

# **GEOTECHNICAL OPPORTUNITIES FOR COMPUTER-AIDED EDUCATION**

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## **ABSTRACT**

The use of technology in civil engineering design has increased significantly in recent years. This has led to an increased need for graduating engineers that have been able to apply this technology while still in the classroom. This paper presents one of several ideas that have been applied in teaching geotechnical engineering courses at Minnesota State University, Mankato.

Various software packages provide opportunities for students to apply fundamental principles of soil mechanics as related to geotechnical engineering design. These applications range from using software available from government agencies in designing driven pile foundations to using commercially-available finite element analysis software to investigate the staged construction of traditional embankments to various other applications.

Many other possibilities exist to create computer-aided learning environments in the classroom and curriculum. Providing students with the chance to use a few of the tools they will use once they begin their careers as practicing engineers is a significant benefit to both the students and their employers. The ability to provide active learning opportunities to students is also a critical portion of the education experience. Incorporating computer-aided tools in the classroom can greatly impact the learning potential of many engineering students.

## **KEY WORDS**

computer applications, geotechnical engineering, computer modeling, active learning, civil engineering education.

## **INTRODUCTION**

The use of technology in civil engineering design has increased significantly in recent years. According to Lowman (1995), the opportunities available for giving students hands-on experience inside and outside the classroom setting are greater than ever. Various software packages have been developed for many engineering applications, both for use in academia as well as in practice. Such technology has rapidly become an essential tool in state-of-the-art engineering design. This has led to an increased demand for graduating engineers that have been able to apply this technology while still in the classroom. This paper presents one of several ideas that have been applied in teaching geotechnical engineering courses at Minnesota State University, Mankato.

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Various software packages are currently available that provide opportunities for students to apply fundamental principles of soil mechanics as related to geotechnical engineering design. Application of these principles promotes learning. "Observational and hands-on assignments can enrich students' interaction with regular course content and help them to see the course's relevance to real-world issues and human experiences" (Lowman, 1995, page 249.)

For the purposes of the geotechnical engineering program at Minnesota State University, Mankato, these applications range from using software available from government agencies to design driven pile foundations to using commercially-available finite element analysis software to investigate the staged construction of traditional embankments to developing various spreadsheet programs to predict bearing capacity of shallow foundations to a number of other applications. The opportunity to apply geotechnical principles in real-life design situations accentuates the learning process. This paper presents a project that uses a finite element package (Plaxis version 8) to evaluate the optimum staged construction sequence for an embankment on a soft clay foundation.

Many other possibilities exist to create computer-aided learning environments in the classroom and curriculum. Providing students with the chance to use a few of the tools they will use once they begin their careers as practicing engineers is a significant benefit to both the students and their employers. The ability to provide active learning opportunities to students is also a critical portion of the education experience. Incorporating computer-aided tools in the classroom can greatly impact the learning potential of many engineering students.

## **CLASS EXERCISE – STAGED CONSTRUCTION OF EMBANKMENT**

### **PROBLEM STATEMENT**

Students enrolled in the CIVE 467 Earth Structures course at Minnesota State University discuss the significance of slope stability and soil strength parameters on designing and constructing traditional highway embankments. In order to more fully understand the principles of slope stability, effective stress, consolidation behavior, etc., students are given the following problem statement as a class project. A similar example given in the Plaxis User's Manual (Plaxis 2004) was used as the basis for this project. (Due to space limitations, additional sections of this project have been omitted. However, exercises relating to the Ordinary Method of Slices, Bishop's Modified Method, and other appropriate slope stability analyses could easily be incorporated to broaden the scope of the project.)

A highway embankment is to be constructed on a soft clay foundation, as given in Figure 1. The slope of the embankment is 3H:1V, the final embankment will be 6 m high, and the top of the final embankment will be 20 m wide. The estimated soil properties have been provided in Table 1. Using this information, perform the following tasks:

- 1) Develop a model of the embankment using the Plaxis software, and estimate the factor of safety of the embankment assuming undrained soil behavior and immediate construction of the embankment to full height.

- 2) Given your results from part 1, comment on the feasibility of constructing the embankment all at once. Comment on various approaches that could be used to increase the factor of safety.
- 3) Use your model to determine a staged construction sequence that will maintain a factor of safety against failure of at least 1.2 throughout the construction process. Consider adjusting lift heights, consolidation times, etc., to optimize the time of construction without compromising your factor of safety at any time.
- 4) Comment on the effects of excess pore water pressure on foundation strength. How much of an increase in foundation strength can be gained with time due to the dissipation of such excess pore pressures?

