

# Virtual Simulator for Advanced Geotechnical Laboratory Testing

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## Abstract

A multimedia software (Geo-Sim) is developed by the authors that provides a realistic environment for performing virtual laboratory experiments to complement and extend the existing laboratory course component related to soil behavior. With an objective of overcoming the limitations of existing pedagogy of geotechnical laboratory courses, this test simulator provides knowledge of experimental apparatus, test procedure, interpretation, and errors associated with the measurement techniques. The results of experiments, for a given set of input parameters, are obtained with the test simulator using previously published experimental data for simulating different soil types and stress paths. The knowledge of learning and teaching styles in engineering education are considered in this research. The software includes a large database of experimental data reported in prior literature for consolidation, direct shear, drained and undrained triaxial, cubical true triaxial, and combined axial torsional testing. This paper presents details of the test simulator and the associated benefits. The discussion includes implementation and evaluation of the software for the students at the University of Tennessee, Knoxville. A demonstration of this software will also be made during this conference.

**Keywords:** Virtual, Experiments, Parameter Effects, Learning Style, Shear Testing, Triaxial, Consolidation

## Introduction

The objective of present paper is to describe a multimedia software (Geo-Sim) that was developed by the authors for performing virtual geotechnical laboratory experiments associated with evaluating the compressibility and shear strength properties. The purpose of this test simulator is to complement and extend the existing laboratory course component related to evaluating the consolidation and shear strength behavior of geo-materials. In this work, effort has been made to overcome the current limitations in achieving the goal of providing the student engineer with a good knowledge of experimental apparatus, test procedure, interpretation, and errors associated with the measurement techniques. The virtual experiments are proposed as an addition to the limited real experiments performed within the existing curriculum at the undergraduate and graduate level.

The geotechnical laboratory has an important role to play in encouraging students to develop a physical sense of the role of fundamental concepts in soil mechanics. These aspects are considered in the Test Simulator (Geo-Sim) for performing simulated experiments. It is important to recognize that the proposed approach uses Geo-Sim only as a SUPPLEMENT to the real laboratory testing. The approach followed at most universities to date includes a basic soil mechanics course at the junior level wherein the students perform laboratory tests to evaluate the soil characteristics. These tests are typically: Particle Size Analysis, Atterberg Limits, Specific Gravity & Density, Proctor Density Tests (Standard and Modified), Direct Shear, Consolidation, Unconfined Compression and Triaxial Test (CIUC, CIDC). With the shrinking budgets and number of teaching assistants available for laboratory instruction, and consistently stable enrollment in Civil and Environmental Engineering programs, some of these important traditional laboratories associated with shear strength testing are omitted from the curriculum. The relatively large number of students involved with each group also makes it difficult to provide "hands-on" laboratory experience for every student involved in the traditional laboratory setup

The Geo-Sim test simulator has been developed in several independent modules consisting of different laboratory simulations. In the preliminary version, the effort was focused on various types of triaxial testing as reported by Penumadu and Zhao (1999), and Penumadu et al. (2000). Subsequently, some other testing methods have been incorporated. The current version of the software includes modules for triaxial compression tests with various specimen boundary conditions, one-dimensional consolidation tests with both incremental load and constant rate of strain method, and a direct shear test. Related information on the instrumentation, specimen preparation, assembly, and testing is provided using multi-media capabilities using short and relevant video/audio clips. This test simulator in its current version has the option of using existing digitized data from published database for simulating various experiments in geotechnical engineering. In the past version, neural network based soil models were used for limited simulation experiments as their development required significant amount of training and testing data that covers the

anticipated ranges of multivariate input parameters. The software supports WINDOWS platforms with multimedia capabilities, and the graphic user facility has been developed using Visual Basic. The Geo-Sim interface also provides opportunities for students to perform virtual experiments to study parameter effects.

### Virtual Experiments using Geo-sim

The development of Geo-Sim test simulator involves five major components: (1) User interface, (2) Simulation Modules, (3) Experimental Database, (4) On-line Quizzes, and (5) Technical Resources.

#### *User Interface*

The Geo-sim interface is designed using multiple document interface (MDI) technology, which facilitates the user to open and manage multiple windows, and possibly perform multiple tasks concurrently. This interface also provides facility of printing the reports and exporting the data to spread sheets for further computations. The Main window provides all the option menus that are used to navigate through various components of Geo-Sim.

