University of Manitoba	Winter XXXX
Department of Civil Engineering	CIVL 7450

Course identification	
Course name:	SOIL PROPERTIES AND BEHAVIOUR
Prerequisites:	Undergraduate Geotechnical Engineering Courses
Lecture hours:	09:00 – 12:00 Thursday

Instructor	
Instructor:	Marolo C. Alfaro, PEng, PhD
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Office hours:	By Appointment

Course description and learning outcomes

Background

The course will focus on elastic-plastic (EP) behaviour of clay soils (and sands, time permitting). The elastic-plastic (EP) behaviour of sands are mostly similar to that of clay soils The framework of elasto-plasticity comes from observations in the laboratory and in field projects which show that deformations in clays are often relatively stiff, rapid, and largely reversible up to an identifiable stress level. Most engineering design keeps stress levels in this range. If this stress level is exceeded, the clay 'yields', deformations are larger, continue for longer, and are non-reversible.

The Modified Cam Clay (MCC) model provides a useful way of describing this behaviour qualitatively, although it needs to be modified and augmented to incorporate anisotropy and viscosity (creep) effects. The model also permits quantitative interpretation of laboratory data and is used as an important constitutive model in many finite models for stress-deformation and slope stability analysis.

Following chapters discuss the relationship between MCC and the behaviour of real clays. Examples will be given of the usefulness of EP modeling in (1) interpreting laboratory data, (2) explaining some empirical relationships between common clay properties, (3) understanding the behaviour of embankments and foundations on soft ground, and (4) outlining some applications for shallow foundations and slope stability analysis.

Critical State soil mechanics grew out of an awareness that the behaviour of clay soils needs to be described as a continuum in a three-dimensional space that combines mean effective pressure, shear stress, and voids ratio. The constitutive model known Original Cam Clay, which was developed by Schofield and Wroth, 1958, was largely theoretical and based on energy and thermodynamics. Dr. John Burland subsequently developed Modified Cam Clay (MCC), which has proved to be a more useful tool for many geotechnical projects. However it, too, deviates rather considerably from behaviour that is seen in laboratory and field tests. Others have extended the basic ideas of Critical State into a series of models that describe the behaviour of real clays in applications that include unsaturation, heating and cooling, creep, and changes in pore fluid chemistry. As well as providing a general framework for understanding soil responses, critical state ideas are increasingly used in numerical modeling, where they form an important part of modern practice. Collectively, the framework for these applications is known as 'elastic-plastic soil mechanics'.

The current course is similar in principle to courses given in the 1980s by Peter Wroth, Guy Houlsby, and David Muir Wood at Oxford University; and by John Atkinson at City University, London. It is largely compatible with David Muir Wood's book *Soil Behaviour and Critical State Soil Mechanics* (Cambridge University Press, Cambridge 1990). The approach taken in this course will provide more detailed treatment of experimental and field evidence, and less emphasis on the mathematics of Cam Clay. It also uses ideas from Laurits Bjerrum (NGI Oslo) on the initial stiffness of natural clays, and the importance of microstructure and viscous time-dependent behaviour.

General Objective

The course presents evidence for the use of elastic-plastic soil mechanics as a conceptual and quantitative framework that provides a helpful understanding of the behaviour of saturated clays.

Course web site

Your Jump Portal Server

Textbook

References

(1) Wood, D.M., *Soil Behaviour and Critical State Soil Mechanics*, Cambridge University Press, UK, 1990.
(2) Schofield, A. and Wroth, P., *Critical State Soil Mechanics*, McGraw-Hill, London, 1968.
(3) Budhu, M., *Soil Mechanics and Foundations*, 3rd Edition, John Wiley and Sons, USA, 2011.
(4) Atkinson, J., *The Mechanics of Soils and Foundations*, Taylor and Francis, London, 2007.

Assignments/projects/exams

There will be a two-hour *mid-term examination* and a three-hour *final examination*. Numerical problems and/or project works will be assigned regularly. They have to be submitted one week after being assigned (unless specified). Late assignments will not be accepted. Answers/solutions will be discussed after the assignments are marked. Please understand the importance of conscientiously completing assignments as an aid to understanding the course work and preparing for the examinations.

The grading of this course will be based on the following scheme:

Assignments	20%
Mid-term Exam	30%
Final Exam	50%
Total	100%

Detailed course content

After a general introduction, the course defines the variables that will be used. It very briefly reviews oedometer and triaxial testing technology and the interpretation of test results. These will be related to the 'traditional' view of clay properties such as those described for example by Terzaghi, Skempton, Lambe, etc.

1. **Introduction:** Outline, organization of the course, soil behaviour and numerical modeling, oedometer and triaxial tests, interpretation of results.
2. **Variables and Definitions:** Elasticity, plasticity, hardening, critical state, etc.
3. **Elasticity and Plasticity.** Field and laboratory evidence for elasticity and plasticity, anisotropic elasticity, representative hardening laws, strain hardening and expansion of the elastic region.
4. **Yielding and Flow Rule in Clays.** Laboratory evidence for yielding, the state boundary surface in p',q,V-space as a development from yield loci in p',q-sections, the flow rule.
5. **Modified Cam Clay.** Outline of the Cam Clay model. Critical states. Prediction of the behaviour of clay in drained and undrained triaxial tests on saturated normally consolidated and overconsolidated clay specimens.
6. **Predictor Methods for Traditional Test Parameters.** Predictors for common parameters such as OCR, A_f, s_u/p', ø′, etc in clays. Applications for assisting in checking and approving results of routine laboratory tests.
7. **Field Evidence for Yielding.** Field applications of elasto-plasticity and yielding of foundations, dams, embankment fills, etc. Case studies.
8. **Elastoplasticity in other applications.** Time and strain-rate effects, creep, secondary compression, delayed compression, elastic viscoplasticity, volumetric and shear creep, relaxation. Applications to embankment performance on soft ground. Introduction to elasto-plasticity for unsaturated soil mechanics, changes in pore fluid chemistry, constant-phase temperature changes, and the use of Cam Clay in slope stability analysis
9. **Worked Problems.** Numerical problems will be examined in class.
10. **Critical State in Sands** ***(time permitting)***