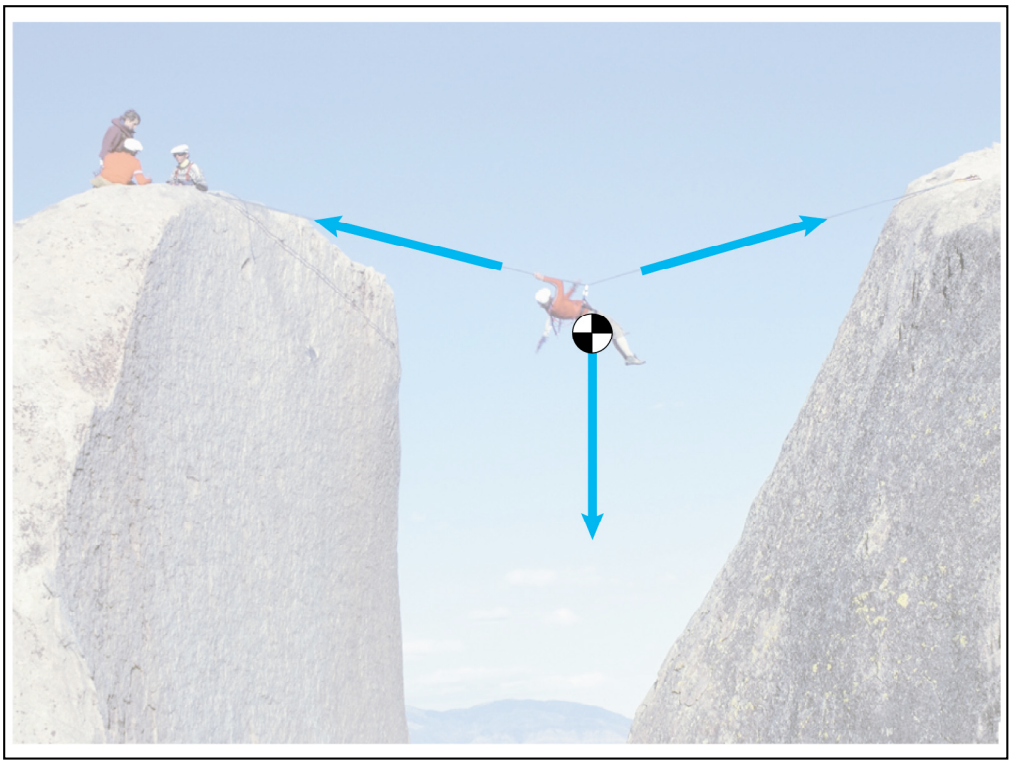
MAKING BASIC MECHANICS COURSES INSPIRATIONAL

A critical account, Searle Fellows Program



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May 5, 2008

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"Enough of what lies beneath. And men who play with dirt.
No glory gained when your greatest works lay hidden below the earth"
Student reaction to an intro course in soil mechanics.

Introduction and problem statement

Aiming to inspire Generation Y students, the **objective** of this project is to redesign a (soil) mechanics course to accommodate inductive learning. It is expected that enhanced inspiration will be conducive to four broad outcomes: involvement, deep learning, critical and inquisitive thinking. The key idea is to map the learning objectives of all the courses I teach onto these broad outcomes. As such, the outcomes define a framework for teaching exciting courses in science and engineering with Generation Y students as the target audience. Hence, within this framework, the **project outcomes** are aimed at inspiring the students and the instructor by:

1. encouraging direct student involvement to take responsibility for their learning

2. helping students acquire deeper learning using their own learning process

3. facilitating the development of critical thinking to bolster competency

4. facilitating the development of inquisitive thinking enabling continuous learning

Figure 1 shows a schematic of the project outcomes and highlights their interconnectivity and collective duality with inspiration.

