Computational Tools for Teaching Graduate Courses in Geotechnical Engineering

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Abstract - **The Bologna Process assigns new challenges in higher education and in geotechnical engineering courses in particular. The ECTS (European Credit Transfer System), based on the student workload required to achieve the objectives of a program study, implies reduction of contact hours between teacher and student. In the graduate courses of Civil Engineering and Geological Engineering, at Faculdade de Ciências e Tecnologia, New University of Lisbon (FCT/UNL), the programmes of geotechnical disciplines were modified, taking into account this reduced time of classes, putting more emphasis on the process of learning, then on the process of teaching. To search for this effective processes of learning, there has been personal involvement of the authors in the development of stimulating and innovative frameworks that motivate students to do private study beyond taught classes and, at the same time, could give them a better understanding of concepts in geotechnical engineering. Being so, students were encouraged to explore current PC programs to solve geo-engineering problems. Commercial software (student version or easily available) was used to solve didactical examples that are presented in this paper, such as spreadsheet applications with Microsoft EXCEL, PLAXIS and SLOPE/W.**

Index Terms – Geotechnical Engineering Education, Bologna Process, Pore Pressures in Consolidation, Slope Stability, Excel, Plaxis, Slope/w.

INTRODUCTION

The Bologna Process aims to engage countries and universities in a process of modernization, facilitating student mobility by attaching credits to the components of an educational programme. In higher education systems, the definition of credits may be based on different parameters, such as student workload, learning outcomes and contact hours. The ECTS (European Credit Transfer System) is based on the principle that 60 credits measure the workload of a full-time student during one academic year. The student workload of a full-time study programme in Europe is, in most cases, around 1500-1800 hours per year and in those cases one credit stands for around 25 to 30 working hours [1].

Being so, student workload in ECTS consists of the time required to complete all planned learning activities such as attending lectures, seminars, independent and private study, preparation of projects and examinations. This workload should be preferably specified in terms of acquiring learning outcomes and competences in order to engage students in this new educational process. So, it is the duty of the universities to engage students in this new educational process, changing some teaching methods and giving opportunities to the students to learn through inquiry. The question is first and foremost about achieving competence doing independent and private study, not about simply acquiring a specific amount of knowledge in attending lectures [2].

In fact, the traditional teaching process based on "chalk and talk" or, most recently, on "presentation and talk", does not engage students in the learning process. Although many media elements such as graphics, sound, animation and interactivity can be combined, sometimes it is applied the same assumption of delivery of content and, despite the technology, teachers have difficulties to achieve interest and emphasis on learning. Even in classes of problem solving, students used to transcribe from the blackboard the resolutions of some practical questions into their notebooks, instead of searching for the solutions themselves.

So, teachers have to encourage students in a deep learning approach, for which it is necessary to develop abilities for lateral thinking and creative problem solving. The idea inculcated should be that their learning process depends very much upon dedication and persistence. In the end of the learning process of the whole subject, they will develop their common sense and their intellect.

In order to achieve these objectives, and make the university a more exciting place of education and learning, the frameworks that are given to the students have to be stimulating and must motivate them. Computational tools are a direct appeal to the modern students and are becoming a more widespread and accepted form of teaching, particularly in engineering education. They can be used to create and deliver software packages on a particular subject in a simple way.

Furthermore, as computer packages are increasingly used in industry, it is important that universities also train students in the use of such packages. In exploring them, students are able to learn at their own rate, rather than fitting into a schedule set by the course program [3].

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This includes understanding the assumptions behind the program, checking the validity of the solution with a simple parallel manual calculation. If they become interested and motivated, students can perform several analyses by setting various parameters and, therefore, compare results and interpret them. It becomes a formative approach providing the opportunity to review and consolidate what they have learned [4].

The two examples presented in this paper have been chosen carefully in order to have the possibility of comparing the results given by simple analytical solutions that are usually solved during tutorials classes and solutions given from solving the problems in personal computers, using software packages available.

The first example deals with the one–dimensional consolidation settlement of fine grained soils under vertical loads. It is presented a simple problem solved by a simple manual calculation, with the finite difference numerical scheme and using the software code PLAXIS.

The second one is about slope stability and evaluation of a safety factor with simple geometry and geological features. The safety factor is determined by a manual calculation and using the software SLOPE/W.

