AN INTERACTIVE VIRTUAL GEOTECHNICAL LABORATORY

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Abstract

The purpose of this paper is to present an interactive multimedia geotechnical laboratory courseware that is suitable for web-based instructions and/or delivery by a CD-ROM. The virtual laboratory courseware consists of a series of tests on soils that a student can conduct as if he/she were in a real laboratory. Each virtual test courseware provides background material and guides the student to conduct the test and to interpret the results. The courseware is intended to enhance learning and knowledge retention and includes testing prerequisite knowledge and quizzes to test retention. Students can explore test situations that cannot be accommodated within normal class or laboratory schedules. When a student accesses the courseware, a folder is created for that student and records of the student's performance are stored in the folder. The folder can only be accessed by an instructor who can use the information to review certain course material that may not be understood by the students or modify the content of the course.

Introduction

Geotechnical engineering, sometimes called soil mechanics or geomechanics, is a required undergraduate course in civil engineering. The course involves the integration of fundamental principles on the physical and mechanical behavior of soils and laboratory tests to determine soil parameters. The test results are used in formulae to design foundations for structures, embankments for dams and roads, tunnels, etc., and for use in analytical and numerical models. Some of the tests, e.g. consolidation test, require careful sample preparation and several days of recording readings and loading the soil sample. There is very little scope for exploration because these are destructive tests that require significant time commitment and real estate (lab) space.

How can we enhance laboratory experience and allow students the opportunity to explore? One way is to use modern communication technologies. Communication technologies have advanced to a stage where we can now significantly improve the transmission and retention of information. Such technologies include multimedia, chat room, web pages, email, conferencing and listservers. There is now a growing trend of using these newer technologies in the delivery of local and distance education. One of the shortcomings of distance learning for courses with laboratory components is the integration of "realistic or hands-on" laboratory exercises with text-based and graphics materials. Attempts (1-7) have been made to create virtual laboratories. These attempts vary in the degree of sophistication, instructional methodology and realism. In this contribution, the author describes the development and integration of virtual laboratory modules that (1) duplicate the real apparatus, (2) duplicate the real laboratory procedures, (3) provide guidance in conducting virtual tests, (4) provide guidance in interpreting the results, (5) provide opportunities for exploration, (6) provide testing and evaluation of knowledge retention, and (7) provide feedback to the students and instructors.

These modules are integrated into a geotechnical multimedia courseware that contains text, interactive animations of the various concepts of geotechnical engineering, images, a glossary, notation, a notepad, a virtual geotechnical laboratory, interactive problem solving, electronic quizzes and computer program utilities.

Virtual geotechnical laboratory test modules

Three virtual geotechnical laboratory test modules are described in this paper. The virtual tests are direct shear, consolidation and triaxial. These tests were selected because they are usually time consuming to perform. The common goals of each module are

- To complement real laboratory testing
- To test pre-requisite knowledge
- To enhance students' abilities to make the connection between theory, experiment and application
- To guide a student to perform all the key test procedures on his/her own sample in his/her virtual apparatus at any time and place.
- To guide the students to interpret the results of the tests
- To let students apply their results to a practical situation
- To test knowledge retention
- To provide feed back to students and his/her instructor

A flow chart outlining instructional items and how they are achieved in a typical module are shown in Figure 1.