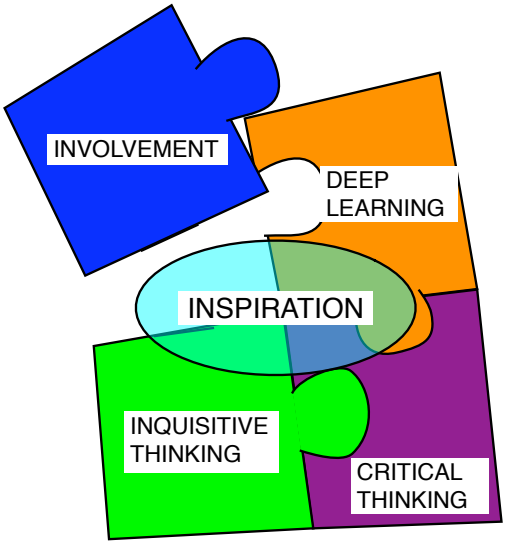

Figure 1. Project outcomes, interconnectivity, and collective duality with achieving inspiration.

Even though the overarching objective is aimed at mechanics courses in general, this project focuses on a particular *required* undergraduate course in civil and environmental engineering entitled "Introduction to Soil Mechanics" or CEE 250. Most of the students that take this course have declared civil engineering as their major. This course is taken here as a prototypical mechanics course in the sense that it is a core course in an engineering curriculum [Felder and Brent, 2003] (e.g., Statics and Dynamics, Physics) and, at the same time, it is heavily dependent on math and Newtonian mechanics. This course, as many core courses in engineering, is perceived by the students as 'dry' and tends to discourage many of them from pursuing advanced careers in engineering and science.

One of the main challenges in core engineering courses is finding the balance between having to cover fundamental material necessary for higher-level courses and the engineering profession and actually teaching the students effectively. Teaching and covering material may not always commute [Light and Cox, 2001]. Furthermore, these courses have been designed to teach (and are currently mostly taught by) Baby Boomers (born between 1946-1964) and seem out of touch with the younger Generation Y (born between 1978-1994) students. Generation Y (Gen Y for short) students have clearly different traits, interests, and learning styles than Baby Boomers [Howe et al., 2000]. Nevertheless, mechanics is being taught the same way it was taught in the 1950's: general theory, followed by some in-class examples to apply the theory, followed by a laboratory to observe the theory, a report to summarize the observed theory, homework to reinforce the theory, (sometimes) a project to apply the the-

ory, and finally exams to evaluate how well students learned the theory. Furthermore, instruction takes place on the board with very little help from visualization[1].

The classical teaching style ignores the traits in Gen Y students and may not be effectively addressing the most important question related to this generation: Why? Generation Y students want to make a difference, and so, relevance is crucial to them [Howe et al., 2000]. This key (and valid) question is somewhat brushed over in core courses because instructors feel it is 'obvious' that the course has relevance given the student's major. However, the relevance question is central in the new education environment where students are not even sure about their major. Anecdotally, out of 16 freshman advisees I currently supervise, 7 have undeclared majors, one transfered to Feinberg School of Medicine, and one came from Weinberg College of Arts and Science. Hence, only about 50% of my advisees is certain about their major in freshman year.

Another important factor defining Gen Yers is their digital nativity. The following statistics about these individuals are quite telling [Junco and Mastrodicasa, 2007]:

97% own a computer

94% own a cell phone

77% use instant messaging with 15% logged on 24/7

34% use websites as their primary source of news

28% author a blog and 44% read blogs

Therefore, information has to be relevant, it must flow fast, and it must exploit the digital world. None of these are typically addressed directly in our core mechanics courses today (e.g., the professor writing board after board in class, transmitting away knowledge [Light and Cox, 2001]).