ONE DIMENSIONAL CONSOLIDATION

The process of consolidation of fine grained soils and the important aspects of time dependent settlement are taught at the discipline of *Soil Mechanics* in Civil Engineering course. The one-dimensional consolidation equation (1) describes the spatial variation of excess pore pressure (u_e) with time (t) and depth (z):

$$\frac{\partial u_e}{\partial t} = C_v \frac{\partial^2 u_e}{\partial z^2} \qquad (1)$$

where the constant C_v is the coefficient of consolidation.

It is a common equation in many branches of engineering. For instance, the heat diffusion equation, commonly used in mechanical engineering, is similar to equation (1) except that temperature, T, replaces u and heat factor, K, replaces C_v.

One of the problems given to the students, illustrated in Figure 1, is the determination of the distribution of excess pore water pressures, within a clay layer, with time, resulting from the applied surcharge. It is necessary to know the excess water pressure at a desired time in order to determine the vertical effective stress to calculate the consolidation settlement.

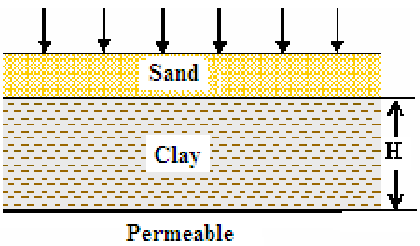


FIGURE 1

SOIL PROFILE PROPOSED IN CLASS

The groundwater table is at the surface, the vertical stress applied is 100 kPa, the coefficient of consolidation is 1,65 m^2/yr and the clay layer is 8 m thick (H).

A solution to the one-dimensional consolidation equation (1) is obtained during classes using the Fourier series. Students are given the well known chart with those series of isochrones representing graphically the solution of equation (1) for different time factors and depths. Students determine the distribution of excess pore water pressures at 2 and 4 meters depth, after 3 years, with simple manual calculations, using the equation:

$$U_z = 1 - \frac{u_e(t)}{u_e(0)} \qquad (2)$$

These results were u_e= 45 kPa and u_e= 60 kPa respectively.

In independent study, students are encouraged to use software packages available to solve exactly the same problem. To get familiar with such packages, students have access to some tutorial sessions in a computer class where they can manipulate computers, no more than two students for each computer.

Finite difference method gives an approximate solution to the consolidation equation and involves only the expansion of the differential equation using Taylor's theorem. Furthermore, it can easily be adopted for spreadsheet applications [5]. So, it is explained to the students how to use Microsoft Excel to solve the governing consolidation equation and how to do the necessary iterations [6]. As exactly the same problem is used (Figure 1), the initial excess pore pressures are 100 kPa uniformly in depth. The upper and bottom boundaries are pervious, therefore the excess pore water pressure is zero at all times greater than zero.

With these initial conditions, the implementation of the finite difference method in the spreadsheet gives results of excess pore pressures, u_e, in each interior nodal point.

Figure 2 represents a series of complete results of the spreadsheet program. The curve representing t=3yrs is in bold.

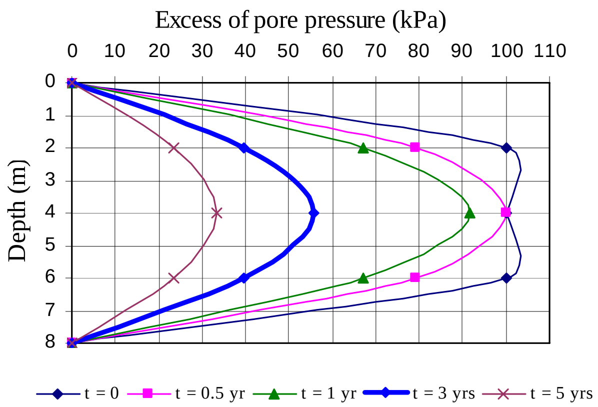


FIGURE 2

RESULTS OF EXCESS PORE PRESSURES ON EXCEL

Commercial software is also used to implement the same problem. PLAXIS is currently available at FCT/UNL and can perform a consolidation analysis and calculate the development of excess pore pressures with time within a soil layer. After explaining the software to the students, they can generate the problem geometry and the finite element mesh. Since the geometry is symmetric, only one half (the right side) is considered in the analysis. It is used a cohesion of 50 kPa and an oedometer modulus (E_{ed}) of 1000 kPa. This modulus is related with the coefficient of permeability (k), using the equation:

$$C_v = \frac{k.E_{ed}}{\gamma_w} \quad (3)$$

The initial excess pore pressure is generated by using undrained material behavior and applying the external load of 100 kPa in the first (plastic) calculation phase [7]. Students were invited to perform consolidation analysis to the same ultimate times of the spreadsheet solution.

