the 27 participants, only four were female (equivalent to a 12%, probably representative of the percentage of female lecturers teaching civil engineering in Spain at present).

2.2 *Instruments*

A two-part inventory was used to carry out the study: the Approaches to Teaching Inventory (ATI) (Prosser & Trigwell 1999, Trigwell & Prosser 2004) and a second inventory designed by the last author of this paper. The ATI was originally developed from research using a relational perspective in order to determine the relationship between teachers' approaches to teaching and students' approaches to learning in the physical sciences in higher education. Since made public in 1999, it has been used in a number of different contexts, mainly to collect data for the analysis of relationships between approaches to teaching and other elements of the same teaching-learning environment. Therefore, it seemed appropriate to use the Inventory in this study. The ATI is composed of 16 items, of which eight are in the Conceptual Change/Student-Focused (CCSF) approach to teaching scale, and the other eight in the Information Transmission/Teacher-Focused (ITTF) approach to teaching scale. Response to all items is on a 5-point scale from *only rarely* true (score of 1) to *almost always* true (score of 5), and all items are scored positively. A list of items, as given in Trigwell & Prosser (2004), is presented in Appendix 1.

Table 1. Learning needs grouped into categories

A – Information gathering and communication	
1*	Teamwork
7	Computing skills
12	Ability to generate notes in class
13	Ability to search for information
14	Ability to complete written assignments
15	Ability to present written assignments
16	Ability to give oral presentations
18	Research skills
B – Knowledge and understanding	
8	Ability to communicate
9	Understanding of concepts and ideas
17	Exam preparation skills
C – Management, creativity and analysis	
2	Time management
3	Critical thinking
4	Problem solving skills
10	Ability to make sound judgments
11	Ability to apply knowledge in practice
D – Social and decision making	
5	Ability to make decisions
6	Commitment and motivation

*Item number in the inventory.

The second inventory is composed of 18 items which aim at identifying students' learning needs from the lecturer's point of view. Each of these items represents a generic competence grouped under each of the four categories shown in Table 1. All items in the questionnaire are measured on a 5-point Likert scale, from *strongly disagree* (score of 1) to *strongly agree* (score of 5).

The ATI was translated into Spanish by the last author and both inventories were printed on the same piece of paper which was handed to each of the participants. The data was analysed using the statistical package SPSS, v.17.0.

3 ANALYSIS AND RESULTS

Results are divided into two categories: (i) definition of lecturers' approaches to teaching, as given by the ATI questionnaire; and (ii) identification of students' learning needs from the lecturer's point of view, as derived from the answers recorded in the second questionnaire.

3.1 *Defining lecturers' approaches to teaching*

For each of the participants, aggregate scores in both the CCSF and ITTF approach scales were calculated. On the basis of these, it was possible to differentiate between lecturers scoring higher in one of the two scales. The intention was to distinguish between those lecturers which, in what is believed to be the same context, favoured one of the two teaching approaches, rather than to classify lecturers as being inherently learning-focused or content-focused. Results from this exercise revealed that 67% of the participants (totalling 18 out of 27) had a higher aggregate score in the ITTF approach scale (content-focused) than in the CCSF scale (learning-focused).

As an additional exercise, the mean aggregate score for both the ITTF and the CCSF scales, considering all 27 participants, was computed. This resulted in a mean score of 34.59 for the ITTF approach and a somewhat lower figure of 32.11 for the CCSF approach. Associated standard deviations were 2.37 and 3.49 respectively (corresponding coefficients of variation, COV, of 0.06 and 0.11 respectively).

The significant higher proportion of lecturers scoring higher on the ITTF approach scale, as well as the higher mean aggregate score for the ITTF scale, are in line with findings previously reported in the literature. Lindblom-Ylänne et al. (2006) showed how there was evidence that approaches to teaching were related to teachers' discipline, and how teachers in the "hard" disciplines – amongst which engineering is included – were more likely to apply a teacher-centered approach to lecturing. Similar observations had previously been made by Trigwell (2002) and also Lueddeke (2003). As mentioned by Lindblom-Ylänne et al (2006), this quantitative derived result is consistent with the studies undertaken by Newmann et al (2002) in which teaching in "hard" disciplines is described as involving mainly mass lectures and problem-solving seminars, or simulations and case studies related to professional settings.

The COV reported above can be interpreted as indicative of certitude by the part of the participants, based on their own experience of teaching, when completing the ATI questionnaire. The larger COV associated with the CCSF items suggests that the respondents had a greater degree of uncertainty about the validity of the CCSF than the ITTF approach to teaching.

In summary, it is possible to conclude, based on the results presented above, that for the sample under consideration (i) the ITTF is favoured over the CCSF approach to teaching, and (ii) there is greater certainty about the validity of the ITTF over the CCSF approach to teaching.

3.2 *Identifying students' learning needs from the lecturer's point of view*

In order to analyse students' learning needs from the lecturer's point of view, the mean score and standard deviation for each of the items presented in Table 1 was computed for the entire population. Results are presented in the form of bar charts in Figures 1, 2 and 3. Each of the figures has two parts: the top graph represents mean scores, whereas the graph below gives standard deviations. Figure 1 presents statistics from all 27 participants; whereas Figures 2 and 3 give equivalent results for those lecturers favouring an ITTF teaching approach and a CCSF teaching approach respectively. It must be noted that Figure 2 is based on the response of 18 participants and Figure 3 on that of only 9 participants. Therefore, conclusions derived from these two figures are necessarily limited by the reduced sample size. Nevertheless, despite this inherent limitation, the insight derived from looking at the two separate groups is deemed to be of sufficient

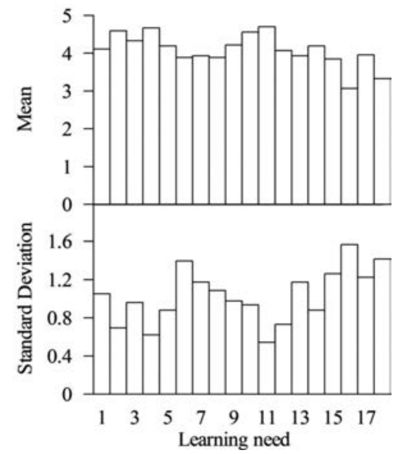

Figure 1. Mean scores and standard deviations for each of the items presented in Table 1: entire sample (N = 27).

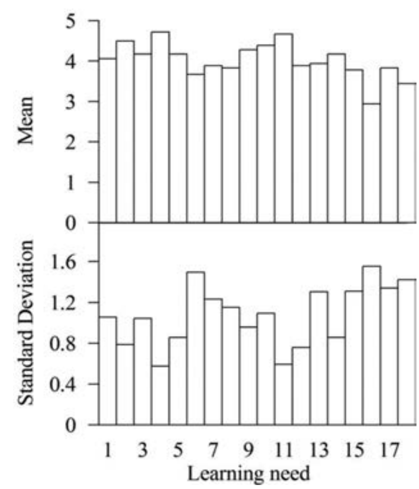

Figure 2. Mean scores and standard deviations for each of the items presented in Table 1: lecturers favouring an ITTF teaching approach (N = 18).

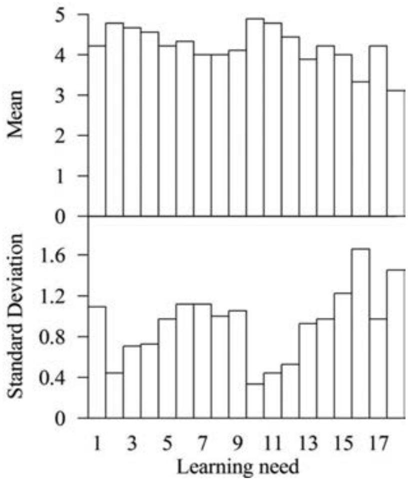

Figure 3. Mean scores and standard deviations for each of the items presented in Table 1: lecturers favouring a CCSF teaching approach (N = 9).

interest to justify the inclusion of these last two figures in the paper.

Inspection of the upper portion of Figure 1 shows the top students' learning needs, as identified by the entire group, to be (in decreasing order of importance, or decreasing mean scores): ability to apply knowledge in practice (11)[1], problem solving skills (4), time management (2), and ability to make sound judgments (10). The same group considered (in decreasing order of importance) research skills (18), and ability to give oral presentations (16) as the students' least important learning needs. There is an interesting correlation between the ranking of a need (based on the mean score) and its standard deviation. The top needs (2, 4, 10, and 11) display some of the lowest standard deviations. In contrast, the bottom needs (16 and 18) have some of the highest standard deviations. There seems to be, therefore, great certainly amongst this group with regards to which constitute the most important students' learning needs; however, when it comes to defining the least important, the data suggests doubt.

Students' learning needs considered of greatest importance by those lecturers who scored higher on the ITTF scale (top of Figure 2) were (in decreasing order of importance) problem solving skills (4), ability to apply knowledge in practice (11), time management (2), and ability to make sound judgments (10). At the other side of the scale, research skills (18), and ability to give oral presentations (16) were considered (in that order) as the least important. As before, higher mean scores are associated with lower standard deviations and *vice versa* (bottom of Figure 2).

Statistics from the nine lecturers which scored higher on the CCSF scale reveal the following preference: ability to make sound judgments (10), ability to apply knowledge in practice (11) and time management (2) (these two learning needs obtained the same mean score), critical thinking (3), and problem solving skills (4). Except for critical thinking, the same top students' learning needs are identified by both groups of lecturers. The order of importance, however, is teaching-approach dependent. In fact, there is a reversal in the order of importance assigned to the top learning needs. Whereas the "ITTF group" considered problem solving skills (4) as the top learning need, the "CCSF group" ranked this as the fourth most important need. Similarly, the ability to make sound judgments (10) was considered as the top learning need by the "CCSF group" of lecturers, whereas the "ITTF group" ranked this as fourth in importance.

Ability to give oral presentations (16), and research skills (18), were placed at the bottom of the list by both groups of lecturers; however, as before, the order of relative importance is teaching-approach dependent. Whereas the "ITTF group" considered ability to give oral presentations as the least important need in students of geo-engineering, the "CCSF group" considered research skills as the least important learning need.

4 DISCUSSION

Notwithstanding the limitations of the present study, some general comments can be made regarding current approaches to teaching and perceived students' learning needs within the areas of geotechnical engineering and engineering geology in Spain. As reported in the literature, there is evidence that lecturers in the "hard" disciplines, such as engineering, are more likely to apply a teacher-centered approach to teaching. The current study, where 67% of the participants scored higher on the ITTF approach scale, further confirms this finding. There are, however, a significant proportion of lecturers that favour the CCSF approach. The small number of participants limits the depth of analysis that can be performed at this stage; thus it becomes difficult to answer, for example, questions such as what is the effect of gender, teaching experience, or academic grading on the preferred approach to teaching geotechnical engineering and engineering geology. These have been left as a research questions for further study. Equally, it is not possible to compare relative percentages of lecturers in geotechnical engineering and engineering geology favouring one or the other teaching approach, with percentages derived from similar studies carried out on lecturers of other subjects included within the civil engineering curriculum. As before, this interesting research question is left open for further study.

Ability to apply knowledge in practice, problem solving skills, time management, and ability to make sound judgments have been identified as top learning needs by all lecturers which took part in the study, irrespectively of their teaching style. In addition, those lecturers with a higher score in the CCSF

[1] The number in brackets refers to the item number in the inventory (see also Table 1).

scale identified critical thinking as an additional top learning need. Despite similarities in their selection there is, however, a marked difference in the relative importance given to each of these, as inferred from mean scores. Whereas the "ITTF group" sees problem solving skills as the most important need, the "CCSF group" places ability to make sound judgments at the top of the list. This result seems to be in agreement with the idea of a content-focused and a learning-focused approach to teaching. In the present case, it is possible to see clearly how the emphasis of the content-focused group is on transmission of skills – in this case that of solving problems. The emphasis of the learning-focused group, on the other hand, is not so much on acquiring a particular skill, but rather on developing a general aptitude – that of being able to make sound judgments. The question, of course, remains as to what top learning need in particular, and what teaching approach in general, would be more relevant to a geotechnical engineer or an engineering geologist, as opposed, for example, to a structural engineer.

It is worth pointing out that all of the top learning needs identified by this particular group of lecturers correspond to those items grouped under the Management, Creativity and Analysis category (Table 1). Although no comments can be made at this stage, and the implications of this result are not clear, this constitutes, nevertheless, an interesting result deserving further study.

In terms of those learning needs perceived as having the least importance, the results should provide some ground for thought. In particular, the low score attained by the need to have the ability to give oral presentations contrasts markedly with the idea held in the profession that engineers – including geotechnical engineers and engineering geologists – need to develop sound communication skills, both written and oral, during their career. Referring to a quote included on a book on writing aimed specifically at engineers (Beer & McMurrey, 1997) and reproduced below:

Communication skills are extremely important. Unfortunately, both written and oral skills are often ignored in engineering schools, so today we have many engineers with excellent ideas and a strong case to make, but they don't know how to make that case. If you can't make the case, no matter how good the science and technology may be, you're not going to see your ideas reach fruition.

> George Heilmeiner, corporate executive of Bellcore, In "Educating Tomorrow's Engineers," *ASEE Prism*, May/June 1995, p. 12.

The limited relevance given to research skills, on the other hand, should not come as a surprise, given the nature of engineering and the expected career path of most graduates, which will lie outside a research environment. Yet, the profession expects engineers to innovate, and innovation requires a certain degree of skill in carrying out research (Bock, 2001).

5 CONCLUSION

The aim of this paper has been to present results from a small study aimed at determining lecturers' approaches to teaching and identifying students' learning needs from the lecturer's point of view within the context of geotechnical engineering and engineering geology in Spain. The study was performed on a sample of 27 academics. Each was handed a questionnaire consisting of two inventories: the Approaches to Teaching Inventory (Prosser & Trigwell 1999, Trigwell & Prosser 2004); and a second inventory designed by the last author of this paper and aimed at identifying students' learning needs from the lecturer's point of view.

Based on aggregate scores in the two scales identified in the first inventory, it was possible to separate between lecturers favouring a content-focused and a learning-focused approach to teaching. Results indicate that for the particular group of lecturers analysed, two thirds of the participants prefer the former to the later. This result is in agreement with findings previously reported in the literature. Results also show that this group of lecturers is more certain of the validity of a content-focused approach to teaching than a learning-focused approach. Evidence presented in the literature shows that there is a link between teachers' approaches to teaching and the quality of students' learning, and a content-focused approach to teaching has been associated with superficial learning on the part of the student. This is an important point to note when analysing current geotechnical engineering and engineering geology teaching and learning, as well as when planning improvements in the education of geo-engineers in Spain. It has not been possible, as part of this study, to investigate the influence of gender, years of teaching experience, and academic grade on favoured teaching approach.

Irrespective of the approach to teaching, there seems to be a general agreement on which constitute the most and least important students' learning needs from those included in the second inventory (Table 1). Both the learning-focused and the content-focused groups of lecturers identified all of the learning needs categorised under Management, Creativity and Analysis as being the most important. These include time management, critical thinking, problem solving skills, ability to make sound judgments, and ability to apply knowledge in practice. There is a difference, however, in the order of importance assigned by each group. Those learning needs identified as being least important to the student include ability to give oral presentations and research skills. As before, the order of importance varies between groups.

In light of the results presented in this paper, two main questions arise. On the one hand, what should be the appropriate approach to teaching geotechnical engineering and engineering geology in Spain. Published research indicates that a learning-focused approach would be more appropriate under all circumstances, since it promotes a deeper approach to learning. Nevertheless, a majority of the participants in this study – some of who have been teaching for over twenty years – favour a content-focused approach. The second question has to do with the reasons for not giving enough importance to communication in general, and oral communication in particular, by this group of lecturers. It is hoped that these two questions will guide further research on the topic of teaching geotechnical engineering and engineering geology, both in Spain as well as in other countries.

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APPENDIX 1: APPROACHES TO TEACHING INVENTORY (TRIGWELL & PROSSER, 2004)

1. I design my teaching in this subject with the assumption that most of the students have very little useful knowledge of the topics to be covered.
2. I feel it is important that this subject should be completely described in terms of specific objectives relating to what students have to know for formal assessment items.
3. In my interaction with students in this subject I try to develop a conversation with them about the topics we are studying.
4. I feel it is important to present a lot of facts to students so that they know what they have to learn for this subject.
5. I feel that the assessment in this subject should be an opportunity for students to reveal their changed conceptual understanding of the subject.
6. I set aside some teaching time so that the students can discuss, among themselves, the difficulties that they encounter studying this subject.
7. In this subject I concentrate on covering the information that might be available from a good textbook.
8. I encourage students to restructure their existing knowledge in terms of the new way of thinking about the subject that they will develop.
9. In teaching sessions for this subject, I use difficult or undefined examples to provoke debate.
10. I structure this subject to help students to pass the formal assessment items.
11. I think that an important reason for running teaching sessions in this subject is to give students a good set of notes.
12. In this subject, I only provide the student with the information they will need to pass the formal assessments.
13. I feel that I should know the answers to any questions that students may pot to me during this subject.
14. I make available opportunities for students in this subject to discuss their changing understanding of the subject.
15. I feel that it is better for students in this subject to generate their own notes rather than always copy mine.
16. I feel a lot of teaching time in this subject should be used to question students’ ideas.

Shaking the Foundations of Geo-engineering Education – McCabe, Pantazidou & Phillips (eds)

A tour through education sites for an engineering instructor: Major stops and impressions

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ABSTRACT: The ultimate goal of this article is to encourage engineering instructors to venture into the engineering education literature. The strategy adopted was to construct a graph of the main categories of literature on education and provide some commentary and key references for each category. This familiarization process has been likened to taking a tour, with the aid of a map (the graph) and a guide (text and references). The map organized topics from education literature in discreet sites, or stops, of theoretical (e.g. cognitive hierarchies) or applied (e.g. learning of engineering topics) interest. The article provides a description of every stop and the impressions of an instructor of geotechnical engineering who took the tour and recorded along the way comments on the tour itself and ideas stimulated by the tour stops, related to shortcomings and possible improvements of university education and geotechnical instruction. The development and testing of the tour pointed to needs for additional research and for identifying the most suitable crossing points between engineering and education.

1 THE NEED, A PROPOSAL FOR A TOUR OF EDUCATION, A PILOT APPLICATION

Despite an emphasis of funding policies on engineering education during the last two decades, results from research in engineering education often face significant barriers to widespread adoption into practice (NSF, 2010). More specifically, answers of 197 US engineering department chairs indicated an awareness rate of 82% but an adoption rate of only 47% for seven engineering education innovations amply described in the literature (Borrego et al., 2010).

Herein it is hypothesized that one possible strategy to increase both rates is to increase the proportion of engineering instructors who read the engineering education research literature and, hence, may feel more comfortable to incorporate some findings in their teaching. An additional premise of this article is that a selective, structured overview of the education literature may offer an engineering instructor a friendly point of entry.

This article proposes such an overview for an intended audience of engineering instructors who wish to become familiar with the education literature. A key element of the overview is a graph of eight main categories of literature on education. Each category is accompanied with a brief commentary and an eclectic selection of very few key references. Studying the overview was likened to taking a tour, with the aid of a map (the graph) showing the sites of interest (tour stops) and a guide (text and references). This article includes (i) the map, (ii) an abridged version of the text with the references and (iii) major comments resulting from a pilot trial of the tour and the ideas it prompted with regards to university education in general and geotechnical engineering instruction in particular.

2 A TARGETED TOUR OF EDUCATION SITES

2.1 *Methodology*

The proposed approach for the familiarization of engineering instructors with the education literature was modeled after traveling on a tour, because a tour has four attractive characteristics. First, it does not require a significant deliberate effort nor presupposes a commitment for in-depth involvement. If a tourist likes a site a lot, they may elect to spend more time in it, if not, they go on to the next site. Second, a tour may be taken in a self-guided mode or with the involvement of an intervening-upon-demand tour facilitator, in an interactive mode. This flexibility allows impatient or ambivalent tourists to opt for the self-guided option, while more relaxed tourists may appreciate the lack of responsibility and any added ad hoc contributions of the facilitator. Third, a tour only includes a selection of sites. There rarely exists a canon for all the stops of a tour, and sophisticated tourists often appreciate being guided to little known uncrowded treasures. Also related to site selection, tourists signing on tours should know in advance the program of the tour, a requirement fulfilled by the map of education. Last, and perhaps most important, a tour is customarily linked to tour impressions, often noted in postcards or diaries meant for others or just for personal use. The above characteristics combined make it less overbearing to suggest to an academic colleague to take the tour and record (or e-mail) impressions, as an added option, than to participate in a seminar and submit homework. By design, the proposed setup shifts the focus of evaluation from the tour participant to the tour itself.

The tour material was put together by the first author of this paper, a civil engineer by training whose activities in the field of engineering education in the last 15 years include, apart from faculty positions in civil engineering departments, a year as a visiting scholar at the Graduate School of Education of UC Berkeley in 2000–2001 and active participation in international committees and networks for engineering education.

As a first test of its potential usefulness, the selective overview of education was used in a pilot tour and at the same time subjected to a review by the second author of the paper, a geotechnical engineering instructor with 5 years of practical experience, and 20 years of teaching experience including 10 years of overlapping administrative experience, who assumed the dual role of tourist-reviewer. In this dual capacity, he offered comments both on ideas generated by the material studied and on the familiarization procedure itself, which are included in Section 3. However, when the roles conflicted the tourist had clear priority, for example, there was no obligation to comment on any dull sites. While preparing the tour guide, the first author also recorded ideas relevant to geotechnical education and related to tour materials, which are also included in Section 3.2.

2.2 *Why a map of education for an engineering instructor?*

This section addresses the weak relationship between engineering education research and practice and puts forth an argument on how a map of education may strengthen it. For some educators involved in day to day teaching, the boundaries between the practice of education and education as a research field are blurred. Others are aware of the distinction between the two, but do not see the usefulness of engineering education research. This reservation is legitimate in the absence of a good number of publicized examples of research results effectively translated into practice (NSF, 2010) in a transportable manner, i.e. adopted in the practice of educators without the involvement of the researchers producing the results. The barriers to be faulted for the lack of awareness are likely to be mainly institutional. It is possible, however, that the skepticism towards adopting engineering education innovations has deep epistemological roots.

The engineering education literature has identified some conceptual difficulties that may be experienced by engineering faculty members as they become engineering education researchers (Borrego, 2007). Such a "difficulty analysis" is missing for engineering faculty at an earlier stage of commitment, when they may consider becoming familiar with some of the education literature. For both categories, the fundamental differences between engineering and education form an important barrier that must be overcome. Borrego (2007) identifies level of consensus as a useful measure of differences among disciplinary fields:

> *"[…] fields with higher level of consensus (engineering, physics) have a tighter integration of knowledge that makes it more risky to attempt a contribution because errors and sloppiness can be more easily detected by others. In fields with less consensus (education, communication), standards of rigor are not as clearly defined and enforced."*

As a consequence, in fields with less consensus, it is more difficult to know what to trust, especially for an outsider unaccustomed to the coexistence of multiple explanatory frameworks or of alternative competing theories. Such is the dilemma of an engineering faculty member approaching education.

The epistemological barrier between engineering and education is compounded by some initial clumsiness or even discomfort potentially experienced by experts when venturing outside their field of expertise. Experts are used to working confidently and efficiently. This confidence of experts results from a variety of attributes and skills: among the foundational attributes is a highly organized structure of specific knowledge (Glaser & Chi, 1988).

Thus, a map of education, such as the graph shown in Figure 1, may help thematic field experts venture into the field of education with a semblance of knowledge structure. To this end, the map is drawn at a coarse level of detail to include only eight groups (I to VIII) of topics. A map may appeal to engineering experts in particular, who tend more to favor graphs over text, compared to their humanities and social science counterparts. Clearly, the map projects the applied perspective of engineering instructors who are mostly interested in finding material relevant and, ideally, useful to their teaching engagements. From this perspective, groups I to VI can be viewed as "theory" and groups VII and VIII as "applications". Topics most useful to engineering instructors (VI and VIII) occupy the center of the graph to stress the applied orientation of the map and the tour.

2.3 *Tour guide & tour stops*

The tour guide consists of a one- to three-page text for each stop. Somewhat abridged versions of the stops are included in Sections 2.3.1 to 2.3.8, together with brief additional commentary. Altogether, the guide is a 20-page long handout. The text is written in a personal tone, which is more suitable for taking the tour in an interactive mode. Texts of early stops include specific questions as a warm up. The text for each stop includes a few references, one to six depending on the stop, of mostly optional reading. From those references, some are highlighted as recommended reading in stops of more applied interest. Copies of a subset of

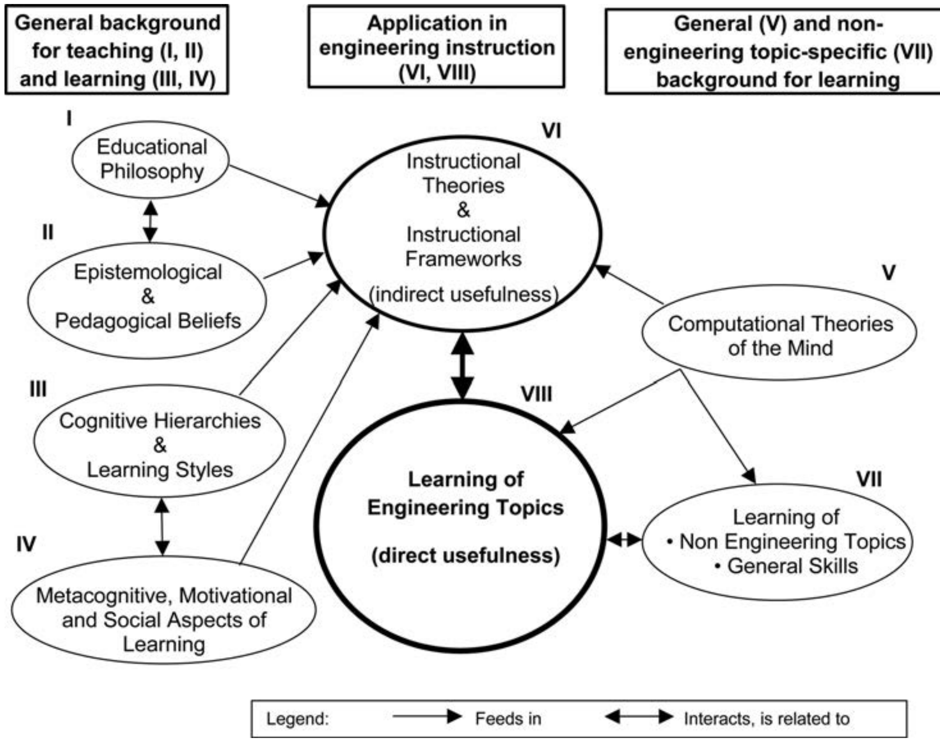

Figure 1. Main groups of topics from the education literature of potential interest to an engineering instructor: Theory (I to VI) and applications (VII & VIII). The center of the map is occupied by topics of immediate relevance to applications in courses (VI) and in particular engineering courses (VIII).

the references, including all the recommended papers, are made available for their easy perusal by tourists. These recommended readings are indicated with an asterisk in the list of references at the end of this paper.

2.3.1 *Educational philosophy (I)*

Instructors are bound to make many instructional decisions on the basis of their educational philosophy, however fragmented or tacit it may be. Inspirational books that help an educator form or enunciate a personal educational philosophy are those with a clear position on the goals of university education, and specific links between these goals and instructional practices. From the inspirational book category, the one-page guide for the first stop selected the book by Bowden & Marton (1998), which clearly adopts the view point of learning (what students do) instead of that of teaching (what teachers do). The guide concludes Stop I with asking for any additional worth-mentioning writings with an educational philosophy component.

Among other usable pieces of wisdom, Bowden & Marton (1998) say about the relationship between learning and discernment:

> *"To discern an aspect is to differentiate among the various aspects and focus on the most relevant to the situation. Without variation there is no discernment."*

This excerpt is characteristic of most philosophy: when understood, the same idea may appear apocalyptically powerful or trivially obvious. As a guide for teaching, the quote by Bowden & Marton (1998) reminds an instructor that if students are routinely taught only one solution method per class of problems, they do not practice discerning the characteristics of a problem that make a method adequate for solving it. As a result, when students are asked to assume the role of a practitioner and choose among hypothetical alternative approaches, they tend to opt for the more accurate (difficult and expensive) solution method, an assortment of necessary and superfluous information, extensive sampling, etc. On a more topic-specific level, the emphasis of Bowden & Marton (1998) on variation will become useful in later stops involving student learning.

2.3.2 *Epistemological and pedagogical beliefs (II)*

This stop concerns beliefs about (i) the nature of knowledge and knowledge acquisition (epistemological beliefs) and (ii) how can instructors facilitate this knowledge acquisition (pedagogical beliefs). It is the belief (!) of the first author of the paper that instructors' epistemological and pedagogical beliefs, her own included, are an amalgam of material originated from sources varying from scientific evidence to unquestioned lay wisdom. To avoid treading on any cherished belief, the one-page guide for Stop II only invites the reader to consider some prompts for epistemological and pedagogical belief detection:

- one scientific truth or different personal constructs of reality?
- can we separate cognitive skills from content?
- is there a difference between everyday learning and university learning and/or should there be?
- the differences between education levels (e.g. high school, college, graduate school) are in degree (e.g. "more of the same") or in kind?

The text does not provide answers, nor does it discuss the inspiration for the questions. For alternative ideas on the different kinds of learning, the reader is referred to Laurillard (2002), whose opinion is that everyday learning is making sense of personal experiences, while academic learning is making sense of the accumulated experience of others. Clearly it is beneficial to have academic learning include experiential learning. However, an individual learning only from personal experiences is bound to have a limited repertoire.

Even if not of immediate application, Stops I and II deserve more attention by instructors and education researchers. The task of education researchers is dual. At a minimum, they should openly acknowledge in their writings their own beliefs. In addition, the engineering education research community should (a) design opportunities for communities of instructors to acknowledge, crystallize and modify beliefs and (b) undertake research projects to uncover beliefs and unstated links to instructional decisions.

2.3.3 *Cognitive hierarchies & learning styles (III)*

The two-page long guide of Stop III includes pieces of education literature, which are among the best known to engineering educators. The term "cognitive hierarchy" refers loosely to the developmental stages of the learner or to the increasing levels of sophistication of cognitive tasks a learner can engage in successfully. A note of caution: as with many education-related writings, the reader should question whether these hierarchies are constructed mostly on the basis of evidence (i.e. following a "what is", descriptive approach) or expert opinion (i.e. following a "what should be", prescriptive approach). Another cautionary note concerns pieces of work that, without stating it explicitly, put forth a prescriptive hierarchy of learning tasks, which can be misinterpreted as a hierarchy of developmental stages.

An example of a descriptive approach is Perry's (1981) study with undergraduate college students, which shows the potential changes of their epistemological beliefs, starting from (i) a dualistic, "right-wrong" belief and an expectation that an authority will tell apart right from wrong, then allowing for (ii) multiplicity, which acknowledges diversity and uncertainty, moving on to (iii) relativism, where the self is viewed as active maker of meaning, and finally reaching a stage of (iv) commitment to certain values within a relativistic framework. Perry (1981) places more emphasis on the transitions between the four positions, and considers the transition from multiplicity (ii) to relativism (iii) as the most critical junction for the teacher and the student, a transition that requires "the capacity for meta-thought, for comparing the assumptions and processes of different ways of thinking".

An example of a prescriptive approach is the hierarchy of educational objectives known as "Bloom's taxonomy". The taxonomy was developed by a committee of college and university examiners. The committee set out to describe in testable ways the components of what some educators mean by "understanding", "deep understanding", "grasping the essence", etc., when referring to desirable student achievements. The taxonomy was published in a handbook edited by Bloom and coworkers (Bloom et al., 1956), hence the name, and proceeds from (1) *knowledge* (recall of specifics, methods, abstractions, etc.), to (2) *comprehension* (make use of materials without necessarily relating them to other material), (3) *application* (use abstractions in particular situations), (4) *analysis* (construct explicit relationships between ideas), (5) *synthesis* (put together elements to form a whole not known in advance) and (6) *evaluation* (judge value of material or methods for given purposes). Bloom's taxonomy, suitably re-annotated for engineering, is used in ASCE's Book of Knowledge (BOK) to describe levels of achievement expected by civil engineering graduates and licensed civil engineers for each of the 24 outcomes in BOK (ASCE, 2008). For example, whereas in outcome "mathematics", level 3 (application) is adequate, outcome "mechanics" requires a level 4 (analysis) for a graduate with a bachelor's degree.

Even engineering instructors completely unfamiliar with the educational literature may have heard of the notions of learning styles, mostly due to often reproduced critiques of instructors who do not strive to tailor instruction to the students' style, which is, presumably, different from the instructors' style. Laurillard (2002) touches briefly on the learning styles literature and concludes with a note of caution that there is no evidence suggesting that these styles are student-specific (i.e. they are rather both student- and task-specific). Perry (1981) also cautions against confusing a supposedly entrenched learning style with an epistemological position under development and subject to modification. In consonance with these cautionary writings, the guide includes only one reference from the literature on learning styles, which argues that knowledge of styles is not meant to guide instructors to match the students' styles but rather to offer a variety of learning tasks in order to both accommodate every student and at the same time help all students stretching in less preferred modes of work (Sharp et al., 1997).

2.3.4 *Metacognitive, motivational & social aspects of learning (IV)*

This stop was originally meant to include the aspects of learning that could not be viewed as "purely cognitive" (if such a decoupling is possible) and, hence, was named "motivational and social aspects of learning".

This is a large and mixed body of literature, concerned with the psychological experiences of learning (including issues of confidence and perceptions of self worth) and the human interaction aspects of the learning experience. In the latter category belong assertions that "learning is a social activity" and, hence, addition of any social aspect to learning is considered as good (although this conflicts with some of the "learning style" theories, according to which certain styles do not enjoy group work).

On further consideration, it was decided to also include domain-independent metacognitive aspects of learning, for which a suitable place is not apparent. The metacognitive aspects of learning refer to the second-level thoughts about the learning process and about its results (let us say in engineering terms, the "quality control and quality assurance" of learning), including a self assessment of ability. Alternatively, they could be thought of as characteristic skills of a mature cognitive development stage and, hence, included in Stop III. Or they could be discussed together with topic-specific metacognitive aspects of learning. Whereas the most suitable categorization remains open, it was decided to include them in Stop IV, partly as an opportunity to highlight the article by Kruger & Dunning (1999) on self assessment, in which many instructors will recognize inaccurate self-assessments of their own students. The main title of the article summarizes its essence: "Unskilled and unaware of it". Kruger and Dunning (1999) consistently found that incompetent participants grossly overestimated their performance and also were less able to assess competence of others. On the basis of their results, Kruger and Dunning argue that

> "*people who use incompetent strategies to achieve success, they suffer a dual burden: not only they reach erroneous conclusions […], but their incompetence robs them of the ability to realize it.*"

On the contrary, at the high end of performance, competent participants underestimate how well they have performed. However, the problem here is not cognitive but lack of information: these students assume that others are like themselves and have also done well. Once competent participants were shown the work of others, they were able to revise their performance and gauge better their percentile ranking.

2.3.5 *Computational theories of the mind (V)*

Stop V is concerned with parsing knowledge, assuming it is possible to do so. If indeed knowledge can be parsed meaningfully in constituent components, this is very useful for instructional purposes. Hence, a dedicated stop. Some parsing attempts were either inspired or reinforced by the way computers work. That is why this stop is named "computational theories of the mind". From Stop V, it is worth keeping as a souvenir one very useful idea:

> *knowledge can be broken down into two categories: "declarative knowledge" ("know that" type of knowledge) and "procedural knowledge" ("know how" type of knowledge).*

According to Anderson and Lebiere's (1998) theory of cognition, declarative knowledge (know that) can be broken down in chunks, upon which procedural knowledge (know how) operates via production rules.

Cognitive psychologists' theory of "knowledge decomposition" is applied to instruction as "task analysis". Gardner (1985) defines task analysis as "a decomposition of a complex task into a set of constituent subtasks", aptly remarking that "traditionally, educators have performed intuitive task analysis to make the job of instruction more manageable". As with most theories in education, instructional task analysis makes the intuition of seasoned instructors more systematic and, most useful to others, more visible. Also as most theories in education, instructional task analysis is meaningful to instructors mainly through applications (examples) in a thematic field close to their own. This is because the specific breakdown and the interactions between "know that" and "know how" seem to be domain specific (Gardner, 1985). Examples of interest for a civil engineering curriculum include complete task analysis in statistics (Lovett, 1998) and statics (Steif, 2004) and partial task analysis in modeling of engineering systems (Pantazidou & Steif, 2008).

Task analysis helps the instructor teach a complex skill, such as design or modeling, in lieu of the alternative "watch me do it". At the same time, task analysis allows the students to see the subparts of a skill and, most importantly, to practice them individually. Although performing individual subtasks may be the end goal in a particular introductory course, from the perspective of a learners' cognitive growth, it will be a means to move up the ladder of performance. This is the perspective through which Dreyfus & Dreyfus (1986) provide additional support for the educational approach of breaking a task into steps and forming rules, while at the same time stressing its limitations. They argue that steps and rules are useful to novices. They claim that learners do not progress abruptly from "know that" (e.g. know the steps or the rules) to "know how" (e.g. selecting the right steps or using the rules in the appropriate circumstances). On the contrary, instruction and experience takes learners through up to five levels of skill: novice, advanced beginner, competent, proficient and expert. The novice starts with some facts and some rules based on those facts. These rules continue being useful for the next skill level as well, because rules allow advanced beginners to accumulate experience, playing the role of training wheels in children's bicycles. But then, exactly as learners need the rules in order to progress throughout the beginner's level, they need to leave aside the rules in order to progress to the next levels.

