Personal reflection of teaching advanced foundation design course

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ABSTRACT
This paper presents course development and lessons learned from teaching Advanced Foundation Design at Ryerson University. This graduate level course considers practical design of shallow and deep foundations for various structures. The topics cover subsurface investigation, foundation type and selection, design principles, shallow foundations, pile design for axial and lateral loads, and pile group. This course was developed eight years ago and modified over the years. So far it has been offered four times to graduate students, on an average of 20 students each time. The tasks for students include attending regular lectures and guest talks, conducting personal readings and individual and team projects, critical reviewing of a research paper, making a presentation, and finishing a final exam. The results from the last four offers will be discussed based on statistical analyses of student compositions, student performance, and feedback. In the end, how to improve the quality of teaching and enhance the students' learning experience for future teaching will be discussed.

RÉSUMÉ.
Cet article présente le développement d'un cours et les leçons tirées de l'enseignement du cours Advanced Foundation Design à Ryerson University. Ce cours considère la conception pratique des fondations profondes et superficielles pour des structures variées. Les sujets couvrent l'investigation sous terre, les types et la sélection des fondations, les principes de conception, les fondations peu profondes, la conception de pieux pour les charges axiales et latérales, ainsi que les groupe de pieux. Ce cours a été développé il y a 8 ans et a été modifié au cours des années. Il a été offert à 4 reprises à une moyenne de 20 étudiants. Les tâches des étudiants consistent à participer aux cours et discussions, à faire les lectures personnelles, les exercices individuels et les projets d'équipe, à faire une revue critique d'un article de recherche et une présentation et, enfin, à compléter l'examen final. Il est donc question dans cet article, de présenter les analyses statistiques de la performance des étudiants pour ce cours et de discuter des méthodes d'amélioration de la qualité de l'enseignement et de l'apprentissage des étudiants.

1 INTRODUCTION

Geotechnical engineering is a very different subject to teach compared to other civil engineering disciplines, even to the closest structural engineering. The main reason behind this is the complexity of geomaterials. Unlike man-made materials, for example, concrete or steel, geomaterials including soils and rocks, are naturally made through different and complicated geological processes. Due to this reason, there are no rigorous theories or simple formulas to apply. The experience and judgement play essential roles in geotechnical engineering. The challenges of teaching geotechnical engineering courses have been subjects of a few international conferences in the past.

This paper presents course development for a graduate level geotechnical engineering course - Advanced Foundation Design at Ryerson University and lessons learned from four offerings during the last eight years.

2 CHARATERISTICS OF GEOTECHNICAL ENGINEERING

Geotechnical engineering deals with work related to soils and rocks. Unlike man-made materials, soils and rocks are naturally made through different and complicated geological processes. Due to the fact that most foundations rest on soil, particularly shallow foundation are required. This course focus on soil mechanics more than rock mechanics. In the evolution of soils, there are at least five important influencing factors: parent material, organisms, climate, topography, and time (Foth 1990). The engineering properties of soils are influenced by its stress history, structure, and many other factors (Holtz et. al 2010).

Typical geotechnical engineering work includes site investigation, soil testing both in-situ and in the laboratory, geotechnical modelling, design, construction, and monitoring. In order to summarize the relationships between different parts of geotechnical engineering work, Burland (2008) introduced the soil mechanics triangle and then later modified it to be the geotechnical engineering triangle, as shown in Fig. 1.

3 OBJECTIVES OF ADVANCED FOUNDATION DESIGN COURSE

Advanced Foundation Design is an advanced level of Foundation Design course offered at the undergraduate level. The focus is to teach graduate students the technical skills to apply their basic knowledge into complicated real life cases. In addition, the homework is designed to address the soft skills required for their

careers. The differences between a foundation design course at the undergraduate level and this graduate course are mainly the following:

1. Ground profiling and modeling of a layered ground;
2. Think the whole process of a geotechnical engineering project through, from planning, investigation, design and construction;
3. Critical thinking and innovation.