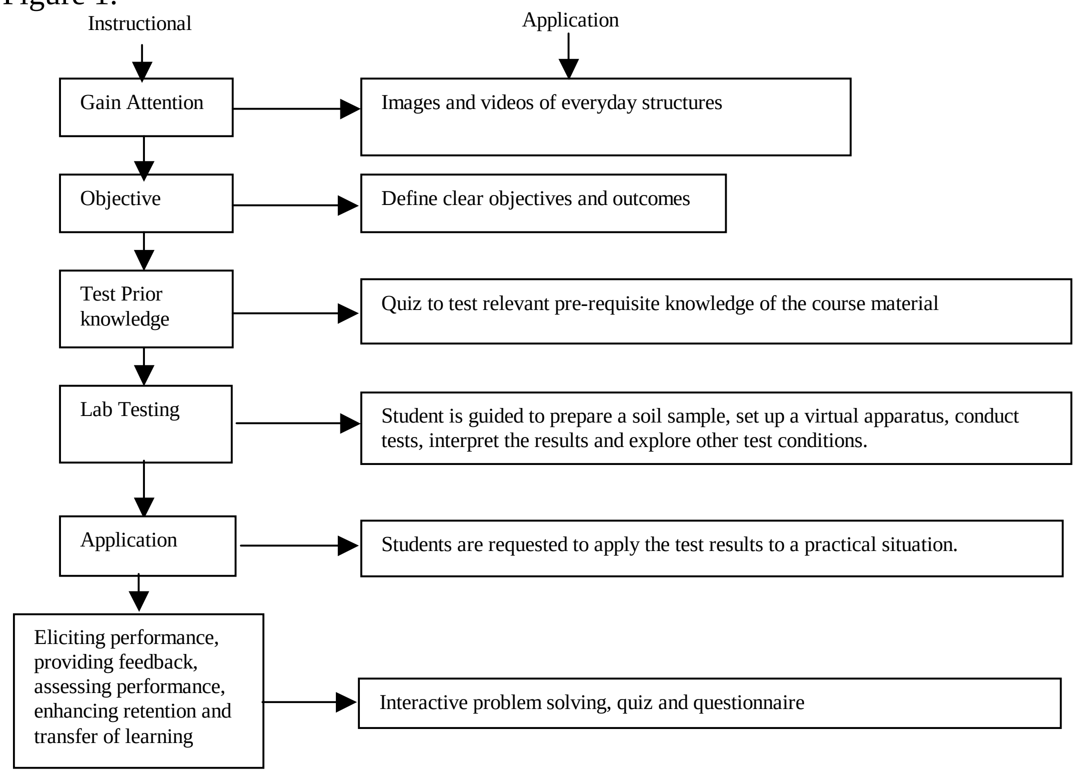
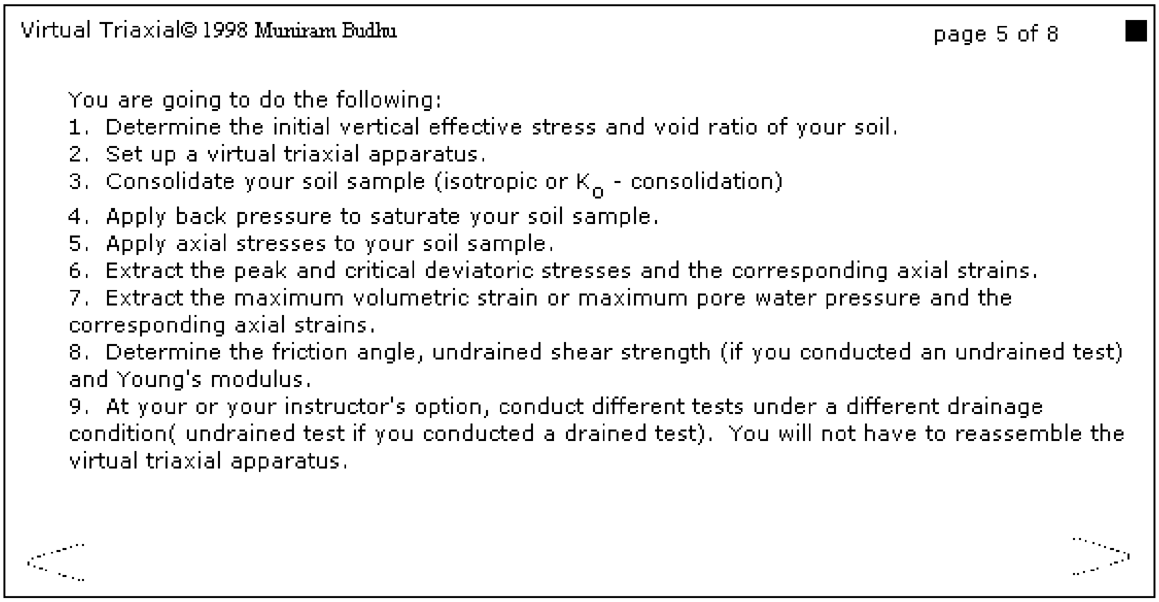


Figure 1 Instructional items and applications in courseware module

Objective and outcomes

The following is an example of informing the student what he/she has to do for a virtual triaxial test.


