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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.

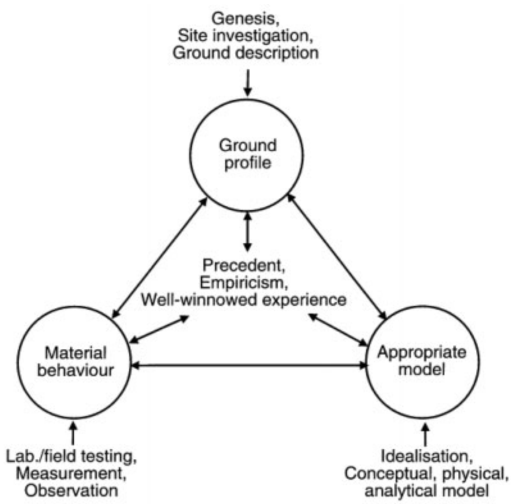

Figure 1. The soil mechanics triangle (adapted from Burland, 1987 by Steenfelt, 2000).

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 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).

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.

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 your 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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