In this project, a paradigm shift is proposed whereby a core soil mechanics course will be revamped to accommodate and inspire Gen Y students. The project empowers Gen Yers by getting them involved directly in the class, it also exploits their digital inclination by having them use virtual laboratories, webcasting capabilities, and blogs. One mayor change in the classroom will be the use of inquiry-based inductive teaching to underscore the relevant topics and put them in context, helping motivate the students [Prince and Felder, 2006]. All of these changes are implemented without sacrificing the key contents of the course.

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[1] Should not be perceived as suggestive of PowerPoint-based teaching. Should be perceived as advocating further use of figures and visual aids in general to facilitate learning.

The project will be implemented during the academic years 2008-2009 and 2009-2010. The first installment of the project in 2008-2009 will serve as a control group with soil mechanics being taught in the classic deductive way. Then, in 2009-2010, the course will be taught by the same instructor but deductively. This new course will be called here soil mechanics Y. Therefore, in 2008-2009 soil mechanics is taught and then in 2009-2010 soil mechanics Y is offered by the same instructor, followed by an evaluation phase where the effectiveness of these courses to achieve the (same) learning objectives is gauged.

The organization of this critical account is as follows. In the next section, the classical deductive approach used to teach mechanics courses is described to help contextualize the proposed methodology. After this, the proposed inductive method is described in detail. The activities planned for the course are contrasted with those in the classical approach. Assessment of the of the proposed inductive teaching is outlined in the Evaluation section. The critical account concludes with some summarizing remarks.

The classical deductive approach

"*In the beginning, there were definitions*"

Soil mechanics is a course that serves to introduce the students to the field of complex material behavior. In fact, many students come into the course without knowing what to expect from the course. Most of their background up to this point has been in clean-cut subjects, such as, calculus, physics, mechanics of materials, etc. All based on very clear, concrete principles. And then they take soil mechanics. A typical course syllabus is included in Appendix A.

The first week or so of the quarter is spent on definitions. What is a soil versus a rock, where do soils come from, and what are some of the defining physical parameters for soils. For example, the classical 'void ratio' is defined as

$$e = V_v / V_s$$

where V_v is the volume of voids or empty pores in the soil and V_s is the volume of solids. The professor draws a picture similar to the one shown in Figure 2(a) to illustrate that a soil in dry state is a combination of solids (grains) and empty spaces. Hence, one can talk about the volume of solid and the volume of voids (emptiness) and use these to define void ratio. A classic abstraction of the solid and porous space is shown in Figure 2(b) and it is typically referred to as the phase diagram.

Clearly, the quarter starts-off by submerging the students in definitions (hence the caption above from a syllabus in our current soil mechanics course). The challenge is to introduce

these important definitions, without overwhelming the students. Furthermore, can we introduce this definitions in a way that allow the students to meet all four project objectives? The answer is not straightforward, but a big part of the solution lies on shifting to inductive teaching by introducing concepts based on inquiry. We will develop these ideas further in the next section.

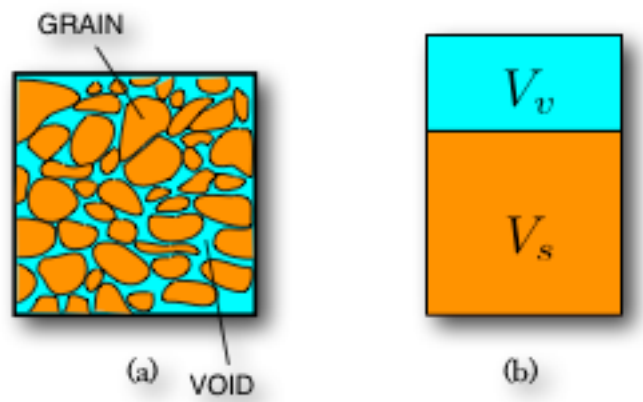

Figure 2. Classic illustration of solid and void volume; (a) idealization of granular material, (b) phase diagram used to represent volume fractions in granular material.