Virtual Triaxial© 1998 Muniram Budhu page 5 of 8

You are going to do the following:
1. Determine the initial vertical effective stress and void ratio of your soil.
2. Set up a virtual triaxial apparatus.
3. Consolidate your soil sample (isotropic or K_o - consolidation)
4. Apply back pressure to saturate your soil sample.
5. Apply axial stresses to your soil sample.
6. Extract the peak and critical deviatoric stresses and the corresponding axial strains.
7. Extract the maximum volumetric strain or maximum pore water pressure and the corresponding axial strains.
8. Determine the friction angle, undrained shear strength (if you conducted an undrained test) and Young's modulus.
9. At your or your instructor's option, conduct different tests under a different drainage condition(undrained test if you conducted a drained test). You will not have to reassemble the virtual triaxial apparatus.

Pre-requisite knowledge

Prerequisite knowledge is tested as illustrated in Figure 2. In this case, a soil profile is presented. Each student has a different soil profile. This is accomplished by generating random values of the thickness of the soil layers, physical and index properties such as unit weight and liquid limit (LL).

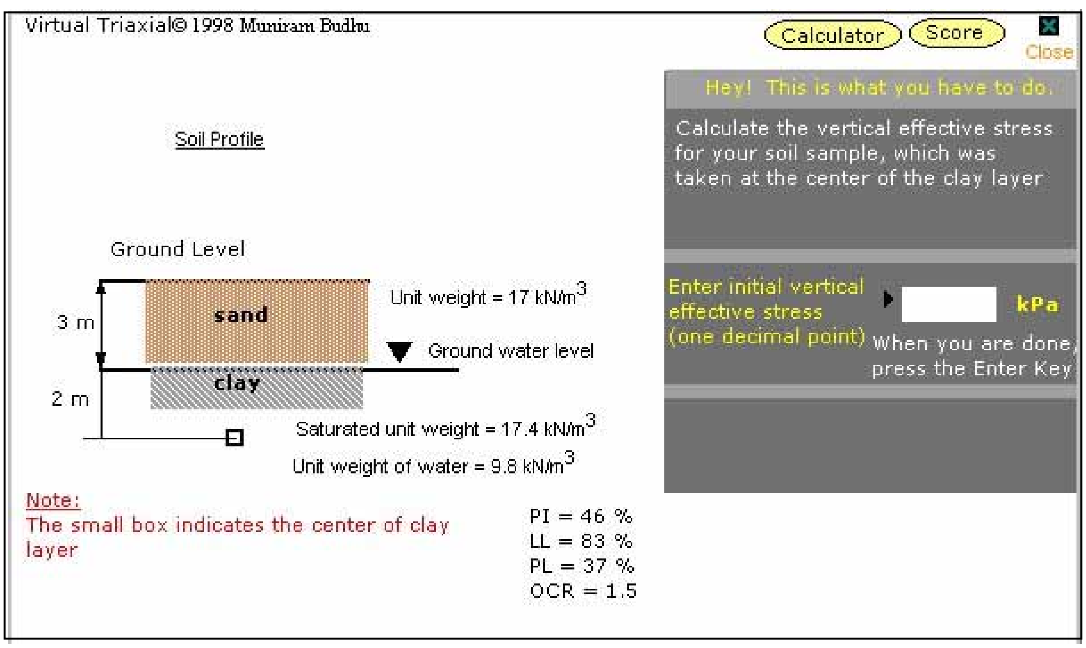


Figure 2 Testing of pre-requisite knowledge

The effective stress principle is an important principle in soil mechanics and to properly interpret the test results the student should know how to calculate the effective stress. When the student enters a value for the effective stress, the program checks whether this value is correct. If it is the student is given a score and can then proceed to the next item in the program. If the value entered is incorrect, the student has up to three trials to get the correct answer. If he/she gets the answer correct on the second attempt, he/she is given full points. Correct answer on the third attempt is one-half the full points. After the third attempt, the correct solution pops out. A record is kept of the student's performance in his/her folder that is automatically generated when the student logs on to the virtual lab. This folder can only be retrieved by an instructor or e-mailed by the student to the instructor. Once the pre-requisite knowledge is tested using the randomly generated soil profile and sample location, the student can view a digital movie showing an actual soil sampling operation in the field.