2.3.6 *Instructional theories & instructional frameworks (VI)*

From the instructor's perspective, often the "core" of teaching is the activities planned by the instructor and involving the students (classroom lectures included).

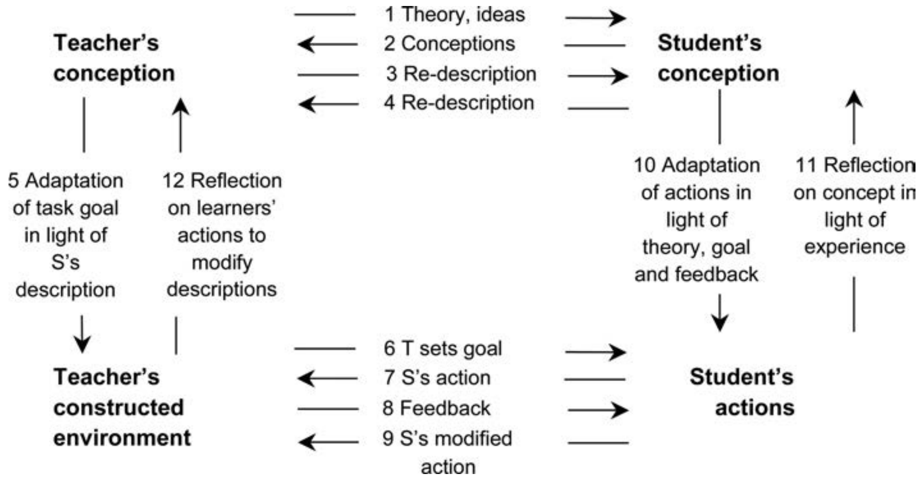

Figure 2. The conversational model identifying the activities necessary to complete the learning process (from Laurillard, 2002).

This is why "Instructional Theories & Instructional Frameworks" occupies a central position in the education map in Figure 1. It is hoped that every instructor will find something usable for course planning in this stop, which is the final stop in the "theoretical" part of the map (the last two stops are content-specific) and, together with Stop VIII, the longest of the tour guide (three-page long).

Regarding instructional theories, it should be reminded that the research base of education rests on methodologies of the social sciences and, hence, engineering instructors may experience discomfort (Borrego, 2007) if expectations are set high. To preempt disappointments, instructional theories may be better described as hypotheses, which, with time, are supported with more evidence. Similarly to Stop IV, instructional theories are perhaps most useful in a retroactive sense, i.e. in supporting a practice of teaching that already appeals to the instructor. One such example of instructional theory is "inductive teaching". Prince and Felder (2006) discuss alternative methods for inductive teaching and learning and the existing evidence in support of such methods. Engineering instructors who are inclined to first give some examples before teaching theory will appreciate this article, as well as proponents of project-based and problem-based learning.

Instructional frameworks consist of a collection of general rules or steps that guide the decisions of an instructor planning a lecture or a course, or designing interventions and instructional materials. One such framework is given by Laurillard (2002) for the design of teaching material in four stages. The framework is based on a "conversational model" proposed by Laurillard to describe the desired interaction between teacher and student, which is shown in Figure 2. Laurillard's interaction model concerns four pillars of the learning process: i) what goes on in the teacher's mind ("Teacher's conception", top left), ii) what goes on in the student's mind (top right), iii) the environment created by the teacher for the student (bottom left) and iv) the student's actions (bottom right). Laurillard considers a discursive part of the learning process (activities 1–4 in Figure 2) as the students communicate their conceptions to the teacher, eliciting a re-description, if necessary (these are the interactions between teachers and students at the level of ideas). There is also an adaptive part, as the teacher modifies the environment created for the student (activity 5) and the students adapt their actions (activity 10). The interactions between teachers and students at an action level include the responses of students (7) to the given goal (6) and feedback by the teacher (8), which is followed by modified student actions (9). Finally, there is a reflective part, which apparently can go on asynchronously with the student-teacher interaction, resulting on the part of the learner in a comparison of the concept with experience (11), hopefully integrating the two, and on the part of the teacher in modifying teaching (12). Laurillard considers that these 12 activities are required to complete the learning process and, hence, this premise may be classified as an instructional theory or hypothesis.

However, it is not necessary for the instructor to agree with the model describing the teacher-student interaction depicted in Figure 2 in order to benefit from the methodology put forth by Laurillard (2002) for the design of teaching material or activities, which includes the following four main stages:

(1) Stating learning objectives, using as sources primarily the experts of the thematic field, but also taking into account the performance of students. When Laurillard's book first came out in its 1st edition (1993), this first stage could be considered as innovative. Today, designing courses and study programs on the basis of learning outcomes and competences is widely regarded as a good practice (ASCE, 2008) and is often required (ABET, 2011).

(2) Recognizing students' needs by asking diagnostic questions to find out what the students actually learn. Bowden & Marton (1998) provide guidance on how to formulate suitable diagnostic questions, which are typically qualitative and expressed in an everyday language, avoiding as much as possible technical terms. Several such studies are available in the literature. One example related to physics is described in Stop VII (Bowden et al., 1992) and two examples related to civil engineering are included in Stop VIII (Pantazidou, 2009; Steif, 2004).
(3) Designing learning activities and teaching materials, which, according to Laurillard (2002), collectively should cover all types of activities depicted in Figure 2.
(4) Testing and refining is the final stage, which will require several iterations especially for computer-based tools of wide dissemination.

It is useful to present a second framework for comparison purposes, the scaffolded knowledge integration framework (SKI) (Linn, 1995). The SKI framework also involves four main stages: (1) identify key topics, identify goals and specify student outcomes, (2) identify student mental models (what students learn), (3) design learning environments fostering autonomous learning and provide support and (4) through assessment, refine the student mental models, student outcomes and learning environments. A comparison of the two frameworks reveals that their differences are due mainly to the sine qua non of learning assumed by the two researchers, i.e. the "conversational model" of Laurillard (2002) and the emphasis of Linn (1995) on providing scaffolding for the student's learning experiences, while at the same time offering opportunities for autonomous learning. Another similarity worth noting is in the analogies used by instructional theories, e.g. "scaffolding" by Linn (1995) and "training wheels" by Dreyfus & Dreyfus (1986), both of which should, ideally, be removed before graduation.

2.3.7 *Learning of non-engineering topics & general skills (VII)*

The last two stops concern the vantage point of the learner for specific topics: the emphasis is removed from what or how the learner should learn and placed on the actual learning experience of every learner. By necessity, what is known about the learning experience is revealed by either observing learners engaged in suitable tasks, or by directly asking the learners themselves, or by combining the two approaches. Research shows that the variation of the learning experiences is limited and, hence, they can be grouped in a few categories (Bowden et al., 1992; Bowden & Marton, 1998). Widely researched topics are those studied in primary (e.g. reading, arithmetic) and secondary education (e.g. mathematics, physics). At the university level, topics researched are typically introductory subjects taught to large audiences, such as statistics and programming, as well as general skills, such as text reading and problem solving.

The interest of the studies belonging in this stop lies, for the engineering instructor, not in their contents per se but in the content types. Some studies reveal the different ways students approach the same task. Bowden and Marton (1998) give such an example for the task "learning from texts", based on research conducted with university students reading the same text: some students choose to focus on memorizing facts from the text, others on identifying the structure of the arguments made in the text. A subcategory of studies focuses on identifying typical student misconceptions, i.e. the different ways students can "get it wrong": this is the type of information needed in Stage 2 of the instructional frameworks discussed in Stop VI. Other studies compare characteristics of the performance of novices (e.g. undergraduate students) and experts in a field (e.g. PhD candidates or professors). Comparisons of experts-novices engaging in physics problems have shown that experts engage in qualitative analysis before solving equations, they categorize problems correctly early on and then, correct categorization leads them to deploying relevant declarative and procedural knowledge (Chi et al., 1981).

Stop VII has as recommended reading one paper on students' understanding of concepts in physics (Bowden et al., 1992). The paper stresses the importance of conceptual understanding, which is often downplayed in engineering. Moreover, it gives a succinct description of the theoretical framework used to discover the "qualitatively different ways in which people experience, conceptualise, perceive and understand various aspects of, and phenomena in, the world around them". For the physics concepts studied in the paper, a few different categories of description are identified and ranked in terms of explanatory power. The authors stress that some of the less powerful understandings do not preclude students from deriving correct quantitative solutions and argue that the lack of conceptual understanding will create problems in later years in subsequent courses. In fact, studies have shown that students able to solve correctly a conventional problem asking for a numerical answer (following a "problem-solving strategy"), fail to answer correctly its conceptual counterpart asking for a trend in phenomena observed (Mazur, 1997).

2.3.8 *Learning of engineering topics (VIII)*

Visitors arriving at the last stop are reminded that the tour is designed for two groups of engineering instructors. One group is made up of those instructors who may enjoy acquiring a broader-than-usual perspective on education. The other group includes those who may also contemplate using results of engineering research in their own teaching and formulating research questions of applied relevance to the teaching of their discipline. The contents of the last stop were chosen primarily with the latter group in mind. They include two topic-specific examples of unpacking students' understanding of engineering concepts.

The first is a small-scale example of probing students' understanding of a geotechnical concept. The scale of the probing activity is such that every instructor can adapt it to most teaching situations. The second example is a large-scale research effort on compiling a complete inventory of the key concepts in statics and of the types of errors students make when solving statics problems. The description of the two examples, which follow below, places emphasis on results that are directly usable by other engineering instructors teaching these topics. Stop VIII closes with a comparison of the theoretical underpinnings of the two examples, drawing on material from earlier stops.

Example 1: The concept of soil structure

Soil structure refers to the arrangement of the soil particles relative to each other and to what holds them together. Although soil structure may be considered a foundational topic of geotechnical engineering, it is seldom discussed at significant depth in courses on soil mechanics or geotechnical engineering, with the possible exception of instruction on the structure of clays. Pantazidou (2009) reports on what students believe about soil structure as revealed by the associations they make with soil characteristics such as permeability and porosity (porosity is the volume of the space among soil particles divided by the total soil volume). The motivation to undertake this work was the observation that many students appear to be confident that clays have small pore space, which very often is not true. Following the tradition of Bowden & Marton (1998), Pantazidou posed the following qualitative question to the students:

> *"In your opinion, in which type of soil you may encounter a higher porosity, in a sand or a clay? How do you justify your opinion?"*

Students typically answer "in a sand" (incorrect answer). The justifications students gave for this answer can be grouped in a few categories, as already mentioned in Stop VII (Bowden & Marton, 1998). The two most popular categories of explanations involve the larger pores of the sand and the higher permeability of the sand (both correct observations). The remaining justifications involve a few physical characteristics of sand (sands flow), indirectly related to porosity (sands compact easily) or permeability (sands dry easily). The hypothesized relationship between pore size and porosity is a misconception, whereas the relationship between permeability and porosity is an overgeneralization. With regards to permeability, when the porosity of a given soil decreases, its permeability indeed decreases as well. However, generalizations across different soils cannot be made without data on their structure. Based on this analysis of the students' conceptions, Pantazidou (2009) goes on to suggest specific interventions, in the form of laboratory demonstrations and simple calculations for model porous media. Although other instructors may find some of the interventions suitable for their courses, it should be stressed that the potential of the interventions to remedy the misconceptions has not been formally assessed.

Example 2: Statics concept inventory

Statics is an introductory course of most civil and mechanical engineering curricula and involves Newtonian physics for the solutions of various multi-body mechanisms at rest (i.e. being in static equilibrium). Mechanical engineering professor Paul Steif has taken a comprehensive approach to teaching and learning of statics and presented his work in a series of publications, from which a selection is included in the tour guide. As a first step, Steif (2004) defined the constituent elements of statics itself and analyzed students' work on statics problems. According to Steif (2004), a typical statics problem can be decomposed to (i) parsing the system, (ii) reasoning about forces connecting parts, (iii) isolating bodies to impose equilibrium conditions and (iv) applying the equilibrium principles to selected bodies. Using his knowledge of statics, Steif identifies a minimal set of four key concept clusters (or "elements of declarative knowledge", following the terminology from Stop V) and four fundamental implementation skills (or "elements of procedural knowledge"). On the basis of his experience with teaching statics, Steif identifies 11 common errors students make, each one relevant to a subset of the aforementioned concepts and skills. Identification of errors at the fine-grain level of key concept or fundamental skill is necessary for targeted diagnosis and intervention. This first publication can be useful to other instructors of statics interested in making comparisons with their own experiences from teaching statics.

As a second step, Steif developed a series of problems accompanied with multiple choice questions, grouped in five classes of typical statics problems (free body diagrams, equilibrium conditions, etc.). Each problem includes one correct and four wrong answers. Each wrong answer represents a correct calculation based on one of the identified misconceptions. One such problem would concern a multiple body and rope system, and the question asked would address the forces in the free body diagram of a subset of blocks and chords. These questions were the basis for developing a Statics Concept Inventory (SCI) of 27 questions, covering the aforementioned five classes of problems (Steif & Dantzler, 2005). Steif & Dantzler (2005) and Steif & Hansen (2006) present results from statistics tests run to ensure that the questions span a wide range of difficulty, that each question indeed tests a specific knowledge chunk, that the SCI correlates to some independent measurement of "ability in statics", etc.

The statics concept inventory is made available to instructors of statics and students in their courses upon request, as a web-based application. The entire concept inventory test can be given to students before and after instruction to gauge the gains in student performance (Steif & Dantzler, 2005). Alternatively, selected questions can be given to students with the additional request of providing written justifications in order to support the selected correct answer and explain what is wrong with each of the other four (Newcomer & Steif, 2008). Such a detailed approach makes the students' thinking visible to the instructor and allows targeted interventions for specific misconceptions. In addition, the instructor can invite students to critique answers given by other students; an in class approach found to be very useful also by Pantazidou (2009).

A comparison of the two pieces of work reviewed in this stop shows that they diverge in their underlying theoretical underpinnings. Pantazidou (2009) investigated students' understanding of soil structure in the tradition followed by Bowden et al. (1992) in Stop VII for physics problems, according to which "each phenomenon, concept or principle can be understood in a limited number of qualitatively different ways". Herein, the research problem lies in formulating suitable questions and grouping the answers in suitable categories of description, which are not predetermined but they are an outcome of the research itself. Steif (2004), on the other hand, based his work partly on the task decomposition ideas presented in Stop V, which seem necessary for the development of a comprehensive concept inventory. Student errors were associated to these pre-determined concepts, in an iterative fashion. At the same time, the two pieces of work reviewed in this stop share one important methodological element, i.e. their data-gathering approach: they were both based on what students believe about engineering concepts or do when engaged in engineering tasks (recall that this is the work carried out in Stage 2 of the instructional frameworks reviewed in Stop VI). Hence, it is hoped that they may serve as examples to other engineering instructors interested in finding ways to learn from their own students about how students themselves learn.

3 IMPRESSIONS FROM THE TOUR

3.1 *Impressions from the touring process*

Overall impressions of the tour were that it provided an engaging and creative framework within which to merge education and engineering topics. As conceived and presented, it required the tourist to accept that it was a tour of a set of relatively mature and thus "static" sites. This may be a vestige resulting from the fact that tours are often given of "historical" sites. The reality is that universities (and indeed all educational institutions and the methods and approaches they use) may be at one of the most "dynamic" periods in their history and so a tourist who is open to change may be more challenged to be accepting of the currently included sites only. Possible approaches to addressing this challenge could be either to add an additional site or two that discusses how the role of both information maturity (e.g. content) as well as delivery maturity (e.g. content consumption) is changing, or to embed additional comments and references in each of the existing sites that describe how that particular factor or consideration may be forced to change with time.

3.2 *Impressions related to university education & geotechnical instruction*

Stop I, educational philosophy, resulted in a very clear stance in favor of also considering other approaches such as the "teach by questioning" mode, a variation of the Socratic approach, minus its slightly condescending overtone. It starts from a question asked by a student, who is then guided through a series of intermediate questions to come full circle and answer the initial question themself.

Likewise, the questions from Stop II reaffirmed a strong belief in active student involvement in learning. The prompt on the possible distinction between everyday and university learning identified memorization as an undesirable characteristic that makes university learning different. The prompt for differences between education levels resulted in the answer "both (in degree and in kind)" by the authors of this paper. The "difference in degree" belief places emphasis on increasing responsibility placed on the students for their own learning as they advance, with the instructor offering at early stages support and later encouragement when students falter. The "difference in kind" belief (or wish!) allows for the possibility of adding new, emergent cognitive skills at advanced education stages (e.g. PhD studies).

Comments on material in Stop III reflected a tacit acceptance of the cognitive stages identified by Perry (1981), judging from the comment that the educational system is to a large extent responsible for students not progressing much beyond the dualistic right-wrong stage, if they are routinely rewarded for recalling the correct information at earlier stages of their education. This realization, when true (often), creates an obligation and an opportunity for the university to break from this tradition from day 1 and match instruction techniques and performance outcomes to the different stages of cognitive growth. The practice of engineering is characterized by uncertainty and relativistic elements in undertakings such as modeling or design. Notions of students on uncertainty and relativism are in the heart of Perry's (1981) scheme. Geotechnical engineers in particular, revere judgement as a means of coping with uncertainty and open-ended problems (Peck, 1991). The more mature epistemological positions of Perry's scheme have the potential to guide explicit instruction on horizontal skills, such as modeling, as well as on the constituent components of geotechnical judgement. As a more modest and generic goal, engineering programs may aim to produce graduates at the mature end of Perry's scheme, ready to handle responsibilities (e.g. decision making) of a technical nature in practice.

Bloom's taxonomy was identified as a suitable intersection point for engineering and education. In order to make educational methods more approachable to engineers, it was suggested to draw analogies to engineering methodologies that follow the same pattern. The method proposed by Leonards (Leonards & Frost, 1992) for investigating failures, independently of Bloom's taxonomy, provides an example of a step-wise procedure involving comparable steps of increasing complexity. The short introduction to learning styles was, as intended, able to draw a critique on how we go about deciding what is worth measuring. The tour guide includes a figure adapted from Sharp et al. (1997), which shows the distribution of a group of students in the four quadrants of the Kolb learning style graph, defined by two axes that measure preferences for information perception (abstract vs concrete) and information processing (reflecting vs experimenting). Noting that both measures have elements of passive vs active involvement, it was argued that it would be more helpful to have as alternative axes "level of involvement" and "type of input" (qualitative vs quantitative).

The metacognitive aspects of learning of Stop IV prompted thoughts on the common assessment methods, such as homework, quizzes and exams, most of which involve delayed feedback. These traditional methods were contrasted with direct feedback loops made possible by flashcards used in class (Mazur, 1997) or, more recently, clickers (http://net.educause.edu/ir/library/pdf/ELI7002.pdf). This immediate feedback may also be useful for students in that it can help address the "unskilled and unaware of it" syndrome (Kruger & Dunning, 1999).

The focus of Stop V on knowledge decomposition in chunks was received with apprehension. The reality is that most things are continuous and the only reason they get broken down into "fragments" is to simplify the presentation of them. Unfortunately, all too often, instructors become focused on the fragmented nature of the material and fail to reinforce that the fragmented descriptions are for illustrative purposes and the true nature of the material is still continuous. A perfect example is the description of learners in five levels of skill – this is a convenience for describing learners but it imposes artificial discrepancies on how individuals are perceived. Further, since only a partial set of factors is often included in assessing learning skills, it was judged as even more disappointing to divide people into artificial categories.

The methods of identifying student misconceptions and specifically the examples given in Stop VIII received a strong critique. A concern was expressed that students are, whether by omission or commission, led to provide the wrong answers, instead of being guided to discover for themselves the correct ones. This is a valid concern: the issue of whether and when identified errors may be artifacts of questioning methods will be addressed in subsequent versions of the guide. For the clay/sand question, the response is clearly impacted by one "sensor" – the optical system – without the advantage of any sensor augmentation. The human eye has the ability to discern individual sand particles however it cannot discern clay particles. If, however, the students were provided a scanning electron microscope (SEM) photo of clay particles (augmented optical image), many might respond differently to the posed question.

An example of addressing this need for guidance is given herein for the concept of geotechnical interfaces. The example illustrates how multiple sensory systems and "teach by questioning" can be combined to assist in unpacking students' understanding of engineering concepts. In introducing the topic of geotechnical interfaces to students, the following approach is used. The students are first asked to describe the roughness of the surface of the desk they are sitting at. Students typically look at the desk surface for a few seconds and while a small percentage respond "smooth" most eventually extend their index finger, place it on the surface of the desk and move it back and forward a few times before responding "smooth". Those who respond after only looking have limited their study to using one sensor only, the optical sensor, while those who use their index finger are adding a second tactile sensor. Obviously they are using their index finger as a stylus, albeit with a tip diameter of about half a centimeter. While they typically provide the same response due to the low resolution of the stylus they have used, they have nonetheless used two sensors and fused the sensor outputs before responding. While it doesn't change their response, it does show recognition of the importance of acquiring as much information as possible before responding. At this stage, the instructor asks that the students consider shrinking themselves down to the size of a clay particle and then answering the same question. While most go through the exercise of looking and touching the surface again, a high percentage of their responses now range from "quite rough" to "very rough". In other words, by simply asking the students to consider scale, they immediately recognize that their response needs to be given in relative terms. By considering themselves at the scale of clay particles, they are in effecting "augmenting" their optical and tactile sensor systems. Identification of the importance of scale frames the recognition to undertake all subsequent discussion of interfaces within the context of relative rather than absolute roughness.

4 DIRECTIONS OF FUTURE WORK

4.1 *Within the education community*

It was already mentioned that the tour material was developed by a civil engineer by training, introduced to education mainly by self-study, i.e. a "non-native of education". While this dual background offers the possible advantage of relating to the potential engineering tourists, it cannot offer the depth of perspective of an education specialist. Hence, future work includes soliciting reviews by two experts, one from some subfield of education, i.e. cognitive psychology, and one expert from engineering education with a combined engineering research and teaching background. Comments will be solicited on the taxonomy used for the tour topics, the contents of the tour guide and the recommended references. Requests will be made for suggestions of alternative maps, which will ultimately allow engineering instructors to choose among tours and pursue different interests. Feedback received from the education expert will be used to balance any potential oversimplifications, while the feedback from the engineering education expert will help with making the tour meaningful to engineering instructors from different disciplines, by varying the applications specific to particular thematic subfields of engineering in Stop VIII.

4.2 *Within the engineering community*

Once the review of the education experts and the respective changes are implemented, civil engineering instructors will be invited to take the modified tour. The aim will be for both authors to attract at least two colleagues willing to offer comments on the usefulness of the tour, one following the tour in a self-guided mode, the other with participation, when called for, by their host author/guide.

5 CONCLUDING REMARKS

This paper is based on the premise that suitable points of entry into the literature of education are needed for engineering instructors. As a potential entry point, the paper proposed a tour of education in eight stops, which can work either in a self-guided or in an interactive mode. The experience of the first pilot tour had the following positive results. It reaffirmed existing beliefs and backed them with references. In addition, it pointed to the nearest existing crossing points between education and geotechnics. At the same time, it highlighted the need to recognize that educational institutions are under significant pressure to adapt to external factors that are dramatically going to change how content is delivered and consumed. This needs to be reflected in future engineering education developments.

Two needs for further work are identified, on the part of the engineering education community and on the part of every disciplinary community, i.e. the geotechnical engineering community in the case of the authors:

- The community of engineering education researchers should focus efforts on producing material missing from a comprehensive tour in Stops I, II and VIII. Work needed includes:
  - (a) surveying educational philosophies and epistemological beliefs of engineering instructors and producing research results related more closely to disciplinary subject matter and
  - (b) shifting the focus from instructional approaches to students' understanding of key concepts.
- The community of geotechnical engineering instructors should restate key questions related to the design of geotechnical engineering curricula and produce answers in a manner that both questions and answers are informed by findings from the education literature. In addition, the community should pursue collaborations with engineering education researchers in research projects targeting student understanding of key concepts in geotechnics.

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Intellectual synergy in the education of geo-engineering

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ABSTRACT: Cognitive psychological considerations can help to understand the essential differences between the levels of BSc, MSc and PhD. Complexity of the interrelationships experienced in geo-engineering parallels those in medicine, i.e. concepts such as symptom, syndrome, diagnosis and therapy. The analogy makes it easier to identify some perspectives and approaches used in geo-engineering, rather different to several other fields of engineering where the problems are treated with well-established models and managing technologies which are much better defined or more deterministic. In this regard, the importance of using case studies in geo-engineering education turns to be as natural as it is in clinics. Geo-engineering is one of the professions where experts comprehending the interplay of academic knowledge, design practice, construction skill, even communication are predestined to co-operate in developing the inventory of case studies for the education curricula of different graduation levels. Simultaneously, students have to be advised clearly about the challenge they are facing and have to engage at their competence level.

1 INTRODUCTION

1.1 *Survey of preliminaries*

By the end of the last millennium, European education policy makers reached the conclusion that the traditional higher education system has to be restructured. The Bologna declaration (1998) opened a new era where the linear structure of bachelor and master levels dominates. Significant efforts were made to establish a European system for accreditation of engineering educational programs based on a network of spontaneous agreements between national and regional institutions (Augusti 2006).

Nowadays 40–50% of age groups enter undergraduate courses and some 15% make a further step to the master level. The system works; albeit diversity of courses, differences in requirements, impact of declining secondary school performance have been, and will continue to be discussed. Several educators share the opinion that most of the accreditation models developed regionally or internationally "seem to be non-uniform, too complex, non-transparent and, moreover, non-precise" (Patil & Codner 2007). There is room for further work.

In particular, the content of the professional subjects became less plausible, for at least four reasons:

- There is a conflict of interest between the faculty knowledge and the actual industry needs.
- There is a time-lag between the waves of education supply and employment demand.
- Higher education institutions try to attract as many students as possible with popular courses.
- By and large, secondary education seems to be unable to prepare its pupils for the competencies needed for traditional university entrance.

Since the main goal of restructuring is to become more competitive globally *via* more practical knowledge of more people, educators, politicians and researchers are continually occupied with questions such as:

- How long should bachelor and master programmes be when separated, or built together?
- Should there be different tracks of bachelor programmes preparing students for employment versus preparing for graduate work?
- To what extent should bachelor programmes prepare for master programmes in the basic sciences?
- What financial quotas should be allocated for bachelor and master programmes?

In this academic environment the clear identification of the undergraduate and graduate levels becomes more important than before, even in those cultures where the linear structure of higher education is a tradition (Ilic 2007). Additionally, there arise the questions of how the role of case studies must be reinterpreted, and how their content and presentation style could be developed to better support the practical side of academic education.

An effort to keep apace with this progress and with the development experienced in construction and computing technologies means that the issue of geo-engineering education is covered at many conferences, seminars and in periodicals. Recent historical surveys (Burland 2008 and many others) explain how the Fathers of the profession stressed the importance of educational aspects and combined their expertise in soil mechanics, structural engineering, and construction technology in teaching via case studies. Not exclusively, but probably most consciously, Peck's courses discussing one-page case studies are referred to as best practice (Rogers 2008).

There seems to be no lack of case studies on geo-engineering activity available for use. By and large, 40–70% of papers presented at regional conferences discuss cases. A series of conferences on case studies in geotechnical engineering will have its 7th instance in 2013 (Prakash 2008) and several collections of case studies are also readily available. The International Journal of Geo-engineering Case Histories has appeared since 2004 and has been accessible free of charge.

While the role of case analyses in engineering education is not particularly significant, it has been of high importance for teaching economics, medicine or law – and geo-engineering. Participants and authors of recent conferences, seminars and studies (e.g. Manoliu 2008) agree the reason is that geo-engineering differs in several aspects from other civil engineering activities. Burland states, that "… *geotechnical modeling involves much greater explicit uncertainties and complexities in idealizing both the geometry and the material properties than in structural engineering*." An understanding of the differences results in different teaching methods. Advanced techniques (such as problem-based learning, enquiry learning, case-based teaching etc.) are reported as being applied successfully (Papadimitriou 2011). However, it seems to be a question open for further discussion, how the cases are to be tailored for educational purposes; even if some general recommendations exist.

1.2 *Some questions of interest*

One of the questions worth discussing is how to identify the bachelor, master or doctor levels of competence defined either in the academic environment (with respect to courses) or in practice (connected with licensing and other professional qualifications). Some levels of academic graduation (such as BEng, MEng, PhD) seem to be determined in the long run, since the European system has been reorganized to this scheme by the Bologna-process. Nevertheless, there exist difficulties of implementing the idea (this might be one of the reasons why the European credit transfer system does not always work seamlessly).

Most branches of civil engineering have accustomed themselves to the Bologna-classification easily. Geo-engineering seems to have some difficulties. A better understanding of the educational purposes and demands of the practice may help to clarify the reasons and to comply with socio-political constraints.

The question of adequate case study selection and tailoring is not independent of education level classification (Orr 2011). Efficient usage of the existing case analysis inventories can be supported this way.

To answer these and similar other questions, there exist several well-elaborated conceptual frameworks. Bloom's taxonomy (1956) of six educational objectives (knowledge, analysis, comprehension, application, synthesis, evaluation), for instance, was selected by ASCE to establish 28 outcomes, all of them defining knowledge, skill and attitude. Compilation of the Civil Engineering Body of Knowledge (describing minimum cognitive levels of achievements for each outcome) with the distinction made between undergraduates' knowledge, experience gained in practice and master's knowledge in this system is an advanced alternative (ASCE 2008).

The authors think that their views merge into the mainstream paradigms of geo-engineering education. With less bumptiousness than the title of the paper would suggest they apply some general concepts and analogies accepted in other professions, and this way hope to contribute to the discussion.

2 LEVELS OF HIGHER EDUCATION

2.1 *Cognitive psychological background*

For decades, researchers exploring artificial intelligence have investigated the learning and experience building mechanisms that are typical for the learning and validation of a profession. They found that different levels of professional knowledge and preparation can be suitably described by the number and complexity of cognitive schemes associated with each, as well as their organization. The system of these schemes building on each other provides a good framework for a number of considerations regarding the mechanisms of cognition (a more detailed discussion of the conceptual framework can be found elsewhere, Méro 2001, Scharle 2008b).

Levels of professional expertise must be qualified according to their complex knowledge bases and paradigms. At different levels, besides the number of cognitive schemes, the jargon, the extent of consciousness of thinking can vary from profession to profession. The number of competency levels worthy of distinction may also vary by professional fields.

Despite these differences, in most instances three or four levels can be characteristically defined, and this classification proves surprisingly applicable for a great variety of professions. Obviously, small differences can result from the nature of individual profession's paradigms and their stability. However, the road leading to knowing the rich collection of complex schemes and to using professional and everyday language adequately and at a high level can be recognized even in such particular fields as architecture, economics or law.

2.2 *The model – an extended understanding*

In the engineering sciences, a whole group of concepts parallel the ideas applied in cognitive psychology. To this group belong, among others the

– observation, recognition, understanding, and anticipation of the phenomenon, situation, and process;
– recognition and description of tasks related to the progression;
– identification and analysis of the necessary and possible interventions;
– clarification and handling of expectable consequences;
– determination and technical execution of intervention steps.

For the technical wording *scheme* can be translated as *model*. With this interpretation, the core of professional knowledge can be conceived as model selection skill based on these elements.

The definition of model in this regard is very broad. It may consist of simple or compound elements. It can be simple or complex. It also encompasses all mathematical, physical, technological and material-tectonic relationships that approximate reality and its behaviour to an extent deemed acceptable in the given circumstances. The application of the model may consist of simple steps, or form a closely related sequence of steps. Indeed, this extended perception is broader than that of the right bottom circle meant by Burland (2008) in the geotechnical triangle.

2.3 *Model inventory – knowledge and selection*

From this perspective *the essence of higher education in the engineering fields can be perceived as the introduction of technical models of phenomena and processes*. Particular curricula include theories and relations that describe reality more or less reliably, explore the validity and applicability of these models, and discuss the prerequisites, methods and steps of application. Professions have their inventories (or treasuries) of models as well.

Simpler or more complex models can describe (but approximate only) simpler or more complex phenomena. A well-educated professional is familiar with the most common and important phenomena, knows the relevant models, and is able to apply them to solve a particular technical problem.

It is sensible to differentiate between levels of professional expertise from the perspective of their relationship to the inventory of models. Certainly, it is not possible to assign one "natural" classification. However, it seems practicable to accept a four-level classification system.

The significance of differentiating between these levels lies in their relationship to recognise phenomena and processes, and to the models used for their understanding and intervention. They can be described by competency as follows.

Assistant – understands the main characteristics of models conveyed by the bachelor or master; may participate in the application of models under guidance with simple steps.

Bachelor – recognizes frequently occurring phenomena; is familiar with the profession's simpler models and their application; correctly selects the models that can be employed for simple phenomena; is able to involve the apprentice in model application by creating simple subtasks; understands and executes the steps according to the model selected by the master.

Master – recognizes phenomena and correctly appraises their complexity; knows the profession's inventory of models and the prerequisites and limitations of their applicability; is able to cooperate with masters of other fields in the solution of a complex problem; is able to select the optimal model to solve a particular problem; grasps the complete process of intervention, and is able to incorporate in particular steps the expertise of the apprentice and bachelor according to their skills; recognizes phenomena that require the further development of the model inventory, understands the way doctors think, and can utilize their recommendations.

Doctor – is able to identify and analyse complex phenomena; knows the profession's model inventory and the limitations of their precision and applicability; expands the range of validity of models, improves and develops methods for their application; attaches models to new phenomena, and if necessary, supplements or creates new models.

The elements of all competencies may appear at all levels of education and there can be broad overlaps for a number of reasons. The educator's preparedness and perspective has an obvious role (plenty of faculty members teach graduate students rather simple models extensively and routinely at the bachelor level of expertise while a good grammar school teacher can make his/her interested pupils acquainted with pretty complex models using the master's perspective).

There is also a great variation in individuals' ability to learn. The same lecture may leave a much greater impression on one student than on the other sitting next to him/her. The traditions of institutions and the cultural patterns of societies can greatly influence the stratification of entire disciplines.

Furthermore, most readers may know top-notch consultants having no academic degrees or titles but a splendid mind always ready to develop or invent original models for complex and sophisticated phenomena. Considered either conscious or serendipitous, these achievements are *artistic* in a sense and seem to reflect the highest level of "competency", even if it was not obtained by learning, by exams or gained by election.

Despite all these sources of uncertainty, in constructing any engineering curriculum it seems to be worth considering its content in accordance with the cognitive categories entailed. This consideration might be extended to the basics needed from mathematics, mechanics and reach out to the theories, models and applications to be discussed in the course. Simultaneously, actual content, presentation techniques (including case histories) and student performance evaluation methods are worth discussing and harmonizing with the qualification rules and licensing procedures applied by the professional engineering chambers or authorities. Efforts of educators, professionals and bureaucrats based on the neutral classification provided by the cognitive psychology may result in a higher synergy and more consistent career visions presentable for the students and the society.

This perspective allows conclusions to be derived for all levels defined above. For instance, it can be conjectured that genuine geo-engineering expertise has much to do with the doctor's level. Nevertheless, to keep the attention close to the point, in what follows, the argument will be focused on the questions related to the undergraduate and graduate levels only.

3 GEOENGINEERING ASPECTS

3.1 *Convergence and distinction*

Convergence experienced between structural and geotechnical bodies of knowledge is reflected and will be explained in such points as:

- identification of kinematic behaviour deserves equal importance;
- developed constitutive models with more sophisticated strength parameters applied;
- designing principles (extended, for instance, to construction stages) are harmonized in continental codes (such as the *Eurocode* series);
- integrated computational models and construction technologies are available for design and implementation.

In spite of this convergence there are some aspects wherein the two bodies are expected to remain different (Orr 2011).

Structural engineers focus on the installation. Their models have boundaries where the interactions with the environment are characterized with variables and quantities (such as loads, spring constants or prescribed displacements) consistent with the structural model.

Geo-engineers notice the long-term and multidisciplinary interaction of structure and ground environment. More complex models with less-balanced approximations about the surroundings of the installation, possible impacts and responses are to be established.

3.2 *Features of geo-engineering*

The circles of the Burland-triangle, amended with a fourth circle representing construction technology, can be imagined as vertices of a tetrahedron. This framework visualizes the key aspects (and activities) pondered by the Fathers and have to be pondered since then by all top-notch geo-engineers. Their skill lies not simply in the knowledge about the strength and kinematic behaviour of soils, mechanics of structures or technologies, but about the interplay of these factors.

Bachelors are educated to see the most fundamental configurations nested in this tetrahedron only. Masters competence involves the panorama or the whole picture. Doctors keep under control the range of validity of the complex models and try to extend the inventory of models if needed. Either aspect may have the same importance for the practice.

It is interesting to find some analogy between geo-engineering and *medicine*. Physicians start with collecting symptoms. Then try to order and organize them to establish a syndrome. Their next goal is to identify a diagnosis, for they may have protocols to apply therapy.

Cases have their roles analogously. In clinics professors are teaching their medical students by walking from bed to bed. They listen to and look at the symptoms and scrutinize the findings provided by laboratories, interpret syndromes and define diagnoses. Finally, the therapy follows. Students at the bedside face questions, alternative *models* of sickness and possible therapies. Intrusions depend on the conditions (such as the patient's state, facilities and medications available, etc.) and may be extended to possible treatments (from specific nurturing to surgical operation). Several days later students can face the results: the observation method works. Synergy is at stake when the professor calls a medical consultation with experts of their particular professional skills.

Without overstressing the analogy it is clear that geo-engineering follows the same approach, because of the inherent structure of the lesson: to face the problem as a whole, to look at the subject as embedded into its interacting environment. The example of stabilizing (or modifying) an existing, particularly an ancient building, as described by Burland (2008) helps to comprehend this attitude for structural engineers. In this regard, problem-based learning is not simply a possibility of inductive teaching with good practical results but a plausible constraint.