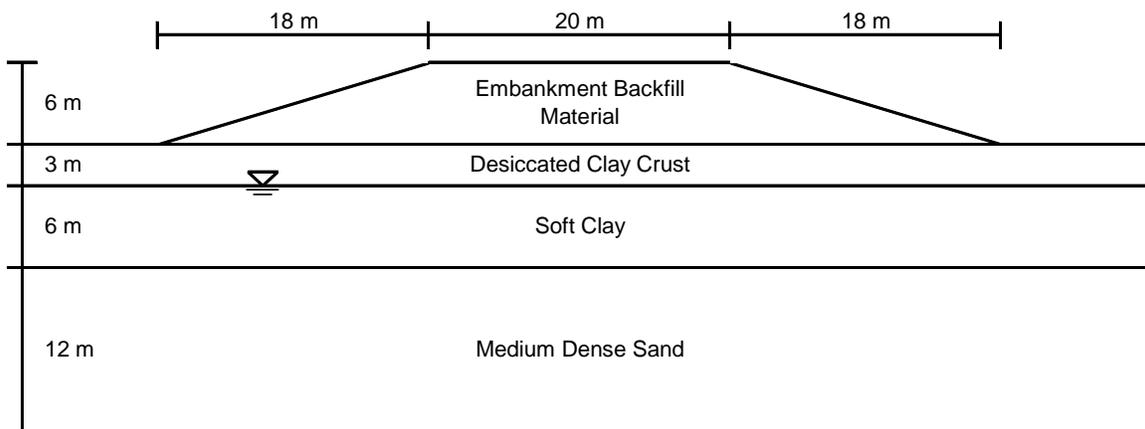


Figure 1: Cross Section of Highway Embankment Project on Soft Clay Foundation

Table 1: Soil Parameters for Highway Embankment and Foundation Material

Soil Type	$\gamma_{unsat}$ ( $\text{kN/m}^3$ )	$\gamma_{sat}$ ( $\text{kN/m}^3$ )	$k$ (m/day)	$E_{ref}$ ( $\text{kN/m}^2$ )	$\nu$	$c_{ref}$ ( $\text{kN/m}^2$ )	$\phi$ (deg)
Embankment Backfill Material	19.0	20.0	1.000	5000	0.3	0.01	35
Desiccated Clay Crust	15.0	18.0	2.5E-04	1000	0.3	2.5	25
Soft Clay	14.5	17.0	2.5E-04	750	0.3	1.5	22
Medium Dense Sand	16.0	19.0	1.000	3000	0.3	0.01	32

## SOLUTION PROCEDURE

The first step for the students is to create a model of the embankment. In this case, symmetry of the problem requires only half of the embankment to be modeled. The procedure for entering the model geometry, boundary conditions, soil properties, etc., can be found in the Plaxis User's Manual (2004). The students will eventually need to discretize the embankment in order to model the staged construction process. Figure 2 provides an example of a Plaxis model of the embankment.

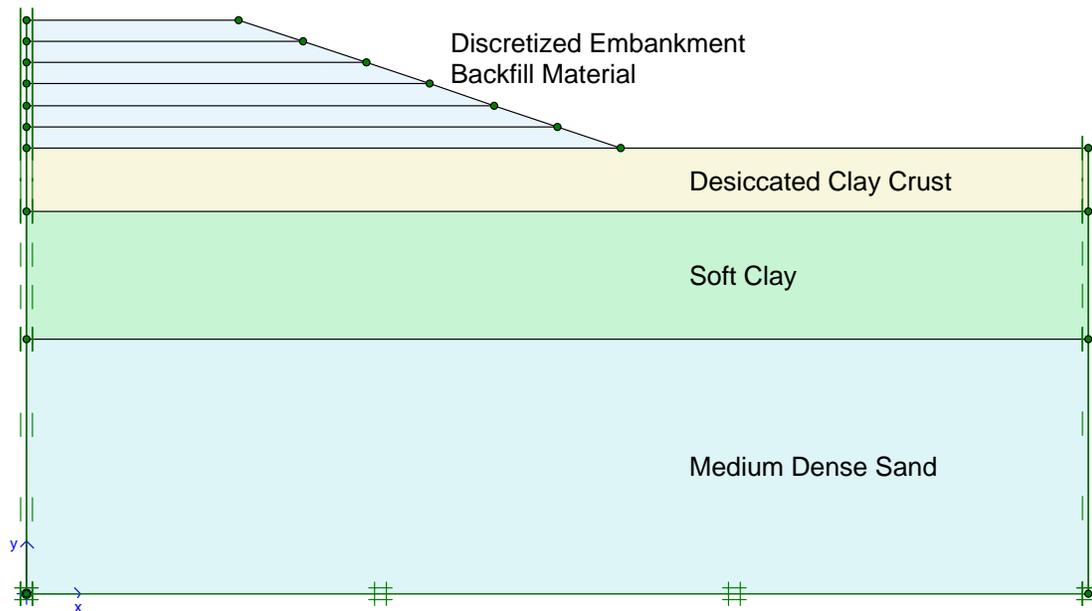


Figure 2: Plaxis Model of Embankment Geometry and Boundary Conditions

Once the students have constructed the necessary geometry for the model, established the boundary conditions, and entered the soil parameters, the next step is to generate the finite element mesh. The intent of the exercise is not for students to become expert in finite element analysis, as this is beyond the scope of this course. However, the students are given enough background on finite element theory that they are able to produce an appropriate mesh using the Plaxis software. An example of such a finite element mesh is shown in Figure 3.

