Numerical Applications in Elementary Geotechnical Design Courses
Goals and Expectations

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Introduction

I am writing this article to describe my experience in teaching the *Introduction to Geotechnical Engineering I* (CME 321) at the Civil Engineering Department of the University of Toronto. I taught CME 321 for the first time in the Fall 2009 semester. The undergraduate class attracted 153 third-year students from civil, mining and mineral engineering, and engineering science (infrastructure option).

In the rest of this document, I will

1. Explain my understanding of the challenges of teaching geotechnical engineering
2. Outline the educational value of numerical modelling
3. Describe how the numerical modelling was used in CME 321, and
4. Provide a summary on how the students described their experience.

Challenge of Teaching Geotechnical Engineering

One challenge of teaching geotechnical engineering options is that students often assume the subject is old-fashioned and uninteresting. As a result, the discipline tends not to attract as many top students as it could.

To address this challenge, my predecessor, Prof. Murray Grabinsky had done a fantastic job incorporating application into the course. Like him, I wanted to include components in the course that would engage students' enthusiasm for 13 weeks. My intention was to leave them with a lasting, positive experience of geotechnical engineering. To do so, I knew I had to expose them to the difficulties and subtleties of the discipline, but without overwhelming them with information. At the same time, the course material had to meet the requirements of Canadian Accreditation Board (CAB). The CAB required the course to maintain a 50-50 balance between engineering science (ES) (in this conventional soil mechanics) and engineering design (ED).

Educational Value of Numerical Modelling

I have studied the application of numerical methods to civil engineering problems since 1998. I researched aspects of finite element analysis in both structural and geotechnical applications. Based on my experiences in numerical analysis, I have come to believe that

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it is an exciting field that offers the tools and avenues for tackling geotechnical challenges.

In addition to their industrial applications, numerical modelling and software tools must be regarded as valuable educational tools. Computational methods connect traditional civil engineering subjects to current and future technologies. They also provide an effective platform within which different sciences and design approaches can interact. I believe that although the foundational principles of a subject need to be taught through the simplest technique – the chalk and blackboard – numerical analysis tools, in the form of software, are very effective in helping students see these principles in action.

One-Dimensional Consolidation Analysis with the Finite Difference Method

In the University of Toronto, numerical methods are covered in *Introduction to Geotechnical Engineering II* (CME 324), the follow-up course to CME 321. Here, students would, for example, use finite element software applications to analyze geotechnical problems such as slope stability analysis. To incorporate numerical analysis therefore into CME 321, it was necessary to choose an approach that would complement what the students would be learning later. The natural choice seemed to be the application of the finite difference method in the analysis of consolidation problems.

The finite difference method is simple, yet widely applicable. Through the solution of the one-dimensional (1D) consolidation problem, the basic elements of the finite difference method can be covered in a one-hour lecture. 1D consolidation is a simple problem; thus the solution to its differential equations with the finite difference method is quite easily understood [refer to 1]. This is achievable by focusing on the following aspects:

1- Partial Differential Equations (PDEs) and numerical approaches for solving them
2- Initial and boundary conditions, and
3- Space and time discretization techniques.

You may be skeptical that undergraduates can grasp the concepts of the finite difference method in one hour; numerical method courses are challenging, even for graduate students. Clearly, that is not possible if the goal is to comprehensively cover the method. However, if the emphasis is on how relevant numerical methods are to geotechnical problems, then it can be done.

The numerical section integrated into CME321, intended to help students understand the initial and boundary conditions of consolidation problems, and appreciate what is involved in practical geotechnical problems. For example, the engineering approach to problems that involve non-uniform stress distributions or multilayered soil profiles could be discussed within this context. I also wanted them to gain first-hand experience with geotechnical challenges such as the reliability (or lack thereof) of soil property values, effect of hydraulic conductivity on how soils consolidate, and the scale and time frame of real geotechnical problems.

Course Implementation

The numerical module introduced the finite difference method, discussed challenges in real engineering problems (such as non-uniform stress distributions and multilayered soil profiles), and applied a software to the course project.

After discussing settlement analysis and covering the numerical solution of the 1D consolidation equation with the finite difference method, I introduced students to Settle^{3D} [2], a settlement and consolidation analysis program. Although at the time I was working at Rocscience Inc. (the company that developed Settle^{3D}), my decision was mostly based on how intuitive and user-friendly the program was. It would allow students to build models and solve problems without getting bogged down by the details of how to use the software.

The following aspects also made Settle^{3D} an attractive tool for CME 321:

1- In contrast to advanced programs based on three-dimensional consolidation theory, Settle3D solves one-dimensional consolidation problems using the finite difference method. Therefore the program perfectly matched the course material presented to students.

2- Settle^{3D} provides the Boussinesq, Westergaard, and 2:1 stress distribution solutions. It also calculates three-dimensional stress distribution using a boundary element approach. These options are classical to soil mechanics and geotechnical design.

3- The program has built-in embankment loading and wick drain functionalities for modelling the acceleration of consolidation settlements. This would make it easy for students to appreciate the material covered under the ED component of the course.

4- Options provided in the application are well described in a theory manual.

The course project involved analysis of an earth dam which was constructed in multiple stages on a 30-meter soft clay deposit in Turkey [3, 4]. Through this case study, students were exposed to construction processes, typical dimensions and profiles of dams, construction time frames, data collection and monitoring, as well as material properties and stratigraphy of soil deposits. The students also investigated the effectiveness of wick drains.

Outcomes of the Numerical Module

I came into teaching the Introduction to Geotechnical Engineering course believing that numerical techniques could contribute to dispelling students' misconceptions about geotechnical engineering. After all, in many ways designing for geomaterials poses much greater challenges than doing so man-made materials such as concrete and steel. I think that the objectives were achieved.

Apart from the usual complaints of little time and heavy work loads, students were satisfied with the experience of working with Settle^{3D}. They were most impressed with the rich diversity of geotechnical engineering problems and the opportunities the field offered. Most of them said that they had gained better understanding of how soil mechanics principles got used in engineering design.

Throughout the course, I repeatedly explained to my students the limitations of graphical methods. Interestingly, it was only when I solved a finite difference example on the blackboard that students grasped exactly how limited graphical approaches were.

I can confidently conclude that the numerical module, especially the project, was successful in meeting the primary objectives. It provided an effective medium for discussing the engineering design components and emphasizing on the theoretical aspects of the course. It was also successful in increasing undergraduate students' interest in geotechnical engineering.

I believe that universities have the responsibility to pay greater attention to the application of numerical techniques in geotechnical engineering. This will help close the current gap between geotechnical practice and the potential of numerical modelling tools; these applications are not unreliable black boxes.

References

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