Figure 3 shows the dissipation of excess pore pressure at various depths with t = 3yrs. The development of excess pore pressures for different times can also be computed.

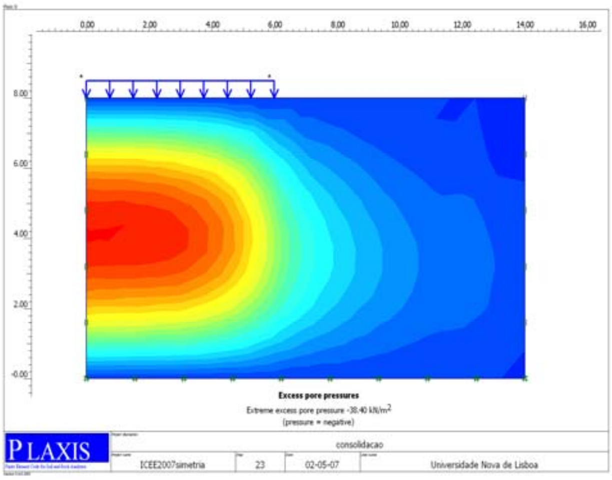


FIGURE 3
RESULTS OF EXCESS PORE PRESSURES ON PLAXIS

Plaxis has the possibility of visual animations. In this example it is possible to visualize the movement of dissipation of excess pore pressures out of the clay layer, which students appreciate very much.

STABILITY OF SLOPES

During their involvement in the discipline of *Mass Movements and Slope Stability* in Geological Engineering Course, students are requested to do at home some calculations applying several limit equilibrium methods for slope stability evaluation whose theoretical basis they have received in the classroom ("infinite slope" method, situation of zero angle of friction, methods of slices, different stability charts, etc.). Thus, they should study, in advance, the subject of limit equilibrium methods, in an attempt to do some training in the resolution of problems of stability analysis, not leaving this task till the last days before final tests.

All different methods try to simulate different failure mechanisms, and these ones depend on slope geometry and, above all, on geology. For instance, if the slope is composed of clayey soil from weathered basalt like the one shown in Figure 5, landslides tend to occur along a circular shear surface.

FIGURE 5
ROTATIONAL SLIDE AFFECTING A SLOPE OF BASALTIC SOIL

Hence, the quantitative assessment of its stability must be done with some method where failure is assumed to occur by rotation of a block of soil on a cylindrical slip surface. Among the methods of slices for slope stability evaluation, the Fellenius, or Swedish, method (Ordinary Method of Slices, according to anglo-saxonian authors [8]), is valid for those geometric conditions. The students are supplied in class of a two-dimension slope scheme with a circular failure surface and some physical and mechanical data, which allows them to calculate the safety factor. Figure 6 represents a simple and homogeneous slope, without neither tension cracks nor any indication of pore-water pressures acting upon the surface of potential failure. The figure includes a circular sliding surface, along which failure may take place, and the potential sliding body is divided in nine vertical slices.

The physical and mechanical parameters of the soil requested for computation are: γ = 16,5 kN.m^{-3}; c' = 18 kPa; ϕ' = 25º.

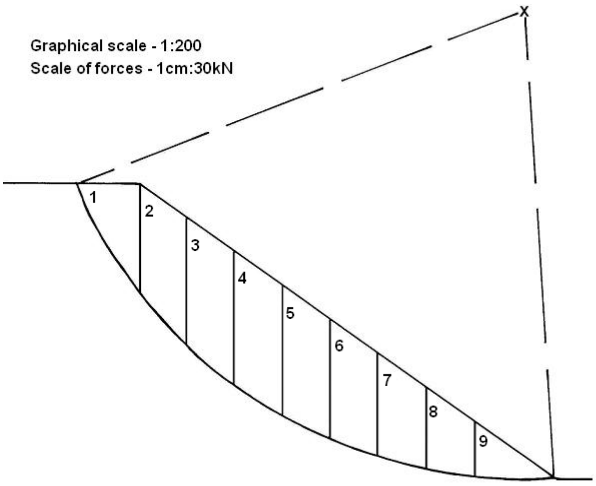


FIGURE 6
SLOPE SCHEME GIVEN IN CLASS

The slices weight is resolved into forces parallel and perpendicular to the slices base (or slice fractions of the failure surface), respectively the gravitational driving force (*T*) and the base normal force (*N*).