Once the mesh has been developed, the initial conditions can be established. As given in Figure 1, the water table is located at the interface between the Desiccated Clay Crust and the Soft Clay, 3 m below the original ground surface. The centerline of the embankment (the left boundary of the model) is assigned as a closed consolidation boundary as an appropriate boundary condition. The right edge of the clay layers are also assigned as closed consolidation boundaries. Otherwise, Plaxis assumes a default of having a free-draining boundary.

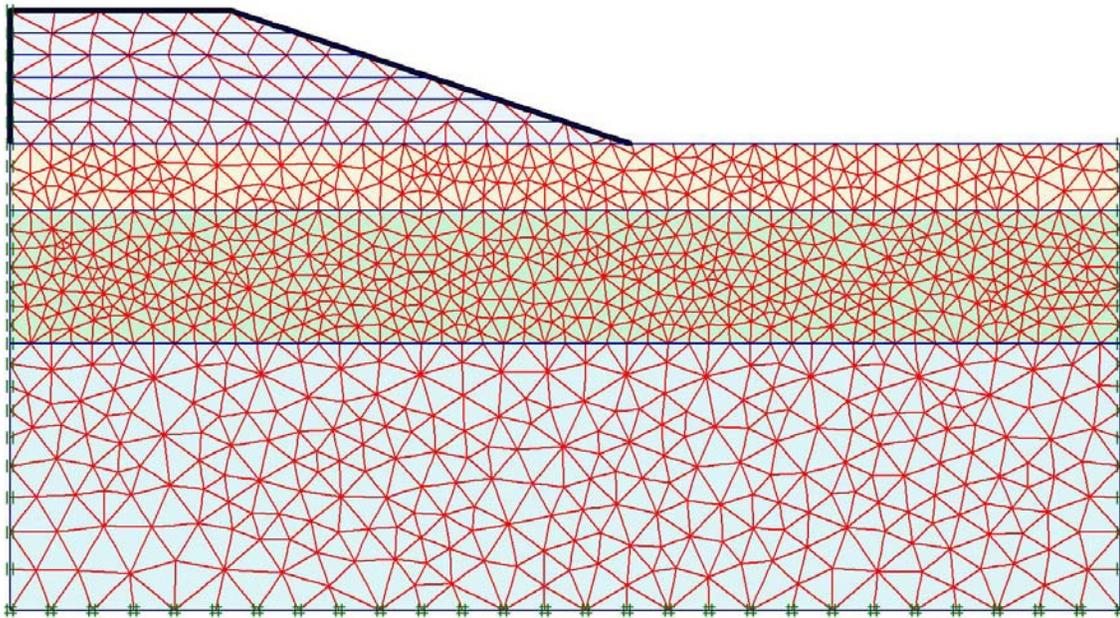


Figure 3: Example Finite Element Mesh for Embankment Model

With the appropriate boundary conditions and the location of the water table established, the initial phreatic conditions can be calculated. Next, the initial stresses in the foundation material are established. This is done by deactivating the embankment backfill material layers and calculating the stresses in the foundation material before construction begins.

With the initial conditions established, the students are able to continue with the project. First, they have been asked to determine what the factor of safety would be if the embankment was constructed immediately and the foundation material not allowed to drain. This can be done in two steps in the Plaxis Calculations process. First, the embankment is constructed using the Staged Construction option under the Consolidation analysis. Again, more detail as to these steps can be found in the Plaxis User's Manual (2004). Once the staged construction has been performed, a  $\Phi/c$ -reduction can be performed to determine the factor of safety against failure of the embankment (Plaxis 2004). For this example, students should find that the factor of safety is less than unity, such that the embankment cannot be constructed all at once.

Now, the students have an opportunity to try a variety of combinations of staged construction lift heights and allowed consolidation times in order to optimize the construction time while not compromising the factor of safety criterion. Their goal is to build the embankment as quickly as possible, while not allowing the factor of safety to drop below 1.2 at any point during construction. They are free to use whatever reasonable lift heights they choose and to optimize their construction schedules. An example of a construction sequence that meets the criteria for the project is given in Table 2.