Sample preparation

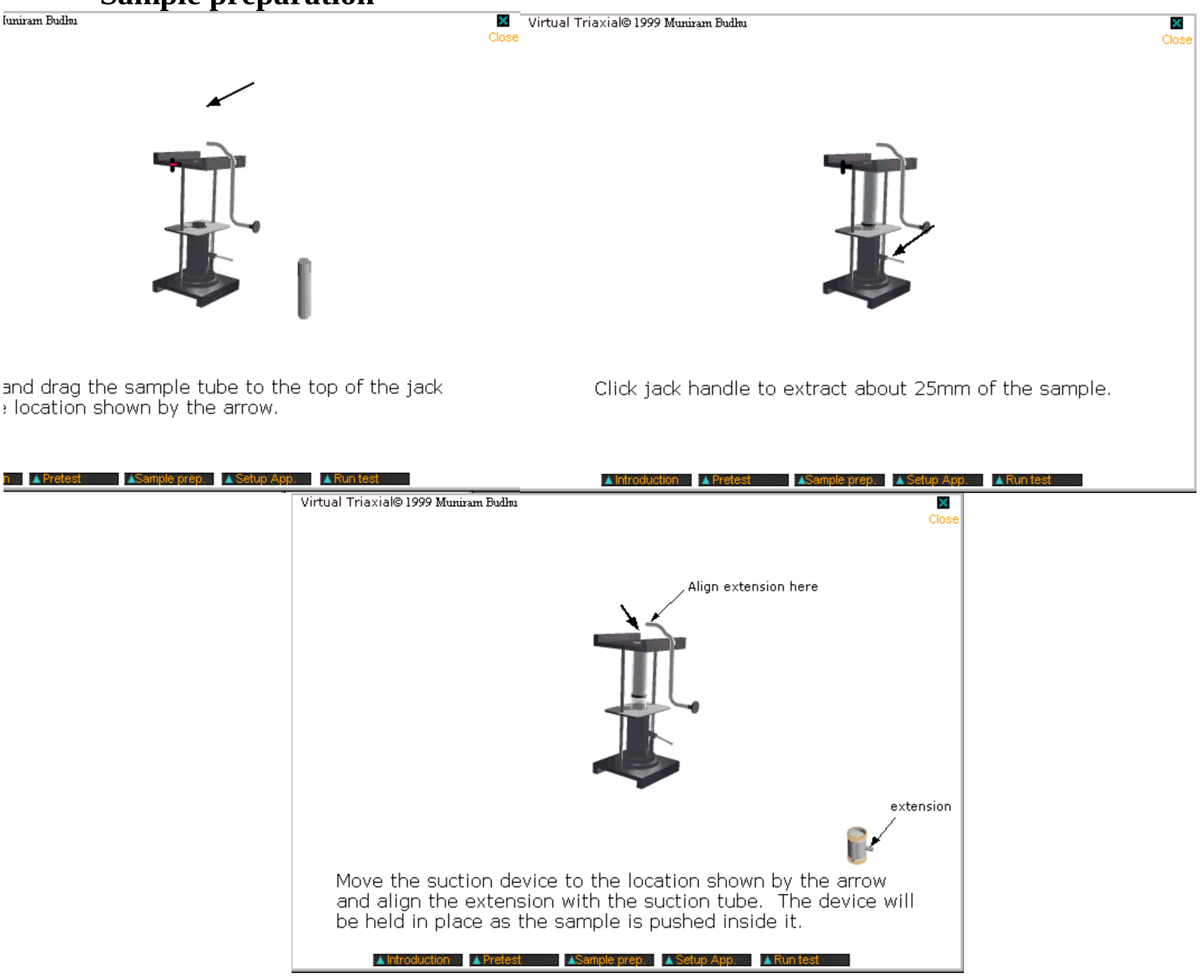


Figure 3 Three of the steps to prepare a soil specimen for testing in a triaxial apparatus