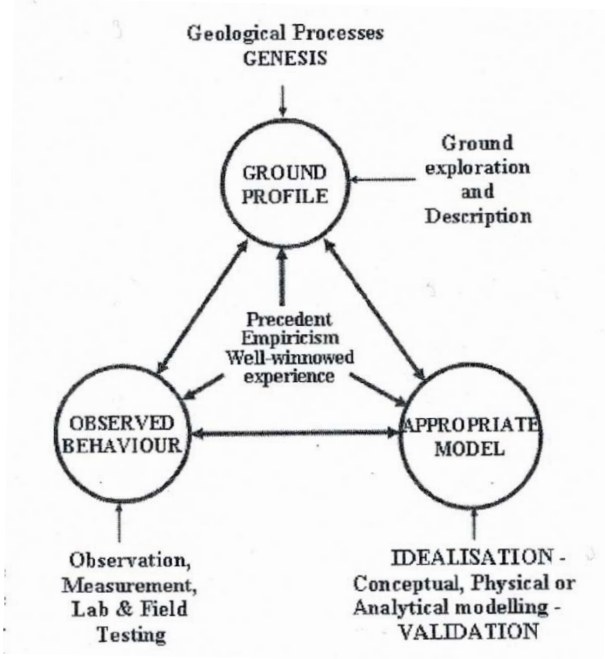

Figure 1 Geotechnical triangle proposed by Burland (2008)

Based on a survey conducted by America Management Association in 2012, there are certain skills that are deemed important. They are summarized as four "Cs:" Creativity, Capability, Collaboration, and Communication. In other fields, like the biology field, Parker (2012) summarizes the skills to be developed during graduate studies, as shown in Fig. 2. These skills are broad knowledge of discipline and interdisciplinary, clarity of thought and effective writing and speaking, integrate scientific reading, deep knowledge of research field, plan and executive research experiments, new insights, and ability to identify important issues for research. All these are similar to the needs for graduate students in geotechnical engineering. In summary, the graduate students should have basic knowledge of their fields, skills to conduct research, and acquire new ideas to their problems.

4 STUDENT COMPOSITIONS

There are graduate students in different programs, including PhD, Master of Applied Science (MASc), and Master of Engineering (MEng) degrees in Civil Engineering. Due to the demand from working professionals, majority of Master's degree students are part-time. The breakdown of student compositions in Advanced Foundation Design course for the four offerings are shown in Fig. 3. It can be seen that there are about 20 students in the class for each offering and more than half of these students are MEng students whose studies are mainly course-based.

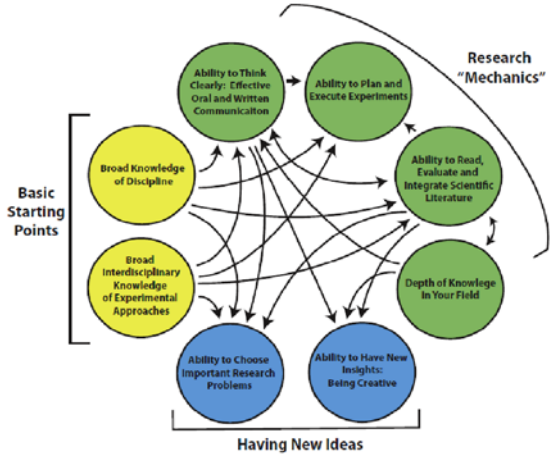

Figure 2 Interconnected skills to be developed during graduate education (Parker 2012)

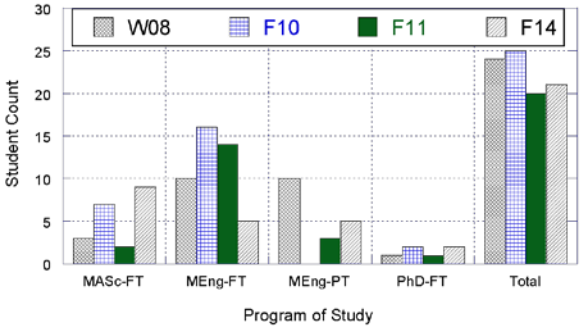

Figure 3 Student composition during four offerings

5 DEVELOPMENT OF SYLLABUS

Since the prerequisites for this graduate course are basic knowledge in Soil Mechanics and Foundation Design at the undergraduate level, this course focuses on advanced topics in shallow and deep foundations. The topics cover subsurface investigation, foundation type and selection, design principles, bearing capacity and settlement of shallow foundation, pile design for axial and lateral loads, pile group, and numerical simulation of foundations using software.

