An educational software for teaching soil consolidation

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Abstract

The educational tool SICOMED_3D has been created to simulate problems of soil consolidation by prefabricated vertical drains. Thanks to its nice interface of windows, the introduction of data is very fast and easy for the students, while providing users with simple handling and powerful calculations. Its graphical environment allows to get representations of the excess pore pressure, local settlements and total surface settlement. SICOMED_3D can also generate an animation that recreates the evolution of the surface settlement during the consolidation process. The software presents, like commercial softwares, the most common options (e.g., save and open cases files, save animations and representations, etc.). Although the program is created to be used in several fields, among others as an engineering or research tool, the main use of interest for this work is for educational purposes. Another important application is as low-cost laboratory practices, as students can experiment by modifying the soil properties, including the depth of penetration of the vertical drain, in a quick, simple and intuitive way.

Keywords: educational software; teaching in civil engineering; applied soil mechanics; consolidation by prefabricated vertical drains.

1. Introduction

One of the main questions that appear when teaching in a Civil Engineering Master is what would be the best tool for students to understand the standard known problems of reference in soil mechanics. Given the extensive experience of the research group components in the numerical simulation of soil consolidation problems [García-Ros (2016)], using the network method and the Ngspice code, the idea of developing a software with a friendly environment to enable students to understand this difficult problem was carried out.

Nomenclature

$c_{v,x}$ horizontal coefficient of consolidation in X direction ($m^2\ s^{-1}$)

$c_{v,y}$ horizontal coefficient of consolidation in Y direction ($m^2\ s^{-1}$)

$c_{v,z}$ vertical coefficient of consolidation ($m^2\ s^{-1}$)

t time (s)

u excess pore pressure ($N\ m^{-2}$)

u_o initial excess pore pressure ($N\ m^{-2}$)

x, y, z spatial coordinates (m)

The network method is firstly based on the electrical analogy and it is detailed in several engineering books and research articles: González-Fernández (2002). In addition, it is used as an educational tool to explain the relationship between mathematical models and physical and engineering processes: Sánchez-Pérez et al. (2016). This procedure, analogy between equations and physical problems, is an undoubted educational subject since many engineering or physical models use the same differential or partial differential equations: Mills (1999). The successful use of educational software in classroom experiences has been presented in previous works: Sánchez-Pérez and Alhama (2016).

In this work is presented SICOMED_3D [García-Ros *et al.* (2016)], a software capable of simulating 3-D soil consolidation problems with prefabricated vertical drains and its use as educational tool. The software has been created by the "Network Simulation" research group of the Universidad Politécnica de Cartagena.

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experiment by modifying the soil properties, including the depth of penetration of the vertical drain, in a quick, simple and intuitive way.

Finally, SICOMED_3D, which makes use of the analogy or equivalence between the electric transport and the water movement in a porous soil due to an excess of pore pressure, is presented to the user through a pleasant communication environment, type windows, leading to "step by step" actions and with multiple options in data entry, file creation, simulation options, obtaining and representing results, etc. The network model files created by SICOMED_3D are executed in the Ngspice software, whose simulation results can be directly consulted through the various graphic representations available: excess pore pressure, local and surface settlements, average degree of consolidation, etc.