The remainder of the quarter is devoted to introducing the students to very important concepts in soil mechanics. As evidenced in the syllabus, the concepts of compaction, effective stress, flow through porous media (Darcy's law), the one-dimensional theory of consolidation, and the theory of strength of materials applied to soils is introduced. Each of these topics is covered deductively: theory → examples → lab → report → homework.

For example, the topic of Darcy's law is introduced by deriving, based on physics, Darcy's equation, which governs flow though porous media. In its simplest form, Darcy's law can be expresses as

$$q = ki$$

where the flow of water q per unit area is directly proportional to the head gradient i via the permeability constant k. The permeability is a material constant that needs to be determined experimentally and measures the easiness for water to flow trough a porous medium. Thus, Dacy's law establishes the theoretical framework. Once the students are introduced to Darcy's law, they use it on a few example problems in class. The experimental setup used to evaluate permeability in a soil is briefly described in class and the students attend a lab later in the week where they 'perform' the actual experiment. A report is written

summarizing the results and observations in the laboratory. Even thought the idea of the experiment is excellent to expose the students to the physical reality, the students are quite passive during the experiment, they mostly observe the teaching assistant perform the experiment. Needless to say, students find the lab experience rather onerous. Here is some feedback on the class CTEC about the laboratory experience: "I would rather be attacked by rabid monkeys wielding compaction hammers than write up another one of the lab reports. Most of the time spent on this class outside class was wasted doing the lab reports and I wish I found more time to do the homework and prepare for the tests."

The following section will describe a proposed revamping of the course, keeping all ingredients in place: theory, examples, lab, report, and homework, but rearranging the order in which they are presented to introduce the material inductively. Also, the laboratory experience will be significantly transformed to involve the students directly and enhance deeper learning and further physical intuition (i.e., critical and inquisitive thinking). None of these changes will affect content.

The proposed inductive approach

"To state a theorem and then to show examples of it is literally to teach backwards"

E. Kim Nebeuts

A well-established precept of educational psychology is that people are most strongly motivated to learn things they clearly perceive a need to know [Alabanese and Mitchell, 1993]. This is certainly true about Generation Y students. In this project we will exploit this precept by using inductive teaching and learning. Instead of beginning with general principles and eventually getting to applications, instruction begins with specifics—a set of observations or experimental data to interpret, a case study to analyze, or a complex real-world problem to solve [Prince and Felder, 2006]. As a matter of terminology, inductive teaching and learning methods can be divided into: inquiry-based learning, problem-based learning, project-based learning, case-based learning, discovery learning, and just-in-time teaching. All inductive methods have several features in common. They are all learner-centered, they all use constructivism, and they all invoke active and collaborative learning [Prince and Felder, 2006]. All of these features will be incorporated into revamping the soil mechanics course in our project.

The particular form of inductive learning that we have chosen is inquiry-based learning. Inquiry learning is the simplest of the inductive approaches and begins when the students are presented with questions to be answered, engineering problems to be solved, or a set of experimental data to be explained [Bateman, 1990]. Hence, inquiry-based learning lends itself

beautifully to mechanics courses since it is rather easy to provide a set of experimental results or a case-study or an engineering problem that is complex and needs a solution. From the standpoint of motivating Gen Y students, the latter two are obviously preferred. In the newly developed soils mechanics course (henceforth called soil mechanics Y), case-studies and complex engineering problems will be used to motivate the course, but experimental results will be used heavily to introduce the theory. This constitutes a major change of paradigm in teaching since now the teaching sequence looks more like lab → theory → examples → lab → report → homework. Note, the lab appears twice in the sequence: the first time it occurs to motivate the topic and to provide experimental data for the theory to be introduced. Furthermore, the experimental data presented will exploit high-tech visualization tools, capable of displaying physical systems very effectively [e.g., see the VizClass environment for mechanics courses, Grimes et al., 2006]. On the second occurrence, the lab experience is focused on performing experiments and reporting on results. The simplest way to exemplify the process is by way of an example.