#### *Simulation Modules*

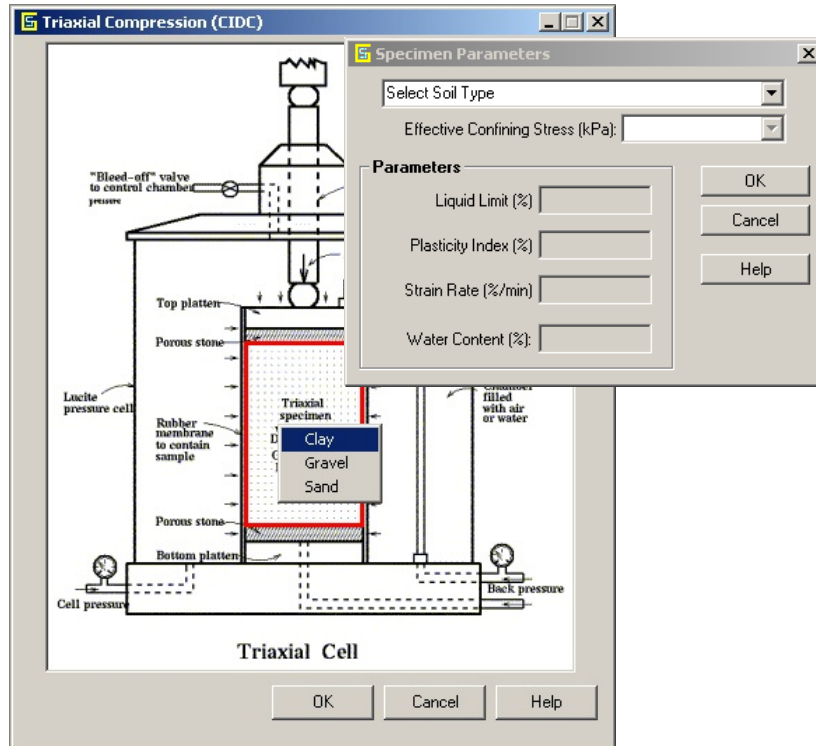
The Geo-Sim test simulator contains several simulation modules. Each module is designed to simulate a particular type of soil testing. At present, the Geo-Sim is fully functional for four of such modules, triaxial compression test on solid cylindrical specimens, and one-dimensional consolidation test, direct shear test, and true triaxial tests on cubical and hollow cylindrical specimens. These simulation modules facilitate the user to go through various stages of the testing. The types of tests covered in each of these modules are summarized in Table 1. The user can also perform the necessary parametric studies for various soils. During the process of simulation, several specific questions are asked to the user in order to evaluate their learning experience.

Table 1: Simulation Modules in Geo-Sim

Module	Tests
Triaxial Compression	CIUC: Isotropically consolidated undrained compression test CIDC: Isotropically consolidated drained compression test UU: Unconsolidated undrained test
One-dimensional Consolidation	Oedometer test or incremental load test Constant rate of strain $K_0$ consolidation test
Direct Shear	Direct shear test
True triaxial	True triaxial test on cubical specimens Combined axial-torsional test on hollow cylinder

In the triaxial module, various stages of triaxial testing are simulated by the user including assembly, saturation, isotropic consolidation, and shearing stages. During specimen assembly, the user is asked to read the vernier scale and input the values for specimen dimensions. The specimen is saturated using back pressure technique, and the user has to apply enough back pressure to achieve good saturation of the specimen. After defining the effective confining stress for isotropic consolidation stage, the simulator goes through consolidation process and shows the measured axial and volumetric deformations. The triaxial compression simulation begins with a window containing schematic diagram of the triaxial setup. The arrangement of entering test parameters is designed to give the spatial feel to the user, as shown in Fig. 1. The selection of soil type and the relevant parameters are entered by clicking on the specimen in schematic diagram. Similarly, the cell pressure and the back pressure are entered by clicking on the corresponding dial gauges. The user is consistently provided with the relevant help while going through the process. The system checks all the necessary parameters during simulation process and informs the user to enter the incomplete information.

The one-dimensional consolidation behavior of fine-grained soils has been traditionally obtained by incremental load test. The constant rate of strain (CRS) one-dimensional consolidation test has gained popularity in the recent past because of its ability to reduce the duration of test and provide more number of data points. Both of these



**Figure 1.** Selection of soil type and its parameters for triaxial compression test simulation

methods can be simulated using Geo-Sim. The user begins the simulation by defining the type of test to be simulated. The next window goes through the specimen assembly for corresponding test method, and the user is asked to define the soil parameters for simulation. Similar steps are followed for the other modules involving direct shear test and true triaxial tests. Figure 2 shows an intermediate step of the specimen assembly during combined axial torsional test on hollow cylinder specimen. Subsequently, in the simulation window, the simulator shows the process of one-dimensional consolidation, direct shear, or shearing stage of true triaxial test on the soil specimen. It also provides the experimental measurements with necessary plots.