It is worth noticing here the role of communication, as well. Burland mentions his experience of difficulties in communications between structural and geotechnical engineers. Recent problems connected with the introduction of the *Eurocode7* show the importance of this aspect. Again, geo-engineers have to be able to communicate rigorously, creatively and clearly the essence of the advanced approach. Instead of providing a couple of strength parameters for the structural engineer, they have to participate in the designing process in case of complex installations.

4 CASE STUDIES IN EDUCATION

4.1 *Role and potential*

Recent overviews clearly outline the educational role and potential of case studies in geo-engineering (Orr 2011). Therefore, some remarks are allowable here only, to help the understanding (Scharle 2008a).

For engineers, as a rule, it is *impossible* to possess all abilities listed for the bachelor and master levels without a shorter or longer experience in practice. During the education term, case studies are at hand to illustrate all points and arguments connected with model identification, creation and application.

Through scrutinizing well-rounded case studies, undergraduates can better prepare themselves to

– recognize frequently occurring facts and events,
– select correctly the models that can be applied for simple phenomena,
– execute instructions given by a master.

Graduates can accelerate and improve their development with case studies helping them to

– recognize and correctly appraise complex problems,
– select the optimal model to solve a particular problem,
– comprehend the complete process of intervention,
– understand the way doctors think, and utilize their recommendations.

This perception of case studies, of course, is neither a new development nor a consequence of the Bologna paradigm. It is stressed, for instance, by the US National Academy of Engineering (2005).

Obviously, adaptability and efficiency of a case study can highly depend on many conditions:

– Cases can be presented either as narrative descriptions or instructive explanations. The first alternative works well for undergraduate students, the second one for graduates.
– Hegemony interests and to-be-protected employment positions can distort correct narrative descriptions or instructive explanations.
– Many case studies convey very simple business messages ("look how interesting the problem we have solved is" and "we are skilled masters of our technology").

Even these types of case studies can help in stimulating the interest of the undergraduates in the subject, but have a low value for teaching or learning.

4.2 *Quality of case studies*

From the point of view of her or his purposes, the teacher has to scrutinize whether a case study contributes to the course performance effectively or even obscure it. Features of efficient engineering case studies are:

– correspondence between the problem or phenomenon and the model is controlled and straightforward;
– essential data of geometry, materials, constraints, impacts etc. are illustrated properly and quantitatively for understanding the problem;
– material characteristics and assumptions (linearity, time-dependency, etc.) are clearly explained;
– kinematics of the engineering behaviour (both expected, and observed) is commented on as clearly as possible;
– applied computational methods are described explicitly, with their assumptions and essential characteristics;
– failures, mistakes made in selecting and applying adequate models are considered and discussed openly.

Many case studies do not correspond with these demands. A lot of papers appear in professional periodicals, conference proceedings and corporate PR folders or leaflets distributed at exhibitions with shortcomings such as:

– data of marginal importance are given ("the site was at a distance of 4 km northwards from the capital");
– information is unbalanced because of the primary competence or partial interest of the author;
– function, importance or attractiveness of the building involved in the case are stressed ("the runway was highly desired by the regional industry");
– derived variables are used instead of physical state or material properties;
– statements are made without comparison with other similar constructions or alternative solutions ("the method we had applied gave a sound solution to the problem");
– calculations are referred to inadequately ("displacements were computed with the FEM"),
– inadequate illustrations are attached to the case.

Experienced case study writers and users can easily add further items to these lists (Pantazidou et al. 2008). At the same time, one has to know that only a few cases allow a perfect study with all the necessary features but without shortcomings.

5 SYNERGY

Understanding the cognitive background, the concepts of the model inventory and education levels offer a space for further interdisciplinary co-operation. To the points mentioned previously several more can be added:

– basics from mathematics and mechanics (reduced to but selected for the inventory);
– methods of decision-making;
– conscious adaptation of advanced software;
– risk management.

6 CONCLUSIONS

1. It is plausible to differentiate two levels of education from the perspective of expertise in recognizing phenomena and processes, and from the relationship to the inventory of models, used by the profession for understanding and intervention.

   Bachelors are instructed to recognize frequently occurring problems, to select correct models for simple phenomena, to execute instructions given by a master. Case studies at this level serve as *examples* highlighting the essential features of a model.

   Masters are instructed to select optimal model for a particular problem, to comprehend the complete process of intervention. Case studies at this level induce considerations about alternative models, selection principles, verification, and validation issues.

2. Models of the geo-engineer have to reflect the essential characteristics of the environment influenced by operations. High-quality models involve ecological, structural, geological, technological etc. considerations, both in design and construction.
3. This complexity appears in several analogies with economy and medicine. State and characteristics of the operated subject may have significance greater than canonical methods of the intervention. This is why the case-based methods are not just plausible but very natural and inevitable educating techniques for geo-engineering.
4. Depending on the competence level defined for bachelors and masters, case studies applied for education have to be differentiated by:

   – content (simplicity or complexity of the model involved);
   – uniqueness or variability of the technical intervention;
   – reliability of the observations and data used for establishing applicable models.

5. Scope of knowledge demanded in math, mechanics, construction technology, site or laboratory identification methods etc. can be determined easily for the bachelor level. At the master level, the scope is more open. Facilities (such as hardware, software, laboratory, tutorial competence etc) of the educating institution may influence the curricula.
6. Streamlining of the case studies available in the inventories is left for the educators. The result depends on their talent, invention and pedagogical skill. Advance in this field could be stimulated.

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Student-centred learning in geo-engineering

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Teaching geotechnical engineering with theory-practice integration: Group project approach

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ABSTRACT: Geotechnical Engineering is a compulsory core Civil Engineering subject in the standard Bachelor's programme of Malaysian universities, as in most other institutions of higher learning elsewhere. What sets the subject apart here appears to be the infamous nickname assigned to it, i.e. 'the killer subject'. The notoriety is founded on the misguided belief that the subject's contents are highly technical and difficult to grasp, partly because the mechanics involving soils are barely visible to the naked eye! With a 'bad' name as such, it is no wonder that many students take the subject with unnatural apprehension and fear. In order to facilitate a better and more effective learning atmosphere, a group project approach was incorporated in the subject, encouraging the students to relate lecture contents and additional reading materials with a real-life geotechnical problem at their doorstep: the campus itself. The University grounds are underlain by deep deposits of soft marine clay, which has rendered construction to be preceded by extensive treatment of the soil. The project enlisted the student groups as consultants to design and propose ground improvement techniques with emphasis on creativity, innovation and cost-effectiveness. Tangible outcomes of a scaled model, technical paper and poster were produced at the end of 12 weeks. This paper presents an analysis and discussion of the exit survey conducted at the end of the project. The embedded project clearly helped ease the students in their learning, and at the same time fulfilled the Programme Learning Outcomes (PLOs) as well as Programme Educational Objectives (PEOs). Besides, the students positively responded to the development of their humanistic skills much emphasised in today's engineering higher education. In short, it is proposed that projects integrating theory and practice be introduced in similar engineering subjects to transform an otherwise dreary subject to an interesting and fun-filled one.

1 INTRODUCTION

The teaching of geo-engineering subjects in universities has always been challenging, and one of the foremost reasons for this is perhaps the inherent complexity of a multi-disciplinary area of study, involving mathematics, mechanics, physics and other disciplines. Saroyan et al. (2004) summarized it well; effective teaching requires a sound understanding of the knowledge as well as the delivery method. Most teachers of geo-engineering subjects are well-versed with their study area and have a good grasp of the subjects, but transmission of knowledge to the students may still be interrupted without effective channeling methods. Disciplinary knowledge alone is not sufficient to achieve teaching excellence, but must necessarily be paired with relevant teaching skills and practices (Kreber 2002).

Effective teaching is generally defined as knowledge delivery, which is orientated and focused on students and their learning (Devlin and Samarawickrema 2010). This can be perceived as teaching attuned to the students' needs and abilities, as influenced by cultural, societal or other environmental factors. As pointed out by Havita et al. (2001), effective teaching is supported by a number of characteristics, where well-prepared and organized teaching materials are not enough on their own. The key characteristics include being engaging, motivating, establishing good rapport and maintaining a positive, vibrant learning atmosphere.

Nonetheless, to conduct lessons in an innovative manner requires going the extra mile and putting in additional effort. This may yet produce encouraging results as expected and could adversely diminish a teacher's enthusiasm and self esteem, or worse, perceived as a threat to the teacher's authority (Staniskis and Stasiskiene 2007). Uncertainties like these could be a hindrance to adopting creativity and innovation in teaching, where teachers are obliged and more inclined to adhere to conventional prescriptive teaching methods.

Project-based teaching represents a good mix of theory and practice, to help students relate lessons taught in lectures with real-life problems or applications. It enables students to develop the skills and confidence to create and maintain their own knowledge bases instead of playing the role of a mere passive learner (McKay and Raffo 2007). Such an active learning environment encourages the students to take charge as the problem-solver, while the teacher shifts to the role of a coach, giving advice, guidance and suggestions instead of dispensing a standard prescription of solutions (Tan 2004). Besides, as the process involves the acquisition of new knowledge by self-learning, it encourages self-regulation (Cavanagh 2008), a positive attribute much needed to excel as a student and future engagement.

This paper presents a group project incorporated in the subject of Geotechnical Engineering for third year students, with emphasis on adopting and adapting existing ground improvement techniques for addressing soft soil problems in construction. The students were formed into 7 groups of 6–7 persons per group (total 47 students), and were given approximately 15 weeks to complete the project. The project was introduced primarily to provide a link between theory and practice for facilitating better understanding of purpose and practical use of the subject. At the same time, it was aimed at instilling a sense of curiosity and motivation to conduct scientific research, though at a much smaller scale and scope. This was to avoid burdening the students in an already packed subject and semester, which could cause unfavourable outcomes as opposed to the intended purpose. An exit survey carried out at the end of the project provided the relevant information and analysis as presented here.

2 DESCRIPTION OF PROJECT

The following is the project brief as distributed to the students at the beginning of the semester. It explains the project background, tasks and expected outcomes. The project was entitled "Ground Improvement: Explore the Unexplored", where students were automatically induced to thinking outside the box while not straying too far from the subject boundaries. Progressing with the lecture, students were gradually and systematically guided to fulfil the project aims and objectives. Figure 1 shows the students in action during the mini exhibition/assessment session, as well as some of the models designed and assembled.

Figure 1. Exhibition and project evaluation session.

2.1 *Project background*

Universiti Tun Hussein Onn Malaysia (UTHM) sits on deep deposit of soft marine clay with low strength and high compressibility. Pre-treatment of the soil by ground improvement is necessary before construction works can commence on these grounds. Various ground improvement techniques are available in the market, such as vertical drains with surcharge, stone columns, mass replacement, stabilisation, etc.

Engaged as an engineer of the geotechnical engineering firm, you are hired by the University to propose a new method to treat the problematic soil. The University *strictly* requires the design to be creative, innovative and cost-effective in terms of time and finance … meaning to *explore the unexplored*!

2.2 *Project tasks*

1. To design a ground improvement method suitable for the UTHM site.
2. To build a scaled model showing the ground improvement method, dimensions: 30 cm $\times$ 30 cm, NOT exceeding 20 cm high.
3. To present the method/design in an A2 size poster (laminated).
4. To present details of the method/design in a technical paper (according to the format given).

2.3 *Project objectives and learning outcomes*

General

- To identify problems encountered in soft soils and formulate solutions using ground improvement techniques.
- To exercise team work and coordination in carrying out a small-scale research project within a given time frame.

Specific

- To design and model a ground improvement method for the UTHM site.
- To justify the choice of method/design with geotechnical engineering and scientific reasoning.

2.4 *Project methodology*

1. Identify problems with construction on the UTHM soft soil.
2. Review relevant literature on the ground improvement methods applicable – background study.
3. Determine the method/design to be adopted.
4. Design the technique/method chosen.
5. Estimate the actual costs involved- time and finance, cost-benefit analysis, etc.
6. Build the model to scale.
7. Prepare the technical paper and poster.
8. Submission: model, poster and technical paper.

2.5 *Project presentation*

Each group will present their findings in a 15 minute slot at the end of the semester.

- Describe and explain the design/method.
- Justify why UTHM should adopt your design/method.
- Highlight the creativity, innovation and cost-effectiveness of your design/method.

2.6 *Project duration*

Approximately 15 weeks- submission and presentation will be before the Final Examinations.

2.7 *Prizes and awards*

- Best design/method award.
- Best model award.
- Best poster award.
- Best technical paper award.
- Best presentation award.
- Best team work award.

3 PROJECT EVALUATION

The design of assessment and evaluation should not be taken lightly to avoid defeating the purpose and aims of the course or subject (Ditcher 2001). Also, Drinan (1998) rightly stressed that assessment should require students to demonstrate understanding and integration of knowledge, otherwise they may 'guess their way from problem to solution without seriously engaging either sources of information or mental faculties'.

Guided by the above, the project assessment was designed to encompass three aspects, namely the written and oral presentations, as well as the physical model produced. Bearing in mind that the project was a part of a subject and not a stand-alone entity, and due to the constraints of time and resources, the level of expectation was ensured to be reasonable and not overly stringent. It was considered more important that the students took responsibility for the group's learning and progress, as demonstrated in the various modes of presentation, than infusing too many technicalities into the project.

An assessing panel of lecturers from different disciplines of civil engineering was engaged to conduct the evaluation. Members of the panel were intentionally diversified to provide the students with exposure to expertise and questions from different areas, for an interesting and stimulating exchange-cum-learning experience during the assessment.

Main components of the project evaluation fell under the following categories: design concept, model, poster, technical paper, presentation and team work. Each category was further divided into sub-components to provide an objective and holistic assessment of the students' work. For instance, the design concept was judged based on the level of creativity and innovation, usefulness, practicality as well as cost effectiveness. Note that the students were informed of the scope of evaluation from the beginning of the project, with the expected outcomes clearly outlined and important points suitably highlighted.

4 PROJECT OUTCOMES

The exit survey conducted consisted of pre-determined elements of the subject, i.e. Programme Educational Objectives (PEO), Programme Learning Outcomes (PLO) and Humanistic Skills (HS). PEO is a long term yardstick while PLO is targeted to be attained upon completion of the subject learning, and both constitute the 'hard' skills of the subject. HS involves the development of 'soft' skills. The survey was prepared to gauge the relevance of the project, and the effectiveness in helping the students achieve the PEO, PLO and HS. Tables 1, 2 and 3 give details of each component respectively. The individual components for each element are further analysed and discussed. To keep the survey simple, the respondent was only required to rate the impact level of each

Table 1. Programme Educational Objectives (PEO).

PEO1	Knowledgeable in various civil engineering disciplines in-line with the industrial requirements.
PEO2	Technically competent in solving problems through critical and analytical approaches with sound facts and ideas.
PEO3	Effective in communication with strong leadership quality.
PEO4	Capable of addressing engineering issues and able to conduct professional responsibilities ethically.

Table 2. Programme Learning Outcomes (PLO).

PLO1	Apply lessons learnt during lectures in practical applications.
PLO2	Acquire additional ICT skills and knowledge by doing the project.
PLO3	Analyze, design and understand the process of construction in Geotechnical Engineering.
PLO4	Identify problems and formulate systematic solutions in the project.
PLO5	Apply scientific methods for a project of R&D (research and development) nature.
PLO6	Recognize and understand the importance of sustainable development and Occupational Safety and Health (OSH).
PLO7	Recognize the roles and ethics of a professional engineer in fulfilling social, cultural and environmental obligations.
PLO8	Communicate ideas effectively through oral, written and ICT applications.
PLO9	Display leadership, entrepreneurship and team working skills effectively.
PLO10	Recognize the need for and the ability to engage in life long learning.

Table 3. Humanistic Skills (HS).

HS1	Communication skills.
HS2	Critical thinking and problem-solving skills.
HS3	Team-working skills.
HS4	Continuous learning and information management skills.
HS5	Entrepreneurship skills.
HS6	Ethics and professionalism.
HS7	Leadership.

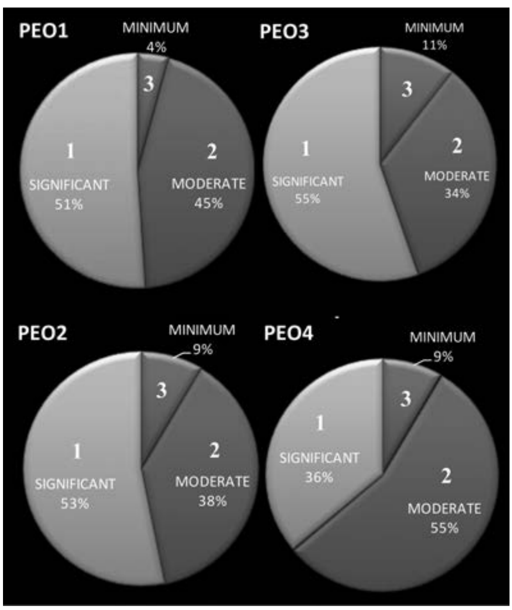

Figure 2. Achievement of the Programme Educational Objectives (PEO).

component as being 'minimum' (3), 'moderate' (2) or 'significant' (1).

4.1 *Programme Educational Objectives (PEO)*

More than half of the students agreed that the PEOs were significantly achieved through the project (Figure 2). PEO4 was an exception, where 36% of the students thought that they were markedly informed of how to address engineering issues and to conduct professional responsibilities ethically, compared to the 55% who claimed that the impact was moderate. This could be due to the dual component encompassed in PEO4, which appears to overlap with HS6 of the Humanistic Skills assessment. Students could have found the former component relevant but failed to see the link in the latter. Perhaps this could be taken as a cue to review PEO4 to ensure better clarity. Only a small percentage of students ($<12\%$) perceived the PEOs to be marginally achieved. Considering that the PEOs would not be measurable until an assessment exercise is conducted among the students several years after graduation, this data is more of a general perception or projected outcome from the perspective of the students.

4.2 *Programme Learning Outcomes (PLO)*

For the 10 PLOs questioned, the impact brought forth by the project was rated as significant and moderate by 42% and 49% of the respondents respectively (Figure 3). These are considered positive indicators of the embedded project in the particular subject teaching. Through self-assessment, the students have ascertained that the project was indeed contributing to the achievement of the PLOs of the subject.

It is impractical and unfair to expect a small-scale research project like this to help meet all the PLOs, though certain components were found to register lower impact compared to the others. Take for instance PLO6 with less than a quarter of the respondents rating the impact as being significant. Occupational health and safety issues were hardly pertinent to the project as it was essentially a conceptual model development study without any site visit or reconnaissance involved.

The positive response for PLOs 3 and 4 reflected the students' improved capability in problem-solving. In designing their respective ground improvement techniques, the students inadvertently underwent the process of reviewing existing methods and technology before being able to adapt, adopt or modify to suit the project requirements, e.g. construction on inland soft deposits. The project execution also involved active discussion and participation by all members of the group, leading to cultivation of ideas, creative solutions and innovative thinking.

These processes are vital in developing the students' analytical power in the face of practical problems, as commonly encountered by engineers on site.

The project presentation in technical paper, poster, model and oral forms have certainly helped built the confidence of the students. This can be seen from the 55% responses quoting the impact on PLO8 (pertaining to communication skills) to be significant.

4.3 *Humanistic Skills (HS)*

Responses on the Humanistic Skills (HS) development were most encouraging (Figure 4), where over half the respondents attested to the positive impact of the embedded project. Nonetheless slightly over 10% of the students did not find their entrepreneurial skills (HS5), ethics and professional moral (HS6) and leadership (HS7) to have made remarkable progress via the project. This could be due to the several factors: (1) not all the groups performed adequate cost-benefit analysis for their respective designs; (2) ethics and moral values, being abstract and intangible elements, might have not been properly understood by the students; (3) while the groups were encouraged to adopt a rotation system for leadership roles, not all followed the suggestion.

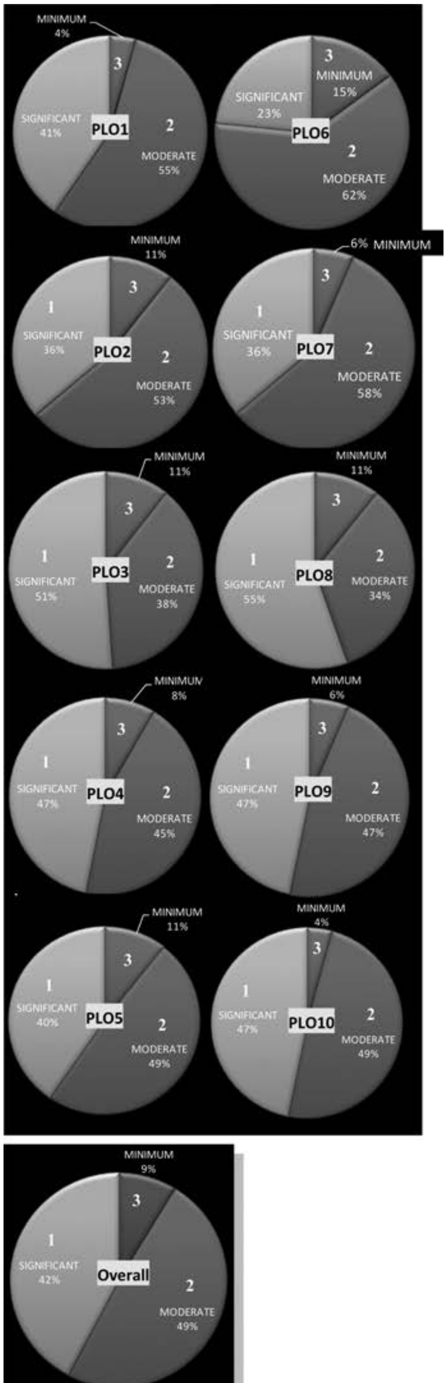

Figure 3. Programme Learning Outcomes (PLOs): post-project survey analysis.

HS2 (critical thinking and problem-solving skills) is closely related to PLO4, where students were expected to effectively identify underlying problems and formulate precise solutions to address the

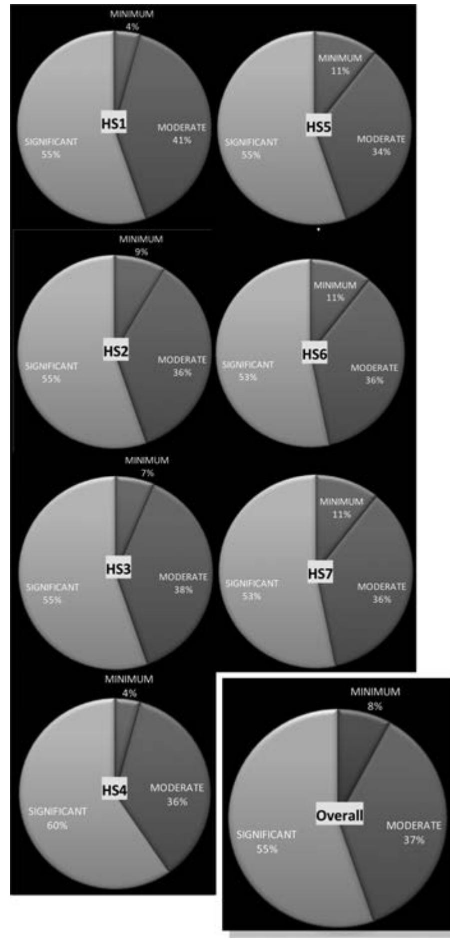

Figure 4. Humanistic Skills (HS) improvement check.

problems. Responses to these two components can be seen to correspond well.

Another interesting observation made from the analysis of this survey is the students' apparent awareness of the implied benefits of project-based learning approach like this. Looking at HS4, 60% of the students saw the project as demonstrating continuous learning potential. It was also perceived to be enhancing their IT management skills, which could be related to the data analysis, presentation aids and materials used in the project. This response is apparently correlated with PLO8, which also shows a very encouraging response from the students upon completion of the project.

5 CONCLUSION

A group project approach as described in this paper is shown to be effective in providing the link between theory and practice for the students, i.e. enhancing the acquisition of 'hard' skills or knowledge. It also helps develop 'soft' skills among the students, the shortage of which is very much lamented f by employers these days. On the other hand, the downside may be extra work for the students, but the benefits certainly outweigh the setbacks. However it ought to be cautioned that project-based learning embedded in core subjects requires careful planning and time management. This would help minimize the risk of overburdening the students and making the subject more burdensome or less fun than before!

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Use of project based learning to teach geotechnical design skills to civil engineering students

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ABSTRACT: This paper describes the use of project based learning to teach geotechnical design skills to civil engineering students at University College Dublin (UCD). The literature on the application of PBL in civil engineering suggests that because of the hierarchical nature of engineering education, PBL is best applied in a hybrid form known as Project Based Learning. A detailed description of how hybrid PBL was implemented in the final year of a civil engineering degree programme is then presented. The module which was developed at UCD provided an excellent mechanism for developing many skills, including problem-solving, innovation, group-working and presentation skills desired by graduate employers. It was clear that the students enjoyed the peer to peer teaching and an increased interaction with staff and external experts which the problem solving nature of the module facilitated.

1 INTRODUCTION

Ramsden (1992) identifies a pervasive feeling developing amongst higher education lecturers that students develop a poor understanding of basic principles and concepts, exhibit poor knowledge retention capabilities and yet by intensive studying before terminal exams succeed in satisfying the assessment criteria. Many universities report high levels of absenteeism, particularly in the early years, and high drop-out rates which are at least in part caused by lack of engagement and boredom induced by teaching methods (Bartsch and Coburn 2003). Mann and Robinson (2009) reported a cross-disciplinary study of the causes of boredom of 211 University students and found that the most boring teaching methods were laboratory sessions, computer sessions and copying lecture notes. The most significant contributor to class room boredom occurred when a PowerPoint presentation was given with no accompanying handout. They note that without careful consideration being given to design and resourcing, alternative teaching methods such as interactive teaching in laboratories can be more boring than traditional chalk and talk or PowerPoint lectures. There is therefore an urgent need to develop a more stimulating learning environment for students.

Considerable debate with regard to the form of education offered to engineers is ongoing. External pressures from industry include calls for the development of design and complementary soft-skills such as improved presentation and report writing. Rapid developments in technology over the past ten years have transformed the lecture theatre from a chalk and talk to a largely PowerPoint driven environment. Much of the course content is now made available on-line prior to class, and both the University lecturers who learned in the traditional format and the current students are dealing with pertinent issues such as relevance, classroom boredom, and absenteeism. Experiential or Enquiry Based Learning (EBL) and Problem Based Learning (PBL) may provide solutions to some if not all of these issues. This paper will consider the basis of PBL and whether and how it can best be applied in professional engineering courses with particular emphasis placed on aligning teaching methods to learning outcomes and the improvement of instruction in design.

This paper discusses the development of a form of PBL, namely; a project based learning design course in civil engineering developed at University College Dublin (UCD). The paper first reviews the application of Problem Based Learning (PBL) in engineering education, and then describes the design of the specific project based learning module. The objectives of this paper are (i) to identify the most appropriate form of PBL in Civil Engineering, (ii) to demonstrate the design and implementation of a PBL course and (iii) to illustrate how evaluation can be used to determine the effectiveness of PBL.

2 WHY USE PBL

2.1 *Background*

De Botton (2001) states that the educational philosophy of Universities can be summarised as follows: "*the* more a student learns about their chosen subject, the better*," and argues that this has remained unchanged for centuries. He quotes the 15th century philosopher Montaigne, who having successfully completed his education at a leading academy added the proviso:

"If a man were wise, he would gauge the true worth of anything by the usefulness and appropriateness to his life".

Smith and Ragan (2005) describe educational philosophical traditions including *Empiricism*, where knowledge is achieved in a continuum (Kolb 1984) which begins with concrete experience, followed by reflective observation, abstract conceptualisation and active experimentation. Rationalists (Constructivists) argue that reality is constructed by the individual or in a group/collaborative setting. Pragmatists, as the name suggests, occupy a middle ground and consider *truth for now* or *state of the art*, where it is accepted that universal truths are unknown, and therefore cannot be taught. Current theories are therefore acknowledged to be imperfect and should be continually tested and modified as the state of the art develops.

Schon (1983) notes that at far back as 1922, Dewey contrasted the inertia associated with education, wherein the knowledge transmitted is the known orthodoxy, to the dynamic developments taking place at the time in the development of steel cantilevered bridges, where Engineers demonstrated reflection in action. Waks (2001) notes that whilst Dewey advocates reflection by scientific thinking, Schon (1983, 1987) suggests the necessary skills to do this cannot be taught in the classroom or laboratory (by scientific theory) but in the design studio. This support of social constructivist theory is of course dependent on some core principles being available to the student, and strongly suggests that a mixture of pragmatism and constructivism present appropriate models for engineering education. Savery and Duffy (1996) noted that the social constructivist philosophy lies at the heart of PBL whereby:

1. What is learned and how it is learned are interlinked.
2. Problematic puzzlement provides the learner with a stimulus to think.
3. Knowledge evolves through discussion and evaluation of our perceptions.

2.2 *Curriculum design*

Mayer (1982) defines deep learning as causing change and incorporating the following key elements: that change is of long-term duration, it occurs as a result of development of the content and structure of knowledge in the meaning of the learner and the creation of a suitable learning environment. Where significant attention is afforded to teaching and learning methods and assessment procedures, and the student takes control of their learning, significant scope for deep learning occurs (i.e. in the process model – see

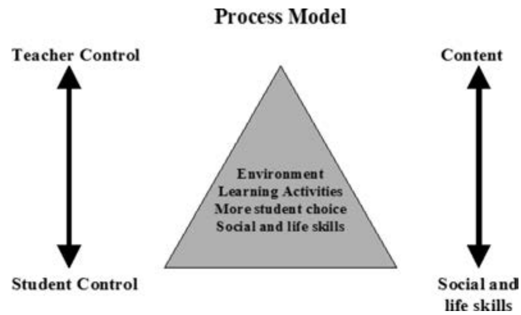

Figure 1. Process Model of Curriculum (after Neary 2003).

Figure 1). Ditcher (2001) notes that a serious impediment to the adoption of deep learning by engineering students is the high number of contact hours required, and the tendency to lecture to large groups being favoured in most engineering schools. She suggests that social constructivist theory would point to the use of Problem Based Learning (PBL) as an ideal model to facilitate deep learning in engineering courses.

The use of PBL has spread rapidly, predominantly in medical education, but also in the spheres of law and engineering. Kolmos et al. (2007) set out some of the key features of the PBL method:

1. Ill-structured and complex questions based on real world scenarios.
2. Student centred active learning occurs.
3. Learning occurs in small groups, considering and reviewing solutions to open-ended problems.
4. The teacher becomes a facilitator.
5. Self-assessment increases the efficacy.

Kolmos et al. (2009) note that many new Universities established from the late 1970's onwards adopted the new educational model and its use spread worldwide (including in older universities) within a range of fields, the most prominent being medical and engineering programmes in Bremen University in Germany, Newcastle in Australia and at Roskilde and Aalborg in Denmark. Whilst the PBL model diversified and was applied across different fields and indeed cultural settings, Kolmos and her co-workers observed that certain principles underpin all methods (see Figure 2).

Barrett (2005) states that one of the key characteristics that separates PBL from other forms of Enquiry Based Learning (EBL) is that the problem is presented first (prior to any other curriculum inputs e.g. lectures). Price and Felder (2006) suggest that this is the polar opposite to traditional deductive teaching and quote E. Kim Nebeuts who eloquently observes:

"To state a theorem and then to show examples of it is literally to teach backwards"

Whilst this true form of PBL has proved to be very successful, particularly in medical education, the forms of enquiry based learning often practiced in engineering schools (such as Aalborg in Sweden

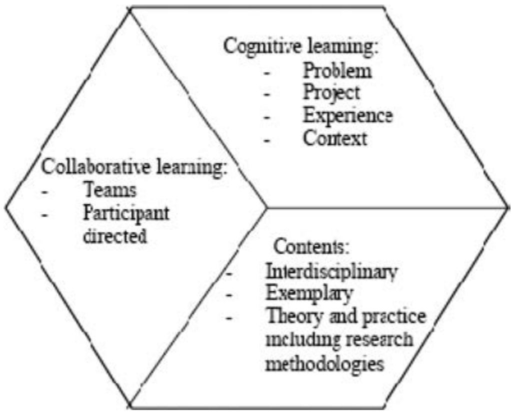

Figure 2. PBL Learning principles (Kolmos et al. 2009).

and the National Technical University in Trondheim, Norway are often described as Project Based or Hybrid PBL. Perrenet et al. (2000) note that in the traditional PBL model learning is self-directed, and in domains such as medical education (where learning is somewhat encyclopaedic), missing concepts may not preclude the construction of valid theories. However, in mathematics and engineering, which tend to be hierarchical, missing essential concepts may result in a failure to learn. They suggest that whilst the development of metacognitive skills (knowing about knowing) will result from PBL, the risk of missing vital concepts and theories suggests that PBL should be used as partial solution to develop professional problem solving skills through the application rather than the acquisition of knowledge. Mills and Treagust (2003) recognise that many of the skills developed during PBL directly align with the competencies or learning outcomes required by graduate employers and accreditation bodies, namely problem solving, small-group working etc. and note that teaching these skills embedded within a technical module is likely to achieve improved outcomes. In noting that engineers practice and therefore must learn in a hierarchical manner within project groups, they advocate the use of Project Based Learning which they differentiate from Problem Based Learning in the following ways:

1. Time – engineering project tasks usually take place over a longer time period than problems.
2. Projects are directed at applying rather than acquiring knowledge.
3. Projects are generally run in tandem with traditional lectures.
4. Time management is a key issue for projects.
5. Self-direction is stronger in project based learning as the learning is directed by the problem.

2.3 *PBL tutorials*

Some of the major problems facing educators who wish to develop PBL courses include (i) the question of how to organise the students into groups, (ii) are there resources available to provide facilitators, (iii) is there physical space available outside of lecture theatres and (iv) how will I phrase the problems? Questions (i) to (iii) largely depend on the available resources and may largely explain the diversity of PBL approaches adopted throughout the world. In general, engineering students are used to working in small (laboratory and tutorial) groups from the time they enter university and the group size appropriate to project based learning (typically less than six students) is very familiar to them. The hybrid PBL or project based approaches can also be operated with a floating facilitator (or tutor) as the students are applying knowledge and creating links rather than creating knowledge and therefore need significantly less scaffolding or support. The question of physical space is an institutional issue. However, faculty members should be cognisant of the benefits in providing project rooms in new and refurbished facilities. Assuming that these obstacles can be overcome through resourcing, the perennial issue of the form of problems to be presented is key to the success of any PBL initiative.

In PBL it is good practice to design problems across a range of media. These might include the use of written problems, pictures, video clips, physical objects etc. (Barrett and Cashman 2009). Whilst in traditional PBL they form a starting point for learning, in project based applications problems tend to be (but are not exclusively) in the form of a written design brief. Problems should be designed to develop a range of learning outcomes, by being progressive and helping to define threshold concepts. The characteristics of good PBL problems are described by Duch et al. (2001). Federau (2006) describes the learning climate model which can be used to ensure the preparation of *good* problems. The ordinate, assignment freedom is a measure of how open the question is. He describes the example of a bridge design exercise “design a bridge to span from A to B”, which if given to a first or second year student who has not studied engineering materials or bridge engineering, will represent a problem with a high degree of assignment freedom. In contrast, if a final year student is asked to “design a concrete bridge to span from A to B” a relatively low score on assignment freedom would result. The abscissa, Active Drive, is a measure of how motivated a student will be to acquire the knowledge required to solve the problem. Put simply, there is a significant pressure on the first or second year student discussed above to self-educate on the basics of bridge engineering, e.g. what spans are permissible for given engineering materials etc. thus resulting in a high value for active problem drive.

2.4 *Assessment*

Assessment of the course should incorporate both student assessments and evaluation of the course itself. In terms of student assessment, lecture driven courses tend to rely heavily on terminal exams backward-looking assessment (Fink 2003) to evaluate student performance. In process based models which use real-life problems, (where possible) it is important to consider a number of critical elements in the assessment procedure in order to enhance the quality of student learning:

1. The use of student self-assessment
2. Clear description of the assessment-Spell out clearly the criteria and standards required.
3. Clearly demonstrate how excellence may be achieved.
4. Through the provision of regular, timely, detailed and constructive feedback.

Wherever possible, learning and assessment should occur simultaneously. An obvious example would be project presentations in which the results of a problem are presented by students, where peer to peer and peer to tutor questioning takes place, and complementary skills such as presentation, public speaking and self-confidence are developed. Through the provision of feedback, an individual or group can evaluate their own progress through a given problem. Kolmos et al. (2007) suggest that questions such as "What did I learn?", "What further knowledge do I need?" And "how could I approach the problem differently the next time?" should be at the centre of self-reflection. They suggest that the more contentious issue of peer assessment should form part of the process. However, to mitigate problems, students should be introduced to this form of assessment using simulated PBL sessions. Continuous assessment (whether in groups or as individuals) is obviously an attractive form of student evaluation and it aligns the assessment with the process of acquiring knowledge. However, terminal exams are also appropriate. Where group assessment is being undertaken as a quality assurance exercise, it is important to get feedback on the efficacies of group working within the PBL environment. Research by Ohland and his co-workers at Purdue University has led to the development of a group evaluation tool CATME Teammaker. It is available as an on-line resource at (http://engineering.purdue.edu/CATME).

Evaluation of the course itself, of the tutors, and of facilitators can take many forms, but should include specifically an evaluation of the curriculum design, facilitation, student experience and effectiveness of learning (Marcangelo et al. 2009). At the programme level, input should be sought from industrial advisory committees or similar bodies and also from colleagues. Feedback from students can be obtained through carefully designed surveys (which are now being implemented online through the blackboard environment) and through focus groups. An additional powerful and often over-looked source of evaluation can be derived from student comments, either during the informal interactions which occur during the tutorial session or on evaluation forms where space is given to free comment. The use of such feedback is discussed in detail by Barret (2008) and Clousten (2007).