Let us consider the topic of Darcy's law again. In the classic soil mechanics approach, as explained above, the students look at Darcy's law in the class and then learn about the laboratory test to measure permeability and *use* Darcy's law to interpret the data obtained in the experiment to extract the permeability k. The approach in soil mechanics Y will be to give students with a quick intro to the permeability experiment and provide them with the data needed to 'derive' Darcy's law. Of course, since soil mechanics is an undergraduate course, the inquiry procedure will be structured [Staver and Bay, 1987], i.e., the instructor will present the data and facilitate the discussion to arrive at a solution.

Table 1 presents data from an actual permebility experiment. From this data, a discussion of how to correctly plot the results will be started and the students will be directly involved in such discussion. Eventually, based on guided discussion, one arrives at the plot of the data shown in Figure 3. It is apparent from this data that the relation between flow and head gradient is linear, there is a constant slope (the permeability) relating these two variables. At this point, Darcy's law is introduced and deductive teaching begins: theory → examples → lab.

Trial	Flow (cm/sec)	Head gradient
1	0.00657	0.09167
2	0.01584	0.20833
3	0.02266	0.29583
4	0.04974	0.63333
5	0.06079	0.79167

Table 1. Data from permeability test.

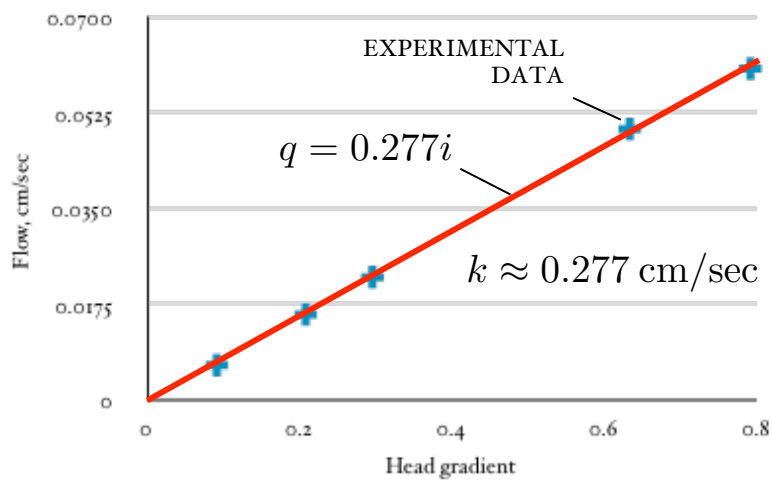

Figure 3. Flow versus head gradient, linear trend clearly reveals constant permeability.

The other major change to the class is revamping the laboratory experience (the second laboratory experience in the lab → theory → example → lab sequence). Five experiments are currently conducted in the classic soil mechanics course. However, students are not able to conduct the experiments directly for lack of training and limited experimental equipment. Consequently, most students in the class are passive during the lab experience, watching the TA perform the experiment. In soil mechanics Y, the five experiments will be conducted very differently to maximize student involvement and exploit their digital inclination.

In soil mechanics Y, the class will be divided into five groups at the beginning of the quarter. Each group will be responsible for demonstrating one randomly-assigned experiment to the rest of the class. Demonstration entails explaining the experimental setup thoroughly and actually performing the experiment. The results will be disseminated electronically and in real-time to the class during the experiment. In this way, we will ensure that the students

become proficient with at least one experiment at a much deeper level than they currently do. Furthermore, the demonstration will not be on site. The group demonstrating the experiment will be in the laboratory while the rest of the class will see the experience via two-way video conference over the internet (e.g., Skype, IM, iChat) and may not be physically present in the lab but connected remotely. The idea is to have the students explain the experiments to their peers and have to answer questions from their peers, opening a class discussion where the TA is a simple facilitator and no longer an instructor. The video conference detail is aimed at exciting the students and liberating them form having to come to the lab every other week in the quarter.