The experimental data together with the soil parameters may be exported to spread sheets and saved on the hard disk for further analysis of data. A summary report of the soil parameters and response curves may be created and printed as necessary. Figure 3 shows a typical report of consolidation test generated using the simulator.

### ***Parametric Study***

The simulator also provides an option in which the user can perform parametric study for the response of soil. For example, triaxial compression behavior under different loading/boundary conditions and the effect of confining pressure and void ratio. The user can create a summary report of the soil response for the chosen parameter values, which may be printed and further used to analyze the soil behavior. This report summarizes the chosen parameter values, key measurements, and necessary plots, such as the stress-strain relationships and volumetric responses from the study.

### ***Experimental Database for Simulations***

A large database of the published experimental data has been created for various types of triaxial compression, one-dimensional consolidation, direct shear, and true triaxial tests. These tests cover a wide variety of the types of soils including gravels, sands and clays.

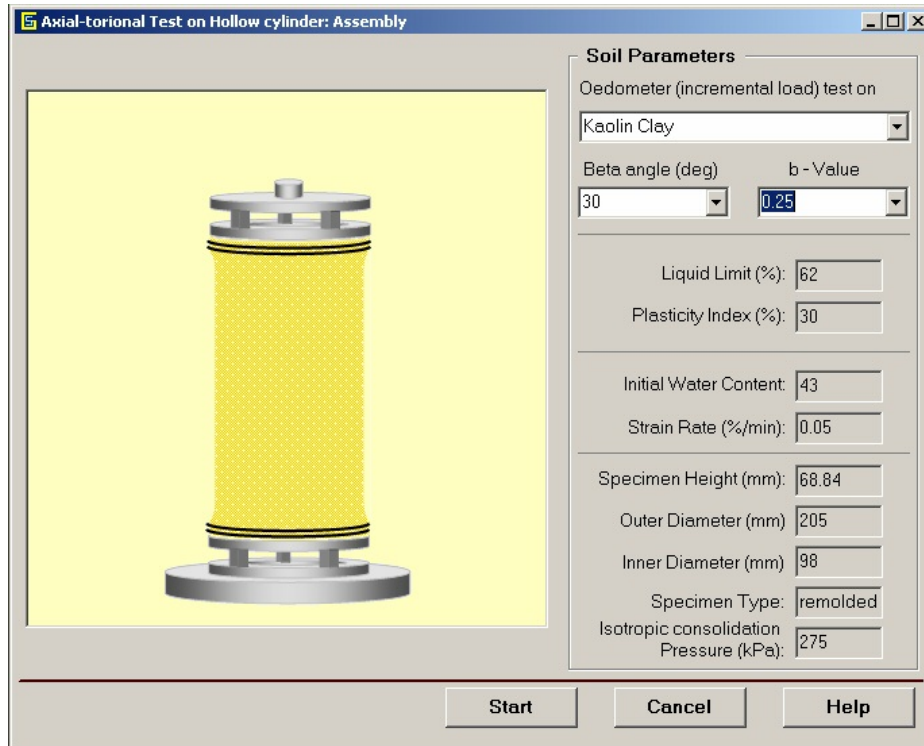


Figure 2. Assembly of axial-torsional test on hollow cylinder specimen

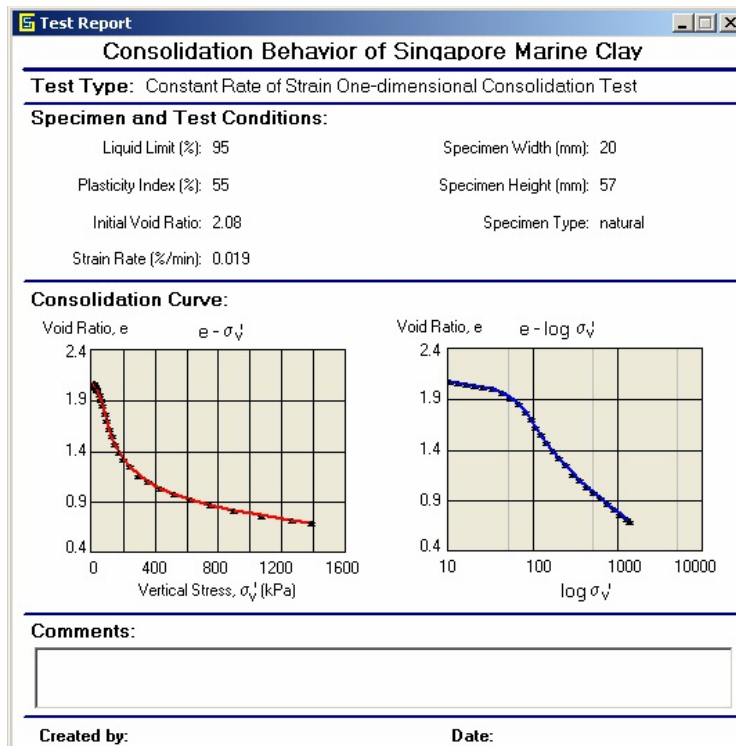


Figure 3. Report of constant rate of strain one-dimensional consolidation test

### ***Online Quizzes with Integrated Help System***

A quiz system has been designed within the Geo-Sim to evaluate the learning experience of the student users. This system is integrated with the simulation modules, and the student user goes through a series of small quizzes popping up before or after the simulations. The user is given an option of disabling the Quiz option when the Geo-Sim is opened. When enabled, the system keeps track of the scores for each quiz and also stores the points given for successful completion of each segment of various simulation modules. The questions in each quiz are based on the relevant technical information for the corresponding segment of the simulation module. After completing a quiz, the user can see the scores for that session and review their answers by comparing with the correct answers provided by the system.

The quiz system provides a question specific and dynamically updated link to the help system. This help system is, in fact, integrated with all the components of Geo-Sim. The help system is designed using HTML help authoring tools, which is beneficial to the user for easy navigation through all the information, searching particular information, and customizing the help by saving favorite links. The main objective behind the development of quiz system was to force the student users to go through all the relevant technical information while simulating the laboratory tests.

### ***Technical Resources for Laboratory Testing of Soils***

The help system contains a large amount of technical information about each of the test method simulated within Geo-Sim. The technical resources include the following information.

1. Background Material (such as Soil Classification)
2. Testing Equipment and its Components
3. Sampling techniques
4. Sensors
5. Test Procedures
6. Error Sources and Limitations
7. Data Analysis
8. Audio-visual resources