3 APPLICATION OF PBL AT UCD

3.1 *Background*

Having considered the role of PBL in engineering education, the final section of this report considers a course which could be described as hybrid PBL and falls very definitely into the category of Project Based Learning as practiced in many engineering schools. The course has been in operation for a number of years and the purpose of the current study is to attempt to improve the course by taking consideration of how recent developments in educational practice might be incorporated in order to optimize the learning outcomes achieved, increase satisfaction, and improve real and perceived operational issues.

Kolmos et al. (2009) present a PBL model which provides a holistic view of the elements which must be considered in a PBL curriculum. The model forms a useful tool to consider the module case studies in civil engineering which is taken by the students in the first semester of the 2 year Master of Engineering course in Civil Engineering at University College Dublin. This new Bologna compliant programme which is described by Gavin (2010) is open to students who have completed a 3 year BSc. in Civil Engineering (or equivalent). In semester I, a series of traditional lecture and tutorial based, core civil engineering design courses are taken which build on the theoretical principles of Structural Engineering and Soil Mechanics developed during the BSc. programme and apply these to real design problems. A Project Based Learning capstone course (Case Studies) is run in parallel with these modules.

3.2 *Objectives and knowledge*

Students joining this module will require prerequisites including the theory of structures and soils (Geotechnics) found in the 3rd year university courses in civil engineering. A key premise of the course is that students will develop an appreciation of the inter-connection between the roles of geotechnical and structural engineers. The module employs group work and weekly presentations to experts in a range of cross and inter-disciplinary projects. A special case study involving collaboration with architecture students is included to develop an appreciation of inter-disciplinary team-work. On completion, the students should be able to:

1. Formulate design solutions to open-ended problems
2. Learn to work in an inter-disciplinary group working environment
3. Develop an understanding of the principle mechanisms through which structures carry load and transfer loads through elements into the ground
4. Consider the wider social and environmental aspects and identify risks associated with their schemes
5. Demonstrate effective presentation skills.

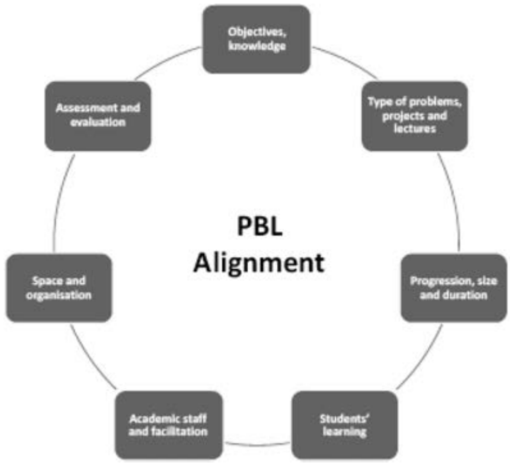

Figure 3. Alignment of elements in a PBL curriculum (Kolmos et al. 2009).

3.3 *Types of problems*

Given the nature of the learning which is required, (application rather than acquisition) the problems will typically be well defined following the PBL definition. However, they contrast strongly with typical text book problems and are relatively open-ended. To encourage diversification and contribute to a real-world feel, the majority of problems are set by experts from industry and are based on current projects. The format is one whereby a brief is issued to the class each Monday morning and they compile a scheme design and present their solutions to their peers, their tutor and the external expert on Friday morning in a question and answers type interruptible presentation format. Case studies are executed over the entire semester (with the exception of the final week of term). The joint civil engineering and architecture case study follows a slightly different one-day format in which larger teams (typically seven members, four engineers and three architects) are given a problem at 9.30 am. From 11 am, tutors are available to provide guidance on schemes (typically one tutor for every two groups). Presentations are made in the afternoon and the session finishes by 5 pm. A typical problem is included in Appendix A.

3.4 *Progression, size and duration*

This involves consideration of the progression in terms of the complexity of problems encountered, and the amount of time given to the PBL exercise within the overall curriculum. Increasing problem complexity at the beginning of the semester is relatively simple. However, in practical terms, the use of outside experts (typically senior engineers from industry) sometimes involves rearranging the pre-determined schedule. One of the case studies which the students find most challenging (from a non-technical standpoint) is the joint work with students from architecture, where students are used to relatively vague project briefs, long deadlines and studio based environments. This contrasts sharply with the engineers who often jump straight in with calculations in a race to find the right solution.

It is important to consider the amount of time that the curriculum gives over to the PBL module. In ECTS credit terms, 33% of the student time in this semester is assigned to PBL. However, the nature of the case studies when compared to the parallel modules which are all assessed based on a terminal exam which occurs at least one week after the end of the semester, inevitably leads to a concentration of student resources on the PBL module.

3.5 *Students' learning*

Although the philosophy, learning outcomes and teaching methods have been considered in some depth, the student who is in the fourth year of their higher education career will be unlikely to have time to recognize this opportunity for self-development. We must therefore provide some supportive guidance to allow them to maximize the potential of the PBL process. To date, this has consisted largely of a relatively unstructured introductory lecture on the operation of the case studies module. Despite this, when asked to comment in an end of semester questionnaire on what they considered to be the benefits of PBL over traditional lectures, respondents stated the following:

"We were forced to learn" and "we developed in-depth learning".

3.6 *Academic staff and facilitation*

The role of academic staff is known to be critical in effecting positive outcomes from PBL and as module coordinator and one of three staff members who act as tutors on this module, up until this year, none had any formal training on how to organize or facilitate a PBL module. Any success of the module to date is probably largely because (somewhat unusually for faculty members) the staff members involved have significant industrial experience which the students see as a significant resource. There is no question that many facets with regard to curriculum updating, assessment and student resourcing can be improved through peer-to-peer tutor training.

3.7 *Space and organisation*

The Civil Engineering Department at UCD recently moved into a new building where the ground floor consists of a number of large project rooms (freely available for project work and study for each stage/year) surrounded by staff offices. The environment is therefore ideal for collaborative project work. The UCD campus is within 4 miles of the city's capital and has built up and maintains a very good relationship with industry. Furthermore, we have access to a large resource of visiting engineers to act as tutors in our PBL initiatives.

3.8 *Assessment and evaluation*

The module is assessed using continuous assessment with group marking (worth 30%) and a final (open-book) individual design exam (worth 70%). Up until now, the assessment has taken the form of standard end of semester course evaluation sheets which were traditionally distributed in a somewhat haphazard format. This year, the course is one of the modules chosen for the new online module assessment tool implemented through blackboard. In addition, for the last two years as module coordinator I have elicited student feedback on their experiences of the PBL modules. This paper presents an example of the use of a case study from the literature in an effort to promote reflective learning in a final year course in geotechnical engineering. Simple design problems were presented to the students in a format similar to how they would be encountered in industry. In the first session, students chose soil parameters from site investigation reports and applied standard design models to estimate footing resistance and settlement. In a follow-up session, predictions were compared to actual footing response and trends such as (i) the effect of mean stress level on the mobilized bearing resistance and (ii) the non-linear stiffness response of soils are introduced in the context of real world design problems.

The introduction of weekly case study problems encouraged student engagement with the topics covered and therein promoted self-learning. As a result, the workshop and tutorial sessions provided an enjoyable educational environmental where detailed discussion on the practical application of soil mechanics principles tool place, promoting learning for students, post-grad demonstrators, and staff members alike.

4 CONCLUSIONS

This review considered the state of the art of the application of Enquiry Based Learning (the term which is used to encompass Problem-based and Project based approaches). Whilst the efficacy of Problem-based learning in multiple domains has been proven, significant research suggests that for hierarchical domains such as Civil Engineering, Project-based learning, where the methods aid application rather than acquisition of knowledge, is a more appropriate technique. The current issues facing engineering education were briefly considered and the combined drivers for change from industry which needs design focussed graduates who can solve problems, innovate and communicate their ideas at one end of the spectrum and students facing issues of boredom in the lecture hall at the other, suggests the increased use of experiential learning methods is critical to the future survival of engineering education.

A case study of a design based capstone course in civil engineering design was considered, where the learning and assessment methods were designed to meet some of the key learning outcomes was presented. A student survey suggests that the course is already achieving many of its stated objectives and it is felt that considering the course design in a more theoretical education framework, where alignment of all elements is considered, should allow for positive development of this course in the future. It is the hope of the author that this may act as an incentive for the development of similar initiatives within the engineering school at UCD and across the wider engineering educational community.

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APPENDIX A – TYPICAL PROBLEM

A flood protection scheme is to be provided in a river valley where the flood level reaches up to 4.5 m above ground level (agl). Prepare an outline scheme that ensures protection of facilities based to the right of the line X shown in Figure A1 if the river reaches +4.5 m for a period of up to 7 days. The length of the flood defence system is 500 m.

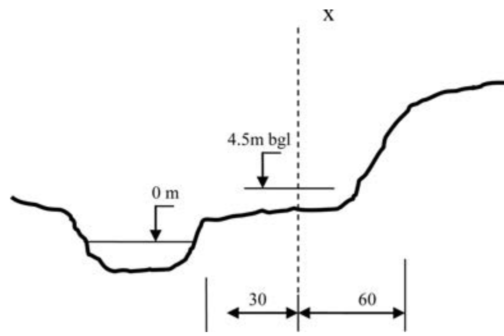

Figure A1. Cross-Section.

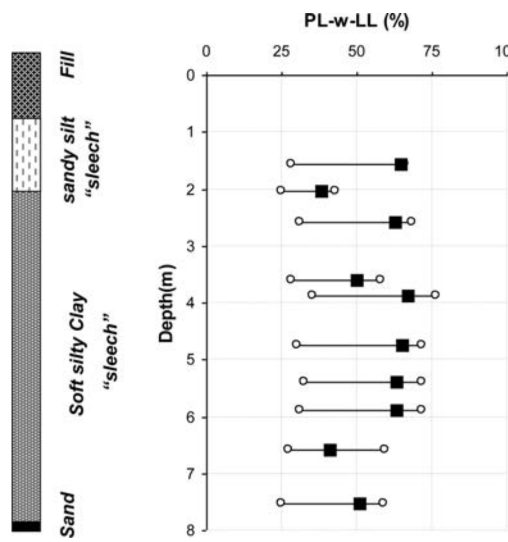

Figure A2. Index tests and composite borehole log.

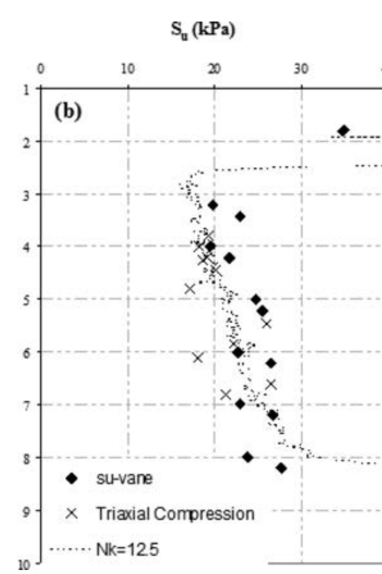

Figure A3. Index tests and composite borehole log.

The composite borehole log for the area (Figure A2) taken along the line X describes the presence of approximately 1 m of fill over sleech to 8 m below ground level. This is underlain by dense/hard boulder clay. The water table is at ground level. Profiles from in-situ test data are shown in Figure A3.

You are required to:

- Propose a suitable scheme design considering overall stability of the geotechnical structure
- Consider the risks associated with your scheme and how these might be mitigated

You have a budget for geotechnical testing (lab or field) which you can use to obtain additional parameters for your design. Each group can specify (up to five tests, e.g. borehole, atterberg limit test etc).

Shaking the Foundations of Geo-engineering Education – McCabe, Pantazidou & Phillips (eds)

Experiences from revising a course to promote significant learning

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ABSTRACT: The second course in a two-course Geotechnical Engineering series was revised to scaffold a significant learning experience in an effort to transform students from active to self-directed learners. The redesign is grounded in literature and based on the forward looking consideration of what students should retain from the course five years after completion. The primary idea is to encourage independent lifelong learning by developing intentional learning strategies. The amended course is offered as a project-based learning (PBL) course incorporating just-in-time and inductive learning at a higher level than the original format which, while active, was more of a deductive approach to the classroom. In addition to several group projects, students also complete an individual project focused on a contemporary issue of their choice in geotechnical engineering as well as engage in classroom discussions of select articles assigned from geotechnical journals or recent conference proceedings. This paper will discuss the revision process as well as the first implementation of the course and will include instructor experience, evaluation and reflections, assessment of student learning gains, and evaluation of the course from the student perspective.

1 BACKGROUND

Geotechnical Engineering at Florida Gulf Coast University (FGCU) is a two-course sequence required by all Civil Engineering majors and taken at the end of their junior and beginning of their senior years. The courses are both taught in the integrated lecture/laboratory format; meeting for 2¼ hours twice a week. The space available, including a lecture room with eight hexagonal tables and extensive white boards, a preparation storage room, and a linked laboratory space, facilitates the integrated lecture/lab experience (Kunberger & O'Neill, 2011). Coverage in the first course is heavily laboratory based and focused on the fundamentals of soil mechanics. The second course is more design, with an equal focus on retaining walls, slopes, and shallow foundations.

2 INITIAL OFFERINGS

The College (formerly School) of Engineering at FGCU was founded in 2005. Since its inception, the Geotechnical Engineering II course has been offered four semesters. The first three semesters were conducted prior to course revisions with single sections of 14 and 28 students in the first two semesters, and a double section of 48 students total in the third year.

The old course was conducted in a style similar to that of other courses taught by the instructor. Material would be presented by the instructor from lesson plans built incorporating the ExCEEd teaching model (Estes et al., 2010). This involves explicit learning objectives for each lesson, a clear and engaging presentation of materials, and multiple opportunities for students to participate in class through examples, in class activities, and models.

Student learning was assessed through four primary types of activities including group projects, individual projects, an individual report (semester specialization) and roundtable discussion activities. Group projects were large assignments each focused on one of the three main topics of the course. The projects were well defined, and although were design in nature, resembled more of an iterative analysis than true design [since many parameters were directly provided]. Individual projects were smaller in scope and again based on each of the main course topics, but often focused on a specific aspect of the general topic rather than the more complete view the group project addressed. The semester specialization was an independent semester long project consisting of ultimate deliverables including a 5000+ word paper, a single page summary handout, and a brief oral presentation. Feedback on milestones throughout the semester (e.g. article summaries, or 50% draft submission) assisted in strengthening these final deliverables. Roundtable activities were weekly discussion forums on journal articles or recent conference proceedings and included related written submissions.

The course was effective in content delivery from both the instructor and student perspective, and assessment of student performance on course learning outcomes and associated program outcomes demonstrated sufficient mastery.

3 REVISION REASONING

While the course was acceptable in meeting stated objectives, the instructor felt it was incumbent to expect more out of students who would be entering the workforce less than 6 months after completion of the course. Many students were quite adept at "typical" problems, but often struggled with those requiring a higher level of critical thinking (e.g. problems where more or less information than what was needed to complete was presented, or ones asking for information in a format previously unseen even though the topic had been covered extensively). Students particularly balked at situations where a specific problem had multiple correct solutions.

Overall, the course worked from a technical knowledge standpoint, but fell short in the professional skills aspect, and lacked the autodidactic (or self-learning) component which would strengthen students' competitiveness in securing a position in industry or graduate school.

The final impetus for revision was the timely offering of a Course Design Academy (CDA) provided in the Summer of 2011 through FGCU's Teaching, Learning, and Assessment Initiative. The CDA was conducted in eight 4-hour sessions spread over a three-week period and brought together faculty from across campus with an overarching goal of each participant leaving the program with a very different course from which they entered.

4 REVISION PROCESS

As part of the initial ABET accreditation of the Civil and Environmental programs, the author was familiar with linking the assessment of course objectives to program outcomes and the expectation that an engineering program should look not only at student achievement upon graduation, but also at student performance several years after graduation. Even with this awareness however, as a young faculty member, the author never considered applying this same concept to a course. The initial CDA meeting tasked participants with answering the question of "What would you like your students to remember five years after taking your course". The response to this question became the building block for course design.

4.1 *A change in focus*

When faced with the situation of having to actually answer the question of what students should take from the course 5 years later, it became apparent that the current course objectives were not the correct response. While the current list was reasonable in the short term, many of the items were ones that would either be second nature to an engineer with five-years-experience or typically completed utilizing either standard reference material or a computer program for assistance. Conversely, the focus couldn't be so far reaching that it eclipsed the foundational knowledge the students' possessed; the objectives had to be achievable for senior students with a single course background in geotechnical engineering.

The result was a reduction in the amount of objectives from 23 detailed foundational ones that skimmed the surface and touched on numerous topics to 8 "significant learning" objectives that delve deeper into fewer focus areas of the same general topics and force students to work at the highest levels of Bloom's taxonomy. The focus of the course then becomes a significant and intentional learning experience from which students can emerge more self-reliant and self-aware.

4.2 *Support from literature*

Studies summarized in Fink (2003) show little difference in performance on concept tests by individuals having taken a course compared to individuals who did not take the course and this difference is reduced as time after the course increases. From a broader perspective research has indicated students experience limited gains in knowledge overall during their first two years in college (Arum & Roksa, 2011). These limited gains suggest a change is needed.

As Richard Felder states in the September 2011 issue of ASEE's Prism magazine, "being a college professor is probably the only profession in existence where no training is routinely given before or after you've started" (Loftus, 2011). And yet faculty members are expected to become exemplar teachers who possess both high intellectual excitement combined with high interpersonal rapport (Lowman, 1995) able to present in a clear and engaging manner while exuding a sense of approachability and caring to students. Extensive research has been conducted on what constitutes effective teaching, from classroom approaches such as recognizing and teaching to the different learning styles in the classroom (Felder, 1996) and encouraging interaction, cooperation and diversity (Chickering & Gamson, 1987), to course structure approaches for creating a hierarchy in specific learning objectives (Anderson, et al., 2001) or course development and assessment (e.g. Wankat & Oreovicz, 1993, Lowman, 1995).

More recent research has considered the impact of various approaches designed to augment the learning experience and transform students from active to self-directed learners (Fink, 2003, NAE, 2005a, Crawley et al., 2007; Ambrose et al., 2010). These "significant learning experiences" as Fink calls them are a result of the integration of learning objectives, instructional activities, and student assessment in an intentional and meaningful manner throughout the development of the course. Regardless of the level of the course within the curriculum, considering how in addition to what and where (classroom, lab, virtual environment, etc.) students are learning can result in an environment that challenges students to reach greater levels of achievement.

Table 1. Lesson activities for each main topic covered in Geotechnical Engineering II

Lesson Number	General Lesson Activities
1	Introduction to Project
2–5	Coverage of Related Material*
6	Review of Examples
7	External Workday (out of class)
8	Internal Workday (in classroom)
9	In Class Design (test on project)

*Often included an additional workday.

These revisions reflect the shift in the knowledge paradigm from students as vessels waiting to be filled to students as constructors, harvesters, and active inquisitors of information (Johnson et al., 1998). They create an interactive classroom where students are encouraged to make connections and expand on concepts, not simply be introduced to knowledge. As a result, students complete the course not only competent in course topics, but also as perpetual learners skilled at adapting to the challenges implicit in today's flat world – i.e. a world comprised of instantaneous connections (Friedman, 2005).

Moreover, this premise supports the development of engineers who have the National Academy of Engineering, Engineer of 2020 attributes including practical ingenuity, creativity, and lifelong learning (NAE, 2005b) as well as those who are "master innovators and integrators of ideas and technology" as noted in the American Society of Civil Engineers vision for civil engineering in 2025 (ASCE, 2007).

4.3 *PBL as the delivery mechanism*

Engineering courses are an almost natural fit for projects. Upper level courses, particularly design intensive ones, virtually always incorporate projects into the expected coursework. However, including projects in a course is not the same as project based learning (PBL). The Geotechnical Engineering II course likely could have been revised without the inclusion of PBL, but integrating PBL as the delivery mechanism supported the instructor's desire to transfer from the academic setting to something closer to what students would experience in practice.

While the overall contact time for the class remained the same, the choice of PBL dramatically impacted the lesson plans. Each main topic ran for roughly 9 lessons (approximately 5 weeks). Table 1 summarizes the activities for each of the lessons, which were similar for each of the three course topics.

Project introductions were followed by brainstorming sessions in which students identified information which was "known" either as provided in the project description or knowledge gained from previous courses, information that could be "found" such as that from literature reviews and standards or soil characteristics that could be determined from provided raw laboratory information, and information that was "needed" such as methods and processes that had not yet been learned. The brainstorming helped students form connections with previous material, realise that more information was present than initially apparent, and also allowed for the subsequent lessons to be determined based on an identification of what was needed to complete the project.

Coverage of related material was presented in short lectures with examples and multiple in class activities allowing students to work with the topic rather than simply observe the instructor performing calculations. The review of examples day was an opportunity for students to ask questions based on extended examples and solutions posted by the instructor or any other questions they might have. For external workdays the classroom was closed, but the instructor was available in the building for questions, while for internal workdays the instructor was in the classroom and students were allowed to work either in the room or elsewhere. In Class Designs were essentially tests on the projects and are further detailed in the *delivery differences* section under *implementation*.

5 IMPLEMENTATION

The result of the revision efforts was an amalgam of new concepts, ideas, and activities paired with select features from the old course. The initial offering of the revised course occurred in the Fall 2011 semester within two separate sections including a total of 43 students.

5.1 *Instructor differences*

As with previous semesters, all students had been enrolled in at least one course with the instructor prior to Geotechnical Engineering II, with some having taken 2, 3 or even 4 courses with the instructor prior to this offering. Because of this, the instructor style was, for the most part, a known quantity for students. While in the past this was a definite strength, with such a drastic change in approach the instructor was concerned perceived expectations of the students might differ from what was provided. For this reason time was taken at the beginning of class to explain how this course differed from previous ones offered by the same instructor.

5.2 *Delivery differences*

The revised course was approximately 60% new features and 40% items from the earlier offerings. The course is composed of 4 main categories of activities: roundtable, semester specialization, individual work, and group work. Table 2 summarizes the assessment mechanisms for each of these categories in both the original as well as the revised course offering. Items that are listed across both columns were unchanged in the revised offering. Additional details on revisions to

Table 2. Assessment mechanisms for the original and revised course offerings for each category of activity

Activity Category	Assessment Mechanism	
	Original Offering	Revised Offering
Roundtable	Written Summary or Quiz on Article*	
Semester	Final Paper, Handout, and Presentation*	
Specialization	article summary	intro and outline
	single short talk	2 group discussions
	50% draft review	75% draft review
		reflective piece
Individual Work	Smaller projects	In Class Designs
Group Work	Well defined group projects	Open ended group projects

*mechanism unchanged from original to revised offering

each of the categories are discussed in the following sub-sections.

5.2.1 *Roundtable*

Roundtable activities, for example, remained unchanged. Students were still expected to read the articles, complete an independent activity (short written summary or brief quiz) prior to discussions, and contribute to the in class discussions. Some articles changed, but this was more a function of the availability of new articles than a desire for a change in focus. Roundtable activities from previous semesters had proven to be effective means of engaging students in contemporary issues (Kunberger & O'Neill, 2010) as well as a means of measuring and contributing to the improvement of student technical writing and synthesis skills (Kunberger, 2011).

5.2.2 *Semester specialisation*

The final deliverables for the semester specialisation (SS) remained the same. Students were also still allowed to select their own topics, providing they related to geotechnical, geo-environmental, or geological engineering. Changes however were made to the preliminary activities.

Two group discussions were incorporated into the first half of the semester. The first involved the creation of groups of 4, pairing 2 students with similar topics to another 2 with topics in a different area. Each student was required to present a brief (less than two minute) description on their topic, the reason for the topic choice, how the topic related to the course, and a brief direction for their specialisation. The group was then asked to give feedback to the student; with a different perspective being provided from the student with a similar topic than those with different topics. The second group activity placed students in groups of 4 again, only this time every member of the group was researching a different topic. Presentations for this activity involved rough drafts of students' single page handouts.

A third group activity involved pairing students to conduct reviews of the 75% draft paper submissions. This was the only group activity in the original offering, and was previously based on 50% draft submissions. Each student was paired with someone covering a different topic and an individual with whom they had not been teamed with previously. They were then asked to provide written comments on the draft papers as well as briefly discuss the drafts with each other. For both this activity and the draft handout group activity, students were provided the final cut sheets on which the instructor would base evaluation and grading of the final submissions. The goal was three-fold: 1) students were required to critically evaluate another's work, 2) students were encouraged to progress with their own work in a timely manner, and 3) students were exposed to the expectations for their final submissions in a format more interactive than simply being presented with the rubric. With all of these activities students received feedback from the instructor in addition to the student feedback received.

A reflective piece was also incorporated as an additional optional activity within the semester specialisation. All activities were designed to encourage students to take ownership of and become more knowledgeable on their topic and more comfortable presenting, giving, and receiving constructive critiques. Expectations of multiple reliable sources, not only summarised, but synthesised, honed communication, critical thinking, and life-long learning skills as well as exposed students to contemporary issues in geotechnical engineering.

5.2.3 *Individual work*

Individual projects were removed from the course, and replaced by In Class Designs (ICD). These ICDs were essentially open-book, open-note tests that students were required to complete individually. The ICDs were linked to each project and focused on a critical aspect of the project topic. Students were required to pass the ICD with at least a 65% in order to receive full credit on the related project submission. Those not meeting that criteria received only the ICD percentage of the associated project grade (e.g. a student earning a 50% on the ICD and an 80% on the group project would receive a 40% on the group project).

In Class Designs were intentionally tied closely to projects such that individuals who reasonably contributed to group activities had an extremely high likelihood of success on the ICDs. For example, the foundations module project provided students preliminary footing dimensions and loadings (e.g. dead, live, and wind) and boring logs and lab soil testing results for a particular building and requested analysis and redesign for bearing capacity and settlement (both total and differential). The associated ICD provided students with design loads and initial footing dimensions, a boring log, and the column layout for a different building and asked students for the same analysis and redesign with respect to bearing capacity and settlement criteria for two footings within the building footprint.

Table 3. Course objectives for Geotechnical Engineering II.

Number	Objective
1	Distinguish between factor of safety and probability of failure and validate their importance in design
2	Incorporate the critical nature of construction considerations into design feasibility
3	Analyse and design rigid and flexible retaining walls for external stability
4	Critique and modify slopes with regards to stability
5	Analyse and design shallow foundations for bearing capacity and settlement
6	Discriminate between sources of information and recognise the infallibility or lack of for multiple source types
7	Correlate solutions generated in computer analysis with associated theoretical constructs
8	Elucidate technical knowledge to multiple audiences utilising various mediums

5.2.4 *Group work*

Group Projects underwent significant modifications in the revised course. As an example, the initial course slope stability project required an analysis for initial and rapid draw-down conditions on a well-defined slope. Dimensions and soil properties were provided and students were expected to perform analysis of various slope ratios, drawing comparisons among the results. The revised project presented students with the real world and close to home challenge of the failing Herbert Hoover Dike surrounding Lake Okeechobee. Students were tasked with determining where, why, and how failure was occurring (or likely to occur), how this might impact other regions of the dike, and constructing a viable solution to the problem. Dimensions and soil properties were provided in the form of Army Corps of Engineer reports, soil surveys and journal articles discussing the situation. The overall final expectations of the project did not change, but the revisions transformed a mechanistic project into a more unconstrained design challenge.

6 RESULTS AND EVALUATION

Results from the initial offering of the course will be presented from the perspective of assessment of student learning gains, student self-evaluation of course performance, student evaluation of course delivery, as well as instructor observations and student feedback.

6.1 *Assessment of student learning*

Overall satisfactory student performance on stated course objectives was achieved. Table 3 lists the 8 course objectives, while Table 4 summarises the percentage of students performing at levels of at least 85%, 70% and 65% for each numbered objective.

Table 4. Percentage of students achieving various levels for each course objective in Geotechnical Engineering II.

Objective Number	Achievement Levels		
	≥85%	≥70%	≥60%
1	98%	98%	98%
2	70%	88%	91%
3	40%	81%	84%
4	63%	100%	100%
5	33%	100%	100%
6	80%	95%	99%
7	81%	91%	100%
8	64%	91%	96%

Table 5. Student self-evaluation of each course objective in Geotechnical Engineering II (n = 34, 80% response rate).

Objective Number	Achievement Levels*		
	Excellent	Satisfactory	Marginal
1	21	10	3
2	16	18	0
3	25	8	1
4	18	14	2
5	18	13	3
6	19	13	2
7	18	23	1
8	10	15	1

*note: no student responded unsatisfactory evaluations

When possible, student achievement was measured from individual submissions rather than group submissions – for example in class designs rather than group projects for objectives 3–5. In general, student performance on all objectives was good, with roughly half the class achieving at a mid-B range (85%) or higher for at least six of the eight objectives, and a third of the class meeting this standard for the other two. A vast majority of the class achieved all objectives at the low-C range (70%), while select few did not achieve certain objectives at the low-D range (60%). It should be noted that student performance on individual objectives is separate (e.g. a student may be in the ≥85% achievement level for one objective, but may not meet even the ≥60% achievement level for a different objective).

6.2 *Student self-evaluation of course performance*

For each course objective, students are asked to self-evaluate their personal achievement on a scale from excellent to unsatisfactory. Results of this self-assessment are presented in Table 5.

Although individual student responses cannot be correlated to student performance presented previously, the general trends have a majority of students evaluating at the excellent to satisfactory level, with

Table 6. Student evaluation of course activities or concepts in Geotechnical Engineering II (n = 34, 80% response rate).

Course Activity/Concept	Average*
Increased knowledge of technical resources	1.71
The semester specialisation was valuable	2.24
Knowledgeable on my semester specialisation	1.76
Project-based nature of course appropriate	1.35
More lecture needed in course	2.94
More structured time needed in class	3.21

*note: 1 = Strongly Agree, 5 = Strongly Disagree

only a few indicating marginal achievement of any course objective.

Comparisons in student performance in the original offering versus the revised offering is somewhat complicated by the fact that the objectives were so drastically changed. Because of this it is not possible to effectively compare student performance on individual objectives. Limited comparisons can be drawn from project averages as well as overall course averages. The Fall 2011 student average on all three projects (84.4) was within one percentage point of the previous 2 course offerings (85.7 in 2010 and 84.7 in 2009). The overall course average for the Fall 2011 (86.7) was also fairly close to that of earlier offerings (86.8 in 2010 and 89.3 in 2009) all of which fall into the high B range. Comparisons do not include the Spring 2009 offering (first delivery of the course) as the topics and number of projects were different and the number of students in the first offering was small.

While the select comparisons above suggest no clear impact on the revised delivery mechanism on student performance it is important to realise two key facts. First, overall student averages are a relatively weak assessment instrument – and even further breakdown of these averages would not necessarily correlate to the impact of the delivery mechanism alone. Second, many of the expected benefits of the revised delivery are not likely to be fully realised until students actually reach the point of being five years or so removed from the course. This analysis would require a longitudinal study that cannot yet be completed due to the recent nature of course delivery.

6.3 *Student evaluation of course delivery*

Students were asked to evaluate various course activities or concepts on a Likert scale from 1–5 with 1 equating to strongly agree, 3 being neutral, and 5 equaling strongly disagree. Table 6 presents a summary of select activities as well as average response values from students.

Students were very positive regarding the appropriateness of the project-based nature of the course. They were neutral to slightly positive about the desire for additional lecture time in the course, which may indicate a comfort level in some regarding independent learning while others would still prefer a more structured learning environment. With respect to more structured time for project activities however, the overall student evaluation sat at neutral to slightly negative, possibly indicating a greater comfort level with working independently on projects or activities compared to the lower level associated with lecture presentation.

6.4 *Instructor observations*

The initial offering of the revised course met many of the expectations of the instructor. Based on concerns associated with the "grieving process" presented in the literature, the instructor took time in the first class to explicitly state why PBL was the method for delivery of the course, and how this method would benefit the students. In addition, emphasis was placed on variations in instructor course delivery of this course from previous courses in an attempt to establish clear expectations early on.

Students were generally receptive to the process of PBL. While the first project and brainstorming session was met with a bit of resistance, later "first lessons" were much more openly accepted, with more students being willing to participate in the process with the realisation of the benefits of early engagement with the material.

Probably two of the most meaningful experiences for the instructor occurred outside of class. Historically, office hours or external workdays usually resulted in participation from only a handful of students. Towards the second and third sections of the course, almost every group took advantage of office hours and visited the instructor during external workdays. Additionally, more than just a single person from the group attended, more often than not a majority, if not all, of the group members came to ask questions simultaneously. The second experience was during one of these visits, when a group of 4 students sat at the instructor's desk asking questions regarding the second project. One student asked, "Can't you just tell us the right answer?" To which his team-mates responded, "Shush, she's not going to do that … we need to ask if our justification for our assumptions are reasonable, not if the answer is right." It was a moment of enlightenment – and sheer joy on the instructor's part.

6.5 *Student feedback*

Students were presented with several opportunities to provide written feedback to the instructor. All of these were in an anonymous format. Below is a selection of student responses to various questions posed by the instructor.

At the end of the course, students were asked to list the top 10 things they remember most from the course. Time was limited, and students were asked to respond with the first things that came to mind. Many students mentioned the three main course topics, as well as various instructor traits. Select comments that the author found most promising with respect to the course meeting “significant learning” levels include the following:

- Made me interested in Geo (Geo I did not)
- Continue to read to stay current
- Many solutions are possible but not feasible
- Research reliability
- My SS material [multiple notes]
- Finally feel confident with my writing
- Factor of Safety is not reliability

While these may only be a small number compared to the overall number of students in the course, each relates to the idea of a deeper and more meaningful learning experience or concepts that are likely to serve the students well long after the completion of their degree.

On the same survey, students were requested to list the single most important thing to keep in the course and why. Many chose not to comment or provided general statements such as “everything” or “nothing stands out” but some of the more specific comments included:

- Design projects – felt like I got a full grasp of the problem, limitations of implemented solutions
- SS – it helps us to explore other geo topics outside of what is learned in class
- SS topic – to facilitate self-learning

Each of these responses provides a “why” indicating the importance the students place on independent and self-directed learning.

The final student comments listed below were provided on the Student Assessment of Instruction forms, distributed by the University and returned to the instructor in the next semester.

- “Don’t change anything! Best class thus far at FGCU! Feels like I know a lot of technical and current geo aspects.”
- “[The instructor] has high expectations of students and work but that is necessary to facilitate learning at a higher level.”

Again, both comments support the belief of the instructor that the course is evolving into a course that provides a higher level of deeper learning for a more complete educational experience.

7 FUTURE OFFERINGS

Based on results from the initial offering, the following is a summary of the key revisions, and the primary reason for each change, which will be included in the next offering of the course:

- Rearrange topics such that projects progress from more to less well defined. For example the foundations project (currently project 3) provided an initial design and extensive soil parameters while the slope project (currently project 2) required assumptions and data validation mainly from external sources.
- Make project due on the same day as the In Class Design to emphasise relationship of two items.
- Make reflective piece for semester specialisation required instead of optional.
- Transition in class presentation of material to out of class review of students prior to class to use face time to reflect, make connections, and expand knowledge.
- Modify external workdays to group office hours, where each group is required to meet with the instructor for a short period of time to discuss questions and progress on the project.
- Incorporate pre and post assessment of student deep versus surface learning using established and vetted national instruments.

It is likely that additional items will need to be created or modified based on feedback from additional offerings of the course, the list above are simply some of the most pressing noted from the initial class.

8 LESSONS LEARNED

Based on the author’s experience with this course revision, the following suggestions are made for those who are considering undertaking a course revision:

- Reflect on the ultimate goal and consider creating a “guiding question” which establishes the global focus of the course.
- Evaluate the current offering to determine what works and doesn’t with respect to the ultimate goal. It may be possible to keep or modify some of what is already present.
- Rethink what needs to be covered during “lecture”. Face time is a valuable commodity and may be better optimised with discussions and interacting with the material rather than simply presentation of the material.
- Recognise that within the finite class time an increase in depth should be balanced with a decrease in breadth. Stressing skills over concepts can provide students with the ability to independently acquire a breadth of knowledge.
- Remember all courses are iterative processes and it is not necessary to complete all revisions simultaneously.

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Promoting active learning in geotechnical engineering

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ABSTRACT: With the frequent use of computer programs, young people nowadays generally lack independent thinking and judgment skills. This paper highlights the approaches that the author has implemented to promote active learning in geotechnical engineering modules. During lectures, only the key concepts of the topics will be presented. During tutorials, students from an active team will make presentations on an assigned topic followed by discussions and interactions by all students in the class. Although some students found difficulties in adopting in the beginning, majority of them later found the above approaches beneficial and started to reap the benefits of their own active learning.

1 INTRODUCTION

In October 2000, 150 engineering educators from 25 countries gathered at Aachen University to look at issues of educating the engineers for the 21st century (Weichert et al., 2001). The issues discussed included the role of global engineer in meeting the challenges of society in the 21st century, internationality and interdisciplinarity, developing personal scales to be a global engineer and other topics. In 2008, the American Society of Civil Engineers published a book on "The 21st Century engineer, a proposal for engineering education reform" (Galloway, 2008). On the other hand, specific issues on education in geotechnical engineering were discussed at the well-attended conference on Geotechnical Engineering Education and Training (Manoliu et al. 2000). It is evident that the issues of engineering education including those specifically in geotechnical engineering are now receiving more attention.