At the end of each experiment, each group will write a report summarizing the experimental data in the usual way. In addition, a blog will be setup where the students will criticize the performance of their peers that presented the lab. The group that presents the experiment will reflect on their individual and collective performance. What worked well and what did not work so well, etc. The blog will serve as a forum to exchange ideas that the other groups can learn from and to once again encourage student participation.

Both classic soil mechanics and soil mechanics Y courses have the same **course outcomes**. The students in this course will be able to:

1. Apply mathematical tools and (soil) mechanics to identify, formulate and solve engineering problems

2.Conduct experiments and analyze data to extract relevant soil properties and report these findings effectively in writing

3.Use (soil) mechanics principles to design engineering systems

4. Participate effectively in team presentations and assess the strengths and weaknesses of the individuals and the team as a whole

It is important to note that these outcomes align very well with Outcomes 3a-3k of the ABET Engineering Criteria [Felder and Brent, 2003]. It is also important to realize that the course outcomes in both versions of soil mechanics must be the same to be able to make fair comparisons during the evaluation phase. In fact, the **learning objectives** for both courses are also identical and will map onto the course outcomes. The course objectives state that the students that pass the soil mechanics course will be able to:

- Describe and classify soils broadly
- Evaluate and design soil compaction procedures

- Use the concept of effective stress to calculate and discriminate between total, effective, and pore water stresses
- Determine soil permeability and use it for seepage calculations
- Specify, conduct, and interpret soil tests to characterize soils
- Use concepts of elasticity and strength of materials to extract material parameters from soil tests and to use such parameters in calculations of stresses and deformations

The soil mechanics Y syllabus is attached in Appendix B for further reference.

Evaluation

Three (semi-independent) metrics will be used to assess the effectiveness of soil mechanics and soil mech Y in achieving the learning objectives and outcomes: regular assessment (exams, homework), exit surveys, and CTEC. These metrics will provide qualitative and quantitative data to help differentiate between the deductive and inductive versions of the course. Additionally, in soil mech Y, the blogs will be used to measure the motivation of the students in the course as the course is being taught, allowing for some real-time changes.

In both classic soil mechanics and soil mech Y, students will take the same examinations and will solve the same homework. Hence, if the assessment in the courses is well-aligned with the learning objectives, comparing the performance from the class in 2008-2009 with that of the 2009-2010 class, will give us a somewhat meaningful quantitative differential measure. However, evaluating whether students in course A achieved the objectives and outcomes of the course more effectively than students in course B is not straightforward to assess. Many factors could affect the numeric values, for example, variations in the quantity and quality of students in the class from one year to the other, the fact that this project is about introducing induction in leu of deduction could bias the instructor, the fact that soil mech Y is taught after soil mechanics could also affect the results, etc. Nevertheless, the comparison seems reasonable and appears to be as unbiased as possible.

Another metric will be provided by short exit surveys measuring the effectiveness of the course to achieve the learning objectives and course outcomes, from the students perspective. This will be a metric coming from the students and not necessarily related to their performance on the course.

Finally, the CTEC in both courses will provide some qualitative and quantitative measures of student's satisfaction. Some additional questions might be included in the CTEC to help compare the effectiveness of the two courses.

Closure

We have presented a critical account aimed at inspiring Generation Y students enrolled in soil mechanics (soil mech Y). The proposition is that inspiration will be achieved by inductive learning via four project outcomes: student involvement, deeper learning, critical thinking, and inquisitive thinking. The soil mech course will be revamped to use a learning sequence involving lab → theory → examples → lab → homework → exam. Technically, the only difference with the classical sequence is the addition of the lab experience before the theory, helping motivate the topic using experimental data. Furthermore, the laboratory experience will be significantly changed, with students being responsible for explaining and conducting experiments directly, exploring video conferencing to increase flexibility. At the same time, discussions will take place using blogs, giving students a forum to ask questions and constructively provide and receive criticism. Finally, the effectiveness of the course in achieving the learning objectives and outcomes will be measured against the backdrop of the classic soil mechanics course performance. This is a meaningful comparison as both courses will have the same objectives, outcomes, and assessment. It is expected that this project will provide us with quantitative and qualitative data to estimate the effectiveness of inductive teaching in engineering and science.