2. Mathematical model

This program reproduces the consolidation of anisotropic soils with partially penetrating vertical drais with a rectangular layout. The flow of water is in the upward direction (towards the soil surface) and horizontally towards the vertical drains, as shown in Figure 1.
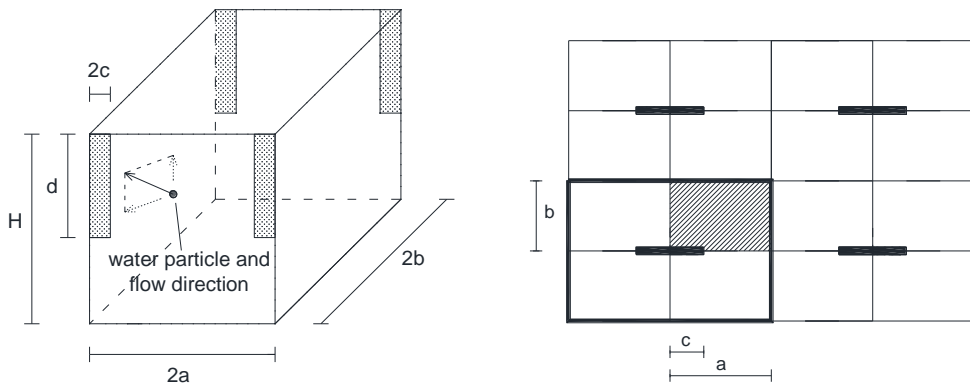

Figure 1. Physical scheme of the 3-D consolidation process with vertical drains.

For the typical section, the mathematical model is governed by equations:

$$\frac{\partial u}{\partial t} = c_{v,z}\left(\frac{\partial^2 u}{\partial z^2}\right) + c_{v,x}\left(\frac{\partial^2 u}{\partial x^2}\right) + c_{v,y}\left(\frac{\partial^2 u}{\partial y^2}\right) \qquad (1)$$

$$u_{(x,y,z=0,t)} = u_{(0 \leq x \leq c, y=0, 0 \leq z \leq d, t)} = 0 \qquad (2)$$

$$\left(\frac{\partial u}{\partial n}\right)_{\text{rest of the boundaries}} = 0 \qquad (3)$$

$$u_{(x,y,z,t=0)} = u_{o} \qquad (4)$$

Where (1) represents the governing equation, (2) and (3) the boundary conditions and (4) the initial condiction.

3. SICOMED_3D

The organization and structure of the program has been designed so that the student have a powerful and useful calculation tool, with a simple introduction of data and interpretation of results. Figure 2 shows a simplified scheme of the basic operation of SICOMED_3D.
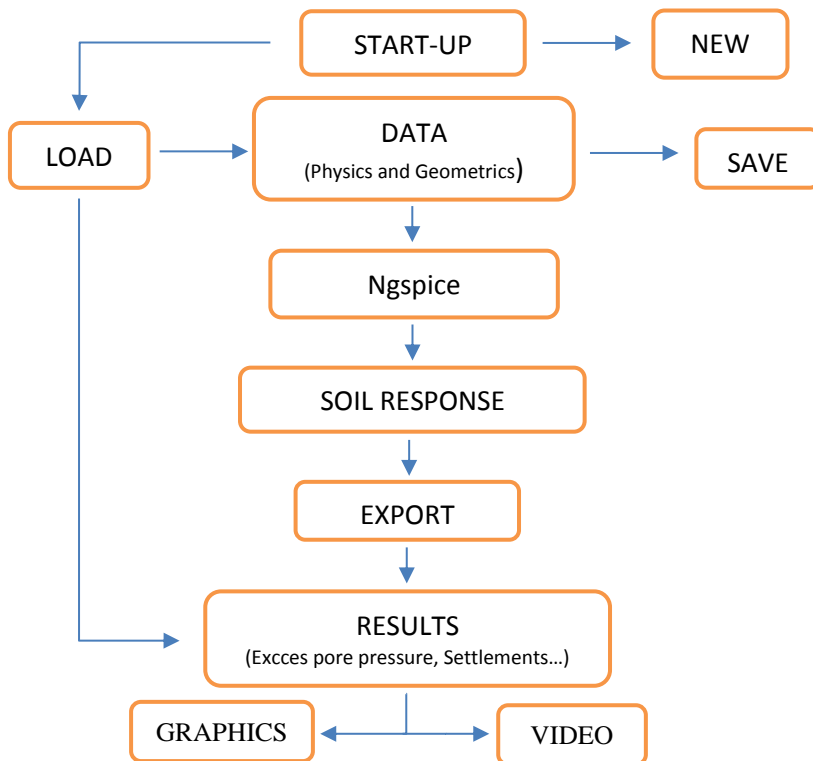

Figure 2. Simplified flow diagram of the program.

