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.

3 THE ASSIGNMENT

3.1 1-D consolidation finite difference solution

The equation of 1-D consolidation is:

$$\frac{\partial^2 u}{\partial z^2} = \frac{\partial u}{\partial t} - \frac{\partial q}{\partial t}$$

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:

$$u_A(t + \Delta t) = u_A(t) + \beta(u_A(t) + u_B(t) - 2u_C(t)) + \Delta q_B$$

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 $\Delta z$, $\Delta q_B$ 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:

$$S = \int_0^H c_v \, dz$$

$$= \int_0^H m_v (q - u) \, dz$$

$$= m_v q H - m_v \int_0^H u \, dz$$

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:

\[
\int_a^b u(z) \, dz \approx \frac{1}{2} \left( u_n + u_{n-1} \right) \Delta z + \cdots + \frac{1}{2} \left( u_2 + u_1 \right) \Delta z
\]

Thus

\[
\Delta z = \left[ \frac{u_n + u_{n-1}}{2} + u_2 + \cdots + u_1 \right]
\]

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 online 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.

REFERENCES

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 be 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, $c_v = 5 \text{ m}^2/\text{yr}$, $m_v = 0.0003 \text{ m}^2/\text{kN}$ and drainage is 1-way. The final embankment height is to be 5 m, and is to be constructed from fill with $\gamma_{\text{bulk}} = 20 \text{ kN/m}^3$. 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 $c_v = 5 \text{ m}^2/\text{yr}$ and $m_v = 0.0003 \text{ m}^2/\text{kN}$.

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 $c_v = 2 \text{ m}^2/\text{yr}$, $m_v = 0.0001 \text{ m}^2/\text{kN}$ 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 $c_v = 0.8 \text{ m}^2/\text{yr}$, $m_v = 0.0003 \text{ m}^2/\text{kN}$ 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 $c_v = 4.5 \text{ m}^2/\text{yr}$, and $m_v = 0.001 \text{ m}^2/\text{kN}$.

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.