Nowadays most young people are familiar with the use of computers since junior/primary schools. They often run computer programs to obtain the results and prepare project reports with the aid of software. While the use of computer programs has many advantages such as very neat and organized presentations that can be easily amended and enhanced, young people often lack the necessary interpretation and judgment skills to make sound assessment of the computer outputs. They often blindly trust the results generated from computer programs without appropriate questioning and independent thinking.

The lack of independent judgment by university students affects the conduct of geotechnical engineering modules. As a subject, geotechnical engineering often requires students to exercise sound judgment to arrive at the most logical solution. As an example, students do not have a gut feeling on whether the computer output of proposing a 1-m wide stem for a cantilever reinforced concrete retaining wall is reasonable and practical or not. This is of course partly due to students' lack of practical experience. However, when they are questioned, they often reply that this is what the computer program has produced and believe that the computer outputs cannot be wrong. They often do not realize that if the wrong data had been inputted into the computer, the program would certainly produce incorrect answers.

In view of the above, the author has experimented with several approaches in the conduct of various geotechnical engineering modules at the National University of Singapore. Different approaches were implemented at various levels of undergraduate and graduate geotechnical modules. The aim is to promote active learning by the students. A good number of scholars had contributed ideas of active learning in the book "Research and practice of active learning in engineering education" (Graaff et al., 2005). This paper will present in detail three such approaches adopted. These include the use of actual field case studies to motivate students to think, the use of textbook rather than lecture notes in the conduct of junior geotechnical modules, and the adoption of active learning groups in tutorial classes. The students' responses to and feedback on the above approaches will also be discussed in this paper.

2 CASE STUDIES TO MOTIVATE THINKING

2.1 *Undergraduate modules*

In many universities, geotechnical engineering modules often start in Year 2 of the undergraduate civil engineering curriculum. Soil mechanics is typically the first geotechnical module covering basic soil properties, seepage and consolidation as well as shear strength. For a couple of years, this author had the opportunity to teach this Year 2 module and realized that many students found the topics of consolidation and shear strength very hard to absorb and a good number of them simply gave up.

Besides stressing on the fundamentals of the topics, the author would bring real life examples from Singapore projects to illustrate to the students why they have to learn these difficult topics. As an example, for the seepage topic, I highlighted the construction of the first underground railway tunnel under the Singapore River in the 1980's where sheet pile cofferdams were built to enable the construction of the cut-and-cover tunnels in dry conditions. Owing to the drawdown of water inside a cofferdam to facilitate dry construction, water seepage into the cofferdam needed to be determined. The concept of flow net and seepage was then gradually introduced. This is followed by the systematic discussions on the importance of various parameters such as permeability of soil and water head difference.

The author then highlighted to the students that the initial design had to be conservative to ensure no severe water seepage into the cofferdam during construction. With the actual field measurements obtained from the first cofferdam, the water seepage was found to be much smaller than the design estimation. The contractor was subsequently able to save cost and speed up the construction by combining the planned second and third cofferdams to a single cofferdam. With this illustrated example, the students realized that what they learnt was indeed practical rather than theoretical and became very interested in the topic. Of their own accord, a good number of them did further literature searches to learn more on the various practical applications of seepage theory.

Consolidation is another topic which students found hard to cope with. After explaining the concept and its applications in detail systematically and slowly, I gave them some real cases to think about. The Nicoll Highway incident (Ministry of Manpower, 2005) with the collapse of the retaining structure after 33 m of soil excavation in soft marine clay that occurred in Singapore in April 2004 was used an illustrative example. Towards the end of the consolidation topic coverage, students were asked to voluntarily submit their calculations on whether the 50-m thick soft marine clay has completed its consolidation settlement under a reclaimed sand fill placed about 50 years ago.

During the lecture, the author chose a couple of student submissions to present and illustrated to them that the thick soft clay was still consolidating. I further explained why the clay was still very soft and why a very deep excavation in thick soft clay could be problematic. Many students found this helpful to overcome the tedious and abstract topic of soil consolidation. More importantly I found a good number of students became very much interested in geotechnical

Figure 1. Photograph of landslide and debris flow in Hong Kong.

engineering and no longer found the soil mechanics module very difficult and too theoretical.

Year 3 geotechnical engineering modules at the National University of Singapore covered the applied topics of slope stability, retaining structures, shallow and deep foundations. Some students who could not cope with the soil mechanics module in Year 2 were still quite lost with the Year 3 geotechnical modules. To motivate them to think on their own and enhance their interest, the author often presented actual field examples related to the topic covered from Singapore and overseas during lectures. I then encouraged them to take relevant related photographs inside and outside the campus when opportunities arise. They should submit the photographs with appropriate short discussions. In cases involving relatively complex topic which could be time consuming for the students, incentives such as bonus mark for course work were occasionally given.

Using an example from the slope stability topic, the author showed them slope instability cases worldwide. As an example, a debris flow slope failure from Hong Kong is shown to them during the lecture, see Figure 1. After explaining to the class the possible reasons for the slope failure and debris flow and their consequences, I informed the students that although Singapore has less steep terrains compared to other parts of the world; it still has many slope stability problems and presented them a slope failure example behind a house (Fig. 2) in Singapore which could be dangerous.

The author then challenged the students to look for warning signs of slope instability such as soil cracks and movements on slopes in Singapore. Some of them responded by sending me photographs they took on potentially unstable slopes. Figure 3 shows a photograph sent by a student on a Singapore slope showing signs of instability with cracks and observed soil movement. I then presented the student photographs to the class and highlighted to them that unlike buildings which must be absolutely safe; it can be difficult to ensure that all the slopes are safe in view of economics and practicality.

On the topic of retaining structures, the author highlighted to the students that they must know the concept

Figure 2. Photograph of landslide behind a house in Singapore.

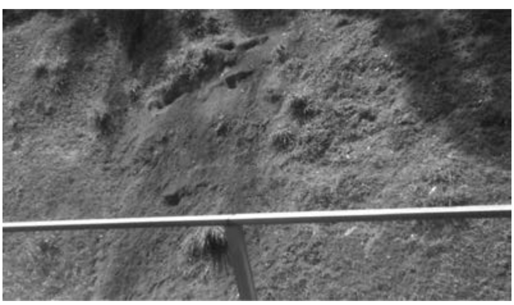

Figure 3. Photograph of a potentially unstable slope taken by a student.

reasonably well and able to think beyond the topic. For example, I impressed upon them that it is important to know that a retaining wall design often involves slope stability check as a properly designed retaining wall may still fail if global slope stability check has been overlooked. That is why the topics of slope and retaining structures are often covered one after the other. In addition, the structural design of a cantilever reinforced concrete retaining wall, which students would be learning in structural design module, is also very important. Case histories had demonstrated that such retaining wall had failed structurally as the steel reinforcement was placed on the wrong parts of the wall stem. The above highlighted that students should be aware of the links among various components of civil engineering.

To further motivate students, the author urged them to take photographs of retaining walls within the campus and shared with the class. Using a photograph submitted by a student (Fig. 4), I illustrated to them the practical aspects of retaining wall design such as typical dimensions of wall stem and base of a cantilever reinforced concrete retaining wall. In addition, the provision of weep holes in retaining walls is very important in Singapore which often experiences heavy downpours. This would enable water gathered

Figure 4. Photograph of a reinforced concrete cantilever retaining wall in campus taken by a student.

Figure 5. Photograph of blocked weep holes on a retaining wall taken by a student.

behind the wall after rain to drain away as soon as possible to relieve the water pressure and hence loading on the wall.

To follow on the issue on weep holes, the author used another student photograph (Fig. 5) to illustrate that the weep holes provided in a retaining wall are often blocked by vegetation and hence maintenance of weep holes could be a major issue. An experienced engineer should not follow the book blindly believing that the weep holes would always function well and be able to drain the water behind a wall effectively. In Singapore, weep holes may be blocked by leaves after heavy rainfalls. Engineers should realize the possibility of water gathering behind a retaining wall could be a long term design issue and may need to check this condition as an extreme event. While full safety factor needs not be warranted in such extreme condition, a competent engineer should check that the wall is still marginally safe should there be water behind the wall.

With the above and other practical illustrate examples, the author reminded the students not to trust the computer outputs blindly and must learn to make correct judgment and interpretations. The ability to make

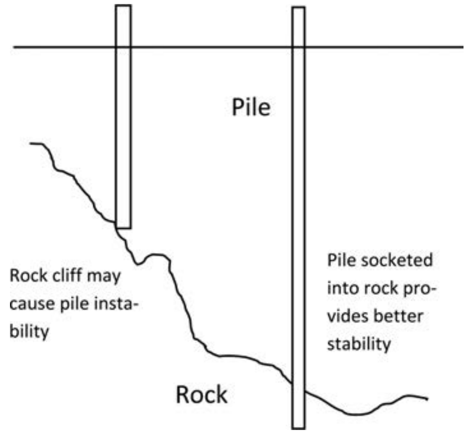

Figure 6. Practical problem in the field highlighted by a part time Master course student.

the right decision based on sound judgment would distinguish a competent engineer from a non-competent one. Hence I further explained to them that despite the many computer programs that are now available to handle complex calculations (some of them are so user friendly that technicians rather than engineers can handle the analysis), good competent engineers are still needed to make the right decisions.

2.2 *Graduate modules*

Many graduate geotechnical modules at the National University of Singapore are open to Ph D research students and master degree students by course work or research. Many of the master course work students are practising engineers and studying their master degree on part time basis. Final year undergraduate students are also allowed to take up to 3 graduate modules to enhance their knowledge in a specified field. Such mix of students poses some problems. The full time graduate research and final year undergraduate students do not have the relevant practical experience to appreciate advanced geotechnical topics such as ground improvement and deep excavations. On the other hand, the part time graduate students are mostly practicing engineers but many of them had forgotten the concept as they obtained their first degree sometime back.

To facilitate a better appreciation of practical problems, the author encouraged the part time students to share with the class the problems they encountered in their day-to-day work. Figure 6 shows a problem on pile installation provided by a part time student in the advanced pile foundation module. During the lecture, I used this example to illustrate the issues that engineers would face in practice and highlighted to the full time students that these issues are normally beyond the materials covered in the classes.

The author also showed the class a lot of photographs that I had been involved as a geotechnical consultant in pile foundation projects in Singapore and overseas. When presenting these cases, I also highlighted the theories and concepts that a practising engineer should possess when dealing with the problems. Both the full time and part time students appreciate this approach as they can benefit from each other. As the module is in progress, a number of full time students start to interact regularly with part time students to supplement each other. The full time students can now appreciate the practical issues faster after discussing with the part time students. On the other hand, the part time students are able to refresh and appreciate the concept and theory readily by interacting with the full time students.

3 LECTURE STYLE

3.1 *Textbook rather than lecture notes*

The recent trend of undergraduate civil engineering curricula is to adopt a broad-based training approach. As such, there are a large number of technical (for example geotechnical engineering), fundamental (mathematics and basic sciences) and humanity (for example human resource management) modules to be covered in an undergraduate course. However, technical modules are still expected to be taught to some depth in order to keep abreast with the latest technical development in a particular area. Hence undergraduate civil engineering students often face a highly crowded curriculum and have little time to appreciate the significant amount of course materials. As a result, students tend to adopt an 'optimal' learning approach to achieve the best grade with minimal effort and little time was spent to understand the fundamentals of the subject matter.

With a heavy curriculum, students often expect lecture notes to be given by the lecturer so that they need to spend the least time to study the subject. Unfortunately this poses problems for the conduct of geotechnical engineering modules. The author used to provide notes to the students. Although the student feedbacks generally revealed that my teaching has been clear and they appreciated I had spent time and efforts to explain difficult concepts, I found many of them still did not seem to be able to keep the concept and fundamentals after the module.

Despite seemingly doing well in their year 2 soil mechanics module, students are often unable to apply the concept learned in year 2 to year 3 geotechnical modules due to lack of basic understanding. To address this issue, I changed my teaching style about 15 years ago and no longer provided lecture notes to the students taking junior geotechnical modules. Instead I only covered the broad concept during lectures using standard soil mechanics texts such as Craig (2004) and Whitlow (2001).

In order not to overload the students, the author did not cover all the topics and mostly spent time on the key concept and fundamentals of the key topics. I informed the students that with the rapid development of new products and techniques, they will always need to learn how to handle new things on their own when they are working. As an example, the use of soil nails for slope stabilization is relatively new. The author highlighted to the students that their seniors 20 years ago would not have learnt this technique at university. However, many of their seniors were able to adopt such 'new' technique and design safely as long as they know the concept of slope stabilization well and able to appreciate the differences in the 'new' soil nail technique compared to traditional technique such as ground anchor.

Unfortunately for senior and graduate level modules, there are usually no suitable textbooks and the author had to provide lecture notes. Despite giving lecture notes, I always emphasised in class that understanding the concept and fundamentals is of utmost importance rather than solving the tutorial questions correctly numerically. A number of students always asked for sample solutions to tutorial examples to enhance their confidence in tackling the subject. This author did not oblige and highlighted to the whole class that in grading the assignment, quizzes and final examination, heavier weighting would be placed on answering the right concept related to the question than the accurate numerical outputs of the problem.

In addition, the author provided actual field problems from my research and consultancy projects. I highlighted to them many incidents and failures in the field were often due to mis-concept rather than calculation errors. As mentioned earlier, I also urged the part time master course work students to bring their site problems to the class for discussions. These field cases indeed raised the interests of many students and a number of them are highly motivated to be involved in the discussion of the field problems presented in the class.

3.2 *'Poser' questions*

As mentioned earlier, practical examples on real life problems were presented during my lectures to cultivate students' interest in the subject matter and to facilitate them to think deeper. In addition, the author often provided supplementary 'poser' questions related to the topic covered and encouraged them to submit inputs for discussions at the next lecture. The approach adopted is similar to the strategies proposed by Silberman (1996) on motivating students to be active right from the start.

The responses from the students are generally encouraging and their passion for the subject has been enhanced. During the next lecture, I would select some 'correct' and 'wrong' answers to present and highlighted to them that one can often learn from 'wrong' answers. The important thing is to get hold of the concept, learn the mistake and then move forward not to repeat the same mistake. I informed the students that making mistake can be a good learning exercise while repeating the same mistake illustrates that the student has just studied blindly and not learnt his/her lessons.

Figure 7. Photograph of failure of pile load test setup (Channel NewsAsia, 2010).

An important message the author passed onto the students is that they should be aware of errors in textbooks and even in design codes. I used the example of an error in BS8002 (1994) in which the incorrect hydraulic head on a retaining wall was presented, as discovered by British geotechnical engineers.

For fundamental topics such as retaining walls, I urged the students to report mistakes found in the textbooks so that I can share these with the class. When presenting the textbook errors spotted by the students, the author urged them to understand the basics and judged whether the mistakes are typos or concept problems.

For advanced geotechnical engineering topics, I highlighted to the students that the mistakes may be due to the state of knowledge at the time of writing and therefore they must be aware of the latest development when working in practice in the future. I illustrated to them how geotechnical theories advance over the years since the early days of Karl Terzaghi's soil mechanics theories.

Failure or near failure construction incidents happened from time to time and some of them are reported in the newspapers. When the incident is related to the module, the author presented them as 'poser' question during my lecture. In January 2010, a pile load test assembly failed during the course of a routine pile load test. The media Channel NewsAsia (2010) reported the incident online and a photograph of the incident is shown in Figure 7.

During the class the next day, I immediately urged the students to submit what they think of the incident so that I can share their thoughts with the class. The responses were overwhelming as the students felt highly motivated to have a chance to look at an actual incident related to the course and this only happens in a rare occasion. The subsequent presentation on student submissions was useful as the students were able to appreciate the incident deeper and I could see how they think as 'learner' civil engineers. I was unable to correct some students' mis-conception and the whole class appeared to appreciate it.

4 TUTORIAL STYLE

4.1 *Active learning team*

To encourage students to put in more efforts in a module, some faculty members adopt the 'continuous assessment' approach with a very high percentage of grading for the many quizzes and assignments. Students have no choice but to spend more times in order to obtain good grades. They often termed such module as 'continuous harassment' rather than 'continuous assessment'. As such, they often neglect other less demanding modules. As the curriculum is already heavy, it is simply not possible for the students to cope if all the modules have heavy continuous assessment components. In order not to overload the students, the author adopted 'active' and 'passive' groups during the tutorials in undergraduate geotechnical modules to lessen the students' workloads (Leung, 2002). Some of the strategies and techniques adopted are similar to those presented by Meyers and Jones (1993).

At National University of Singapore, undergraduate students attend common lectures in large lecture theatres and then divided into groups for their experiment and tutorial classes. Typically there are about 25 students in each tutorial group. Tutorial classes are generally problem-solving classes in which the tutors would present and discuss the solutions of the tutorial problems given in the lectures. Students then raise questions to clarify the solutions presented in the tutorials.

Many students do not attempt the tutorial questions before the class due to heavy workloads. They typically remain passive, often ask few questions and 'blindly' accept the solutions presented. As such, most of the tutorial classes do not achieve the purpose of mutual tutor-student interaction due to one-way transfer of knowledge from the faculty members to the students. The conduct of geotechnical tutorials is no different from other subjects.

To tackle the lack of interaction during tutorials, I developed the 'active learning team' tutorial method. To lighten the students' workloads, students from each tutorial group are divided into three teams. By rotation, one team would be assigned the active learning team for a tutorial class. A team leader was assigned and he/she played the role of coordinator by distributing the workloads among members and arranging the order of presentations.

The active team was only told to make a short PowerPoint presentation to highlight the key aspects of the discussion topic. Besides textbook and lecture notes (if available), students were free on how they approach the discussion topic. Many active learning teams were indeed innovative by referring to reference books, published papers and the World Wide Web. Active interactions and discussions among group members were strongly encouraged.

The active team members would make presentations followed by questions and discussions from the other two 'passive learning' teams. This enabled the active team members to acknowledge the view points of others and to understand the subject matter further after addressing the queries raised by fellow students. After the discussions, the active team would submit a short report to cover the essential and important points of the topic and distributed it to the whole class. In this way, all students in the tutorial group were able to learn without spending too much time and efforts on the large number of topics covered in the lectures.

4.2 *Interaction among groups*

As there are many discussion topics for each subject (for example slope stability), different topics will be given to the 8 tutorial groups. In general, four discussion topics will be given to the eight groups so that there is always a common topic between two groups to provide some competition as well as check and balance. As an example, the four discussion topics on slope stability include importance of shear strength of soil, effect of ground water table after slope excavation, vegetation on slope and the method of slope stability analysis. These topics represent a wide selection of important discussion topics in slope stability analysis that practising civil engineers should be aware of.

When the active learning team format was first put up, the students were skeptical and asked 'what is expected', or simply 'tell me what to do'. They were told they have a complete free hand and the process is entirely open-ended. They should always try their best to impress the faculty members and fellow students. The students were informed that their efforts would be rewarded as they and their fellow passive team members would learn a lot from each other in the process. After the first batch completed the active learning tutorials successfully, considerably fewer questions and concerns were raised in subsequent batches as they generally learned the ropes from their seniors following the style of their sample presentations and reports. Of course the discussion topics changed every year to ensure that each batch was able to learn on their own rather than copying from their seniors.

As Asians are generally less outspoken than Europeans or Americans, the author has to ask the first few questions during the first tutorial. I then continue to encourage the students to ask questions and persuading them that asking questions is often the best way of self-learning. After the students have more or less warmed up to the situation, they have no problems of raising queries such that subsequent questions and discussions become more lively and constructive. The active team students soon learn that they should look at a given problem from a wider angle or should have gone deeper on certain aspects of the discussion topic. At the beginning of the semester, the 45-minute tutorial typically finishes earlier. However toward the end of semester, it is not uncommon that the tutorial stretches beyond 45 minutes.

Upon feedback from the faculty member and passive team members, the active team is asked to prepare a short report for grading. The team leader is requested to report if any of his/her team members has not been active or never contributed to the process. Active teams who have made useful and interesting presentations are encouraged to post their PowerPoint files online to be appreciated by all students. The faculty member would review all the 8 tutorial group reports, made necessary modifications, fix the mistakes and highlight the important points in the reports.

Reports with serious technical errors would be returned to the students for re-submissions. If feasible, reports on the same discussion topics may be combined to provide a coherent and wider coverage of the discussion topic. These reports will be made available to all students who are informed that some of the materials will appear in the examinations. They are also encouraged to report mistakes in the submissions. Thus the students are able to appreciate the subject matter deeper. They very much appreciate it as they are better prepared for the quizzes and the final examination. Such a team work approach is elaborated in Kember (2000).

With the increase in the number of graduate students at the National University of Singapore, the undergraduate tutorial classes are now typically conducted by graduate students so that the faculty staff's teaching workload can be reduced. I continue to encourage the tutors to carry on the active learning team tutorial format to ensure good interactions during tutorial classes.

5 STUDENT FEEDBACK

At the National University of Singapore, student feedback is sought after all the lectures have been completed but prior to the final examination. This is to achieve fair and unbiased inputs by the students as the degree of difficulty of the final examination may affect the students' assessment of the modules and their lecturers. The student feedbacks basically consist of 2 parts: (a) quantitative inputs on a selection of questions on teaching and the module, and (b) qualitative inputs on the faculty member and module.

As with any new style of teaching, some students will find it difficult to adopt. For the first batch of implementing the above mentioned lecture and tutorial styles mentioned above, the qualitative scores were generally less favourable. A good number of students had unfavourable inputs such as 'the lecturer should be responsible by giving lecture notes and conduct tutorial properly by providing solutions to the tutorial questions.' Many students did provide constructive inputs on how to improve the process and some of their inputs were implemented by the author for the next batch.

With fine tuning of my lecture and tutorial styles, the numerical scores of teaching feedback in terms of both the faculty member and the module improved considerably. More heartening is that many students began to appreciate the teaching and tutorial style and reap the benefits of active and independent learning. In addition, many students had now overcome the fear of the basic soil mechanics module and became very much interested in geotechnical engineering. This is because they could relate the topics they learned to practice and hence developed a passion for the subject matter.

The success of the teaching and tutorial styles can be reflected in some of the student inputs. These included 'poses questions for us to think about and to let us learn independently'; 'able to understand the concepts better with his method of teaching'; 'encourage self-learning'; 'helped me understand how to apply knowledge and then has enhanced my ability to learn independently'; 'teaching philosophy to encourage self learning is essential to generate innovative thinking and ideas in engineering'; and 'fundamental concepts and understanding is the most important in learning'.

It is interesting to mention one particular case of feedback. During one tutorial, one student had totally forgotten that she has been assigned to be the leader of the active learning team of a particular tutorial class. Obviously the tutorial was a disaster for her and the whole class. After the class, the author then worked closely with the student and required her to upload her discussions and inputs on line to be shared and discussed by the whole class.

A couple of years later, I received a letter from the student who has since graduated thanking me for my help in her geotechnical modules. In fact, since I pushed her to do the tutorials, she became very much interested in the subject and scored well in the geotechnical modules. Because of this, the student had chosen to work as a geotechnical engineer.

6 CONCLUDING REMARKS

With the frequent use of computer programs, many young people are unable to grasp concepts and fundamentals well. This affects the conduct of geotechnical engineering modules. This paper presents several approaches adopted by the author in conducting geotechnical module lectures and tutorials at various levels. For junior modules, the author only covers the key concepts from the textbook and facilitates the students to think deeper and independently. 'Poser' questions are provided from time to time to motivate them to delve more deeply into the subject matter. For all levels, actual field case studies are introduced to enable students to appreciate the practical applications of the subject matter.

For graduate modules with a mix of full time and part time students, the students are facilitated to learn from each other. Field problems brought in by the part time students who are practising engineers are shared with the full time students who have no practical experience. The part time students are encouraged to interact with the full time students as many of them graduated sometime back and became rusty in their concepts.

In order not to overload the students, the tutorial classes are divided into active and passive learning teams to facilitate them to learn together without spending too much effort on the large number of topics covered in the modules. The lecture and tutorial styles appear to be able to motivate the students' interests in geotechnical engineering. In addition, they have benefited by learning actively and independently.

In the author's opinion, there is no single winning teaching method. The teaching method developed by a faculty member may not be suitable for another member or another type of module. It is thus important to note that a successful teaching method can be highly open ended and the key is to facilitate learning by the students on the concepts and fundamentals on their own as far as possible.

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Shaking the Foundations of Geo-engineering Education – McCabe, Pantazidou & Phillips (eds)

Sport and soil mechanics – analogies to aid student learning

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ABSTRACT: It is well recognised that students' understanding of complex ideas can be aided by analogies with separate topics, preferably in an unrelated subject area (in this case, outside of engineering). Additional benefits may be gained by having a suite of such linkages between the subject area being taught (e.g. soil mechanics) and one common analogy area (e.g. sport), as a means of consolidating several new concepts. Sport tends to have a broad appeal among engineering students and the authors have found that sporting analogies have proven effective in teaching certain soil mechanics concepts. The purpose of this paper is to bring a few of these analogies together into a single engaging and fun document to be made available to students taking introductory soil mechanics courses.

1 INTRODUCTION

Many engineering subject areas taught at university are founded on a few core concepts and principles which are often elusive to students, and soil mechanics is no exception. For example, the challenge of teaching a fundamental soil mechanics concept, *effective stress*, has been illustrated by the results of a survey of Irish geo-engineering practitioners reported by McCabe and Phillips (2008). From a list of six topics including effective stress, basic parameters (such as water content, Atterberg limits, density, void ratio etc.), shear strength, compressibility, permeability/groundwater flow and stress beneath loaded areas, respondents surprisingly ranked effective stress as the least relevant of these to their work even though it underpins most of them. Atkinson (2008) lists an over-emphasis on standards and codes ahead of basic principles and a stagnant "*teach what I was taught*" approach in university education among several reasons why some geotechnical engineers may be lacking in competence.

On a positive note, several authors have shared the instruction strategies that they use to promote effective student learning in soil mechanics and geotechnical engineering modules. Airey (2008) discusses the merits of learning through laboratory and analytical/numerical projects. Geotechnical case histories can serve as a powerful tool for teaching (e.g. Phillips 2008) and Orr and Pantazidou (2012) consider the relationship between specific learning outcomes and the corresponding suitable types of case studies and case data. Jaksa (2008) advocates the use of a multi-faceted approach to soil mechanics instruction, and provides a comprehensive list of resources (including physical demonstration models, videos and case history/failure references) which have been used with success.

In the context of engineering education, Felder and Silverman (1988) state that "*students learn in many ways – by seeing and hearing, reflecting and acting, reasoning logically and intuitively, memorizing and visualizing and drawing analogies and building mathematical models; steadily and in fits and starts*." An analogy is a teaching strategy which uses a concrete reference to develop a comprehension of something more abstract. When used carefully, Dagher (1995) has shown that analogies can be an effective means of communicating scientific concepts. Donnelly and McDaniel (1993) used multiple-choice testing to compare learning of scientific concepts expressed in either traditional literal form or through an analogy. While basic-level questions were answered most accurately when concepts were expressed literally, more difficult questions were answered most accurately when concepts were expressed analogically. However, more effective cognitive transfer is not the only benefit of using appropriate analogies in teaching; Heywood and Parker (2010) and others have recognised their effectiveness in engaging students in the learning process. The authors of this paper also propose that additional benefits may be gained by having a suite of linkages between the parent subject area being taught and one common analogy area.

Sport tends to enjoy a broad appeal among students of civil and environmental engineering and construction-related programnmes, and in this paper, the authors show how four important areas of soil mechanics can be explained with simple analogies to various sports or sports-related activities. The paper is intended to serve as a self-contained, engaging and fun document for use in parallel with introductory soil mechanics modules, and it is hoped that the cumulative effect of grouping a few sporting analogies together here might be greater than if they were considered individually.

2 WEIGHTLIFTING AND STRESS HISTORY

The idea that the stress to which ground was subjected in the past (possibly thousands of years ago) can have a major bearing on its strength and stiffness today can be an alien concept to engineering students as it is not a feature of the other materials, such as concrete or steel, with which they are familiar. Weightlifting (or muscle building in general) can be used to help to explain the significance of stress history in soil mechanics and to define the overconsolidation ratio (OCR); the ratio of the maximum previous vertical effective stress (known as the pre-consolidation or yield pressure) σ'_{vy} to the current vertical effective stress σ'_{v0}. A cartoon such as that shown in Figure 1 is an excellent way to capture students' attention in the classroom before an explanation of the analogy unfolds, as follows:

(i) Lifting weights of a sufficiently high intensity causes muscle fibres to tear but they repair themselves within a couple of days and become stronger than they were originally. Improvements to strength will accrue over time if weightlifters continue to push their boundaries. The stronger the arm muscles (for example) are, the less the effort associated with everyday lifting (such as several bags of shopping).

(ii) Soil that is strong and stiff today has previously been subjected to much higher stresses than it is currently experiencing, or alternatively phrased, the current stress in the soil falls below its preconsolidation or yield pressure. By way of analogy, someone who has previously loaded muscles to high stresses (the highest being the muscle's yield stress) will be strong and therefore should find the muscle stress imposed by the bags of shopping to be relatively comfortable.

(iii) The analogy can be extended further by considering the ratio of the maximum weights lifted by the weightlifter in the gym to the weight of the shopping bags. The higher this ratio, the easier the act of carrying the shopping will be. In soil mechanics terms, a similar ratio applies ($OCR \geq 1$) as defined above. A weaker person will find the same bags more difficult to carry, as the muscle stress involved will be closer to their muscles' yield point (i.e. lightly overconsolidated, low OCR value) or may even surpass the previous yield point to create a new one (normally consolidated, $OCR = 1$). A stronger person can lift shopping bags with ease, as the stress on the muscles is well below yield and the muscle can be thought of as heavily overconsolidated (i.e. it has a high OCR value, $OCR \gg 1$).

(iv) This is a good stage to explain why specific soil types have different OCR values; for example a strong and stiff high OCR glacial till may once have been subjected to the weight of up to 1 km of glacial ice, whereas a soft and compressible estuarine deposit will have a low OCR as it will be at or close to its highest ever stress level. This serves as a convenient lead-in to a more thorough explanation of the process using e-log σ'_v curves ($e =$ void ratio).

The analogy has been found to be effective in indicating that stiffness and strength of soil are dependent on previous stress levels in the same way as that the strength of a weightlifter is dependent on the degree to which he/she has extended his/her muscles in the past. It is pointed out to the students that we normally talk about muscle strength and not stiffness, so strength and stiffness are used somewhat interchangeably here with the purposes of explaining the concept (which of course is not generally appropriate in engineering).

Figure 1. "POPEYE" cartoon used in lectures to introduce the muscle building and stress history analogy.

3 VARIOUS SPORTS BALLS AND SPECIFIC SURFACE AREA

Atkinson (2007) indicates that coarse-grained soils (silt-sized and coarser) essentially behave like an assembly of marbles of different sizes whereas clays have two main features which distinguish them from fine-grained soils. Clay grains can change in volume significantly as the loading and water content changes. Also, the effect of a small electrical charge carried by clay grains becomes significant. As particle sizes decrease, the surface forces diminish with the square of the effective diameter, whereas the self-weight forces diminish with the cube; consequently the effects of surface forces are relatively more important in fine-grained than coarse-grained soils. This phenomenon

Table 1. SSA values for clay minerals and clean sand (after Atkinson 2007).

Soil grain	SSA (m^2/Mg)
Kaolinite	$[1–2] \times 10^7$
Illite	$[0.65–2.0] \times 10^8$
Montmorollinite	up to 840×10^8
Clean sand	200

Table 2. SSA values for various sports balls.

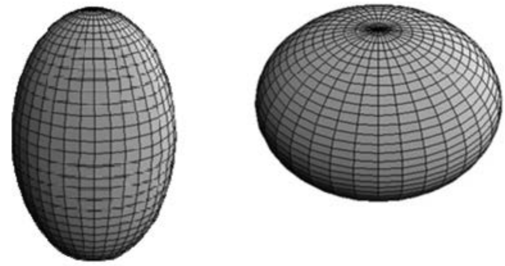
Ball	Mass (g)	Diameter (mm)	SSA (m^2/Mg)
Volleyball	270	210.1	513.5
Roulette ball	1	10	314.2
Basketball	600	243.5	310.5
Tennis ball	56.7	63.5	223.4
Golf ball*	45.93	42.67	124.5
Cricket ball	160	72.3	102.5
Pool ball	160	57	63.8
10-pin bowling ball	7200	218	20.7

*Dimple free golf ball assumed

is captured by a quantity called the Specific Surface Area (SSA); defined as the surface area per unit mass. Typical ranges for three clay minerals and clean sand are shown in Table 1 (after Atkinson, 2007).

Without any prior knowledge of soil particle shapes or sizes, the default assumption that students make is that soil particles are spherical. Therefore the idea of SSA can be introduced in a fun way by asking them to rank a number of balls used in various sporting activities in order of SSA. The ranking for eight such balls is listed in Table 2; based on typical mass and diameters values derived from the internet. The students respond competitively and many succeed in placing the volleyball and the 10-pin bowling ball correctly at the ends of the spectrum, although the intermediate ones are naturally much more difficult to position correctly. They learn that it is not just diameter (and hence surface area) that governs SSA, but that density is also relevant. Students are then referred to the values in Table 1 to help them put the values for real soils in the context of those calculated for the various sports balls.

Once this concept is understood, the idea of particle shape can be introduced by asking them which of a rugby ball (or any oblong ball such as an American or Australian Rules football) and soccer ball, assuming the same volume in each case, has the greater SSA. Most guess correctly based on intuition that the rugby ball has the greater surface area per unit volume. It can then be mentioned that clay particles tend not to be spherical in shape but tend to be either platy or needle-like and have even higher SSA values than spheres of the same volume. Oblate and prolate spheroids (i.e. deformed spheres, see Figure 2) can conceptually (if not strictly) be analogised with platy and needle



$$S = 2\pi\left(a^2 + \frac{ab}{k}\sin^{-1} k\right) \qquad S = \pi\left(2a^2 + \frac{b^2}{k}\ln\left(\frac{1+k}{1-k}\right)\right)$$

$$k = \sqrt{1 - \frac{a^2}{b^2}}$$

Figure 2. Prolate (left) and oblate (right) spheroids and associated equations for surface area used to help conceptualise the influence of shape on SSA.

like shapes respectively. For the more mathematically-inclined students, a comparison of the surface areas per unit volume of oblate and prolate spheroids (the latter is the rugby ball shape) with that of a sphere can be implemented in a spreadsheet. The equations for surface area (S) are given below where a and b are half the major and half the minor axis lengths of the spheroids respectively and the value of k is common to both equations. The comparison requires a condition of equal volume to be imposed, i.e. $r^3 = a^3b$ (where r is the sphere radius).

Finally, it is highlighted to the students that in real clay soils, behaviour is likely to be influenced by a diffuse double layer and the formation of peds (stacks of individual particles), and as such, the surface area available for physic-chemical reactions is reduced.

4 POOL BALLS AND VOLUME CHANGES IN SANDS

The effect of the initial density of a soil (i.e. whether it is loose or dense) on its behaviour when sheared is an important concept in soil mechanics, often explained in the context of the shear box or direct shear test. It is probably the first time that students appreciate that volume changes and shear strength are intrinsically linked, so many struggle with this concept.

Students who have played pool or snooker are aware of how to arrange the balls in (i) their tightest possible configuration (i.e. when they are racked together in the triangle at the outset of a game) and (ii) the loosest possible configuration while still maintaining contact, a square grid. As a lead in to the volume change discussion, the students can be asked to extend this to 3-D and calculate the void ratio (e) corresponding to the densest (i.e. rhombic) and the loosest (i.e. cubic) packing. The correct answers are $e = 0.35$ and $e = 0.92$ respectively; Barnes (2000) and Lancellotta (2009) textbooks cover this topic well.

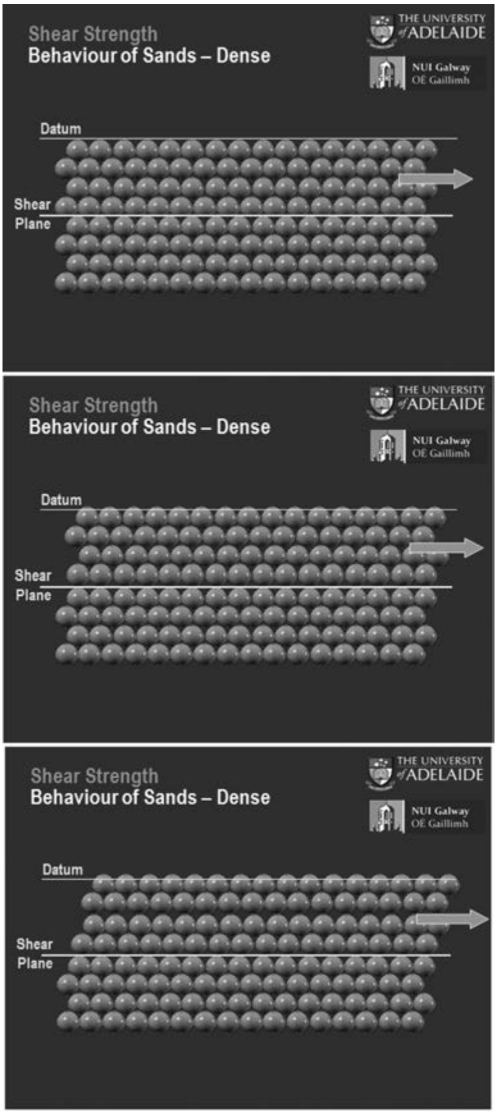


Figure 3a. PowerPoint animated slides using pool balls to explain dilatancy in dense sands.

