Engineering Tripos Part IIA, 3D2: Geotechnical Engineering II, 2021-22

Leader

Prof G Viggiani [1]

Lecturers

Prof G Viggiani

Lab Leader

Prof G Viggiani

Timing and Structure

Lent term, 16 lectures.

Prerequisites

3D1

Objectives

As specific objectives, by the end of the course students should be able to:

- Analyse stress and strain in three dimensional conditions and define pore pressure parameters
- Understand the applications of elasto-plastic models with isotropic volumetric hardening to the behaviour of soils
- Use the Cam Clay model to predict changes of stress and volume in simple shear and triaxial tests
- Predict the onset of yield, failure and ultimate critical states of soil elements subject to any stress path
- Recognise the origins of the undrained strength of clay, and estimate excess pore pressures induced by shearing
- Recognise the origins of the super-critical strength of dense sand and overconsolidated clay in terms of interlocking and dilatancy
- Assess the influence of effective stress history on lateral earth pressure
- Assess the stability of slopes
- Recognise the potential sources of brittle failure in dilatant sands and overconsolidated clay
- Diagnose the delayed failure of overconsolidated clay slopes, and suggest counter-measures
- Diagnose quick clay flowslides, and suggest counter-measures
- Understand the main available tools for geotechnical site investigation, with a focus on field testing
- Apply the theory of cavity expansion in an elastic perfectly plastic medium to the interpretation of pressuremeter test
- Apply the thoery of cavity contraction in an elastic perfectly plastic medium to the prediction of tunnel stability and convergence

Content

Whereas module 3D1 was concerned chiefly with the limiting equilibrium of plastic soil bodies and soil consolidation, 3D2 aims to address modelling of the mechanical behaviour of soils and geotechnical structures.

Soils are an order of magnitude more compliant than steel or concrete, so designers have to limit the mobilisation of soil strength to keep ground strains small enough to guarantee the serviceability of adjacent structures. Furthermore, some soils are inherently brittle, and their strength can deteriorate if they are permitted to strain excessively; this can lead to unexpected catastrophic failures. In geotechnical engineering, therefore, strains are often more important than stresses.

The Cam Clay model of soil behaviour is introduced to link concepts of consolidation and shearing, to envision drained and undrained soil behaviour within a single conceptual framework, to distinguish between yielding and failure, and to contrast stress paths that lead to brittle softening with those that lead to stable hardening. These comparisons and contrasts are central to the correct characterisation of soils for geotechnical decision-making. They are the subject of the first example paper.

The module continues with the assessment of the stability of natural slopes and cuts, the characterisation of in-situ stress states as a function of the previous stress history of the site, and considers the stress paths which they will follow as a result of construction. Particular materials, stress paths, and changes in environmental conditions can lead to catastrophic failures. The key to avoiding such failures is either to improve the ductility and continuity of materials and structures, or to take the utmost care in controlling soil strains in service. This material is the subject of the second example paper.

The final part of the course addresses the fundamentals of geotechnical investigation with a focuse on field testing. The objectives, extent, frequency and layout of investigations for the geotechnical characterisation of a site are discussed and the main available geotechnical field tests, including dynamic and static penetration tests, vane shear test, and pressuremeter tests are illustrated. Radial solutions for cavity expansion and contraction in an elastic perfectly plastic medium are applied to the interpretation of pressuremeter tests in clay and bored tunnelling, respectively. This material will form the subject of the third example paper.

Topic 1: Basics - Soil Stress-strain, 3D Stresses & strains and their invariants, pore pressure parameters

Modelling in geortechnical engineering (Lecture 1)

Modelling forms an implicit part of all engineering design but many engineers are not aware either of the fact that they are making assumptions as part of the modelling or of the nature and consequences of those assumptions. The lecture is an introduction to the course iproviding an overview of the evolution of modelling and the shift of modelling paradigms in science and engineering and in soil mechanics.

Stress/strain invariants (Lecture 2)

3D stresses and strains, Lode's coordinates, strain and strain invariants, work conjugates, pore pressure parameters, stress paths.

Topic 2: Strain hardening elastoplasticity

1D elasto-plasticity (Lecture 3)

Additive decomposition of strain, elasticity, admissible stress, yield criterion, elastic range, flow rule. Kuhn Tucker condition, consistency condition, plastic multiplier. Isotropic and kinematic hardening. Elasto-plastic stiffness.

Linear elasticity and Mohr Coulomb strength criterion (Lecture 4)

Isotropic linear elasticity. Mohr Coulomb Yield criterion with associative flow rule. predicted behaviour for drained and undrained triaxial compression and triaxial extension. Limitations and possible ways to overcome them.

Plane strain stress paths (Lecture 5)

Stress paths in the ground arising from a variety of construction processes, and relating to a range of representative locations. Use of vertical and horizontal equilibrium equations to estimate total stress paths due to simplified cases of vertical loading or horizontal unloading. Correlation with effective stress paths dictated either by undrained or drained soil conditions. Predicting the approach of soil states to limiting strength envelopes.

Topic 3: Cam-Clay

Shearing of soils: work and dissipation, yield surface and normality (Lecture 6)

Taylor's work equation. Yield surface in effective stress space. Normality principle guarantees maximum dissipation, providing a plastic flow rule. Derivation of the Cam Clay yield surface. Compressibility and volumetric hardening.