The calculations for stability conditions are repeated for each slice and the equation of the equilibrium balance, simple enough and linear because this particular method denies interaction forces between the slices, allows a simple and proper hand calculation of the problem. That equation can be written as:

$$FS = \frac{Lc' + tg\phi'.\Sigma N}{\Sigma T} \qquad (4)$$

FS: safety factor
L: failure surface area
c', ϕ': strength parameters (effective cohesion and friction angle)
ΣN: Summation of the base normal force of all slices.
ΣT: Summation of the gravitational driving force of all slices.

The results that students are expected to reach are presented in Table I:

TABLE I
RESULTS OF HAND MADE COMPUTATION FOR THE VALUES OF WEIGHT VECTOR COMPONENTS N AND T

Slices	Volume (m^3)	Weight (kN)	N (kN)	T (kN)
1	12,16	200,64	126	195
2	20,16	332,64	222	246
3	19,20	316,80	243	204
4	19,20	316,80	264	177
5	18,24	300,96	267	138
6	16,32	269,28	252	96
7	13,44	221,76	216	57
8	10,08	166,32	162	24
9	7,36	121,44	121,5	6
			(ΣN)1873,5	(ΣT)1143

Figure 7 shows the final shape of the slope scheme.

Plotting the values of ΣN and ΣT in equation (4), the safety factor computed by the students will be approximately 1,33.

Subsequently, the students are invited to do the same calculations of slope stability evaluation using the same Fellenius method but, this time, using the software program SLOPE/W, incorporated in a set of geotechnical programs edited by GEO-SLOPE International, Ltd. It supplies a version for students of item SLOPE/W that uses the limit equilibrium theory for computation of the safety factor of the slope, both in soil or rock. In its teaching guide [9], made with didactic objectives for learning purposes, the software allows:

a) to analyze slopes with one or two soil layers over the bedrock;

b) to insert for each soil layer its total specific weight, cohesion and friction angle;

c) to include pore water pressures with one piezometric line;

d) to test circular and non-circular surfaces;

e) to compute safety factors using different methods of slices.

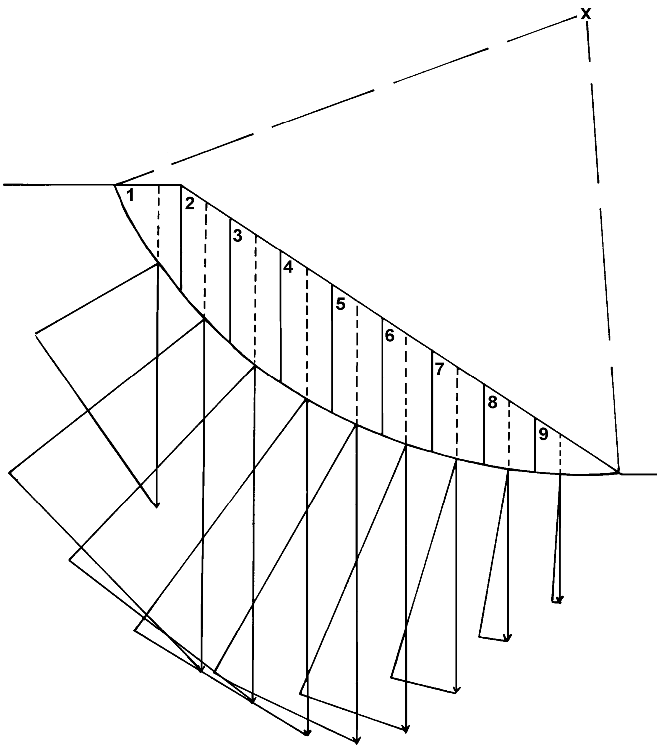


FIGURE 7
SLOPE GRAPHIC ANALYSIS (FELLENIUS METHOD)

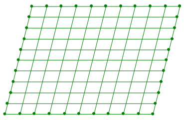
Specifically with this program, students are allowed to easily recalculate the safety factor using several methods of slices including Bishop simplified, Janbu simplified or Spencer methods. These three ones, for instance, present much more complex calculations because all of them do admit inter-slice forces (only the normal component of these forces for the two first ones and both the components for the third one). So, the safety factor equations start to be nonlinear, mathematically more rigorous, making more difficult the calculations, which include iterations.