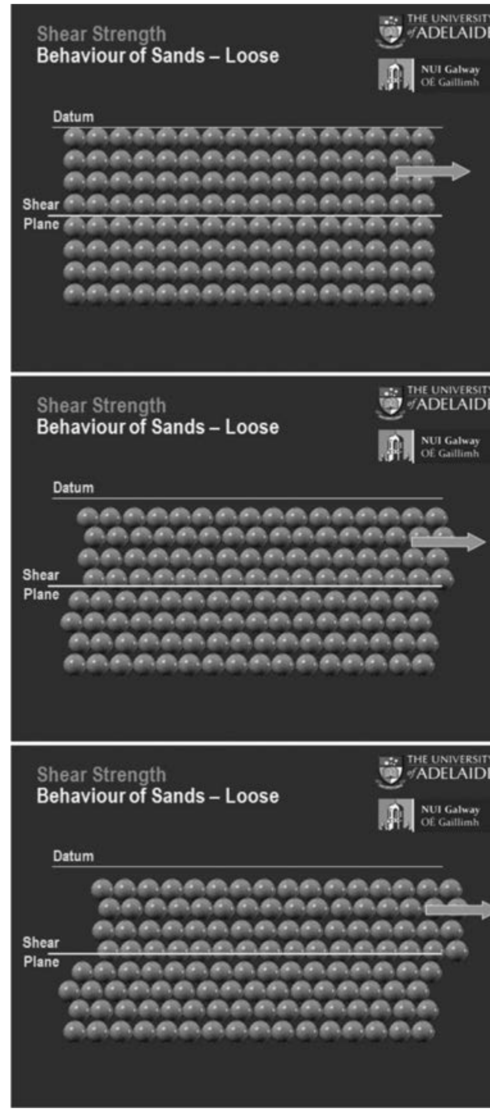


Figure 3b. PowerPoint animated slides using pool balls to explain contraction in loose sands.

At the University of Adelaide and NUI Galway, a simple series of animated PowerPoint slides are used to explain (in 2-D) why loose soils contract and dense soils dilate (expand) when sheared. In these slides, the individual soil grains are represented as pool balls.

The series of slides used to explain dilatancy in dense soils is shown in Figure 3a. The starting point is assumed for simplicity to be the tightest possible configuration. It is clear that, in order for relative horizontal movement to occur between rows of pool balls, the balls must first of all displace vertically (out of the 'trough' in which each is sitting), which gives rise to an overall increase in volume of the soil (gauged relative to the datum line shown). An equivalent set of slides is used to explain contraction in loose soils, assuming for simplicity, the loosest possible starting point (Figure 3b).

Students are advised that the final void ratio at critical state conditions (e_{crit}) is independent of the initial density (whether looser or denser than e_{crit}). These slides can be used as a simple starting point for other models of dilatant behaviour, such as the sawtooth dilatancy model, e.g. Houlsby (1991).

5 STRETCHER (USED IN FORMULA 1 ACCIDENTS) AND EFFECTIVE STRESS

The analogy with sport in this case may be a longer shot than in the previous cases – but the vacuum mattress

Figure 4a. Vacuum mattress with hand pump (Source: Wikipedia, 2012).

has been used as a stretcher to remove drivers injured in Formula 1 crashes in the past. Vacuum mattresses are used by emergency personnel as a stretcher over short distances and to immobilise patients, especially in the case of vertebra, pelvis or limb trauma. As shown in Figure 4a, the mattress is a sealed polymer bag (larger than an adult human body) that encloses small polystyrene balls, with a valve, straps and handles. In its inoperable state, when the mattress valve is open and exposed to atmospheric pressure, the balls are relatively free to move and the mattress can be moulded beneath the patient. Air is then withdrawn from the mattress through the valve by means of a hand-operated pump and the valve is then closed. The suction causes the balls to press together and the mattress becomes hard and rigid (Figure 4b).

This example is introduced in lectures after the axiom of effective stress is explained, described by equation [1] for saturated soils:

$$\sigma' = \sigma - u \qquad [1]$$

where σ' is the effective stress, σ is the total stress and u is the pore water pressure. The effective stress does not equate directly to the intergranular pressure, but is a stress which indicates the distribution of load carried by the soil skeleton over the whole area being considered (it cannot be measured).

In the vacuum mattress analogy, σ' is related to the contact loads between the polystyrene balls and u the

Figure 4b. Vacuum mattress in use as a stretcher.

air pressure inside the mattress. Equation [1] can be used to show that as the air pressure reduces (i.e. u reduces) and σ remains constant, then σ' must increase which gives the mattress its rigidity and strength. This analogy, which can be used in conjunction with the more widely-used vacuum-packed coffee packet analogy, provides a solid frame of reference for students as they grapple with the abstract application of effective stress in soils.

6 EFFECTIVENESS OF SPORTS ANALOGIES

From a class of 66 third-year geotechnical engineering students at the University of Adelaide, Jaksa *et al.* (2009) reports that 91% of the students found that a range of demonstrations used (including two in this paper) improved their learning and understanding of the topics, 89% found them to be engaging and relevant, and 92% believed that they understood the concepts presented in this course.

3rd year Soil Mechanics students at NUI Galway were surveyed specifically about their views on the sporting analogies presented in this paper. The same three questions above were posed here, and the 55 responses on a 5-level Likert scale (1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, 5 = strongly agree) averaged 4.3, 4.3 and 4.1 respectively. A selection of specific feedback comments from the NUI Galway students is provided in Table 3.

7 CONCLUSION

In this paper, the authors have shared some simple analogies between sport and soil mechanics concepts used in teaching at the University of Adelaide and NUI Galway. Weightlifting is used to explain OCR and

Table 3. Student feedback comments on the effectiveness of the sporting analogies.

"*The analogies helped to make otherwise vague and difficult-to-explain ideas and principles much easier to grasp (in particular the mass-to-surface area ratio analogy that used various forms of sports balls).*"
"*Everybody will have an understanding of some sport, whether it's participating or watching. Therefore sporting analogies can relate the unknown to the known and help students understand the concept more quickly.*"
"*The pool ball concept for dense and loose soils was an easy concept to grasp and this worked very well.*"
"*I found the weightlifting example very useful for gaining an understanding on the topic of OCR. Using these analogies is beneficial for studying also as it sticks in the mind which is helpful for exam situations and working through problems.*"
"*I found the visuals easier to comprehend and relating the examples to sports made the subject more interesting and less intimidating.*"
"*I think that it is an effective method of engaging students in the topic as most students are involved in sports or can relate to different sports. It makes the topic more relevant to use by using something we know about … the analogies are unusual, they catch the students' attention more and draw them deeper into the subject.*"
"*I thought that the sporting analogy used when tackling the overconsolidation ratio was very useful. I had to think about it for a while but when I understood the link between the two, it made it very easy to remember what the overconsolidation ratio was all about.*"
"The visual images also help to keep the sports references fresh in my mind and from there my understanding of some concepts."

stress history, various sports balls are used to explain the concept of specific surface area, pool/snooker balls are used to explain dilatancy and contraction in sands, and a vacuum mattress stretcher is presented as a practical application of the effective stress principle.

Experience at both universities suggests that analogies and demonstrations in general are effective, and that the sporting analogies presented herein are engaging and succeed in conveying certain concepts. This paper may also serve as a fun reference document for students in introductory soil mechanics courses elsewhere, as a component of the multi-faceted approach to geotechnical education advocated by Jaksa (2008).

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Integrating professional geotechnical practice into the curriculum

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ABSTRACT: Although we cannot teach geotechnical experience, we can integrate professional geotechnical practice into the curriculum and start to develop students' own experience. This paper describes activities developed at the University of Bristol aimed at linking theory and practice in geotechnics to support the professional development of MEng Civil Engineering undergraduate students. Through undertaking geotechnical designs, planning and interpreting site investigations, and studying case histories showing the use of geotechnical instrumentation, students deepen their knowledge and understanding, and appreciate the importance of engineering geology. A minority of students participate in an optional field course during which they examine soils, rocks and geomorphology of coastal landslides. Another optional course on soil-structure interaction provides a structured introduction to the use of geotechnical finite element analysis. These activities are found to engage the students and deepen their learning to a greater extent than traditional lecture courses. By the time they graduate many students can solve routine geotechnical problems but are hopefully aware of the limitations of their knowledge. Some of them are inspired to become geotechnical professionals.

1 INTRODUCTION

Traditionally, many geotechnical professionals have been educated with a first degree in Civil Engineering followed by a specialist higher degree. In the UK that model is under threat since many graduates have major loans to repay and are reluctant to undertake postgraduate study. The final year cohort of students at Bristol contains generalist civil/structural/water engineers amongst whom are potential geotechnical specialists. Indeed for a significant minority of graduates their first destination is employment as a graduate geotechnical engineer in an engineering consultancy. The core courses have been designed with the needs of the generalist graduate in mind (see Table 1) but they are also intended to provide a good foundation for the geotechnical specialist.

Undergraduate geotechnics courses tend to focus on the imparting and acquiring of detailed knowledge but are often not very good at helping students to integrate their knowledge, nor to develop independent critical thinking. Students are adept at absorbing information, reproducing it in examinations, and then forgetting much of it. *Education is what remains after one has forgotten everything he learned in school* (Einstein 1950) but we all hope that students will retain some key basic concepts. We also hope that all our graduates will be able to solve some routine geotechnical problems, and that at least some of our students will develop a curiosity and passion for geotechnics that will remain with them for life.

Like many others, the writer has been strongly influenced by collected writings of Terzaghi (1960) in *From Theory to Practice* and by Burland's (1987) Nash lecture on the *Teaching of Soil Mechanics*. Indeed Burland's soil mechanics triangle (Fig. 1) has formed the backdrop to course development at Bristol. Whilst in introductory courses there is necessarily a focus on soil material behaviour and applied mechanics, it

Table 1. Aims of Bristol core geotechnical courses.

- to educate and inspire the next generation and to nurture their curiosity;
- to enable graduates to solve routinegeotechnical engineering problems with confidence.
- … from Theory to Practice …

and specifically

- to produce generalist civil engineering graduates who:
- are not "afraid" of Geotechnics and can communicate confidently with geotechnical specialists;
- have some knowledge of soil as a material, of site and laboratory investigations, andhave an adequate grasp of Engineering Geology;
- have a sound understanding of the fundamental concepts of soil mechanics and can apply them in setting up and analysing a range of practical problems;
- can distinguish models from reality: soil mechanics triangle
- have basic competencies in the design of foundations, retaining walls and slopes; (category 2 – Eurocode 7)
- appreciate the importance of case histories and precedents, and have some knowledge of the historical development of soil mechanics;
- appreciate the interaction between construction and the surrounding environment;
- are curious about Geotechnics and are aware of the limitations of their knowledge.

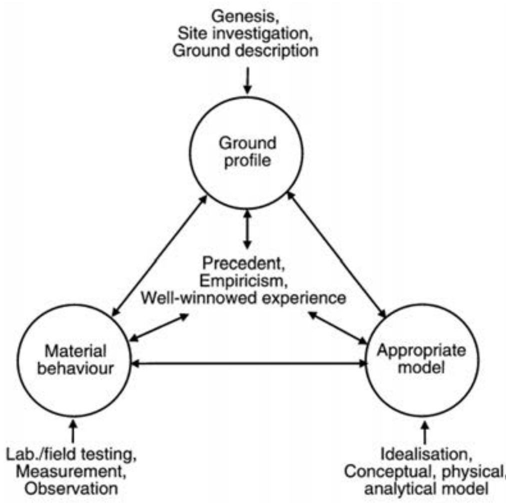

Figure 1. The soil mechanics triangle (adapted from Burland, 1987 by Steenfelt, 2000).

is also important to integrate these idealizations with the realities of the actual ground conditions on site and of geotechnical performance. Traditionally academic and practicing geotechnical engineers took a holistic (or systems) view, but nowadays some engineers in practice and many academics seem to consider that the geological influences on a project are secondary. Indeed it has been expressed strongly to me that some graduates from engineering geology and geography courses are better at taking an over-view of a project than many engineering graduates. The borderline between geotechnics, geology and geomorphology cannot be sharply defined (Henkel 1982), so it is vital that engineering geology be fully integrated in the engineering curriculum and that the links be strongly emphasized.

Burland (1987) and Steenfelt (2000) also emphasise the importance of sharing well-winnowed experience in some detail and teaching the practice of geotechnical engineering. As Steenfelt wrote, the *value of precedents and experience cannot be overemphasised* but undergraduates have little professional knowledge and experience to build on and cannot simply absorb the experience of others.

This paper focuses on aspects of the Bristol courses that integrate theory with professional geotechnical practice. Through undertaking mini-projects and case studies, students' own geotechnical knowledge and experience is enhanced and their interest stimulated – important aspects of professional development. Brief summaries of the activities are given which hopefully will encourage discussion.

2 EDUCATIONAL BACKGROUND

In the present climate there is great pressure to teach more students in large classes for less cost. At the same time we are aware that traditional lecture courses are not particularly effective at encouraging student learning (Baillie & Moore 2004) and of the benefits of case studies (Davis & Wilcock 2004). In a geotechnical context, Akili (2007) quoting Bloom (1956) states that *learning* is more than simply the acquisition of knowledge. Increasing levels of learning and/or comprehension are:

factual knowledge;
comprehension (using factual information and explaining facts),
application (applying facts to solve problems, analyzing concept structures),
synthesis (creating something new by using different components), and
evaluation (exercising judgments and comparing new facts with existing knowledge).

Akili suggests that not only does traditional teaching fail to take students through all levels of learning, but it also fails to engage students in the teaching-learning process. Rather *we need to replace traditional approaches of teaching by utilizing pedagogies of engagement and simultaneously, bringing practical problems and issues that practitioners usually face, into the classroom* (Akili 2007). Alternative approaches are also a good way of supporting different student learning styles.

The majority of engineering students are engaged by project work that develops and applies their knowledge, and particularly like working on *real* projects. They take pride in their work, and indeed many will spend a disproportionate amount of time improving its presentation. Many universities have responded to this and students on MEng courses often undertake major design projects. Indeed this is required by the Engineering Council (2011) who state that graduating Masters level students *will have the ability to integrate their prior knowledge and understanding of the discipline and engineering practice with the development of advanced level knowledge and understanding, to solve a substantial range of engineering problems, some of a complex nature. They will have acquired much of this ability through individual and/or group design projects. Ideally some of these projects would have included industrial involvement or be practice-based*. The geotechnical aspects of major integrated design projects can be extremely challenging. For example, a student group may be designing an urban development with a significant basement necessitating a geotechnical finite element analysis. In the writer's experience students often need more regular support than can be given by industrial partners alone.

Major individual and group design projects need and deserve time-consuming supervision. Burland (1987) gives examples of some very challenging geotechnical design projects but acknowledges that they can only be run for small groups of students. Nevertheless it is possible to adopt more limited case studies and problem-oriented project-based learning for larger numbers of students. These typically involve the students carrying out directed learning (research, data analysis and design) focused on particular aspects of geotechnical engineering. For the reasons outlined above these can really engage the students and also can bridge the gap between university theory and geotechnical practice.

3 FROM THEORY TO PRACTICE AT BRISTOL

A number of activities – design exercises, case studies, mini-projects – have been developed at Bristol to both engage the students and contribute to their professional development. Some of these activities are designed for large cohorts of MEng undergraduate students, and some for smaller groups. These are briefly introduced in the following sections; hopefully there is sufficient detail for readers to envisage what is undertaken and perhaps to adapt the ideas for other contexts.

3.1 *Geotechnical design*

A thorough grounding in soil mechanics requires students to develop an ability to analyse and solve problems through calculation. While this is necessary it does not generally engage the student's creativity. To give Bristol students some experience of geotechnical scheme design, all third year students undertake an intensive two-day exercise to produce conceptual designs of a motorway interchange near Bristol. Borehole logs and results of laboratory and field tests on the geotechnical materials in the vicinity of the site are supplied, and a number of geotechnical charts and solutions are provided. The site is underlain by weak compressible estuarine alluvium. This is the first occasion that many students have encountered real data, and the first time they have used geotechnical calculations to support design decisions. The project is summarised in Figure 2.

On the first day, students are guided through a series of preliminary calculations that inform their design decisions. Some iteration is required when they find that the strength is not sufficient to support a 10 m high embankment without ground improvement. By the end of two days most students have produced workable designs for staged construction of embankments, and have also given thought as to how the project would be undertaken in practice.

This mini-project (2.5 credits) can only be undertaken after students have learned the fundamentals of soil mechanics and geotechnical analysis. It provides a useful stimulus to students to grapple with some difficult issues, and there are many fruitful discussions with staff. While the timescale constraints result in students working under pressure, for many there is a sense of achievement afterwards. The output is contained on two A2 sheets of paper (without appended material) and experience shows that designs from 100 students can be ranked and a mark assigned in about two days. General feedback is then given to the cohort as a whole.

A new interchange is required for the M49 motorway north of Avonmouth in order to provide vehicular access to an industrial area. You are required to produce conceptual designs for the geotechnical elements of this interchange. A location map is given together with borehole logs and results of laboratory and field tests on the geotechnical materials in the vicinity of this site. The area is liable to flooding so the carriageway levels are at least 2m above surrounding ground levels. It will be seen from the laboratory tests that the soils at the site are weak and compressible and can only gain strength through consolidation, which takes time. You are expected to consider two alternative designs and to suggest how a choice between these solutions might be reached. One of these designs should take the access road over the motorway; the other should take it under the motorway. The output must be contained on two A2 sheets of paper.

Specification: The two A2 sheets of paper should contain:
- The two outline designs for the elements of the interchange - clear drawings accompanied by explanatory sketches, graphs, calculations and text;
- annotated sketches of elements of the interchange indicating expected mechanisms of response and load paths;
- an indication of the additional work required during subsequent detailed design;
- proposals for additional geotechnical investigation that you think would be essential/desirable before completing a detailed design;
- an outline of the expected construction process and sequence, indicating the strategy to be adopted to keep the motorway traffic flowing;
- a description of the design process that you have followed and the route by which you have reached your design conclusions for each of the two alternatives.

To help you to make some approximate design estimates, a series of preliminary calculations are suggested, and a number of geotechnical charts and solutions are provided. It is suggested that you develop your layout before the start of the project; you may wish to refer briefly to part 6 of the Design Manual for Roads and Bridges.

Figure 2. Third year mini-design project on motorway interchange to be built over compressible subsoil.

While the motorway interchange project is undertaken individually, third year students also undertake an integrated design project (10 credits) working in groups. The project, run intensively over two weeks, is to undertake initial designs for a major water resource system in the River Irfon catchment in mid-Wales. Groups of five students undertake site appraisal, hydrological analysis, desk study of the geology, design of the dam, spillway and aqueduct, environmental assessment, and a preliminary costing. All students visit the valley to examine several possible dam sites that they have identified, and the designated geotechnical engineer visits a possible quarry and a borrow area for core material and critically examines soil and rock exposures. The visit concludes with a visit to Llynne Brianne rockfill dam located in a neighbouring catchment. For many students, this project is one of the highlights of the course and it gives the geotechnically minded student a taste of reality. A major limitation of this type of project-based learning is that 80% of students work on the non-geotechnical aspects of the project.

3.2 *Site Investigation*

Most civil and structural engineers in practice will specify and interpret geotechnical site investigations at some time in their career. A considerable number of construction projects run into difficulties due to inadequate ground investigation. Thus it is appropriate to include some teaching about investigations in the core undergraduate geotechnical courses. One of the aims of the Bristol courses is that students should *have some knowledge of soil as a material, of site and laboratory investigations, and have an adequate grasp of Engineering Geology* (see Table 1). Many students already have some initial hands-on experience of soil as a material through play on a beach, but it can be developed further in laboratory classes through focused soil description exercises (following Burland 1987) and experiments (Nash 2012), and even further on site visits and geotechnical field courses (see below).

A course on site investigation provides a good opportunity to link theory with professional practice. The writer has developed a final year course that includes both lectures and a mini-project that has been found to engage the students. Initial lectures outline the planning of a ground investigation, including desk studies and a discussion of the extent of the site work. Tables suggesting borehole depths are give in Eurocode 7, and these are related to the zone of ground to be affected by the future development. Drilling and sampling is described and the detailed output of the investigation shown on borehole logs is explained.

Further lectures discuss sample disturbance, interpretation of in-situ tests including SPT, in-situ vane test, CPT and CPTu and pressuremeter tests and the selection of characteristic soil parameters. The aim of such lectures is not purely to describe the tests, but nor is it to delve very deeply into the analytical theory. Rather it is to explore the basic interpretation, and to demonstrate how the results may be used to obtain soil parameters. While codes of practice and senior engineers in industry will give some guidance on using correlations between in-situ tests and soil parameters, *students need to be reminded time and again of the original basis of the empiricism. Real dangers exist when empirical expressions take on the guise of fundamental laws* (Burland 1987). In the writer's experience correlations are frequently used in practice without reference to the original research; it is the role of the university to inculcate an awareness of the literature.

At the end of the lecture course all students undertake a mini-project outlined in Figure 3. Working in groups of three, they interpret a borehole log, undertake desk studies and plan investigations for specific developments. The sites chosen are all in the Bristol region and the geological map is made

1. Borehole log interpretation

Review the attached borehole log. Make sure you can envisage everything that has been done and why, and can understand the details given. Consider construction of a 6 storey building on an adjacent site. Assuming that the ground conditions are similar to those given in the borehole log:

Which strata are potentially suitable for carrying foundations?

What are the likely foundation options?

What are the groundwater conditions? What are the implications of these?

Would you advise using a basement? What might be the associated problems? How might they be overcome economically?

What additional suitable and economic site investigations would you recommend for your client's site?

Prepare notes on one sheet of A4 for a meeting with your client.

2. Desk studies

For each of the proposed developments listed below, undertake a desk study identifying the likely geology* and ground conditions, the key geotechnical problems and possible solutions.

Recommend a suitable and economic site investigation (indicating appropriate numbers depths and types of boreholes and probing, and a general indication of sampling, in-situ tests, laboratory tests) giving your reasoning.

A. New oil storage tanks at Avonmouth 535E 810N (Estuarine Alluvium over Mercia Mudstone)

B. 4-storey housing cut into rock slope at Hotwell Road, Bristol 575E 725N (Dip slope in sandstones and mudstones)

C. Large housing estate at Dundry, South Bristol 562E 669N (Landslipped Lias clay and overlying superficial structures)

D. Swimming/diving pool complex at Harbourside, Bristol 580E 725N (Brownfield site over Alluvium over Triassic sandstone, with high water table),

Present your recommendations for each project on a sheet of A4. Be prepared to make a client presentation at a date to be decided on any one of these projects.

** Hints: The 1:50000 geological map of the Bristol area is available - make sure you really understand it. Draw a cross section to natural scale showing the geology and the proposed development.*

Figure 3. Final year project on Site Investigation.

available[2]. Students write brief reports (one side of A4 per site) advising a client on the significant geotechnical problems associated with each development and the implications for foundation design. An important aspect of this project is the collaborative learning involved; students review one another's work before submitting it for group assessment (2.5 credits).

Reading the submissions and giving feedback is quite time-consuming, and can only be done by someone with some practical experience of site investigation. At the end of the course there is a seminar at which students present their work for whole class discussion. This is a good opportunity to give more feedback, and may involve practicing engineers who bring a useful practical and economic perspective. The seminar is

[2] The geological interpretation in Figure 3 is provided here for information, and has to be worked out by students.

held a few weeks before final examinations and is a stimulus to revision.

This project has numerous benefits. It generally engages the students who like the sense of undertaking desk studies for real life projects, and indeed it develops their own geotechnical experience. It links back to their study of engineering geology in previous years and demonstrates the importance of integrating the geological interpretation into the geotechnical engineering. Feedback from students is generally very positive, and occasionally feedback has been received from graduates that it helped them undertake their first desk studies in industry.

3.3 *Geotechnical field course*

In the past, undergraduate civil engineering courses in the UK were expected to include field courses in geology; although this is no longer a requirement, it is still considered desirable (Joint Board of Moderators 2009). With increasing student numbers and reduced resources, it is difficult to run a meaningful geotechnical field course for large numbers of students. At Bristol a field course for up to twenty-four students forms part of an optional course on Slopes and Dams, and particularly appeals to potential geotechnical specialists. Held on the Isle of Wight near the start of the third year, the course introduces students to real soils and natural processes; some details are given in Figure 4. Examining soils, rocks and geomorphology in the field in a structured way (see Fig. 5) is often a revelation. During the field course, students undertake a wedge analyses to back-analyse the major compound landslide at St. Catherine's Point and propose strategies for improving the stability of more minor landslips. Afterwards the students draw their observations together into a report (3 credits). Such field courses are an excellent way to link theory and practice.

A three day field course on the Isle of Wight is intended to:

1. develop students' ability to describe exposures of soils in the field;
2. develop students' awareness of sedimentary geology;
3. examine coastal geomorphology, including landslide features, mudflows, rockfalls, and relate these to the geology;
4. consider strategies for coastal protection in areas of active degradation.

Students undertake geological mapping at Alum Bay, visit many coastal and inland landslides, and undertake a more detailed study of the St Catherines Point landslide, including a hand back-analysis. Afterwards they are required to submit a report on the field course illustrated by sketches, photographs and diagrams.

Figure 4. Geotechnical field course on the Isle of Wight.

Figure 5. Examining soils on the Isle of Wight.

3.4 *Case studies*

One of the detailed objectives of the courses is that graduating students should *appreciate the importance of case histories and precedents, and have some knowledge of the historical development of soil mechanics* (see Table 1). This echoes the views of Burland (1987) and others and emphasises the importance of well-winnowed experience in the soil mechanics triangle. Many of us illustrate our lectures with well-chosen descriptions and photographs of projects, landslips and failures with which we are familiar, and the students undoubtedly appreciate and benefit from these explicit links between theory and practice. At the same time we may make reference to published papers, but in practice few undergraduates voluntarily take a copy of *Géotechnique* home for bedtime reading.

Part of the final year course at Bristol is a study of some geotechnical case histories. Following lectures describing geotechnical instrumentation, there are several lectures on well-known examples where monitoring has been used as an integral part of the project to ensure safety, and the Observational Method (Peck 1969) is introduced. Examples are also given of projects where use of instrumentation was not successful. This is a good opportunity for external lecturers to be invited to share their experience. Subsequently students undertake a detailed study for themselves in which they have to read and review several papers, and write a short essay on the use of geotechnical instrumentation in practice (2.5 credits – see examples given in Fig. 6). Last year many students found the exercise to discuss the role of instrumentation on the Crossrail project very interesting, and several found it helpful in obtaining subsequent employment.

3.5 *Soil-structure interaction*

An introduction to soil-structure interaction is given in lectures to all final year students at Bristol. This briefly examines the influence of ground deformations on foundation response, methods of design of new foundations, the response of existing structures to ground displacement (including types of movement and damage), and the response of the ground to construction of excavations and tunnels.

Geotechnical design practice is changing very fast and the use of bespoke geotechnical software is ubiquitous. The widespread availability of 2D and 3D finite

1. Review published case history

Summarise a published case history on geotechnical observation and monitoring. Select a paper that interests you from the list. You should also read Peck's 1969 Rankine Lecture paper on the Observational Method in Geotechnical Engineering.

Specification:

- describe context: outline of project;
- why was monitoring required?
- what was monitored and why were these quantities chosen?
- how were these quantities monitored?
- what conclusions were drawn and what were the consequences of the observations?
- present and discuss <u>your</u> views of the monitoring programme.

Note that your own views and interpretations are important; do not merely summarise the published information.

2. Purpose of geotechnical instrumentation

Construction of the £15.9 billion Crossrail project beneath central London is just starting. It will necessitate construction of new twin-bore 21 km tunnels and a number of deep station boxes. What main purposes will geotechnical instrumentation serve on this project? What is meant by the term *observational method*? Illustrate your answer with reference to several published case histories involving underground construction, describing at least one project in detail. Explain what was monitored, how and why, what the consequences of the observations were, and what conclusions you have drawn about the monitoring programme.

Note: A list of case history papers is attached. You should also read Peck's 1969 Rankine Lecture paper on the Observational Method in Geotechnical Engineering.

Figure 6. Specification of final year case studies on Geotechnical Instrumentation and the Observational Method.

element (FE) packages has resulted in a presumption that these tools will be used routinely; at least superficially, their output looks impressive. The writer suspects that some graduate engineers are undertaking geotechnical finite element analyses of complex problems involving soil-structure interaction, often without deep understanding of what the program is doing and without close supervision.

How should universities respond to this? It is often argued that universities should teach the fundamental knowledge and that industry should focus on abilities (e.g. Steenfelt 2000), but this seems an inadequate response. The writer believes that universities should provide a structured introduction to the use of finite element packages to those students who are particularly interested in geotechnics. We need to equip them with the knowledge and skills to undertake analyses responsibly.

Two approaches have been explored at Bristol through the development of final year option courses. In the first, students were introduced to geotechnical modelling through guided reading from Muir Wood (2004) and hands-on experience.

The second course (10 credits), developed by the writer, is more practice-oriented and is particularly focused on soil-structure interaction (see Fig. 7). At the outset there are lectures introducing finite element analysis and constitutive models. Then students start to teach themselves to use Plaxis 2D (Plaxis 2009) by working through the examples in the Plaxis tutorial manual on their own, and seeking help in weekly computer support classes. In the coursework, students explore for themselves the validity of simple numerical models. After carrying out hand calculations of the bearing capacity and settlement of small foundations, they undertake parallel FE computations. Students start to gain confidence when they find that numerical analysis can match closed form solutions, but they are also exposed to some of the pitfalls and are surprised when the match is poor. At this point they are encouraged to read Potts' (2003) Rankine lecture and to refer to Muir Wood (2004). The remainder of the course consists of two mini-design projects (see Fig. 7), in which the students explore soil-structure interactions associated with building foundations and a sheet-piled excavation. Again the students are required to undertake hand calculations in parallel with the FE analyses, which provides a good opportunity to revisit basic geotechnical theory.

In the support classes students are encouraged to explore and interpret as much of the output graphs and plots from the FE analyses as they can, and this often leads to extended dialogue with staff. Eventually students have to draw everything together in a final report. Reading the submissions and giving feedback is quite time-consuming, and can only be done by someone with some practical experience of such FE analysis.

Having run the course in this way for several years its strengths and limitations have become apparent. Many students have started to develop a critical appreciation of FE analysis, but while the course provides a structured introduction which is useful professional development in preparation for a geotechnical career, it still skates over the surface of what is happening in the black box. Students need more time to understand constitutive models and explore their behaviour embedded in the finite element programme. Although there are short courses to train graduates in the use of finite element programmes, graduates will need to be self-directed and guided to develop real understanding of models. This needs to be addressed by universities and industry in the future.

3.6 *Final year design project*

As mentioned above, final year students at Bristol undertake a major integrated design project (40 credits), working in groups of three, four or five students. A wide variety of projects are undertaken each year; recent projects have included *Design of new Colston Hall, Bristol; River Avon crossing; Gravity foundation for offshore wind turbines; Rammed earth slum housing; Transport interchange at Bristol Temple Meads; Tallinn Town Hall; Golf driving range Dubai City; Zero carbon factory*. These projects are multi-faceted and each student takes responsibility for one or more

The coursework is in three sections:

1. Initial studies - A comparison of the bearing capacity and settlement of various foundations as predicted by hand calculations and Plaxis. How good is the agreement? Why might the results be different? Consider the influence of the coarseness of the mesh, and the distance of the outside boundaries. Draw conclusions from this study about the validity or otherwise of your Plaxis calculations.

2. A foundation problem, to explore the effect of changing foundation type and stiffness on total and differential settlements and bending moments in the substructure of a 6-story reinforced concrete office building supported by pads, strips or a raft.
   - A. using Plaxis 2D (modelling the soil as a continuum);
   - B. analysis of the same problem modelling the soil as springs using GSA (or Plaxis).

   Comment on which analyses are the most appropriate. Evaluate the dimensionless flexibility of the raft/soil and compare your numerical results with theoretical solutions. Draw conclusions from this study about the design proposed and about how varying the foundation structure influences the deflections and bending moments. Advise on the best foundation arrangement.

3. An excavation problem, in which a six metre deep excavation in granular soil is to be constructed close to an existing masonry building. Undertake hand calculations for propped and cantilever walls. Model the excavation with Plaxis, and examine the influence of changing the stiffness of the sheet-pile retaining wall and the effects of introducing a top prop on bending moments induced in the wall and on the movements outside the excavation. Evaluate the dimensionless flexibility of the sheet piles/soil and compare your numerical results with theoretical solutions. Draw conclusions from this study about the design proposed.

Specification: Summarise your findings in a report of maximum 20 sides A4 plus hand calculations in an Appendix.

Note: except for the initial studies on settlement of shallow foundations, use a Mohr-Coulomb constitutive model, drained or undrained as appropriate.

Figure 7. Final year project on soil-structure interaction.

aspects; often groups are supported by an engineer from industry. Most projects need foundations and so provide a good opportunity for students to undertake an additional desk study and to interpret site investigation data if it is available, thus drawing on the lecture content from the main final year geotechnical lecture course. In some projects the geotechnical design can be extremely challenging, perhaps necessitating a finite element analysis; students who have taken the soil-structure interaction course are well placed to undertake this. Towards the end of the course, each design is presented on two large posters at a poster session at which industrial advisors and academic staff are present. This is followed up by submission of a sixty-page report with accompanying work files. These projects are generally of high quality and students are extremely proud of their achievement. For aspiring geotechnical engineers, they provide an excellent opportunity to develop their experience.

4 CONCLUSIONS

The overall aims of the geotechnical courses set out in Table 1 have certainly influenced the development of the undergraduate MEng programme in Civil Engineering at the University of Bristol, and are linked to the learning outcomes of each course. Many of the core activities described here (site investigation desk studies, case history studies and mini-design project) are suitable for use with cohorts of 100 students. The more specialist activities such as the field course and the course involving finite elements are much more suited to smaller groups. All these activities need input from academics with professional geotechnical experience, and can benefit from additional input by industry-based engineers. Although the activities are only briefly described, hopefully there is sufficient detail for readers to envisage what is undertaken and perhaps to adapt the ideas for other contexts.

Feedback from students indicates that for many, this window into geotechnical practice is stimulating and rewarding. Asked to comment on the best aspects of their final year, students wrote of the Geotechnics course "*I enjoyed it because you could see how theory was put into practice*". "*I liked being given independence to read around the subjects so that I could gain a broader understanding*". "*I enjoyed it because of its application to real life projects*".

It is argued that embedding professional development in geotechnical engineering into the undergraduate curriculum brings many benefits. It can engage students in geotechnics to a much greater extent than traditional lecture courses so that they really develop their competences across the whole spectrum of the soil mechanics triangle. By the time they graduate many students can solve routine geotechnical problems but are hopefully aware of the limitations of their knowledge. Taken together, the activities provide the opportunity to explore the wide scope of geotechnical engineering, and appreciate the importance of engineering geology. Some students are even inspired to become geotechnical professionals.

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Context, rigour and enjoyment in geotechnical education

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ABSTRACT: This paper outlines how geotechnical education is being delivered in the University of Limerick's (UL) new civil engineering programme. The undergraduate programme adopts a student centred approach and employs Problem Based Learning (PBL) as its central pedagogical approach. The following account outlines how the second of three geotechnical modules is delivered through an integrated design trigger or problem. The geotechnical module is one of four subjects involved in an architect designed multi-storey reinforced concrete structure. The design documentation is developed to tender stage and formally presented to the client at the end of a fifteen week semester. Working in small teams and liaising with the architect and client encourages students to learn about leadership, communication skills, personal responsibility, reflective practice and self assessment – all skill deficits identified by professional bodies in young engineers.

1 THE CHALLENGE FOR GEOTECHNICAL EDUCATION TODAY

One of the many challenges facing students studying geotechnical engineering is the apparent diversity and multiplicity of concepts, procedures and empiricism that exist within the subject. The student becomes overwhelmed and can end up throwing in the towel in frustration. In geotechnical engineering, learning is not a linear process as it can be in subjects like structural design or structural analysis. The skills for the latter can be acquired by a diligent student practicing the techniques. This is not necessarily the case in geotechnics where nature plays such an important role in determining the engineering behaviour of soils. However, in reality, there are relatively few key concepts that form the backbone of the whole discipline e.g. effective stress, consolidation theory, seepage and total & effective stress analyses. So, once the student is equipped with a fundamental understanding of engineering geology the remaining topics are merely extensions or applications of the key concepts.

Therefore, given a syllabus that is designed to capture the core material, the teacher's job is to ensure the content is delivered in a way that engages and motivates the students to learn and become skilled in the application of the principles of soil mechanics. This is best accomplished by providing a context for the learning to take place – this paper deals with the latter.

Whether we like it or not, international research and anecdotal evidence points to the demise of the 'traditional' lecture, i.e. the art of passively transferring the notes of the lecturer to the notes of the students (some would argue without passing through the heads of either!). Students have voted on this form of instruction as a meaningful learning experience. Unless they perceive the lecture as something that adds value to their learning, clever students may stay away and learn by studying the material at a time that suits their schedule. It is worth noting however, that the 'right' type of lecture or learning seminar has a significant motivational value. McKeachie & Svinicki (2006) lists the following benefits of a lecture:

1) To present up-to-date information – i.e. to bridge the gap between the latest scholarship until it appears in textbooks.
2) Summarising information scattered over a variety of sources.
3) Adapting material to the background and interests of a particular group of students at a particular time and place.
4) Helping students to read more effectively by providing an orientation and conceptual framework.
5) Focusing on key concepts and principles.

So the question arises: what format should a lecture take in 2012? It should engage the student in the learning process by actively 'doing things' in class. We should employ active learning techniques to support carefully planned lecture material so students will be inspired to delve deeper and to master the essential concepts. This paper presents how the second in a trilogy of geotechnical (undergraduate) modules is delivered using a 'learning by doing' approach. The paper presents the geotechnical concepts covered and how these have been weaved into an integrated design project that also involves three other subject areas.