Data entry is done through a graphical interface consisting of a total of three windows, which appear consecutively as the data entry is completed. In the first screen, Figure 3, the data related to the geometry in plant of the problem (total length, total width and width of the drain) are introduced, as well as the reticulation, which will allow us to obtain a better precision in the calculations the greater this one.
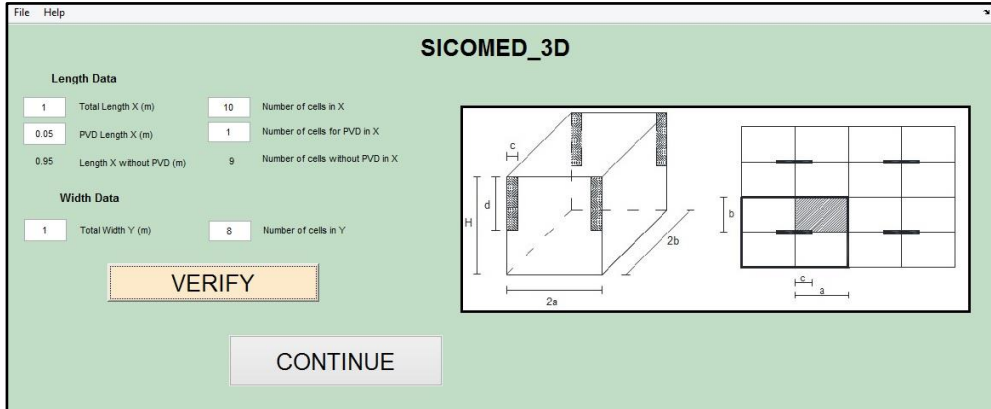

Figure 3. First data entry screen.

In the second screen the data related to the geometry of the strata, as well as the coefficients of consolidation, are introduced. The program allows the definition of up to 3 different layers, which allows students to experiment and understand the phenomenon of consolidation by varying the properties of these. Moreover, through a dropdown tab, the student can choose the depth of penetration of the drain, checking the influence that this can have in the phenomenon of consolidation.

Finally, in the third screen, the parameters related to the simulation required by the program are introduced: surface applied uniform load (N/m^2), initial time from which results are desired, final calculation time, maximum time increment between each iteration and a relative tolerance parameter that uses the Ngspice program to reach the convergence of the problem. Once all this data has been entered the simulation can start, using the calculation button. Figure 4 shows a capture of this third data entry screen.

Figure 4. Third data entry screen.

At the end of the simulations students can have a visualization of the results graphically. The program offers up to 6 possibilities of representation of results (one of them includes a video animation that shows the evolution of the surface settlement), which are selected through a dropdown tab. In this way, the student can know the information sought in a simple, fast and accurate way. The following section shows some of these graphics.

4. EXAMPLE OF LEARNING WITH SICOMED_3D

Since 2012, the CIETAT Master has been taught at the Universidad Politécnica de Cartagena, focused on water and soil engineering. In the course "Soil Mechanics", the students have to deepen in the most relevant concepts of this discipline, a task that is not simple and that needs the appropriate tools to achieve the success of teachers and students. In the case of soil consolidation, the SICOMED_3D program, developed by the "Network Simulation" research group, stands as a very useful tool to facilitate student learning, which deepen in this part of the soil engineering through experimentation with fast computer simulations.

A set of real consolidation scenarios is proposed, from which the students will determine the soil parameters (thicknesses, hydraulic conductivity, pore index, etc.) and other necessary information to be subsequently introduced into the program and run the calculations.