When a field sample is brought to the laboratory, a specimen has to be prepared for testing. Sample preparation requires experience and skill, and it is often a tedious operation. Sometimes a teaching assistant or the instructor will prepare the sample for the students and set it up in the apparatus prior to laboratory class. In the virtual laboratory, the student extracts a soil specimen using a virtual soil extractor and prepares it to set up in the virtual apparatus. Three of the steps of the virtual sample preparation process are shown in Figure 3. The student is guided in all phases of sample preparation and if an error is made, he/she can repeat the process. For sand sample, the extension in Figure 3 is mounted on the bottom sample platen of the apparatus and a hopper is dragged and placed above it. Particles resembling sand are generated and rained down the hopper at prescribed rate to produce the desired density of the sample.

Setting up the virtual apparatus

The student is shown the various parts of the apparatus and is then requested to set up the apparatus using drop and drag activities. The parts shown in Figure 4 allow the student to set up the cell of a shear box test. An exploded view of the cell is shown on the left of Figure 4 to help the student to visualize the completed cell. The student is prompted to move each part and if a part is snapped into position it is correctly placed. Each activity is monitored and the student is prompted to repeat the process if the activity results in an incorrect setup.

Figure 4 Parts of the cell a direct shear test hat the student will set up using drag and drop interactions.

Once the cell is setup correctly, the student sets up his/her virtual apparatus using drop and drag interactivity (Figure 5). The student moves the shear box cell to the apparatus, then places a load bar on top of it, and then attaches the nuts to the bolts to lock the load bar.

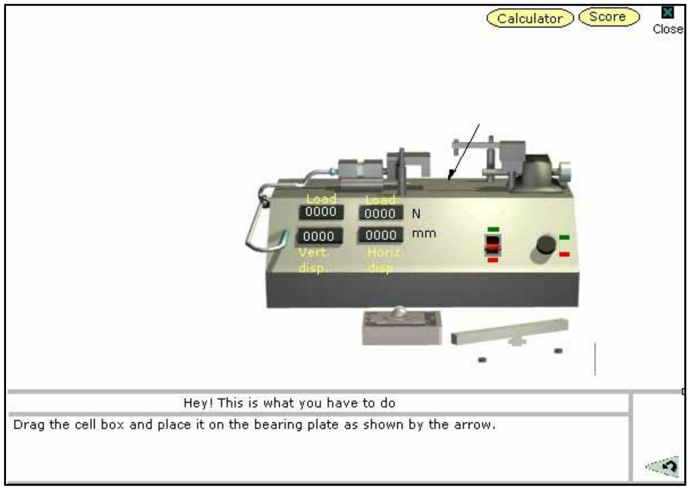


Figure 5 Student uses drag and drop activities to set up a virtual shear box.

Testing phase

The student applies vertical loads by clicking an air valve to open in and allowing air to pressurize a pneumatic jack. The bottom of the cell (a split box) is displaced relative to the top by a stepper motor that is activated by the student clicking a switch to start the stepper motor. A light near the switch changes from red to green to signal that the motor is on. Sound is also used to replicate real switching sound. The displacement rate is preset. The student then observes the changes in shear force and displacements from virtual digital readout units (Figure 6). Graphs of shear force versus horizontal displacements and vertical displacements versus horizontal displacements are displayed to match the virtual digital readout units. The results are predicted using the modified cam-clay soil model (8). The author modified the modified cam-clay model to mimic real soil test results. For example, a perturbation function was added to offset some test values so that the results show the kind of non-smoothness that are characteristic of real tests.