Reflecting on the second iteration of this trigger (a problem that 'triggers' new learning) reveals interesting challenges to student learning, understanding and engagement. For the lecturing team, education as a human encounter and the motivation of student learning continues to provide intriguing challenges. Finally, the successes and challenges with the approach are discussed and some commentary provided for teachers considering adopting a student-centred teaching model.

1.1 *Educational philosophy of civil engineering at the University of Limerick*

In general, students entering university are expert in rote learning and have exhibited this skill to great effect in solving structured problems (Flynn, 2011 and Quinn, 2011). Being asked to solve messy unstructured problems at university therefore comes as a significant shock. It requires a sea change in the students' educational approach adopted here-to-fore. Changing habits embedded over fourteen years of didactic education poses its own challenges and requires fostering the maturity to accept ones personal learning responsibilities. In addition, we have found providing an induction to Problem Based Learning (PBL) in first year and working through triggers of increasing complexity as the students move through the programme gradually breaks down the barriers of rote learning and promotes free and independent thinking.

The University of Limerick (UL) civil engineering programme adopts Problem Based Learning as its principal educational approach. PBL involves presenting students with a problem prior to the delivery of subject material. Students work in self-selected teams of five or six and combine their prior knowledge to identify what's already known about the problem. They then determine their research needs and each group member independently undertakes this work. The research findings are then shared when the group next convenes and this process is repeated week-on-week until they arrive at a solution. The path to an acceptable solution follows the project programme developed at the outset and this is reviewed and modified as required at the end of each week. Progress is guided by two facilitated PBL sessions of two hours duration per week (i.e. 4 hours per week) and students usually find it necessary to hold additional meetings outside these facilitated sessions. The PBL sessions are facilitated by an experienced external consulting engineer and one academic team member that is not teaching on the Integrated Design Project (IDP) modules. The tutors carefully monitor and guide the PBL process so the students are clear about the material that each must master, e.g. effective stress, foundation sizing and evaluation of settlement. Guidance is also provided on the activities that can be sub-contracted within the group to achieve greater efficiently, e.g. gathering historic and current Ordinance Survey maps for the site.

Interestingly, we have noted the students work hard to identify and assimilate the required knowledge – and because of this, they tend to take ownership of the knowledge, retain it longer and better understand its value in solving the assigned problem.

1.2 *Changing the educational paradigm*

The motivation for change at UL is driven by a universal acknowledgement that the time-honoured educational approaches are no longer effective. Robinson (2010) outlines the historical context for the traditional educational approach which evolved to serve post industrial revolution employers. This approach served industry well; as the people entering the workforce were equipped with the skills required for a lifelong career. However this one set of skills is no longer sufficient. In today's world, our approach to educating innovative problem solvers must adapt to meet the needs of a rapidly changing and highly technological world.

Felder (2012) in examining the traditional and emerging educational paradigm, highlights four focal issues for engineering: (1) how engineering curricula should be structured (2) how engineering courses should be taught and assessed (3) who should teach and (4) how the teachers should be prepared. In a related vein, Redish and Smith (2009) in looking beyond content, highlight the importance of context for directing and inspiring learning:

"A good knowledge of the facts, equations, and even concepts is only the beginning. What matters more is that the students learn the practice of science and engineering – not only the knowledge needed but how to use that knowledge in authentic contexts. Much of the interest in engineering education today is on understanding and developing these skills of practice."

Building on this, Miller (2010) gives an excellent account of how engineers for the 21st century are educated at Olin College. The account summarises the history, funding, market research and the rationale that informed their unique approach – it even includes an example of how success was engineered from adversity after their building programme ran past the scheduled opening date. There can be little doubt that this fledgling place of educational innovation is having a profound influence in creating engineers for the future.

1.3 *Responding to the call for change*

The entire first semester of third year civil engineering at UL is devoted to a single Integrated Design Project. The design is completed in a fifteen week semester which precedes an eight month cooperative education placement. To reflect its importance, the project accounts for 60% of the student's final grade for the semester. The remaining 40% is for an end of term exam in each of the courses listed in Figure 1.

These exams focus the students' attention on analysis and design skills as they are developed during the project. Peer and self assessment are also incorporated as part of the 60% as is a personal reflection on the learning gained through the IDP.

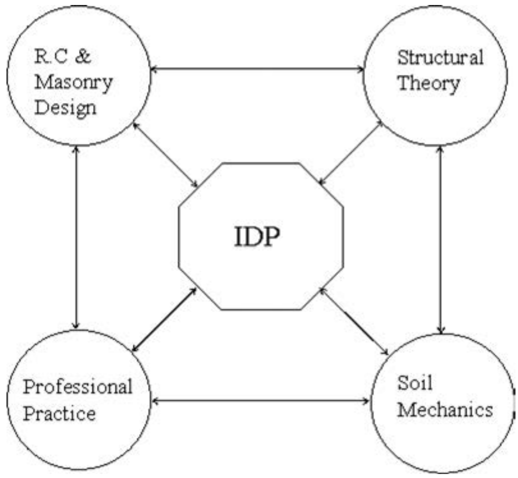

Figure 1. The Integrated Design Project (IDP) Subjects.

The project involves the design of a multistory reinforced concrete structure on a challenging geotechnical site. Working in groups, the students visit the site on a number of occasions; they also work with the design architect to develop a structural scheme. The design drawings presented to the engineers are completed a year in advance by UL 4th year architectural students – an experience that mirrors the reality of engineering practice. It is fair to say that the creations proposed for the same site can be structurally challenging – but experienced staff carefully guides each team in the development of a robust structural scheme.

A project plan using MS Project is also developed and a total station survey of the site performed. The preparation of a geotechnical desk study for the site and hence a site investigation and/or a laboratory test programme forms a significant component of the soil mechanics module. The gathered data is used to measure the strength and stiffness properties of the soil so foundations for the structure can be designed. A combination of hand drawn details and CAD drawings form part of the final comprehensive project report.

The teaching staff tracks progress via a mid-semester presentation that is formatively assessed. During these open presentations, teams get to compare and evaluate their progress relative to their peers and any issues or gaps in knowledge can be addressed at this stage. At the end of the semester the completed project is presented in a day long seminar that is open to the campus community and invited guests from industry. The project concludes with individual interviews to assess if each student has met the learning outcomes for the project.

2 GEOTECHNICAL COMPONENT OF THE IDP

2.1 *Details of the soil mechanics module*

As noted earlier, the soil mechanics module is the second in a suite of three geotechnics courses taken by the civil engineers – It focuses primarily on strength, stiffness and compressibility properties of soil (Figure 2). By way of context, the preceding module covers: recent geology, soil classification, seepage, effective stress and compaction theory. The third module on geotechnical engineering design is taken in final year (i.e. following the IDP). The latter focuses on slope stability, deep foundations and retaining structures. Proprietary software is introduced for the first time in the design module. Students use software to improve the efficiency of their designs and to undertake parametric sensitivity studies.

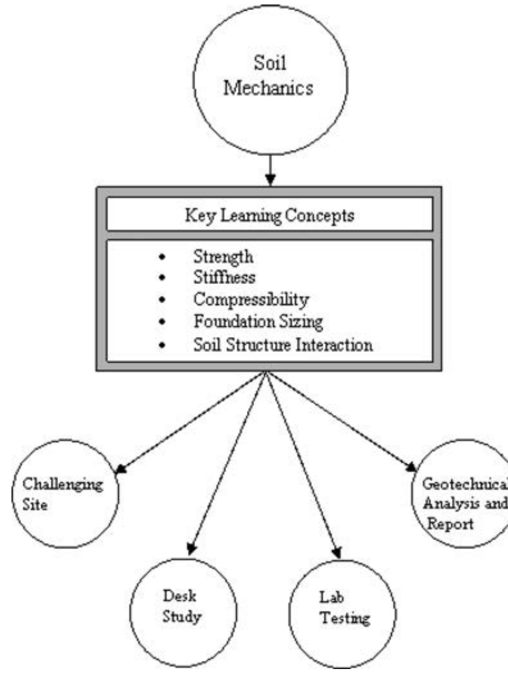

Figure 2. Soil Mechanics Module Details and Tasks

Adopting a PBL approach requires creativity on how best to elicit the geotechnical rigour normally specified upfront in a didactic mode of delivery. For example, the IDP module has no prescribed programme of laboratory testing, yet each team is expected to identify and undertake appropriate tests to satisfy the project's design needs. Students are also expected to identify the geotechnical concepts required to develop a design solution. During this process, the teams encounter topics that require expert guidance and these needs are addressed through learning seminars provided by the lecturer in the specific subject areas.

To reinforce the rigorous aspects of the discipline, each module has between two and three timetabled hours a week set aside for formal learning seminars. The pre-planned seminar topics are presented by the lecturer and occasionally students will request additional seminars particularly when they encounter challenging concepts. All seminars are carefully aligned with the tutors' guidance notes for each facilitated PBL session. This allows tutors to listen to group discussions and where necessary, intervene gently to nudge wandering debates back on track.

2.2 *Staff and student workload*

Each module on the IDP is worth 6 ECTS credits. This equates to approximately 125 hours of total study per module or 500 hours of work for the entire project. Student feedback suggests that this can increase to fifty or sixty hours per week when project milestones are due. The process is also demanding on the academic staff. Each staff member is involved in delivering the module content, providing formative feedback on interim submissions, attending mid-semester presentations, facilitating individual interviews at the end of the semester, organising the end of semester seminar and setting and correcting a final exam and project submissions.

2.3 *Technical student challenges*

As each design reflects a particular architectural concept, every structure is different – in simplest terms: the spans and loading arrangements will vary per structure. No two designs are identical. The engineering design process starts by investigating the history of the site, determining the influence of geology on the design and the impact of the proposed development on surrounding structures. The essential geotechnical design parameters are identified, soil samples acquired and appropriate laboratory tests performed to determine these parameters. The results are used to proportion foundations and assess the soil-structure interaction effects under the design loads.

As the site is generally selected along an estuarine or coastal setting, non-uniform strata depths are the norm. It is therefore important that students recognise the need to check that the differential settlements and relative rotations remain within threshold limits for framed structures.

2.4 *Grading to guide learning*

Students are intrinsically motivated to achieve good grades and this fact is used to focus learning effort as shown in Table 1. Note the end of semester interview receives the highest proportion of the marks (20%). This is intended to remind the student of their personal learning responsibisssslity. The next highest proportion of the marks is for the technical report (15%) which emphasises the importance of written communication skills in engineering.

Pop quizzes (10%) are used to encourage and reward students that undertake assigned reading ahead of learning seminars. The quizzes are delivered at the start of each seminar and are assessed using electronic clickers. The clickers gather student responses to multiple choice questions based on the assigned reading. This technology allows the lecturer and student to get instant feedback through bar charts projected using

Table 1. Grading of the IDP Component of the Soil Mechanics Module.

Task	*Percentage grade*
End of project interview	20%
Geotechnical report	15%
Pop quizzes	10%
Peer & self assessment	7.5%
Reflection	7.5%

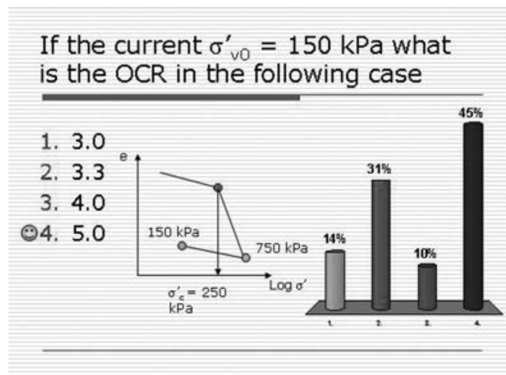

Figure 3. Typical Pop Quiz MCQ with feedback provided.

PowerPoint (Figure 3). The correct answers are also added to the display immediately after polling and the results can be saved and emailed to the students as a revision aid.

Finally, every opportunity is taken to make each assessment activity an opportunity for new learning or the reinforcement of existing learning.

3 THINKING ABOUT THINKING

3.1 *Reflective practice*

This is part of what Pellegrino (2006) refers to as a "metacognitive" approach to instruction. Its power resides in helping students to take control of their own learning through defining clear learning goals and monitoring progress in achieving them. During the IDP, each student submits an interim reflection on their learning and a final reflection at the end of the semester. These are powerful writings and can be very empowering for the student. It would appear the students find this process helpful in consolidating their thoughts, identifying where they have done well and where the opportunity for greatest improvement resides. On occasion, some students feel compelled to offer feedback rather than reflecting on their learning. Feedback is always useful for improvement and we have not discouraged such offerings. However, in order to develop an ability to reflect and distinguish between this and feedback, we ask students to separate any feedback from their reflections.

3.2 *Peer and self assessment*

At the start of the trigger, students agree the criteria against which their contribution and performance will be assessed. Each team discusses their values and expectations for achieving a successful project outcome and summarise these on a team whiteboard. Then in a plenary session, the facilitator consolidates the offerings from all teams on a master whiteboard. A single set of criteria is agreed from this list and these form the basis of a peer and self assessment grading rubric. At the end of the IDP each student completes the rubric, assessing their own contribution and that of each team member. Anonymity is preserved by submitting the evaluations through the university's online learning management system. This is a very effective tool in achieving honest self appraisal with student self assessment grades tying in with their average peer assessment grade.

3.3 *Learning styles, leadership and group dynamics*

Over the past four years we have experimented with group selection in order to 'design' good group dynamics. This topic is worthy of further discussion but for the purposes of this paper, it is suffice to say we have found little merit in our efforts. Self-selecting teams provide no better or no worse outcomes in terms of group dynamics. We have also found that leaders emerge in every group regardless of its mode of selection.

Having undertaken the Index of Learning Styles survey (see Felder and Spurlin, 2005) in their first year of the programme, the students are aware of the diversity of learning styles that exist within the class and within each group. They also appreciate and acknowledge the benefits that different approaches to learning can bring to solving unstructured problems.

4 INTEGRATION OF SKILLS AND WHAT EMERGES AT THE OTHER END

The subject of soil mechanics continues to academically challenge students. As they grapple with the complexity of the integrated design process, they may be slow to, or neglect to engage with some important geotechnical questions, for example: how will the ground respond when loaded? What is the implication of such a response for the stability and serviceability of the building?

The tendency for this information to remain uncoupled is prevalent. For example, the connection between bearing capacity and movement (consolidation) is not so obvious to the students – analyses are performed as two standalone activities that are not connected or related in any way. Therefore, considerable time and effort is spent in the learning seminars trying to unify these concepts. The role of stress history, overconsolidation, rate of loading, particle size distribution and soil classification in both the strength and compressibility of the soil are debated. In addition, the incorporation of stress path sketching has been helpful in re-coupling the concepts. It is acknowledged that mastery of stress path sketching takes a significant investment of students' time. So, emphasis is placed on gaining a qualitative understanding of the loading path and the corresponding compression response under the applied foundation stress (Figure 4).

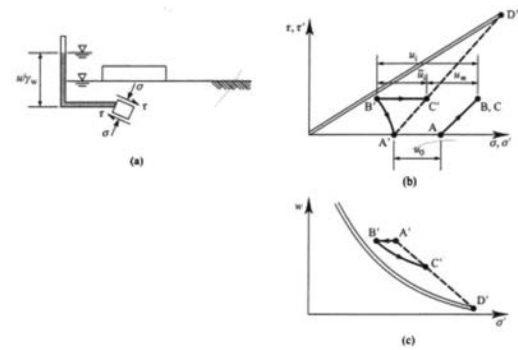

Figure 4. Changes of total and effective stress during loading and consolidation of a foundation (Atkinson, 2007).

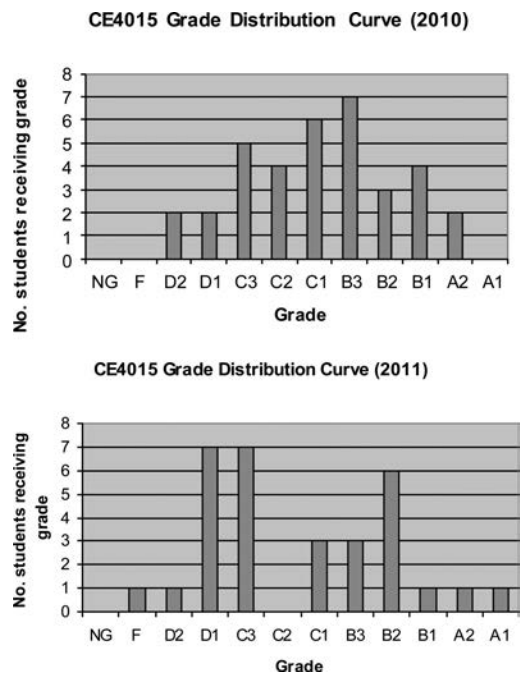

Figure 5. Overall module performance for 2010 and 2011.

The bar charts shown in Figure 5 illustrate the overall module performance. It can be seen that a relatively small number of students obtain A's and high B's. These are followed by a large cohort obtaining low B's and C's. The performance of students at the lower end of the distribution is attributed to a lack of engagement rather than lack of ability. This opinion is supported by the fact that the average university intake points for all students who have undertaken the IDP is within 16% of the maximum possible score in the Irish leaving certificate examination - a clear indicator of academic ability.

It is evident that, non-engaged students challenge the group dynamic – they can generate poor feeling if the group ultimately carries them through the project. This is no different in any other educational model. However, the price of this tactic is paid when the student is interviewed at the end of the semester and particularly when the peer assessment grades are submitted. We have found the individual interview to be a powerful tool in measuring the learning outcomes for both the individual subjects and the IDP. It is also one of the main motivational factors in students taking responsibility for their learning. We have also noted that students, who work hard to identify and assimilate the required knowledge, tend to retain the information and exhibit a better understanding of the technical concepts.

To further investigate the effectiveness of the IDP, we engaged the university's Centre for Teaching & Learning to conduct focus group research with the 2010 and 2011 cohorts. The findings reveal some benefits and concerns of the students. Chief amongst their concerns is the significant workload associated with the IDP compared with that of their peers in other courses. Students are also disappointed that their extra effort is not necessarily reflected in their overall QCA/GPA. This highlights the ongoing toil between seeking high results over understanding and mastery of the course material.

On the positive side, the IDP illustrates that 'new' skills can be developed within existing teaching methodologies without the need for new courses or modules. The 2010 cohort (the post co-op group) feel the PBL process and the IDP experience built their confidence and self-belief when it came to undertaking unfamiliar tasks. The following quotations from the post- co-op group suggest a general positivity towards a learning-by-doing approach to education:

"PBL is a great way to apply theory to practice. We get to design real life problems that combine subjects and formulas and see how a project all fits together. From my own experience in modules outside of PBL there is a tendency to just study the past papers before exams and work out the answers to examples in the days before. For me most of this is forgotten and is just a way of getting through the test. Whereas in PBL we are required to write reports on projects we have completed and to do this we must really understand the subject. I remember many of the methods used to solve problems through PBL modules from three years ago. Whereas for other modules, I would need to cover them again to get the basics."

"Working in a team encourages the asking of questions to other students, building relationships with peers and motivates creative thinking."

"I think it is a good thing as you learn how to work as a team, and how to deal with different people and personalities that work in the group, which at times may be either difficult or easy. But it is something that you have to learn to be able to do in future careers, whatever they may be."

"The workload can seem heavy because most of the projects we do are open ended, and they are worked on right up until the deadline."

In conclusion, both cohorts enjoy the flexibility and autonomy of the PBL teaching model. They also acknowledge the power and efficiency of learning through group work – confirmation of the adage:

> *"I pay the schoolmaster, but 'tis the schoolboys that educate my son."*
>
> Ralph Waldo Emerson
> (1803–1882)

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Some reflections on the use of a cooperative learning model in Soil Mechanics courses

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ABSTRACT: The implementation of the Bologna Process enforced a significant change on the traditional learning models, focused mainly on the transmission of knowledge. The use of a cooperative learning (CL) model in the Soil Mechanics courses (undergraduate level) of the Department of Civil Engineering, University of Aveiro, Portugal, is described. The students were confronted with situations recreating a professional atmosphere in Geotechnics. Mandatory team project assignments were allocated, where each student had to fulfil both specific and rotational roles. All students performed the necessary functions (different in each project), representing the corresponding role – jigsaw. These roles had, as much as possible, a parallel to functions normally fulfilled by engineering professionals. The impact of the implemented model was assessed using students' feedback, monitoring of marks and questionnaires. Their results are presented and discussed. Some additional reflections on the impact of the CL system on the teacher's work are also included.

1 INTRODUCTION

1.1 *Scope*

Traditional engineering educational strategies such as lecture, laboratory experiences and homework have been criticized because they inadequately prepare engineering students to engage in the collaborative partnerships that are essential for the practising engineer (Stump et al. 2011). These methods have also been criticized because they promote passive learning and a compartmentalized curriculum that may not prepare students for the innovative and flexible role of engineers in today's society.

To fulfil the industry's increasing demands, it is generally accepted that Civil Engineering graduates and postgraduates should have broad technical knowledge, significant generic competences and soft skills. Some examples are: efficient communication, orally and in writing; development of human relations, particularly the ability to work in a team; ability to work with a computer.

To respond to the demands of the Bologna process in changing the learning paradigms, to increase the employability of the Civil Engineering graduates and postgraduates at University of Aveiro (UA), Portugal, and to improve the overall quality of the program, the author implemented some non-traditional teaching and learning strategies in most of the courses under her coordination. The author then analyzed their impact to assess the effect of such strategies on enhancing students' learning.

In two sequential Soil Mechanics courses a cooperative learning system was used. The aim was to enhance students' learning while helping the development of soft skills and creating opportunities for the students to become familiar with typical numerical tools currently used in Geotechnics.

After the implementation of the Bologna Process in Portugal, all Civil Engineering students have to complete a 2nd cycle degree (M.Sc.) to have full access to the profession. Thus, a secondary aim was to prepare the students better to develop scientific research work and to write a dissertation.

The first format of such a model and the initial perception of the impact on students has been presented and described by Pinho-Lopes et al. (2011). In a companion paper, Pinho-Lopes (2012), the use of computing and software in this model is presented.

2 BACKGROUND

2.1 *Cooperative learning*

Cooperative learning (CL) is a form of active learning. Prince (2004) says that active learning is generally defined as any instructional method that engages students in the learning process. Active learning requires students to do meaningful learning activities and think about what they are doing. According to Felder & Brent (2009), active learning is anything course-related that all students in a class session are called upon to do other than simply watching, listening and taking notes. Quoting several authors, Prince (2004) tries to distinguish between two forms of active learning: collaborative and cooperative learning. The author mentions that collaborative learning refers to any instructional method in which students work together in small groups toward a common goal. As such, collaborative learning can be viewed as encompassing all group-based instructional methods, including cooperative learning. In contrast, some authors distinguish between collaborative and cooperative learning as having distinct historical developments and different philosophical roots. In either interpretation, the core element of collaborative learning is the emphasis on student interactions rather than on learning as a solitary activity.

Lara & Repáraz (2005) state that CL consists of the didactic use of reduced groups, in which students work together to maximize their own learning and that of others. According to Johnson et al. (1998), CL refers to work done by student teams producing a product of some sort under conditions that satisfy five criteria: positive interdependence, individual accountability, face-to-face interaction for at least part of the work, appropriate use of interpersonal skills, and regular self-assessment of team functioning (Felder & Brent 2007a). Smith et al. (2005) report that extensive research has shown that relative to traditional individual and competitive modes of instruction, properly implemented cooperative learning leads to greater learning and superior development of communication and teamwork skills.

Engineering and science are traditionally taught deductively (Prince & Felder 2006). The instructor introduces a topic by lecturing on general principles, then uses the principles to derive mathematical models, shows illustrative applications of the models, gives students practice in similar derivations and applications in homework, and finally tests their ability to do the same sorts of things on exams. Little or no attention is initially paid to the question of why any of that is being done. What real-world phenomena can the models explain? What practical problems can they be used to solve, and why should the students care about any of it? The only motivation that students get, if any, is that the material will be important later in the curriculum or in their careers (Prince & Felder 2006).

Stump et al. (2011) present a summary of the state of the art on collaborative learning. The authors highlight that it is important to note that not all collaborative activities are successful. Simply putting students together does not guarantee knowledge construction or increased academic achievement, and researchers have devoted considerable effort to discover the conditions that promote effective and ineffective collaboration. Slavin (1996), quoted by Stump et al. (2011), maintained that a common group goal is necessary for collaboration to be effective, and that achievement of the group goal should be evaluated via individual performance of each group member, e.g., a final math unit grade for each group member should be derived from the average of all group members' quiz grades. More recent studies however, have focused on characteristics of the collaborative exchange itself as the unit of analysis.

Mourtos (1997) highlights two good reasons for using CL in engineering classes. First, research has repeatedly shown that students learn better when working with each other than when working in isolation or competing against each other. Second, it forces students to practice team and small group communication skills which are a must in the real world.

Adams et al. (2011) present interesting perspectives on engaging future engineers. About the work of Marilla Svinicki they say: "learners do not really understand until they can apply that understanding to a personal demonstration of the learning. This is actually the principle behind the effectiveness of active learning. It is based on the fact that learning requires feedback, and interaction with the environment provides the best and most generalizable feedback. Observing someone else solving a problem results in a shallow understanding (…). Solving it yourself makes all those connections real. The implications for teaching are fairly obvious, and yet we frequently ignore them. We act as if once we have said it students have understood and learned it. In reality it isn't until they have been required to do it that learning occurs".

Reed Stevens introduces the concept of a socio-technical engineering education. A re-imagined engineering education starts from two basic principles: (1) the socio needs to be balanced with the technical and (2) it should be as hard (or as easy) to pull apart the socio from the technical in the educational experience as it is in the realization of successful engineering projects (Adams et al. 2011).

Jigsaw is a cooperative learning structure applicable to team assignments that call for expertise in several distinct areas (Felder & Brent, 2007a). For example, in a laboratory exercise, areas of expertise might include experimental design, equipment calibration and operation, data analysis (including statistical error analysis), and interpretation of results in light of theory, and in a design project the areas might be conceptual design, process instrumentation and control, safety and environmental impact evaluation, and cost and profitability analysis (Felder & Brent, 2007a).

A good structure for cooperative learning assignments has been developed by Michaelsen, where all cooperative learning assignments should be characterized by "The Three S's": same problem; specific choice; simultaneous report (Triten 2001).

Instructors who attempt CL frequently encounter resistance and sometimes open hostility from the students (Felder & Brent 2007a). Some strategies to deal with dysfunctional teams are put forward by Felder & Brent (2001). They state that often group conflicts stem from different expectations group members have for one another. To get groups off to a good start, the group members should prepare and sign a list of ground rules they all agree to observe. Then a few weeks into the semester, the teachers should make the groups revisit their lists and evaluate how well they are doing in meeting the expectations they set for themselves. An in-class troubleshooting exercise is a good tool for equipping students to deal with specific interpersonal problems that may surface (Felder & Brent 2001).

2.2 *Bologna process in Portugal*

Before the Bologna Process in Portugal there were four levels of studies: 3 years ("bacharelato"); 5 years ("licenciatura"); 2 years ("mestrado"); 3 to 4 years (Ph.D.). The most visible transformation from the Bologna Process in Portugal was the degrees' reorganisation in three cycles: 1st cycle, 3 years ("licenciatura"); 2nd cycle, 2 years ("mestrado"); 3rd cycle, 3 to 4 years (Ph.D.).

The engineers' professional organization in Portugal demands a minimum of 5 years' scholarship for civil engineers to be responsible for all types of projects. Thus, most civil engineering programs are organized in two integrated cycles (1st and 2nd cycle) leading directly to a M.Sc. degree.

The Bologna process also implies changes of the teaching and learning process. In fact, shifting the emphasis from teaching to learning is one of the major consequences of such reform.

3 CASE STUDY

3.1 *Soil Mechanics courses*

Presently the Civil Engineering degree in UA is organized in 2 integrated cycles of 5 years (10 semesters), corresponding to 300 ECTS. ECTS stands for European Credit Transfer System. Each ECTS credit unit represents 25 to 28 hours work, which includes, apart from class time, individual study time, preparation of reports, bibliographical research, preparation for examinations, etc. (UA 2010).

The Civil Engineering program at UA includes two consecutive Soil Mechanics courses in the 3rd year, thus included in the 1st cycle (undergraduate).

The aim of the Soil Mechanics I (SMI) course is the understanding of basic concepts and fundamental quantities of Soil Mechanics, so that, later, they can be applied in the design of civil engineering structures. The syllabus is grouped into:

1 Physical properties and soil identification. Sedimentary and residual soils;
2 Stress state in soils. Capillarity;
3 Water in soils. Seepage;
4 Compressibility and consolidation of clay soils.

The Soil Mechanics II (SMII) course is focused mainly on the mechanical behaviour of soils (in particular, its strength). Concepts, theories and methods generally used for the design of civil engineering structures are presented. Emphasis is placed on works where the stability depends essentially on the soil's strength. The field tests generally used to characterize the mechanical behaviour of soils are also presented. The course syllabus is grouped into:

1 Introduction to shear strength of soils. Shear strength and stress-strain relationships in sands and in clays;
2 Lateral earth pressures; Earth retaining structures;
3 Stability of slopes and embankments;
4 Sampling and in situ tests.

All the stability analyses are carried out using both global safety factors and the partial safety factors approach from Eurocode 7 (EN 1997-1:2004).

The Soil Mechanics courses correspond to 6 ECTS each and typically have 60–90 students per school year. The weekly timetable of SMI consists of one Theoretical-Practical (TP) lesson with a limited number of students (up to 45) and a duration of 2 hours, which includes a practical component, and one Practical (P) lesson with a duration of 2 hours and limited to 25 students. The weekly timetable of SMII consists of 2 TP classes.

More details can be found in Pinho-Lopes (2012).

3.2 *Cooperative learning model used*

3.2.1 *Model and assessment*

The implementation of this CL model has been done right after a workshop in the UA on the subject by Richard Felder and Rebecca Brent and their suggestions have been the first inspiration. A jigsaw model which included mandatory team projects was implemented, with "The Three S's" characteristics.

In this first year (2007/2008) this CL model was used in both SMI and SMII courses. This was continued in the SMI course, where a teaching team of 2 or 3 people has been working. Later, for the SMII course, a "lighter" version has been adopted, as the author has been teaching the course on her own.

The assessment system implemented was defined using suggestions by Felder & Brent (2007b) and included two assessment elements: four team projects, developed during the semester, and one test. For the students who failed there was a second chance of passing – a final exam, where the team projects' mark was still considered.

The team projects were compulsory to all students. During the semester, students prepared four projects (one per syllabus' chapter) and presented some of them orally to teachers and colleagues. The projects to be presented were chosen by the teachers, based on the necessity of clarifying some key points.

The projects were prepared in groups of four students with specific individual functions in each work and mandatory rotations. These roles were: laboratory/informatics technician, analyst, reporter and coordinator. This way, all students performed the four established functions (a different one in each project), representing the corresponding role – jigsaw project system.

The laboratory technician had to carry out laboratory tests to identify and characterize a soil sample. The informatics technician had the responsibility of using numerical tools, e.g. finite element programs. Such numerical tools are freeware versions, with student licenses, of commercial software currently used by engineers when studying geotechnical problems. Writing spreadsheets and analysing, interpreting and discussing the results obtained was carried out by the analyst. The reporter assumed the preparation of the written part of the project, which included a short state of the art and a description of the work of his/her colleagues. Last, the coordinator had to organize the group, guaranteeing that all members followed the deadlines and exchanged information.

These roles had, as much as possible, a parallel to functions normally fulfilled by engineering professionals. Thus, a jigsaw project system was implemented, promoting positive interdependence between students. Areas of expertise were defined, corresponding to the several roles (literature review, theory, experiment, data analysis, etc.). At the beginning of the semester, the students assigned with a particular task were put together in expert groups and each group received specialized training, resources and checklists. Each team member had to make sure that his/her area of expertise was covered adequately in the team project.

To allow students to fulfil the different roles defined, each project includes different perspectives of the corresponding part of the syllabus. Thus, on each project it is necessary to prepare a short state of the art on the subject, to carry out laboratory tests or to perform numerical simulations, to do calculations using theoretical solutions and to compare and criticize the results obtained. When possible, the same geotechnical problem is used throughout the semester, allowing students to analyze different perspectives of the same problem. More details on the problems prepared, particularly on the use of computing and software on these projects, are included in a companion paper (Pinho-Lopes, 2012).

All the team members had to orally present part of the work and answer questions from both teachers and colleagues, regardless of their function.

To get individual accountability, the test covered all subjects of the course's syllabus and the individual mark on the project was obtained by applying a weight to the team's project mark, based on the students' self and peer assessment within the group (according to Felder & Brent 2007b).

All information was available for students via the e-learning system at UA, where group areas were created, allowing groups to save and exchange files, e-mails and short messages.

Later another task was assigned to the team coordinator: read and summarise a scientific paper in English on the projects' subject.

Currently, in the SMII course, there are fewer team projects (1 to 2) and the roles are not imposed. The whole team is responsible for all the work. Individual accountability is also done in the same way.

3.2.2 *Group formation and functioning*

The teachers grouped the students based on their answers to a questionnaire on both the marks obtained in previous courses and the time available for group work. Students were grouped heterogeneously, in terms of marks, trying to ensure balanced groups (each group including students of different levels and with compatible schedules).

Grouping the students caused some complaints. In some more extreme cases the teachers' intervention was necessary in order to get some groups to dialogue and to better organize themselves. Thus, it was necessary to define some strategies to resolve such conflicts. Using suggestions by Felder & Brent (2007b), two types of approaches were used: 1) brief sessions in the theoretical-practical lessons to discuss typical problems, followed by in-class small group brainstorm and sharing of strategies (1 per semester was sufficient); 2) promotion of meetings of teams in conflict with a teacher to promote the dialogue and to define problem solving strategies. In some cases one meeting was enough, nevertheless, in some more difficult cases, it was necessary to join the group in conflict with a teacher more than once (Pinho-Lopes et al. 2011). These groups were more closely supervised by the teachers, to observe if and when the approaches used to overcome conflicts had been successful. The peer assessment after each project confirmed such success.

3.2.3 *Teachers' role on the CL model*

Adapting the teaching strategies used was essential, in order to adjust them to the teaching team's aims. The author believes that in a CL model there is also a need and a place for traditional teaching, for example, in the form of lecturing and individual problem solving. Such strategies were kept and conciliated with the CL approach.

Ensuring the relevant subjects were covered adequately before their practical application in the projects was achieved by doing a very thorough lessons' programming (both contents and sequence). In the theoretical-practical lessons, lecturing of the fundamental concepts was aided by slides and, whenever possible, they were applied in simple problems (worked on by the students). Such a strategy was used to consolidate the concepts and "force" an active posture. A compilation of practical problems was prepared for the practical lessons, including exercises simulating real cases and tests and exams from previous years. They were given to students, without the corresponding solutions.

The CL model obliged teachers to adopt different roles as it demanded different skills. For example, it was essential to convince students of the method's importance, by explaining the parallels between the academic working conditions and professional life. To help solve team conflicts, it was fundamental to organize team meetings, listen to the students and make them talk to each other, and, occasionally, to deal with some emotional reactions.

After each project, the report was assessed and the corresponding marked-up report was available to each group. A more general document, including the most common and more significant mistakes and problems observed, was also made available to all students. The aim was to improve the reports of the following projects as well as providing feedback.

To support the oral presentations, additional elements were prepared: templates and layouts; documents with general rules and with suggestions on how to organize a successful presentation. Brainstorms during theoretical-practical lessons on good versus bad strategies and postures to adopt during presentations were also highlighted.

4 ASSESSMENT OF THE CL MODEL

4.1 *Research methodology used*

When first using this CL model, the author felt the need to evaluate its success and impact on students' learning. Therefore, different and complementary strategies were used: students' feedback during the semester; marks monitoring; and questionnaires at the end of the semester. Results from the 1st and 2nd editions in the SMI course are presented and discussed by Pinho-Lopes et al. (2011).

During the semester, informal opinions regarding the implemented evaluation system were asked of students (orally and written, anonymously).

To better understand the efficiency of the implemented model, a statistical analysis of the number of students enrolled, which attended, evaluated and obtained pass mark was carried out.

Questionnaires were prepared and divided into two large blocks of questions: 1) course organization and implementation; 2) functioning of the teams during the projects. For most of the questions a five-point Likert scale was used.

This paper includes new results from the assessment of the CL model in the SMII course (1st edition – 2007/2008).

4.2 *Main results from the assessment*

The CL model was described to students in the first lesson. The first time this was done, the students were very resistant and suspicious. There were two main reasons for such an attitude: 1) the increased work and responsibility associated with the cooperative learning model; 2) the nature of the groups' formation. Most students were used to working in groups with friends and were not willing to be in teams with people they did not know. To overcome such problems, the teachers explained the CL objectives and the expected benefits. Moreover, they also promoted some simple team building exercises during theoretical-practical lessons and raised some brainstorm questions to promote a more active behaviour.

During the semester, the students complained they were having problems associated with: the group formation, some group conflicts, different perspectives and ambitions for their marks, the course workload, using and understanding the software and the weight of the projects mark on the final mark (in the 1st edition of the CL model).

Table 1. Distribution of the assessment results.

Course	SMI		SMII
Year	2007*	2008^{+}	2007*
Nº of students			
Enrolled	91	63	75
Starting the course frequency	84	56	72
Quitting before finishing all projects	2	0	0
Concluding the continuous assessment	73	56	61
Pass	48	41	39
Fail	21	13	20
Quit	4	2	2
Undergoing the final exam	25	22	33
Pass	10	17	28
Fail	15	5	3
Quit	1	0	2
Undergoing a type of assessment	77	56	69
Pass	58	52	66
Fail	16	4	3
Quit	3	0	0

* School year 2007/2008; $^{+}$ School year 2008/2009

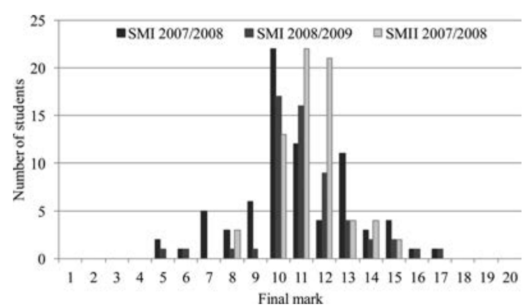

Figure 1. Distribution of the final marks in 2007/2008 and 2008/2009.

