Engineering Tripos Part IIA, 3D2: Geotechnical Engineering II, 2017-18

Leader

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Lecturers

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Lab Leader

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Timing and Structure

Lent term, 16 lectures.

Prerequisites

3D1

Objectives

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

- Use plastic deformation mechanisms, compatibility factors, and equilibrium factors to predict structural distortions by scaling up shear stress-strain curves
- 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 ("apparent cohesion") of clay, and estimate excess pore pressures induced by shearing
- Recognise the origins of the super-critical strength ("true cohesion") of overconsolidated soils in terms of interlocking and dilatancy
- Assess the influence of effective stress history on the current state of lateral earth pressure.
- Derive and plot stress distributions around expanding or contracting cavities.
- Analyse the pressuremeter test using elasticity and plasticity, and be able to deduce strength and stiffness parameters from a test curve.
- Analyse the stability of, and settlement due to, tunnel construction.
- Generate appropriate values of shear stiffness, or mobilised shear strength, for soils with power law stress-strain curves beyond their linear-elastic limit.
- Recognise the potential sources of brittleness in soils, and suggest appropriate stress path triaxial tests to better define the problem
- Diagnose the delayed failure of overconsolidated clay slopes, and suggest counter-measures.
- Diagnose quick clay flowslides, and suggest counter-measures.
- Assess the stability of slopes.

Content

Whereas module 3D1 was concerned chiefly with the limiting equilibrium of plastic soil bodies and soil consolidation, 3D2 aims to address ground deformations and to avoid brittle failures. 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 examples paper.

The module continues with 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. Pressuremeter testing of soils gives data of their in situ stress-strain behaviour which can also be assessed via triaxial tests on samples trimmed from high-quality cores. Such stress-strain data can be applied within plastic deformation mechanisms to the prediction of ground displacements in the design and construction of tunnels, retaining walls and foundations. These strain-related issues are addressed in the second examples paper.

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 is the subject of the third examples paper.

Topic 1: Basics: Soil Stress-strain, 3D Stresses & strains and their invariants, Prof K Soga

Stress/strain invariants and soil behaviour (Lecture 1)

Typical stress-strain behaviour of sand and clay, Dilation, contraction and critical state, total and effective stress, 3D stresses and strains, strain and strain invariants, stress paths.

Direct shear, simple shear and triaxial test (Lecture 2)

Different laboratory test methods to evaluate stiffness and strength of soils. Undrained and drained tests.

Topic 2: The Cam Clay model, Prof K Soga

Shearing of soils: work and dissipation, yield surface and normality (Lecture 3)

Taylor’s work equation, recast in terms of shearing resistance comprising friction and dilation angles. Yield surface in effective stress space. Normality principle guarantees maximum dissipation, providing a plastic flow rule. Derivation of the Cam Clay yield surface.

Critical states,normal compression, and yield (Lecture 4)

A Cam Clay yield surface projected over an elastic swelling-line on a specific volume plot. Derivation of a critical state line parallel to a normal compression line; 3D state surface of shear stress, effective normal stress and specific volume.

Understanding drained and undrained shearing using Cam-clay model (Lecture 5)

Drained shearing of soil at a given density, but from points of normal consolidation and overconsolidation; different peak angles, same ultimate angle. Undrained shearing from same points; different peak undrained strengths, same ultimate strength. Remoulded undrained strength is due to friction, with effective stresses modified by excess pore pressures induced by shearing; is only a function of density.

Stress-strain relationship (Lecture 6)

Development of stress-strain relationship of Cam clay model. Application of numerical programs for modern geotechnical analysis.

Topic 3: In situ stresses, stress paths, and pressuremeter testing , Prof R J Mair

Stress history dictates in situ lateral earth pressure (Lecture 7)

Sedimentation, burial, erosion, and variations of water table. Overconsolidation ratio, definition of earth pressure coefficient and its variation with stress history. Influence of lateral extension due to an adjacent excavation.

Stress paths for retaining walls and foundations (Lecture 8)

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.

Stress paths and triaxial tests (Lecture 9)

TaylorStress paths in the ground arising from a variety of construction processes, and relating to a range of representative locations. The capability of assessing soil response in appropriate triaxial stress path tests on representative samples recovered from the field.

The pressuremeter test (Lecture 10)

Meynard and Self-Boring Pressuremeters. Kinematics of cylindrical expansion in soil shearing at constant volume; derivation of strains. Radial equilibrium equation. If soil were linear elastic – cavity pressure versus cavity strain, shear modulus. Radial and circumferential stress changes at the cavity boundary, zero excess pore pressures.

Inferring soil stiffness and strength from a pressuremeter test (Lecture 11)

Gibson and Anderson solution for perfectly elastic-plastic soil. Cavity pressure versus logarithm of expansion ratio. Estimating undrained strength both from plastic gradient, and from extrapolated limit pressure. Alternative solution for power-law soil; Bolton and Whittle solution for unload-reload loops.

Application of pressuremeter data to tunnel design and construction (Lecture 12)

Tunnelling technology, face support, ground loss, settlement trough, lining pressure. Equivalent radial contraction of a cylindrical cavity. Estimating ground loss as a function of tunnel support. Stability of a tunnel face.

Topic 4: Avoiding catastrophic soil failures - Prof K Soga

Deterioration of overconsolidated clays – delayed failure of slopes (Lecture 13)

Example: Skempton's London Clay slopes and LUL embankments. Analysis: cyclic mobilisation of internal friction in excess of critical state angle leading to ultimate failure. Need to design for critical state friction and worst pore water pressures. The error of relying on “true cohesion”.

Quick clay flowslides – origins and avoidance (Lecture 14)

Example: Rissa landslide. Analysis: structure of quick clays, wetter than liquid limit, but peculiarly quasi-stable. Role of isostatic uplift, sodium ion concentration reducing due to fresh water leaching.

Slope stability analysis (Lecture 15 & 16)

Analysis methods to assess the stability of slopes in sands and clays. Infinite slope, effect of groundwater flow, embankment construction.

Examples papers

There will be three examples papers directly related to the lecture course, given out in weeks 1, 5 and 7.

1. In situ state, stress paths, pressuremeter tests.
2. The Cam Clay model.
3. In situ states, stress paths, pressuremeter tests and ground movements.

Coursework

One laboratory exercise on Soil classification.

[Coursework Title]

Learning objectives:

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Practical information:

- Sessions will take place in [Location], during week(s) [xxx].
- This activity [involves/doesn't involve] preliminary work ([estimated duration]).
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Full Technical Report:

Students [will/won't] have the option to submit a Full Technical Report.

Booklists

Please see the Booklist for Part IIA Courses [2] for references for this module.

Examination Guidelines

Please refer to Form & conduct of the examinations [3].

UK-SPEC

This syllabus contributes to the following areas of the UK-SPEC [4] 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.

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