The students then have a wide range of possibilities in the graphical representation of results: the program allows obtaining both the excess pore pressure (Figure 5) and the local

settlements for one or two columns of soil (chosen from the values of its X,Y coordinates) in the desired time interval. It is also possible to know the values of these unknowns for any point on the soil (from its X,Y,Z coordinates), the accumulated surface settlement (for one or two columns of soil) and the average degree of consolidation on the whole medium (Figure 6). Finally, by means of a powerful graphic animation, it is possible to check how all the surface settlements are produced, as the consolidation process advances (Figure 7).
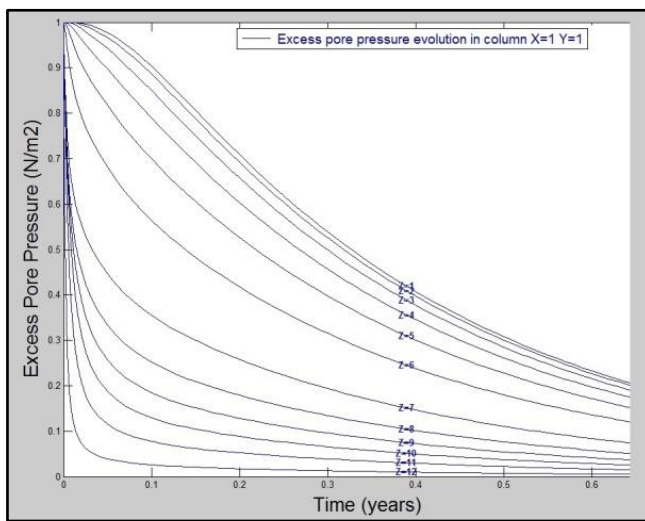

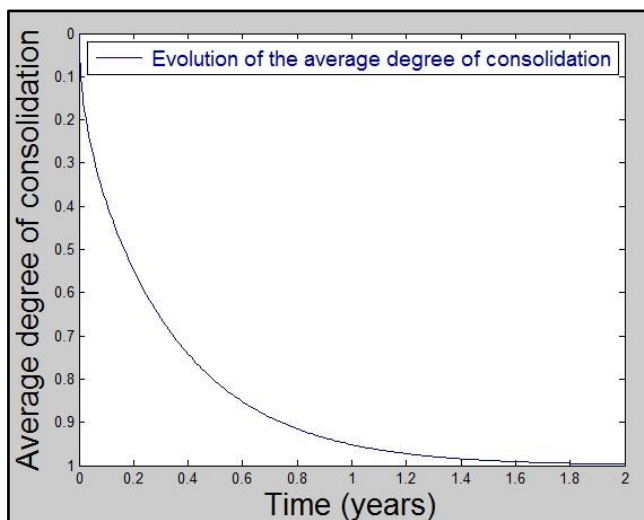*Figure 5. Excess pore pressure evolution in a column of the soil.*

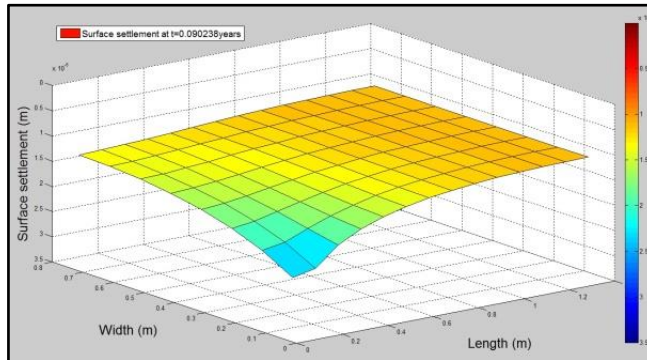*Figure 6. Average degree of consolidation.*

Figure 7. Capture of the animation of surface settlements evolution.

5. CONTRIBUTION

The educational tool SICOMED_3D, created to simulate problems of soil consolidation by prefabricated vertical drains, provides the student of Soil Mechanics of the UPCT CIETAT Master with a tool that greatly facilitates the understanding of this soil improvement technique through experimentation. Supported by a pleasant graphical environment, the program provides a wide range of results, which the user can consult in a quick and easy way. The scenarios modelled with SICOMED_3D will be explained in class to check the student's understanding of the problem.

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