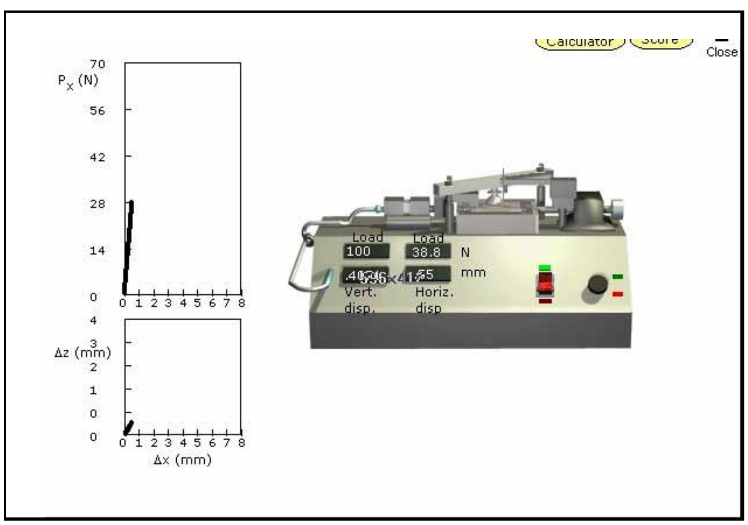


Figure 6 Student observes the changes in shear-displacement behavior of the soil specimen under the desired vertical load

Interpretation of results

After the first test is completed, the student is prompted to enter the desired vertical load for the second test. The student does not prepare a new sample or reassemble the apparatus. Graphs showing the results of the second test are shown next to the first test so that the student can compare the results. After three tests have been conducted at different vertical loads, the student is prompted and guided to extract values to interpret the test results. The student set-ups the apparatus for the first test only. A typical set of values extracted from three direct shear box tests at different loads are shown in Figure 7. The student then calculates the friction angle of the soil. Each answer is automatically checked and the student is given points depending on whether he/she gets the answer correctly on the first, second or third attempt. A record is also kept for the instructor.

These are your results. Calculate and enter the friction angle (1 decimal point) for each test.

Test	P_z N	P_x N	ϕ' Degrees
1	100	35	
2	200	70	
3	300	105.7	

Figure 7 Student is prompted to calculate the friction angle from the test results.

Exploration

Students can now explore other types of tests without sample preparation and assembling of the apparatus. One such exploration is the effect of initial density on the response of soil to shearing.

Application

Once extraction of the required soil parameters and exploration are done, a practical situation is presented and the student is prompted to apply his/her results as illustrated for the consolidation test in Figure 8. In this case, the student extracts soil parameters from the virtual consolidation test and is prompted to use these results to calculate the settlement of a building that is to be located on his/her virtual soil profile

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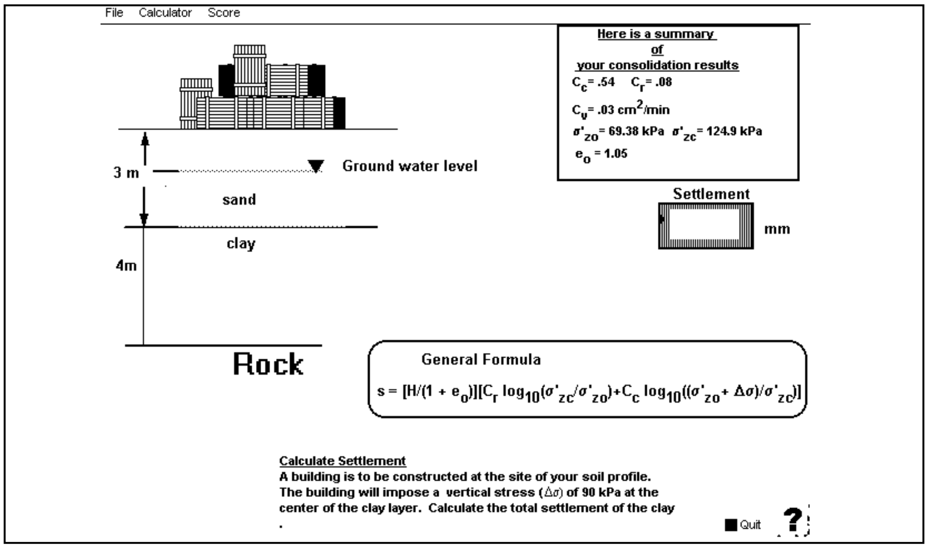

Figure 8 Application of virtual consolidation test results to a practical scenario.