The delivery of this class was not following strictly any text book, though the recommended text book is any of the following:

1) Reese LC, Isenhower WM, & Wang ST. 2005. Analysis and Design of Shallow and Deep Foundations, John Wiley & Sons, Inc;
2) CGS 2006. Canadian Foundation Engineering Manual, 4th edition; and
3) Hsai-Yang Fang (Ed) 1991. Foundation Engineering Handbook, 2nd edition, Springer-Verlag New York, LLC.

The contents are taught through three-hour weekly lectures during the whole term of 12 weeks, in addition to interactive discussions, readings, and guest lectures.

In the Fall 2014 term offering, the final grade was evaluated based on three components: homework (40%), term project and presentation (20%), and final exam (40%).

6 HOMEWORK DESIGN

In the Fall 2014 term offering, there were a total of three homework assignments, which were to be finished by each team of three students. The same team also worked on a critique of a research paper. In order to control the quality and difficulty level, their research paper was selected from three top journals that had to be approved by the instructor. Based on this research article, a 1-2 page critique was required from each group along with a 15 minute group presentation in front of the whole class. The final exam was a three hour open book exam with 30% conceptual questions and 70% calculation questions.

6.1 Hard Skills Development

The homework assignments were designed to let students develop technical skills in different aspects of course content, including soil investigation, shallow foundation design, and deep foundation design for a new hypothetical leaning tower.

6.1.1 Team Project Requirements

The superstructure of this New Tower is to be designed exactly as the existing Leaning Tower of Pisa, Fig. 4. The site will be located 1 km on the east side of the existing tower. Due to the close distance from the existing tower, the investigation information from the existing tower can be found through many research articles and it can be assumed that the same conditions exist for the new tower for shallow and deep foundation design.

Due to new material being used, the dead load of the new tower on the ground level is estimated to be 200 kPa, a live load of 50 kPa, a simplified uniform wind load pressure of 1kPa. The effect from earthquakes is ignored to simplify the problem. The project also has settlement requirements: a maximum total settlement of 5 cm and a maximum differential settlement of 2.5 cm. The students were required to design the foundation below the ground surface.

6.1.2 Site Investigation Homework

The student groups were required to develop a site investigation plan and address the following questions:

- Develop a site exploration plan and laboratory test program for this New Tower project.
- Write a geotechnical report summarizing your site exploration
- Rationalize your site exploration, including boring hole number, depth, kinds of testing, etc
- Interpret your test results (using nearby data as your test data)
- Give your design recommendations and suggested allowable bearing pressure for potential shallow foundation.

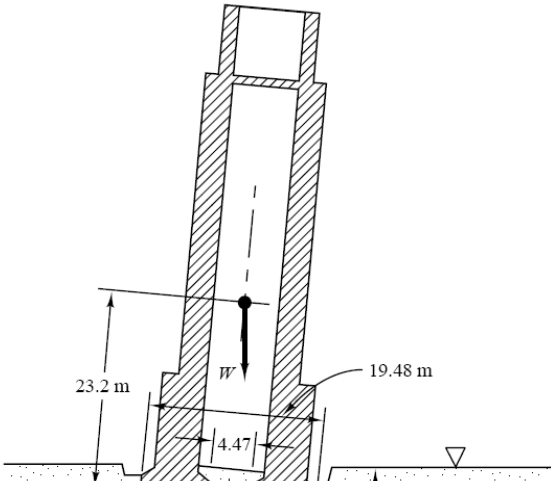

Figure 4 The new leaning tower for team projects

6.1.3 Shallow Foundation Homework

The student groups were required to develop a shallow foundation design for the hypothetical new tower and address the following questions in the submission:

- Figure out all related geotechnical properties from given references or online
- Design a reinforced concrete shallow foundation for the New Tower
- Calculate manually the foundation settlement of the new tower to meet the settlement requirements
- Verify your design and calculation using Plaxis 2D software (simplify with one layer of soil)

6.1.4 Deep Foundation Homework

The student groups were required to develop a deep foundation design and address the following:

- Design a pile or shaft foundation for the New Tower
- Calculate the foundation settlement of the New Tower and Check with TZPile software for single pile settlement
- Propose a more efficient foundation type for the New tower and rationalize your proposal

6.2 Soft Skills Developments

These assignments were also intended to build the students' soft skills - four "C" skills identified before.

6.2.1 Creativity

Creativity is the ability to develop a safe and economical foundation solution to meet the project needs. Students are required to design a shallow foundation and a deep foundation for the leaning tower. Due to the eccentricity of loading, the students are required to be creative in order to develop an efficient foundation for this project.

6.2.2 Capability

Capability is the ability to apply basic knowledge to get the design done. The students were required to calculate both the bearing capacity and settlement of the new tower. The hand calculation work was also required to be checked by finite element software, Plaxis. Most students had to learn the software in order to finish the homework. The differences between hand calculation and numerical simulation should be discussed in the submission.

6.2.3 Collaboration

Collaboration is the skill to work with others and be a team player. Almost all the homework and critique work were conducted by a team of students. In order to build up the responsibility of each student, the group leader was required to rotate among the students and the responsibility to task planning, for coordination and submissions. The group leader would receive a bonus or punishment for the quality of the submission.

6.2.4 Communication

Communication is to sell the idea or design effectively with a clarity of communication. All submissions except final exams were required to be submitted in a technical report format. The team also presented their research critique in front of the whole class.

7 RESULT EVALUATIONS

During Fall 2014 term, there were a total of 36 students registered for this course at the beginning of the term. After three or four weeks, the number of students was reduced to the final number of 21, among which one student was auditing the course. A total of 7 groups were formed with one group of 2 students and the rest of 3 students in each group.

In the end, the average grade for the whole class was an A- with the official minimum grade of C for grade students. Among 20 graded students, three students received a final grade of A+, two of A, nine of A-, four of B+, and two of B-. The breakdown of each part for the 20 graded students are shown in Fig. 5. It shows that most students were actively participating in the homework and term project. The students got lower grades mainly due to poor performance on the final exam.

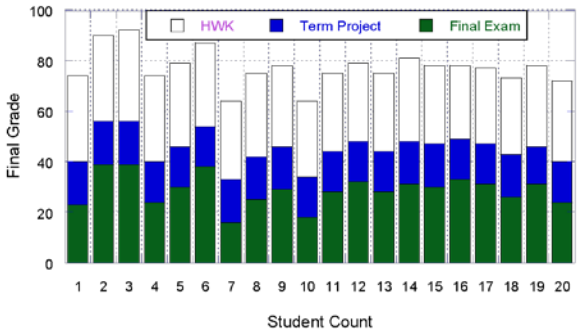

Figure 5 Final grade distribution among 20 graded students in Fall 2014 term

8 LESSONS LEARNED AND FUTURE PLAN

Through the last four offerings, I found that the most challenging part is the training of creativity. In the Fall 2014 term, there were barely any groups that could propose a foundation layout to efficiently accommodate the eccentricity from the superstructure. In addition, the students were not very quick in learning new tools, like Plaxis software. Their basic knowledge was weak, like the understanding and simplification of a three-dimensional problem into a two-dimensional model. The other main part was to create a ground profile in a layered ground and design a foundation properly on a simplified ground model.

The encouraging things are that the students could quickly pick up the format in a technical report and showed the progress in their reports. The communication and team work were also good.

In the future, the weight of the final exam shall be lowered and the weight for individual work will be increased. The time allocation shall be balanced more between shallow foundation and deep foundations. The training will still focus on the four "C" skills. The creativity training can be improved through more reading assignments to the students.

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