In the data analysis, the information is provided for interpreting the experimental data for generalized material behavior based on the basic concepts of soil mechanics. The audio-visual clips of 2 to 5 min on specific topics are played within the help system using Flash player.

### **Implementation and Evaluation of Geo-Sim**

Past surveys using Kolb's (1984) learning style inventory approach indicate that the civil engineering students can be categorized as 'convergers' or assimilators' regarding their *preferred* learning style (Felder and Stice, 1992). These results, in conjunction with the 'cone of learning' indicate that simulating the real experience becomes an important learning aspect of a typical geotechnical student. There are a number of advantages to using the test simulator for performing virtual experiments in soil mechanics education. They provide the students with a realistic appreciation for magnitudes and sensitivity to system parameters and allow them to examine the relationship between such parameters.

The Geo-Sim simulator with triaxial module was implemented at the University of Tennessee, Knoxville in advanced soil mechanics class of Fall 2004, and introduction to soil mechanics class in spring 2005. The students were asked to download the installation files from the course website, and install Geo-Sim on their personal computers. They were asked to go through all the segments of triaxial, consolidation and direct shear modules. No serious difficulty was reported by the students during the implementation. The feedback from the students showed that the whole exercise was a good learning experience for them, and it helped them understand the soil behavior as observed from the laboratory experiments. Based on the Geo-Sim simulations, a set of assignments are being developed for the students that concentrate on creating the lab reports and using the experimental data for detailed analysis of soil behavior. The student response on these assignments showed that they gained more in-depth knowledge of the soil behavior by using the realistic experimental data and performing the analysis with the help of technical resources provided in Geo-Sim.

## Summary

Virtual experiments provide the students with an opportunity to learn more comprehensively about various aspects of the laboratory testing. It enables the student to perform tests more rapidly than with conventional equipment, and thus to perform supplemental 'simulated' tests with different initial conditions, thereby enhancing their understanding of soil behavior. It is well recognized that mechanical behavior of soil is relatively complex and the response can be a combined influence of many parameters. The magnitude and sense of these influences is generally described in lectures. Rarely do the results obtained by students in a laboratory reflect these influences, and thus the students are left with a conflicting picture of soil behavior. The students can use the post processor of the simulator for analysis and report preparation at the end of virtual experiments. The software is designed such that the testing components are modular in nature. Accordingly, additional experiments can be added as individual modules. The details of various modules, evaluation mechanism, and technical resources provided in the simulator were discussed in this paper. The results of implementation and evaluation of the simulator in undergraduate and graduate courses were also briefly discussed, which appear to be promising.

## Acknowledgements

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