Engineering Tripos Part IIA, 3D1: Geotechnical Engineering I, 2017-18

Module Leader

Dr G Biscontin [1]

Lecturers

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Lab Leader

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Timing and Structure

Michaelmas term. 16 lectures.

Objectives

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

- Use data of water content and density to calculate saturation and voids ratio.
- Specify appropriate compaction criteria from soil laboratory data.
- Calculate vertical profiles of pore water pressure, total and effective stresses.
- Determine soil compressibility and calculate uniform ground settlements.
- Determine isochrones of excess pore pressure for various transient flows.
- Relate soil permeability, soil stiffness, and the coefficient of consolidation.
- Find the time required for various degrees of soil consolidation.
- Specify “drained” or “undrained” direct shear tests, and interpret them.
- Use Mohr circles of total or effective stress to interpret triaxial tests.
- Perform upper and lower bound limit analyses of drained and undrained soil.
- Analyse limiting equilibrium with slip planes and slip circles as mechanisms.
- Search for the least optimistic mechanism of failure in soil using either f or cu.
- Perform simple design calculations of a strip footing on clay and sand.
- Perform simple design calculation of a retaining structure in clay and sand.
- Make allowances for groundwater pressures in drained stability calculations.

Content

Structures depend for their stability on the ground which supports their foundations. Furthermore, many structures are actually built of soil (road, rail and flood embankments, dams, road bases and rail beds, waste repositories) or have to retain soil as their prime purpose (basement walls, quay walls, tunnels and pipes). So all Civil and Structural Engineers should understand soil behaviour and be able to apply this understanding in geotechnical engineering design and construction. This course introduces soil as a product of nature and focuses on its material properties and behaviour in engineering applications. Soil comprises solid grains, water and sometimes air. The solid phase is an interlocking aggregate of soil grains that can deform and rearrange; the fluid phase inhabits an interconnected pore space through which flow can take place. Total stresses, arising from loads or from the self-weight of the soil itself, have to be partitioned between these two phases. Pore pressures arise firstly from hydrostatics, but are modified by the effects of viscous drag when the fluid is flowing. Once pore pressures have been discounted, the remaining *effective stresses* must act between the grains, giving rise to deformations of the granular skeleton and therefore to displacements at the ground surface and possible distortions of any connected superstructures. This partition of stress is known as the principle of effective stress; it is the key to understanding soil behaviour and is the main theme of the first example paper.

If loads or deformations are imposed on a saturated soil body whose voids are free of air, and whose pore fluid can therefore be regarded as incompressible, and if they are applied so quickly that fluid has no time to escape, then the process is described as “undrained” and the soil must deform at constant volume. The process of transient flow, taking soil from an “undrained” to a “drained” state, can lead either to consolidation (fluid drains out, and soil gets denser and stronger) or swelling (which is the opposite). These phenomena lead to the familiar cracking-up of houses founded on soft clay soils that compress under load, or stiff clay soils that shrink in dry weather. The magnitude and rate of such volume changes forms the theme of the second examples paper. In addition to being prone to volume changes, soils are also relatively weak in shear – perhaps 3 orders of magnitude weaker than concrete. Once again, the possibility of transient flow dictates the outcome. After large shear distortions, “undrained” soils ultimately display a constant undrained strength, familiar to someone remoulding modelling clay between their fingers. If, on the other hand, the loads or deformations are imposed so slowly that the fluid can move completely freely, the process is described as “drained” and the soil deforms at constant pore pressure. In these circumstances, the strength of the soil is dictated by friction and interlocking between its grains. Ultimately the soil will display a constant internal angle of friction, familiar as the angle of repose of dry sand in sand dunes. Given enough time, underwater slopes in clay also rest at their angle of repose, as do sands. Tests to establish the drained (sand-like) or undrained (clay-like) strengths of soils, will be introduced and explained. These tests are covered at the start of the third examples sheet.

Once it has been established that a given undrained shear strength, or alternatively a given angle of internal friction, can be relied upon, the next step is to be able to make calculations to demonstrate whether a soil body will remain stable under its own weight, or under the loads applied by structural foundations, for example. This module extends the plastic analysis of structures, first encountered in Part IB Structures, to bodies made of soil. Both “upper bound” style calculations based on assumed failure mechanisms, and “lower bound” calculations based on demonstrating equilibrium through Mohr’s circles, will be introduced. The stability of foundations and earthworks – both “undrained” and “drained” – will form the main part of the third examples sheet.