Assessment of knowledge retention

To assess learning and retention, the student completes an electronic quiz as depicted in Figure 9 for the triaxial test. The student has access to his/her score at any time. He/she can e-mail his/her score in the virtual lab and a record of the answers to the quiz to an instructor. Most of the questions on the quiz have values that are randomly generated. Thus, no two students are likely to have the same answer to a particular quiz. The student can access Microsoft's calculator anytime from Win95/98 by clicking a calculator button.

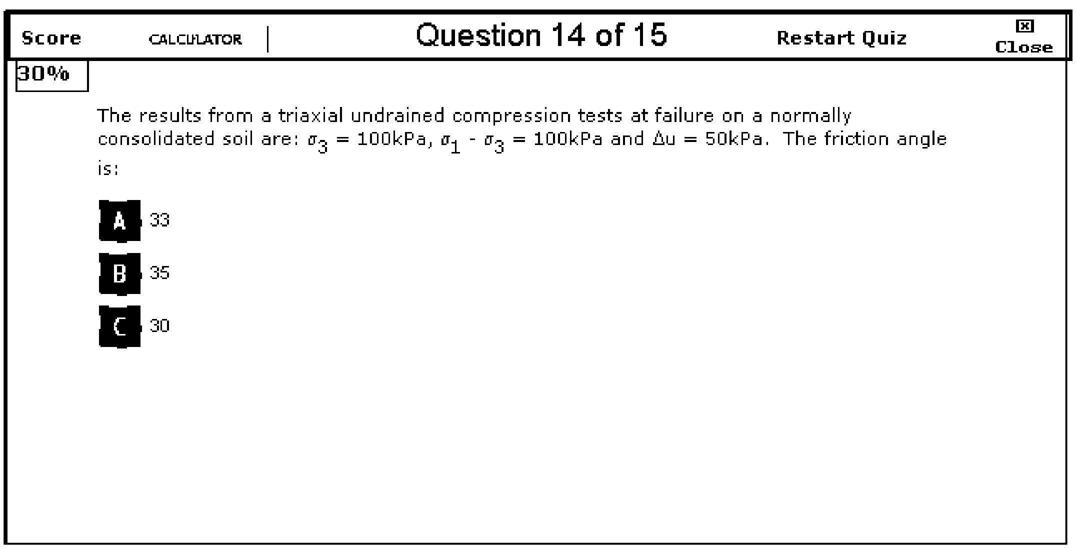

Figure 9 A sample problem in a quiz

Evaluation of modules

During the last two academic years (1999 and 2000), students in civil engineering taking the geotechnical engineering course at the University of Arizona were separated into two groups. One group (Group A) did the real laboratory before the virtual laboratory. The other group (Group B) did the virtual laboratory first and then the real laboratory. In a questionnaire to evaluate the effectiveness of the modules (only the triaxial and consolidation tests modules were evaluated) to transmit information, 95% of the students in both groups agree that they understood the material better because of the use of interactive animation. Eighty five percent of the students in Group B reported that they were able to perform the real laboratory tests better because they conducted virtual laboratory tests before the real laboratory. Sixty seven percent of the students in Group A felt that they would have done the real laboratory better if they had done the virtual laboratory before the real laboratory. Eighty eighth percent of this group also felt that they would have learned more about the fundamental material if they did the virtual laboratory before the real laboratory. All students felt that the animations make them feel as participants in the learning process. Examinations that test knowledge gained in the laboratory were not conducted. Student and faculty evaluations at other institutions are ongoing.

Conclusions

A comprehensive set of modules for virtual geotechnical laboratory testing of soils has been presented. Each module makes use of interactive animation to replicate real laboratory tests. Preliminary evaluation of the modules are encouraging – students felt that their learning of the basic teaching material and their performance in real laboratory tests were enhanced. These virtual laboratory modules can be particularly useful for distance learning.

Acknowledgement

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BIOGRAPHICAL INFORMATION

MUNIRAM BUDHU is a Professor of Civil Engineering & Engineering Mechanics at the University of Arizona. He obtained his Ph.D from Cambridge University and serve as a Visiting Professor at St. Catherine's College, Oxford University in 1995. Professor Budhu is working in the area of Web-based multimedia simulations for training, education and instructions; geomechanics and lattice modeling, and model-based simulations. He consults in multimedia training and course development.