Because of that, it is more suitable for a good understanding of the calculation methods, the adoption in class of a simple and didactic way for assessing slope equilibrium in which students compare results taken from the computer with those obtained on a sheet of paper using pen, square and calculator machine.

The model consists of the same simple profile slope, with the same dimensions, composed by a single "layer" of basaltic soil over the bedrock with the same physical and mechanical data described for the hand calculation example. The geometric references are presented in Figure 8. These coordinates enable a slope profile drawn by the program as the one presented.

The manipulation of the software is explained to the students in a computer class-room. With SLOPE/W programme, the students can easily search for the minimum safety factor possible for that geotechnical scenario. They must pay attention to the grid of rotation centres disposed over the slope scheme (Figure 8), each of them corresponding to circles of three different radius.

Coordinates (X,Y):
Terrain: 0,22 – 10,22 – 35,4 – 42,4 – 42,0 – 0,0
Bedrock – below 0,0 – 42,0



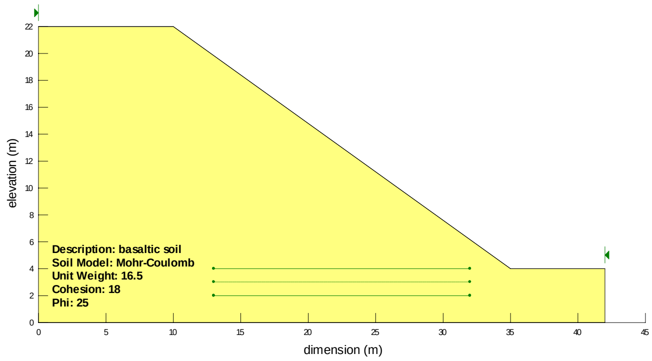


FIGURE 8
THE SLOPE STABILITY PROBLEM PRESENTED

The result value of 1,31 stays quite near the one computed from the hand calculation example (Figure 9), as it was expected even if the program computations includes 30 slices instead of 9 slices in the hand computed example.

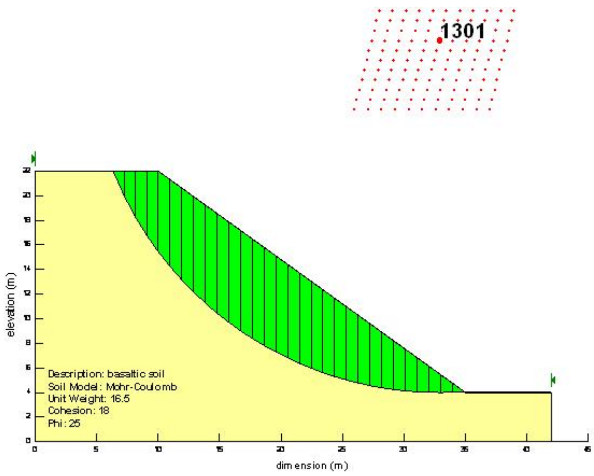


FIGURE 9
THE RESULT OF THE SLOPE STABILITY PROBLEM COMPUTED BY SLOPE/W

The failure surface of that example was drawn in a way that it should give a similar result of that obtained from the computer, so the students could check their results.

CONCLUSIONS

The Bologna Process with its ECTS is a student centered system that is specified in terms of learning outcomes and competences to be acquired. Being so, it demands from students extra responsibilities as it measures independent and private study as well as contact hours with teachers.

Thus, it is a teacher's job to create stimulating and innovative frameworks that motivate students to do private study beyond taught classes. The use of personal computers has become widespread and can be used for independent study to assist students in exploring and solving engineering problems and, at the same time, can give them a better understanding of fundamental concepts in geotechnical engineering.

To solve manually the two problems presented in this paper, students had to search for the solutions themselves even in the tutorial classes in the sense that it is more important to motivate students to identify and deal with the problem rather than solving it for them. Software packages were used for further practice and to develop abilities for lateral thinking and creative problem solving.

The interest and participation of the students on these challenges demonstrated the possibilities of dealing with knowledge in a perspective of acquiring competences and not a retention of specific and voluminous contents.

They were mobilized for questioning and for creativity learning, feeling that they were capable of overcome more complex tasks.

Introduction of geotechnical computer software in university also helps students to have a good connection with their future work in industry.

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