Topic 1: The granular continuum

Basic definitions of soil constituents, and their packing

Phase relationships. Density of grains and water; voids ratio and saturation; water content, unit weight. Classification of soils using particle size distribution curves; void sizes, internal erosion. Relative density of sands. Atterberg’s classification tests – plastic limit, liquid limit, and plasticity index of clayey soils.

Soils in nature, and the principle of effective stress

Deposition and formation of natural soils. Loading history: normally consolidated and over-consolidated soils. The principle of effective stress. Stresses beneath level ground: total vertical stress, hydrostatics and pore pressures, vertical effective stress. Water table, capillary zone. Trial pits, boreholes and tube samples.

Steady state seepage & slope stability

Steady 1D flow through soil: seepage potential, hydraulic gradient, permeability proportional to void size squared, natural percolation of rainfall. Stability of infinite slopes dry, submerged and with seepage

Topic 2: Compression and Compaction

Artificially formed soils: compaction

Proctor compaction test. Compaction energy; optimum water content; degree of saturation. Controlling compaction in the field: monitoring dry density as a practical alternative to voids ratio, relative compaction. Clayey soils: brittleness and wetting-collapse if compacted dry of optimum, softness if compacted wet of optimum.

Compressibility and stiffness)

Uniaxial compression of a skeleton of elastic, crushable grains by voids migration. Oedometer test, ultimate drained data of compression versus effective stress. Data of sands and clays; compressibility and stiffness.

Topic 3: Consolidation

Transient flow & the Oedometer Test

Excess pore pressures due to 1D loading, the use of parabolic isochrones to depict transient flow. 1D consolidation of a unit cell with single drainage: parabolic isochrones, areas and gradients, consolidation parameters. Interpreting transient compression in oedometer tests using square root of time. Differences between times required for normal consolidation and swelling. Creepc.

One-dimensional consolidation in the field

Subdividing the ground into layers, using representative oedometer data, and summing compressions into ground settlements. Application to land reclamation. Use of surcharging to reduce consolidation times. Consolidation due to changes in the groundwater regime.

Topic 4: The shear strength of soil

“Direct” and “simple” shear tests: undrained and drained

Direct/simple shear test. “Drained” tests at constant effective normal stress. Dilation / contraction to a critical state, mobilised angles of friction and of dilatancy; typical data of a sand and a clay. Residual friction of polished slip surface in pure clay.“Undrained” tests at constant volume; typical data of a sand and a clay. Limiting shear speeds for drained and undrained behaviour in a shear box test.

Topic 5: Limiting equilibrium of geotechnical structures

Shallow foundation design in clay : vertical loading

Bearing capacity of a shallow strip footing on clay. Upper bounds; kinematically admissible mechanism, shear strength, global work or equilibrium. Slip circles and slip planes for non-dilatant soils. Lower bounds; statically admissible stress field, shear strength, equilibrium everywhere. Uniform undrained shear resistance cu.

Shallow foundation design in clay : combined loading

Bearing capacity of a shallow strip footing on clay under combined loading. Uniform undrained shear resistance. Effect of vertical, horizontal and moment loading.

Shallow foundation design in sand : vertical loading

Bearing capacity of a shallow strip footing on sand. Uniform angle of friction; stress discontinuities, dry sand. Weightless soil. Upper and lower bounds.

Shallow foundation design in sand : effect of self-weight and water

Bearing capacity of a shallow strip footing on sand. Effect of self-weight. Influence of water table.

Stability of retaining structures in clay

The stability of retaining structures (walls, cuts and excavations) in clay is examined using plasticity theory. Limiting pressures on retaining walls; estimates of active and passive pressure, tension cracks. Solutions are derived for undrained conditions.

Stability of retaining structures in sand

The stability of retaining walls in sand is examined using plasticity theory. Limiting pressures on retaining walls;

estimates of active and passive pressure, Solutions for limiting earth pressures on rough walls. Solutions are derived for drained conditions, and attention is given to the influence of groundwater.

Examples papers

There will be three examples papers directly related to the lecture course, given out in weeks 1, 3 and 6.

Basic relationships for a granular continuum

Consolidation and swelling

Soil strength, and the limiting equilibrium of soil bodies

Coursework

Atterberg Limit Tests

Learning objectives:

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-
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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.

US3

An understanding of concepts from a range of areas including some outside engineering, and the ability to apply them effectively in engineering projects.

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