Critical states, normal compression, and yield (Lecture 7)

Stress dilatancy and critical state. Radial compression lines, critical state line. 3D state surface of shear stress, effective normal stress and specific volume. Drained and undrained shearing of soil at a given density, from points of normal consolidation and overconsolidation

Undrained shear strength, predicting behaviour of geotechnical structures using using Cam-clay model (Lecture 8)

Undrained shear strength. Predicting behaviour of smooth retaining wall and embankment on soflt clay. Staged loading. Development of stress-strain relationship of Cam clay model. Application of numerical programs for modern geotechnical analysis.

Topic 4: Slope stability - avoiding catstrophic failure

Slope stability analysis (Lectures 9 and 10)

Occurrence of slope failure in the UK and worldwide. Examples. Modes of movement: falls, topples, slides, and flows. Analysis methods to assess the stability of slopes in sands and clays. Infinite slope, effect of groundwater flow. Finite slope undrained. General Limit equilibrium methods.

Avoiding catastrophic failure on the dry side (Lecture 11)

Selection of mechanical parameters for the design of engineered slopes. Factors promoting failure on the dry side: brittle failure for dilatant sand and overconsolidated clay. Need to design for critical state friction and worst pore water pressures.

Delayed failure in clay slopes and catastrophic failure on the wet side (Lecture 12)

Delayed failure in clay slopes due to progressive softening on cycles of wetting/drying. Factors promoting brittle failure on the dry side: quick clay flowslides, volumetric collapse on saturation for partly saturated slopes.

Topic 5: Geotechnical Site Investigation

Geotechnical Site Investigation (Lecture 13)

Requirements of geotechnical site investigation. Objectives, extent, frequency and layout of investigations for the geotechnical characterisation of a site.

In-situ testing (Lecture 14)

Procedures and interpretation of Standard Penetration Test (SPT), Cone Penetration Test (CPT), Field Vane, and pressuremeter tests

Topic 6: Elasto-plastic radial solutions

Cavity Expansion (Lecture 15)

Cavity expansion in elastic perfectly plastic medium. Application to the interpretation of pressuremeter test. Estimation of soil properties from pressuremeter tests in clay: in-situ total horizontal stress, shear modulus, undrained shear strength.

Cavity Contraction (Lecture 16)

Cavity contraction in elastic perfectly plastic medium. Applications to bored tunnelling. Estimation of support pressure required for tunnel stability. Tunnel convergence and settlements above tunnels.

Examples papers

There will be three examples papers directly related to the lecture course, given out in weeks 4, 5 and 7.

1. The Cam Clay model.
2. In situ state, stress paths, slopes.
3. Radial solutions

Coursework

One **laboratory** exercise on **Consolidation and shear testing of clay**.

Learning objectives:

- measure the one-dimensional stiffness of the clay over different stress ranges and overconsolidation ratios;
- measure the coefficient of consolidation of the clay and deduced its permeability;
- select suitable values of the one-dimensional compressibility parameters;
- measurre the ultimate drained shear strength of the clay under various conditions.

Practical information:

- Sessions will take place in the Structures Teaching Laboratory, every Wednesday and Friday afternoon during the month of February
- This activity does not involve preliminary work.

Full Technical Report (optional):

Design of an artificial island

The soil parameters measured in the laboratory will be used to evaluate three outline design schemes for an artificial island constructed on clay.

For each scheme, the students will be asked to estimate:

- the consolidation settlement,
- the required time to complete construction
- the caisson's foundation sliding strength

Booklists

Please refer to the Booklist for Part IIA Courses for references to this module, this can be found on the associated Moodle course.

Examination Guidelines

Please refer to Form & conduct of the examinations [2].

UK-SPEC

This syllabus contributes to the following areas of the UK-SPEC [3] standard:

Toggle display of UK-SPEC areas.

GT1

Develop transferable skills that will be of value in a wide range of situations. These are exemplified by the Qualifications and Curriculum Authority Higher Level Key Skills and include problem solving, communication, and working with others, as well as the effective use of general IT facilities and information retrieval skills. They also include planning self-learning and improving performance, as the foundation for lifelong learning/CPD.

IA1

Apply appropriate quantitative science and engineering tools to the analysis of problems.

KU1

Demonstrate knowledge and understanding of essential facts, concepts, theories and principles of their engineering discipline, and its underpinning science and mathematics.

KU2

Have an appreciation of the wider multidisciplinary engineering context and its underlying principles.

E1

Ability to use fundamental knowledge to investigate new and emerging technologies.

E2

Ability to extract data pertinent to an unfamiliar problem, and apply its solution using computer based engineering tools when appropriate.

E3

Ability to apply mathematical and computer based models for solving problems in engineering, and the ability to assess the limitations of particular cases.

P1

A thorough understanding of current practice and its limitations and some appreciation of likely new developments.

US1

A comprehensive understanding of the scientific principles of own specialisation and related disciplines.

US2

A comprehensive knowledge and understanding of mathematical and computer models relevant to the engineering discipline, and an appreciation of their limitations.

Last modified: 06/01/2022 14:39

Source URL (modified on 06-01-22): https://teaching.eng.cam.ac.uk/content/engineering-tripos-part-iia-3d2-geotechnical-engineering-ii-2021-22

Links
[1] mailto:gv278@cam.ac.uk
[2] https://teaching.eng.cam.ac.uk/content/form-conduct-examinations
[3] https://teaching.eng.cam.ac.uk/content/uk-spec