Appendix A

CE 250 – Fall 2007
Introductory Soil Mechanics

Professor Richard Finno
Room A128 Tech
491-5885
r-finno@northwestern.edu

Office hours:
M W 2:00 – 4:00

Course Outline

Topic	Date	Reading Assignment (Holtz and Kovacs)
I. In the beginning, there were definitions…	9-26	1.1-1.7
Phase relationships	9-28, 10-1	2.1-2.3
Index properties of soils	10-3, 5	2.4-3.2
Soil structure	10-8	4.1-4.9
II. Compaction		
Concepts and engineering significance	10-10, 12	5.1-5.4
Practical considerations	10-15	5.5-5.7
III. Water in soil and the effective stress principle		
Capillarity	10-17	6.1-6.2
Water-induced volume changes	10-19	6.3-6.5
Water flow through soil	10-22	7.1-7.4
Effective stress	10-24, 29, 31	5-7.6, 11.7
Seepage and flow nets	11-2, 5	7.7-7.11
IV. One-dimensional consolidation		
Magnitude of settlement	11-7, 9, 12	8.1-8.11
Rate of settlement	11-14, 19, 21	9.1-9.8
V. Shear strength of soil		
Mohr's circle of stress Mohr-Coulomb failure	11-26	10.1-10.2
criteria	11-28	10.3-10.4
Shear strength evaluation	11-30	10.5
Drained shear strength of sand	12-5	11.1-11.2, 11.6
Undrained shear strength of clay	12-7+lab period (?)	11.9.1-11.9.13

Laboratory

Laboratory sessions tentatively will be held on Wednesdays at 6:00 p.m. in room AG40 according to the following schedule. On days when no lab is scheduled, additional lectures may be given or the time may be used to answer questions. Your TA is Mr. Izzat Katkhuda, a graduate student in geotechnical engineering. His office is in room AG50, and his phone number is 7-1392 and email is i-katkhuda@northwestern.edu.

Soil Classification	10-3	"Quicksand"	11-7
Compaction	10-10	Consolidation	11-14
Permeability	10-24		

Ground rules: CE 250

Textbook:

Holtz, R.D. and Kovacs, W.D., An Introduction to Geotechnical Engineering, Prentice-Hall, Inc. Englewood Cliffs, New Jersey, 1981.

Exams:

Hour exams are tentatively scheduled for October 26, November 16, and December 3.
The final exam is scheduled for Thursday, December 13 at 9:00 a.m.

Homework:

Assignments will be given weekly from the text and other sources. Homework will usually be assigned on Monday of each week and will be due the following Friday. Full credit will not be given for late assignments.

Laboratory reports:

A laboratory report will be due the Monday after each experiment has been conducted. Formats of the report will be discussed in the lab session.

Grading:

At the end of the quarter, I will average your work with the following weighting factors:

Homework	15%
Laboratory reports	10%
Class participation	5%
Hour exams 3@15%	45%
Final exam	25%

Because the final exam will cover material from the entire quarter, if your final exam grade is higher than your cumulative average as determined above, you will receive the grade from the final exam. *This option is available only if all homework and lab reports are turned in on time*. If your final exam grade is lower than your cumulative average, you will receive the grade corresponding to the cumulative average. **However**, if you fail to turn in any homework or laboratory assignment, *you will receive an incomplete for the course*.