In Table 1 the assessment results distribution referring to SMI, 2007–2008 and 2008–2009, and SMII, 2007–2008, is presented.

In terms of academic success, the CL model resulted in the approval of 64% (SMI 2007/2008), 83% (SMI 2008/2009) and 88% (SMII 2007/2008) of the enrolled students. The greatest majority of the approvals correspond to the continuous assessment. From the students that underwent a type of assessment, 75% (SMI 2007/2008), 93% (SMI 2008/2009) and 96% (SMII 2007/2008) passed.

In 2007/2008 the success rate for SMII was higher than for SMI. Most of the students indicate that after a 1st experience with the CL model that they were more comfortable with it.

Figure 1 shows the distribution of the final marks. There is a reduction of the fail marks (under 10) from the 1st edition (SMI 2007/2008) to the following ones. Relative to the global average marks, there is a slight improvement, which is expressed in an average rating of 10.8 (SMI 2007/2008), 11.2 (SMI 2008/2009)

Table 2. Results obtained for block 1 of the questionnaires: course organization and implementation.

			NVA*	Mode	Mean	SD$^+$
Q1	SMI	2007/2008	31	3	3.52	0.570
Q1	SMI	2008/2009	55	4	3.75	0.615
Q1	SMII	2007/2008	67	4	3.66	0.538
Q2	SMI	2007/2008	32	4	3.91	0.689
Q2	SMI	2008/2009	51	4	3.92	0.659
Q2	SMII	2007/2008	66	4	3.95	0.689
Q3	SMI	2007/2008	30	4	3.13	1.008
Q3	SMI	2008/2009	51	4	3.45	0.832
Q3	SMII	2007/2008	63	3	3.38	0.682
Q6a	SMI	2007/2008	31	2	2.45	1.362
Q6a	SMI	2008/2009	55	2	2.58	1.487
Q6a	SMII	2007/2008	67	2	2.52	1.119
Q6b	SMI	2007/2008	31	3	3.39	0.715
Q6b	SMI	2008/2009	55	4	3.55	0.812
Q6b	SMII	2007/2008	65	4	3.58	0.827
Q6c	SMI	2007/2008	31	4	3.71	0.824
Q6c	SMI	2008/2009	54	3	3.54	0.946
Q6c	SMII	2007/2008	66	4	3.74	0.686

* Number of valid answers; $^+$ Standard deviation
Q1 – Course degree of difficult (1 – Very easy; 5 – Very hard);
Q2 – Adequacy of the study elements indicated (1 – Lower; 5 – Higher);
Q3 – Adequacy of the assessment methods to the defined objectives (1 – Lower; 5 – Higher);
Q6a – Adequacy of the proposed activities to the course contents – work volume appropriate to the available time (1 – Lower; 5 – Higher);
Q6b – Adequacy of the proposed activities to the course contents – degree of difficult/complexity (1 – Lower; 5 – Higher);
Q6c – Adequacy of the proposed activities to the course contents – interest and relevance (1 – Lower; 5 – Higher).

Table 3. Results obtained for block 2 of the questionnaires: functioning of the teams during the projects.

			NVA*	Mode	Mean	SD$^+$
Q13	SMI	2007/2008	31	1	2.9	1.491
Q13	SMI	2008/2009	55	2	2.58	1.228
Q13	SMII	2007/2008	66	3	2.71	1.274
Q14	SMI	2007/2008	30	3	3.10	1.296
Q14	SMI	2008/2009	55	2	2.85	1.177
Q14	SMII	2007/2008	65	3	2.72	1.139
Q15	SMI	2007/2008	31	5	3.84	1.416
Q15	SMI	2008/2009	51	5	3.84	1.255
Q15	SMII	2007/2008	64	5	3.91	1.137
Q16	SMI	2007/2008	31	4	3.52	1.235
Q16	SMI	2008/2009	52	4	3.67	1.044
Q16	SMII	2007/2008	65	4	3.55	0.830
Q17	SMI	2007/2008	31	4	3.77	0.990
Q17	SMI	2008/2009	52	4	3.62	0.911
Q17	SMII	2007/2008	65	3	3.55	0.811

* Number of valid answers; $^+$ Standard deviation
Q13 – The teachers should interfere more in the groups' internal organization (1 – Less; 5 – More);
Q14 – The teachers should interfere more in the groups work (1 – Less; 5 – More);
Q15 – Does the groups' formation by the teachers have influence in the practical works final marks (1 – Little; 5 – Much)
Q16 – Personally, you admired, learned or absorbed some competence (people, organization, motivation, written communication, presentation in group) from another group colleague (1 – Little; 5 – Much);
Q17 – With the implemented teaching and learning model in the course, did you learn something else beyond the corresponding formal contents? (1 – Nothing; 5 – Much more)

and 11.4 (SMII 2007/2008). The average mark of the approved students is similar in all editions: 11.7, 11.5 and 11.6 in SMI 2007/2008, 2008/2009 and SMII 2007/2008, respectively.

Tables 2 and 3 show some of the results obtained from block 1 (course organization and implementation) and block 2 (team projects), respectively, of the questionnaires for SMI and SMII.

The number of students that answered the questionnaire is very different in the 1st edition, SMI 2007/2008 (32, 38% of the total students who attended the course) and in the following: SMI 2008/2009 (55, 98% of the students) and SMII in 2007/2008 (68, 94% of the students). Such difference results from the moment the questionnaires were given. For the 1st edition (SMI 2007/2008), this was done at the end of the following semester, while in the next editions they were handed out at the end of the corresponding courses.

The majority of the students that answered the questionnaire considered that the degree of difficulty was medium to high (Q1) and that the assessment methods were adequate (Q3). The item most criticised by the students was the workload, which was considered to be in excess to the available time (Q6a), although they thought that the proposed activities were interesting and relevant (Q6c), even in terms of degree of difficulty and complexity (Q6b).

The students were asked (Q13 and Q14) about the teachers' interference in the team's internal organisation and in the project's development. The collected students' opinions were very antagonistic and random (coefficients of variation range from 41% to 51%); therefore, no clear conclusion can be put forward.

The analysis of the students' answers allowed establishing that they considered the team formation by the teachers had a significant influence on the final marks of the projects (Q15).

Finally, the students answering the questionnaire considered, almost unanimously, that the implemented learning model also led to the development of skills and knowledge other than the formal course contents (Q16). Some questions were also introduced about the projects added value to the students' preparation for future engineering work. It was somehow shared among students that this model has advantages in their preparation for "real life" and for their future role as civil engineers (Q17).

4.3 *Teacher's perspective*

The author observed that some students tend to compartmentalize contents, reaching different maturity levels according to their role in each project. In some cases each team member was worried about fulfilling their own tasks, with no exchange of information within the team. Therefore, in those cases there wasn't a work review by the other team members. The main explanations relate to the way the coordinator faced his/her role, which in some cases led to a lack of team dialogue, a weak task planning and using all the time available to complete tasks, not allowing the other team members to do an effective work review. For some students it is easily identifiable (by the answers in the exams) in which project they were coordinating for the team.

Using this CL model meant a significant extra workload for the lecturers, which is difficult to quantify, as an accurate assessment of such an impact was not carried out. For example, the lecturers spent many hours answering students' questions, particularly near the projects' deadlines. In SMI the lecturers distributed the workload and each of the 3 or 2 lecturers (depending on the edition) was responsible for a different project. In the SMII course the author did it on her own, using the same model in the 1st edition and a "lighter" version in the following editions.

The CL model demanded, namely: preparing additional documentation for students (for example, to support the preparation of oral presentations, templates and rules for the projects' reports); assessing all the written reports, which included preparing generic documents with global comments on each project; creating the team projects (adequate to the level of knowledge of the students, representing real life cases that are possible to solve in the time available); and helping the students to overcome the difficulties faced during the projects' preparation.

In the SMI course the students/teachers ratio (about 30 students per teacher) made the method's implementation easier, while in the SMII course, such a ratio (60 to 90 students per teacher) completely overwhelmed the author. The ratio in SMI enabled teachers to provide students with a closer work monitoring and allowed the resolution of small conflicts generated during the preparation of the projects. In SMII this was also done in the same way.

To enable the success of a CL model it is essential to provide opportune and adequate feedback to students. More, their commitment on preparing the team projects has to be mirrored by similar effort from the lecturers. Such demands result in a severe additional workload. In Portugal (as in many other countries) the performance of lecturers is mostly based on their research work, measured, for example, as the number and type of research papers published, the capacity to attract research funding, the number of Ph.D. students completing their theses, etc. Thus, no or little accountability is made of the efforts to enhance student learning or the quality of the courses and programs.

Nevertheless, the CL method implemented is more satisfactory for the author than the traditional one. In fact, observing the students' enthusiasm when carrying out laboratory tests and using numerical tools is quite rewarding. The comprehension of the basic concepts and, simultaneously, the magnitude of their practical application by the students are more efficient, which was observed, for example, during lessons and by the type of questions students raised during the projects' development.

This CL model and the need to solve some conflicts between students increased the personal contact between the author and the students. In some cases, where some of them strove to deal with their team colleagues, they were not "allowed" to give up. Later many of them recognized the importance that this had on their personal development. Many of those students still come to the author for advice and prepared their M.Sc. thesis under her supervision.

With regard to the soft skills acquired by the students, the author could also observe them later, when the first students learning with this method had to develop research work (M.Sc.). These students showed a positive attitude towards the use of numerical tools and laboratory work and, simultaneously, fewer difficulties associated with the use of spreadsheets and text processors. More, the stress associated with the oral presentation of their work was smaller, even for shy and timid personalities.

It is also important to state that 6 students from the 1st and 2nd edition where this CL model was implemented on the SM courses prepared their M.Sc. theses in cooperation with a building company. Such work was included in a competition involving students from other universities and the prize was a paid 6 months' training period. The judging panel included technical staff from the company, the students' supervisors in the company, as well as external advisors. From the 6 students of UA (2010 and 2011), 5 were awarded. In the 2011 edition of the competition, 3 (out of a total of 4) winners were from the Civil Engineering degree at the UA. The partners from the building company were surprised with the quality of the students and their preparation to embrace professional work.

5 CONCLUSIONS

In this paper a case study referring to the implementation of a cooperative learning model in two sequential Soil Mechanics courses was described. This was done using a jigsaw system to prepare team projects which had a correspondence with real geotechnical problems (adapted to the level of knowledge of the students'). These projects included carrying out laboratory tests and a generalized use of spreadsheets, text processors and numerical programs, for example with the finite element method.

The use of such learning strategies was found to be adequate and led to enhancing students' learning, as well as acquisition of generic and soft skills necessary for any civil engineering professional.

However, some students tend to compartmentalize contents, reaching different maturity levels according to their role in each project. This can be overcome, for example, by maintaining opportunities (practical lessons) where all students use hand calculations to solve problems, practising all course contents. Moreover, the final exam, where all contents are assessed, is essential for students to realise the level of understanding expected.

In short, the implementation of such a model was and can be successful, depending, on one hand, on the size of classes and/or the teaching teams, and, on the other hand, on the impact on the lecturers' career of such effort. Its impact on the students learning and competences is clear and surely justifies the use of a CL model, even in a "lighter" version.

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Learning through doing: Using geotechnical research to prepare undergraduates for graduate school

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ABSTRACT: During the past three years, seven undergraduate students have worked as assistants on four large-scale geotechnical centrifuge experiments. The research investigation focuses on soil-structure interaction during earthquakes and includes an extensive experimental component. Given the project scope, the undergraduate participants, who were advised primarily by graduate student mentors, served as essential team members during each centrifuge test. During eight- to ten-week appointments, the students contributed to experiment design, model construction, equipment design, instrumentation calibration, data collection and analysis, experiment documentation, and data reporting. Assessment results show that the student experiences translated into increased understanding of important engineering concepts and greater interest in continued education. In this paper, the authors discuss the process of recruiting and preparing undergraduates for their appointments, the learning outcomes defined for the undergraduate participants, the methods used to assess the learning outcomes, assessment results, and recommendations for working with future undergraduates.

1 INTRODUCTION

1.1 *Project background*

During the past three years, seven undergraduate engineering students from California Polytechnic State University, San Luis Obispo (Cal Poly) have worked as research assistants (undergraduate researchers) on a project sponsored by the National Science Foundation (NSF). The research project, titled "NEESR-SG: Seismic Performance Assessment in Dense Urban Environments" and sometimes referred to as the *City Block* project, is an ongoing experimental study into the influence of soil-foundation-structure (SFSI) and structure-soil-structure (SSSI) interaction on the seismic performance of urban building-foundation systems. The project team is a collaboration between six universities and organizations, and has included: six co-principal investigators, a post-doctoral scholar, seven graduate students, and the staff of the Network for Earthquake Engineering Simulation (NEES) equipment site at the University of California, Davis. In addition to time spent at U.C. Davis, the undergraduates have participated in research activities at U.C. San Diego and U.C. Berkeley. Undergraduate researchers and graduate students from the most recent test are pictured in Figure 1.

Figure 1. Graduate and undergraduate team members standing with a completed model before moving it to the centrifuge.

1.2 *Motivation*

The goals for recruiting undergraduate researchers for this project were three-fold. First, due to the complexity of the experimental test series, it was desirable to recruit additional team members to contribute to model construction, experiment documentation, and data collection/analysis. Second, several graduate students participating on the project team had expressed interest in pursuing academic careers. Therefore, mentoring undergraduate researchers provided excellent opportunities for these graduate students to gain valuable mentoring, teaching, and advising experience. Third, the project team wanted to provide undergraduates with the opportunity to learn via a meaningful research experience. The hands-on nature of the centrifuge model experiments provided many new learning opportunities for the undergraduates. In helping to plan and execute the research experiments, the undergraduates were also able to apply and practice skills learned in the classroom. The nature of the research activities and opportunities for collaboration with graduate students and faculty researchers provided an ideal setting for the undergraduates to learn about graduate school and the skills necessary to succeed as independent-minded researchers.

The first two goals noted above were covered in some detail in a recent conference paper, along with conclusions regarding the overall success of the graduate student mentoring program (Fiegel et al. 2011). In this paper, we focus on the third goal: using a geotechnical engineering research project to prepare undergraduate students for future research and graduate school.

1.3 *Learning objectives*

The undergraduates were not recruited to simply work as project technicians. Creating a structured learning experience for the participants represented a critical project objective. The undergraduate researcher experience was specifically designed to help the undergraduates learn and practice skills important for performing successful independent research. An equally important goal was to help these same undergraduates understand what it takes to be a successful graduate student.

The three key learning objectives associated with the research experience were: (1) learn to conduct and document an experiment; (2) learn to function effectively within a large research team; and (3) learn to summarize and present the technical and experiential aspects of the research. These objectives were articulated to all of the project team members, including the undergraduates. Specific performance metrics used in the assessment of the undergraduate researchers' progress are summarized in Table 1. Performance metrics were defined as specific skills and abilities the students were expected to demonstrate by the end of the research appointments.

1.4 *Focus of this study*

In this paper, we present: (1) an overview of the undergraduate researcher program, from recruitment to post-appointment assessment activities; (2) evidence of activities that increased the undergraduate researchers' abilities to conduct independent research; (3) post-appointment survey results indicating the success and shortcomings of the undergraduate researcher program; and (4) recommendations for facilitating improved research experiences in the future.

Either one or two undergraduate researchers have worked on-site at U.C. Davis for each of the four centrifuge tests completed to date. Two of the tests took place during the summer. The other two tests occurred during the school year, requiring the undergraduates to take a quarter-long (10 week) leave of absence from school. Table 2 summarizes the completed centrifuge tests and appointments.

Assessment data was collected from six of the seven undergraduates who participated in the project. As noted later in this paper, these assessment results indicate that the undergraduates valued their research experiences.

2 PROGRAM DEVELOPMENT

2.1 *Undergraduate research experiences*

Well-designed and carefully mentored undergraduate research experiences involving unique and meaningful laboratory, field, and/or analytical based projects have

Table 1. Learning Outcomes and Performances Metrics.

Learning Outcomes	Performance Metrics
Conduct and document a research experiment	1) Calibrate, install, and troubleshoot instrumentation 2) Construct soil and structural models for the centrifuge 3) Collect and analyze experimental test data 4) Document and report experimental test results
Function effectively on a multi-disciplinary research team	1) Behave in a professional and respectful manner 2) Accept and analyze feedback on work performance 3) Articulate critical path issues associated with the centrifuge test 4) Evaluate different communication styles 5) Apply active listening technique
Summarize both the technical and experiential aspects of the research experience	1) List the primary objectives of the research project 2) Describe the principal findings of the research project 3) List the attributes of a successful graduate student 4) Describe a typical work day for a graduate student 5) Write an effective technical paper or report 6) Compose and deliver an effective oral presentation

been shown to provide significant benefit to the participants. Such experiences provide undergraduates with opportunities to acquire, practice, and refine numerous skills. These skills include: formulating a research hypothesis; investigating the current scientific literature; designing an experiment; designing or modifying equipment; calibrating and troubleshooting instrumentation; interpreting data and results; modelling test data; and communicating research findings (Kardash 2000). Success in helping to produce research breakthroughs has been shown to lead to increases in self-confidence and independence in undergraduate researchers (Seymour et al. 2004). In addition, undergraduate research participants are more likely to pursue graduate school and research opportunities (Hathaway et al. 2002). Comprehensive studies have been conducted to assess specific outcomes related to undergraduate research experiences in science and engineering (e.g. Kardash 2000; Seymour et al. 2004; Zydney et al. 2002). Evaluations of assessment results show that undergraduates with research experience report greater enhancement of important cognitive and personal skills and are more likely to pursue continued education. These benefits were envisioned as desirable and achievable for undergraduate researchers on the *City Block* project. Therefore, the undergraduate research program was developed accordingly.

2.2 *Developing program structure*

Past experiences and observations of the authors showed clearly that successful undergraduate research experiences are tied to careful planning, mentoring, and assessment (Fiegel et al. 2011). Sutterer et al. (2005) discuss the design of appropriate and valuable undergraduate student research experiences based on their efforts in establishing an NSF Research Experiences for Undergraduates (REU) site at their own institution. They conclude that successful undergraduate research programs should focus on relationships, meaningful research, planned learning, and creation of a community of learner/researchers. Such elements were incorporated into this program.

The undergraduate research experiences for this project incorporated several unique features, including a structured learning environment with well-defined and assessable objectives. Undergraduate research was not a primary focus of this project in the original proposal, yet considerable time was devoted toward the development of the learning outcomes and performance metrics presented in Table 1. It was reasoned that a structured learning environment would benefit both the undergraduate researchers and the project team.

Another unique aspect of the research program is the fact that graduate students were asked to serve as the primary mentors to the undergraduates as they completed their research appointments. In assisting the graduate students with their mentoring responsibilities, the principal investigators took time to articulate learning outcomes, provide teacher training, provide leadership training, and provide regular feedback on performance. The approach taken to "mentor the mentors," as described in some detail in Fiegel et al. (2011), helped the graduate students to develop good interpersonal rapport and meaningful relationships with the undergraduate researchers.

For a focused research study like the *City Block* project, the definition of undergraduate student learning outcomes and performance metrics is not common. However, this upfront work helped the graduate students to better understand their roles as research mentors and made assessment of the mentoring program much easier. Assessment efforts considered: (1) undergraduate student qualifications and career goals, (2) undergraduate student survey results (prior to and after the research appointment); and (3) student work products. In reference to these work products, undergraduate researchers were given a number of options for updating their progress and demonstrating their achievement of learning outcomes. Traditional reporting methods included report preparation, contributions to paper preparation, oral presentations, journal entries, and research poster development.

Based on work by Hanson et al. (2010; 2011), undergraduates were also given the opportunity to report on their progress using contemporary methods. Technology-enriched approaches used in the *City Block* to date include: a photo essay describing research progress; a graphical timeline of research activities with critical paths identified; a digital video production summarizing research progress; and three-dimensional renderings and computer animation to describe model test configurations. Providing the students with the option of using alternative reporting methods allows for the incorporation of various

Table 2. City Block Test and Student Appointment Descriptions

Test ID	Appointment Description	Goals of Experimental Work
HBM02 (Mason et al., 2011a)	Two students, summer appointment (July–Aug 2009)	Baseline seismic response of two frame structures
HBM03 (Mason et al., 2011b)	One student, school year appointment (Nov–Dec 2009)	SSSI response of two adjacent frame structures
HBM04 (Mason et al., 2011c)	Two students, summer appointment (June–July 2010)	SSSI response of a transmitter-receiver pair
NWT01 (Trombetta et al, 2011)	Two students, school year appointment (April–June 2011)	Superposition of in-plane and anti-plane SSSI effects

learning styles (Felder & Silverman 1988) into the undergraduate research program. More recently, the undergraduate researchers have completed learning styles surveys before beginning their appointments. Results have been shared with the graduate student mentors and principal investigators to help better understand the undergraduates and the fact that they have different and predictable ways of communicating, behaving, and learning.

3 PROGRAM OVERVIEW

3.1 *Undergraduate researcher recruitment and preparation*

Due to the complicated nature of the experimental test series, it was ideal that the program applicants demonstrated as least a junior-level knowledge of geotechnical engineering and structural design principles, above-average academic performance, and previous laboratory experience (expected to be from coursework). Different marketing approaches were utilized to advertise the undergraduate research positions, such as: presentations by a principal investigator during meetings of student professional organizations (e.g. ASCE, SWE, and SHPE), e-mail announcements to upper division students, and technical/experiential presentations by former undergraduate researchers to their peers. Details regarding the recruitment process, the candidate assessment rubric, and the qualifications of the candidates are included in Fiegel et al. (2011). Table 3 summarizes the educational goals and current education status of undergraduate researchers who participated on this research project to date. Based on these results, the undergraduate research appointments appear to have stimulated interest in continued education and research.

To acquaint the undergraduate students with the research project, a 'reader' was developed, which included publications on centrifuge modelling principles, soil-foundation-structure interaction, and effective communication (Fiegel et al. 2011). Specific examples included *City Block* conference publications (e.g. Mason et al. 2010; Chen et al. 2010), centrifuge modelling publications (e.g. Kutter 1995), introductory earthquake engineering references (e.g. Kramer 1996), and internal documents such as previous test plans, literature summaries, and data reports.

Before arrival on site, the undergraduates were also required to make contact with their graduate student mentors to begin building a rapport. During the later tests, the graduate student mentors also presented short geotechnical engineering and SFSI 'lessons' to the incoming undergraduate researchers. These pre-appointment activities resulted in undergraduate researchers who were excited about being involved in the experimental component of the work and knowledgeable in the research topics they were to address. The pre-appointment activities also allowed the graduate student mentors to practice their teaching skills, which was especially valuable to those planning to work in academia.

3.2 *Research activities*

The specific on-site research activities performed by the undergraduate researchers varied from test-to-test. There was generally a correlation between the increasing complexity of the test series (from Test #1 to Test #4) and the complexity of the tasks given to the individual students. In addition, the graduate student mentors became less reluctant to cede control of individual details of model construction and instrumentation during later tests, due to the satisfactory performance of the early program participants. This allowed the undergraduates to perform tasks that are more complex. Figure 2 shows an undergraduate researcher as she works on instrumenting a model after it has been placed on the centrifuge arm.

In general, each student was given the chance to be involved in four phases of each test: (1) construction of the centrifuge model (e.g. assembling the structural models, placing the foundation soil, recording

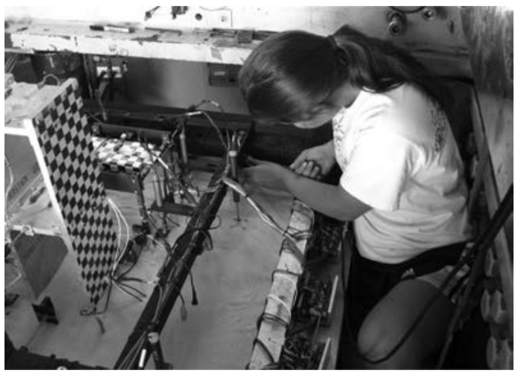

Figure 2. An undergraduate researcher working on instrumentation in the tight confines of the centrifuge arm.

Table 3. Summary of Educational Goals and Current Education Status for the Undergraduate Researchers (UGRs).

UGR No.	Pre-Appoint. Education Goal	Post-Appoint. Education Goal	Current Education Status
1	B.S.	M.S. (Coursework)	In graduate school
2	B.S.	M.S. (Thesis)	Planning to apply to graduate schools
3	M.S. (Coursework)	M.S. (Thesis)	Currently applying to graduate schools
4	M.S. (Thesis)	Ph.D.	Planning to apply to graduate schools
5	M.S. (Coursework)	Ph.D.	In graduate school
6	B.S.	M.S. (Thesis)	In graduate school

important measurements, etc.); (2) instrumentation of the model (e.g. calibrating transducers, applying strain gages to structural components, etc.); (3) data acquisition (e.g. troubleshooting instrumentation, performing preliminary data analyses using pre-programmed Mathcad sheets, etc.); and (4) project documentation (e.g. capturing and organizing digital photographs and videos, preparing CAD drawings, contributing to research notebooks, etc.). In addition, undergraduate researchers that participated during Test-3 and Test-4 contributed to the authorship of the data reports, which included preliminary data reduction and analyses.

The undergraduate researchers were also given tasks that allowed them to utilize their specific skill sets. One undergraduate researcher, an architectural engineering student, was proficient in developing three-dimensional models using AutoCAD. As a result, he was tasked with developing detailed models of the completed centrifuge models, including instrumentation and displacement reference frames, as shown in Figure 3.

In addition to on-site tasks, the undergraduate researchers also participated in post-experiment activities. These activities included post-appointment presentations to their peers at Cal Poly during student organization meetings, poster presentations at technical conferences, and participation in special events/ contests at technical conferences. For example, undergraduate researchers won awards for their submissions to the media competitions at the 2010 NEES/PEER (see Figure 3) and 2011 NEES/MCEER "Quake Summit" annual meetings.

4 REALISATION OF LEARNING GOALS

4.1 *Geotechnical engineering concepts*

The undergraduate researchers reviewed, learned, and practiced important geotechnical engineering concepts and skills through a variety of methods, including (1) reading papers and other assigned references, (2) solving practice problems, (3) participating in mini-workshops taught by the graduate student mentors, and (4) building the centrifuge model and interpreting test results. The assignment of reading materials before arrival at U.C. Davis allowed the undergraduates to study the principles of centrifuge modelling and important concepts related to soil-foundation-structure interaction. The students were then encouraged to discuss these readings with their graduate student mentors. These discussions led to a number of opportunities for one-on-one interaction and teaching. Typically, the undergraduate researchers had a number of questions regarding the stress-dependent nature of soil behaviour, which is particularly important for the understanding of centrifuge modelling principles.

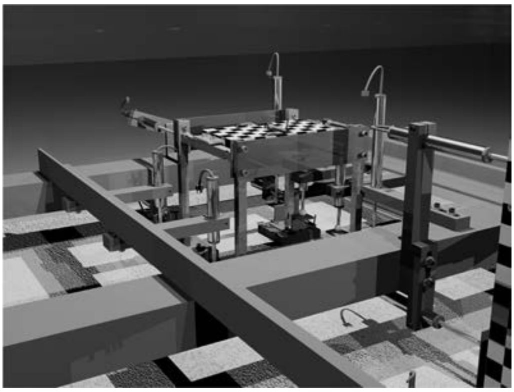

Figure 3. Three-Dimensional rendering developed by an undergraduate researcher that won the award for 'Photo Favourite' at the 2010 NEES/PEER Quake Summit.

Other important geotechnical engineering concepts addressed during the project included mass-volume relationships, contact pressures beneath footings, failure modes for shallow foundations, shear strength theory, foundation settlement, and cone penetration testing. For example, during model construction, the undergraduates applied their knowledge of mass-volume relationships as they helped pluviate the model sand. The models were each pluviated to a relative density of 80 percent, which required mass-volume calculations based on the experimentally-determined minimum and maximum dry densities before precisely calibrating the pluviator. During testing, the undergraduate researchers also helped to pre-process the recorded data, and were exposed to a number of geotechnical earthquake engineering concepts, such as the development of response spectra from recorded ground motions, determining the natural period of the soil model, and the extraction of key ground motion intensity measures.

4.2 *Graduate school skills and lessons*

In addition to specific geotechnical skills and concepts, the students learned a number of skills applicable to future research and graduate school endeavours. In anonymous exit surveys completed by the undergraduate researchers, each identified a number of skills that they developed during their appointments. One student, who is currently a M.S. student, noted that he (or she) learned a great deal about "*documentation of the process, and the expectations of quality therein.*" A second student, who is currently planning to apply to Ph.D. programs, noted a new appreciation for the level of organization required during experimental research, saying:

> "*One of the many great research skills I learned during my undergraduate experience during the City Block Project was organization. With the application of hundreds of accelerometers, displacements gauges, strain gauges, and so on, it became apparent that a great deal of organization was going to be needed to keep track of each of the hundreds of instruments.*"

Finally, a student who is currently planning to apply to M.S. programs recalled the experience of developing a poster presentation saying:

"[My] mentors graced me with a great deal of feedback on summarizing key data/photos/text to use on the poster ... Feedback on the presentation poster included creating a hierarchy of topics, arranging the display of photos, and writing a clear/concise introduction and conclusion."

The undergraduate researchers also noted examples of how the appointment prepared them for graduate student life. One student noted that he learned more about the time commitment and dedication required of successful graduate students, saying:

"I realized, through my undergraduate researcher experience, that graduate school is like a job and should be treated with the same dedication."

A second student made comments about the time management skills required of graduate students, saying:

"I [received] some really good advice, such as the importance of balancing a difficult workload with a hobby or something you enjoy."

5 EVALUATING PROGRAM SUCCESS

5.1 *Exit survey results – performance metrics*

During the anonymous surveys, students were asked to rate their ability to complete various research tasks both before and after their appointment (using a scale of 0 to 5, defined as 0 = not able to complete the tasks and 5 = able to complete the tasks independently). These tasks are similar to the performance metrics presented in Table 1. The results of these self-assessment surveys are presented in Figures 4, 5 and 6. In these figures, the average self-assessment score is presented for each question. Grey columns report the average undergraduate researcher self-assessment of their skills before their appointments. Black columns report the average undergraduate researcher self-assessment of their skills after completing their appointments. Note that there was no pre-appointment survey of these specific skills. Both the 'before appointment' and 'after appointment' self-assessment surveys were completed by the students after completing their appointments.

There was marked improvement in the average response to each skill question in all three categories: technical summarization skills, multi-disciplinary teamwork skills (for a team composed of geotechnical, structural, and architectural engineers), and research skills. The smallest gains in self-assessment scores came in the multi-disciplinary teamwork category, where the students initially assessed their skill at a level of 4.0 and assessed their final skill level at 4.3. The greatest gains came in the category of research skills, where the overall self-assessment increased from 2.5

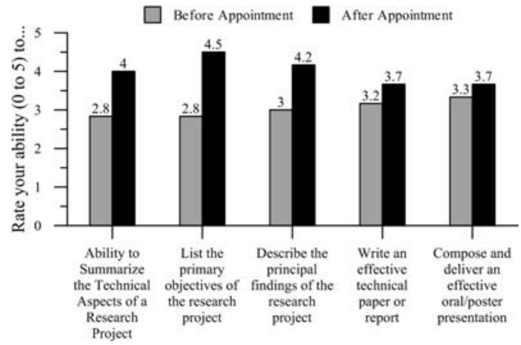

Figure 4. Undergraduate researcher Self-Assessment: Technical Summarization.

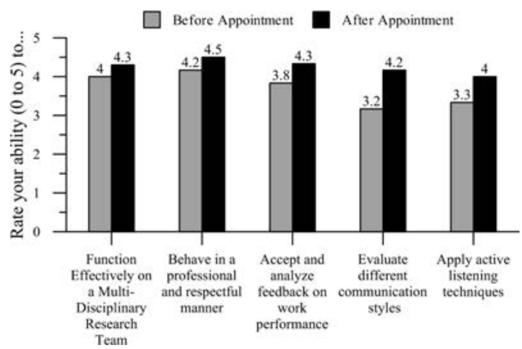

Figure 5. Undergraduate researcher Self-Assessment: Multi-disciplinary Teamwork.

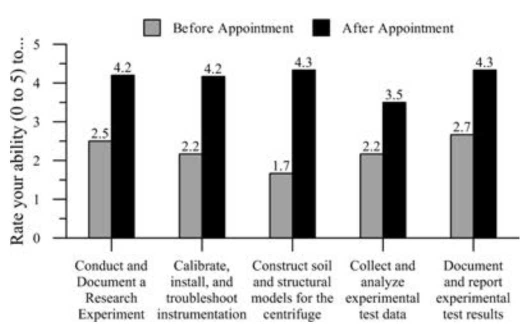

Figure 6. Undergraduate researcher Self-Assessment: Research Skills.

to 4.2 when asked to rate their ability to "conduct and document a research experiment."

Overall, the highest average scores were in categories of 'experiment construction and documentation', such as: instrument calibration and installation, documenting experimental results, and listing the primary objectives of the research project. As can be seen from the figures, the lowest average scores were in categories of 'post-experiment skills', such as: writing an effective report, analyzing experimental data, and composing an effective presentation. Although, the undergraduate researchers did feel that they gained competency in these critical skill sets as well. During future appointments, it will be a primary goal of the mentoring team to provide the students with more (and varied) opportunities to sharpen their data analysis and presentation skills.

5.2 *Exit survey results – graduate school motivation and preparedness*

The undergraduate researchers were also asked to provide information regarding their motivation and preparedness for graduate school. As can be seen in Table 2, there was an increase in the overall desire of the students to pursue research-based graduated degrees, post-appointment. Five of the six students who responded to the exit survey indicated that they were planning to pursue either a thesis-based M.S. or a Ph.D. after completing their appointment. Only one of these students indicated that they desired a research-based advanced degree before enrolment in the undergraduate researcher program. One current M.S. student noted in the exit survey:

"The value of me having such a direct and up close look at grad school simply can't be overstated. It was pretty much my sole inspiration for an advanced degree."

In addition to the specific skill questions discussed in Section 5.1, those undergraduate researchers currently enrolled in graduate school were asked to rate (on a scale of 0 to 5) their preparedness for graduate school. When asked if the skills they learned as an undergraduate researcher translated to success in their graduate school careers, the average rating was 4.8. When asked if their undergraduate researcher experience prepared them for a typical graduate school workload, the average rating was 4.5. When asked if the undergraduate researcher experience motivated a desire to pursue future research appointments, the average score was 4.7. Although the sample size is small, these results appear to indicate that the program was successful in motivating and preparing the undergraduate researchers for graduate student life.

The current graduate students also provided feedback regarding how the undergraduate researcher experience could be re-tooled to better prepare future students for graduate student life. One current M.S. student suggested that,

"Perhaps the delegation of a more structured task, seen through from beginning to end, may be more grad-school like than jumping around from one odd task to another."

This sentiment is similar to the results of the self-assessment surveys, where students felt that their 'deliverable skills' were underdeveloped, when compared to their 'model construction and documentation skills.'

6 CONCLUSIONS

Each student provided a unique skill set to the team, as well as unique challenges for their graduate student mentors. Although the undergraduate researchers have generally reflected positively about their experiences and the survey results have shown that the students are more confident in their skills post-appointment, a number of lessons have been learned by the graduate student mentors. These lessons include the following:

- Providing the undergraduate researchers with reading assignments and practice problems before beginning their appointments prompted them to seek out their mentors for clarification of complex concepts. This accelerated the development of the mentor-mentee relationship.
- Each undergraduate researcher lived at U.C. Davis for an extended period alongside, and in some cases in the same apartment as, their mentors. This allowed them to observe and experience first-hand the graduate students' workload. Graduate student role-modelling was an important aspect of this project.
- The undergraduate researchers who were able to participate in the authorship of data reports and/or present their experience at conferences and/or meetings generally reflected more positively on their appointment. Non-traditional reporting methods have been well received.
- Undergraduate researchers who were able to participate in a variety of tasks generally reflected positively on their experience. Although a 'capstone' experience, such as an oral or poster presentation, is recommended in this case.
- While the self-assessment surveys provided valuable insight into the success of the program in developing independent researchers, little tangible data was gained as to the effectiveness of student learning in relation to specific structural and geotechnical theories and concepts. This will be considered in future project assessments.

The increased interest in experimental research and graduate school displayed by the undergraduates are a result of the close mentor-mentee relationship. The authors provide the following suggestions for those interested in developing similar programs:

- If possible, recruit multiple undergraduate researchers to work together. The camaraderie developed between students in similar 'out of comfort zone' positions increases enjoyment of the appointment and mimics the rapport developed between lab-mates in graduate school.
- Preparation of the graduate student mentors is key to the success of the program. Providing readings on teaching pedagogy, leadership, project management, interpersonal communication, and learning styles is key to this preparation.

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This book comprises the proceedings of the international conference **Shaking the Foundations of Geo-engineering Education** (NUI Galway, Ireland, 4-6 July 2012), a major initiative of the International Society of Soil Mechanics and Geotechnical Engineering (ISSMGE) Technical Committee (TC306) on Geo-engineering Education. SFGE 2012 has been carefully crafted to showcase a diversity of effective and engaging approaches to geo-engineering education while raising awareness of how crucial this effort is to the future development of the engineering profession.

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