Various approaches will lead to a number of required construction times. Some students will attempt to construct the embankment with the largest possible lift height, which will also

increase the required consolidation time needed to obtain a sufficient factor of safety with subsequent lifts. Other students will apply smaller lift increments that will allow a smaller amount of time between subsequent lifts, due to smaller excess pore pressures developing in the undrained material. As various combinations are undertaken, the students will get a better appreciation for the importance of construction sequencing, especially with respect to soft foundations.

Table 2: Construction Sequence for Highway Embankment Construction

Description of Step	Cumulative Time to Completion of Step	Factor of Safety
Construct First 2 m of embankment (2 m total)	0 days	1.223
Allow 60 days of Consolidation	60 days	1.841
Construct Additional 2 m of embankment (4 m total)	60 days	1.233
Allow 180 days of Consolidation	240 days	1.573
Construct Final 2 m of embankment (6 m total)	240 days	1.226
Long Term Factor of Safety		1.744

At any point in the construction sequence, students will be able to examine the excess pore pressure distribution, the effective stress distribution, the deflections of the embankment and foundation material, etc. As an example, Figure 4 shows the deflections in the model following the  $\Phi/c$ -reduction after primary consolidation has been completed. This shows the failure surface expected to develop in the embankment/foundation system. As previously noted, students may be asked to compare factor of safety results obtained from Plaxis to those obtained either by hand- or spreadsheet-calculations of the factor of safety using the Ordinary Method of Slices, Bishop's Modified Method, etc. Also, the students may evaluate the excess pore pressures generated during the construction process, and monitor the dissipation of the excess pore pressures with time.

## CONCLUSIONS

Many tools are available for engineering students to provide them with active learning opportunities to enhance their educational experience. Not only do such tools allow improved learning opportunities, but the experience of using such tools will also benefit them in the engineering profession, since many of these programs are applied in practice. Giving students to opportunity to use a variety of software packages in their academic careers can be a significant benefit to them.

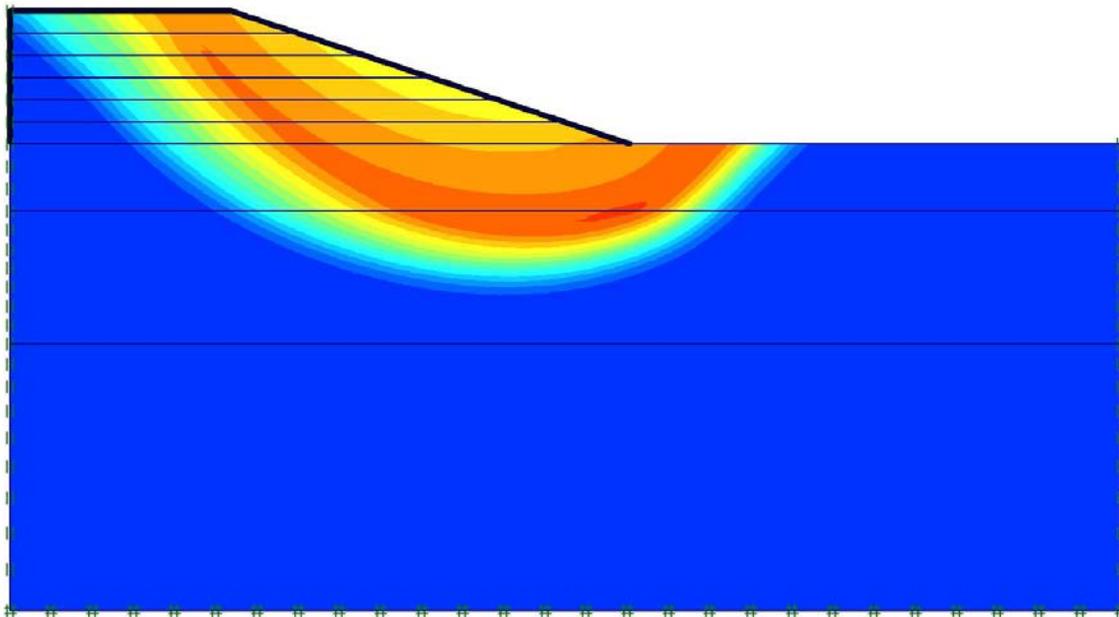


Figure 4: Embankment Model Deflections After Long-term  $\Phi/c$ -reduction

This paper has described one such application of a learning tool used to analyze an embankment constructed on a soft clay foundation. The Plaxis finite element software package has been used at Minnesota State University, Mankato to allow students to gain a better understanding of the undrained response of a soft foundation during embankment construction, and also allows students to use their creativity in developing a construction sequence that optimizes the time required to construct the embankment. Not only do the students become familiar with the basics of finite element modeling, but they are also provided with the opportunity to gain a deeper understanding of basic soil mechanics concepts discussed in the class. Providing students with similar opportunities to actively learn about various concepts can make a significant difference in the quality of education provided.

#### ACKNOWLEDGMENTS

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