Appendix B

CE 250: Introduction to Soil Mechanics

Course description

This is an introductory course to the broad field of soil mechanics. Students in the course will be exposed to basic soil science and geology, underscoring their interception with engineering as a whole. The course is aimed at giving students a fundamental introduction to the challenges and opportunities encountered in soil mechanics, its impact in civil engineering, and its crucial importance in critical societal problems.

The main method of communication in this class is email and through the course website located in Course Management System (CMS), a.k.a. Blackboard at http://courses.northwestern.edu

Instructor

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Course Outcomes

It is expected that by the end of this class, students will be able to:

1. Apply mathematical tools and (soil) mechanics to identify, formulate and solve engineering problems

2. Conduct experiments and analyze data to extract relevant soil properties and report these findings effectively in writing

3. Use (soil) mechanics principles to design engineering systems

4. Participate effectively in team presentations and assess the strengths and weaknesses of the individual and the team as a whole

Learning Objectives

After students take this introductory soil mechanics course, the following objectives should have been achieved:

- Describe and classify soils broadly
- Evaluate and design soil compaction procedures

- Use the concept of effective stress to calculate and discriminate between total, effective, and pore water pressures
- Determine soil permeability and use it for seepage calculations
- Specify, conduct, and interpret soil tests to characterize soils
- Use concepts of elasticity and strength of materials to extract material parameters from soil tests and to use such parameters in calculations of stresses and deformations

Class Times and Location

Class will meet Monday, Wednesday, and Friday from 11-11:50 a.m. in Tech L361. Also, there will be class and/or discussion sessions will be held those weeks when there is no laboratory scheduled (see below).

Laboratory Times and Location

Lab session are on Wednesdays at 6:00 p.m. in room AG40 according to the following schedule:

Experiment	Date
Compaction	Oct 14, 2009
Permeability	Oct 21, 2009
Consolidation	Nov 18, 2009
Shear Strength	Dec 2, 2009

At the beginning of the quarter, the class will be divided into four groups. Each group will be assigned a lab experiment at random. The group is responsible for successfully conducting the specified experiment and for explaining the procedure to the rest of the class. This, of course, will require preparation before hand. There are three specific outcomes that the presenting group is responsible for and will be evaluated against:

1. Thoroughly explaining the experimental procedure to the rest of the class

2. Successfully conducting the experiment and making the resulting data available to the class

3. Writing a three-page max lab report as a group explaining the procedure and the results

Every member of the presenting team is required to write a critical account of the team's performance and their own contribution to the team on the course's blog.

Similarly, each member of the other three groups are required to submit item 3 above and individually critique the presenting group performance on the course blog.

During weeks when there is no lab scheduled, the allocated time will be used to lecture and/or answer questions.

Textbook

M. Budhu. *Soil Mechanics and Foundations.* John Wiley and Sons, Inc. Hoboken, NJ, 2007

Grading

Item	Weight
Homework	15%
Lab component	25%
Midterm	25%
Final	35%

Topics

Subject	Reading Assignment
Overview of soil mechanics	Chapter 1
Geological characteristics of soils	Chapter 2
Physical characteristics & properties	3.1-3.6
Soil classification schemes	3.7-3.8
Dry unit weight and compaction	3.9-3.10
Intro to flow through porous media	4.1-4.4
Darcy's law	4.5-4.6
Flow through layered soils	4.7-4.9
Determination of hydraulic conductivity	4.1
Intro to stress and strain	5.1-5.4
Hooke's law	5.5
Plane strain and axisymmetry	5.6
Stress and strain states	5.7
Total and effective stresses	5.9

Subject	Reading Assignment
Lateral earth pressure at rest	5.1
Stresses in soil from surface loads	5.11
1D consolidation	6.1-6.3
Primary and secondary consolidation	6.4, 6.6
1D consolidation laboratory test	6.7
Shear strength of soils	7.1-7.5
Mohr-Coulomb failure criterion	7.6
Practical implications of M-C criterion	7.7
Lab techniques to determine shear strength	7.9

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