# Engineering Tripos Part IIA, 3D4: Structural Analysis & Stability, 2017-18

### Module Leader

Dr F Cirak [1]

### Lecturers

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### Lab Leader

Dr F Cirak [1]

### Timing and Structure

Lent term. 16 lectures.

## Aims

The aims of the course are to:

- Provide students with an understanding of elastic methods of structural analysis.
- Ensure that students recognise that an understanding of stability and the failure of structures by buckling, is a key part of understanding structural behaviour.

## Objectives

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

- Determine stress distributions in asymmetric open sections, taking account of bending, shear, torsion and warping effects.
- Calculate the relevant section properties for complex sections.
- Apply Virtual Work.
- Analyse grillages under out-of-plane loading.
- Solve beam bending problems using Macaulay's method, and to obtain influence lines thereby.
- Explain the reciprocal theorem and the importance of influence lines.
- Recognise the shortcomings of the structural analysis learnt thus far and appreciate the need to include stability as a fourth concept in any complete theory of structures.
- Draw stable and unstable paths on a load/displacement diagram for various bifurcation and snap through models.
- Understand how elastic stability may be determined from the total potential energy and may be described by the eigenvalues of the total stiffness matrix.
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- Determine elastic critical loads for simple structures by eigenvalue analysis, whilst appreciating the importance of imperfection sensitivity and the limitations of such analysis.
- Apply approximation methods based on energy to determine the stability of simple systems.
- Understand second-order beam theory, using s and c functions.
- Understand how the tangent modulus and double modulus theories of inelastic buckling led to the column

paradox, and how this was resolved by Shanley's analysis, thereby presenting further difficulties for a general theory of structures.
- Understand the importance of lateral-torsional buckling of beams.
- Understand how of the above ideas combine in the context of column design.

## Content

There are two themes in this module: elastic analysis & stability and buckling of structures. Each section leads on from and extends a corresponding section of the first or second year courses in Structures.

In the first course the aims are to extend the elastic analysis of beam elements as given in Part I to cover asymmetric sections in bending, to revise the determination of shearing stresses in beams, to consider the torsion of open section beams, including effects due to restraint of warping) and to introduce the concept of shear centre. The course will cover the analysis of beams via differential equations, and their efficient solution using Macaulay's method. This will be applied to beams on elastic foundations, as well as to normal beams. The reciprocal theorem will be introduced which will lead to the study of influence lines. The course will also cover some new applications of virtual work, grillages and other beams curved in plan, and the cable catenary.

In the second course the aims are to understand the fundamental principles of structural stability, to become familiar with common types of bifurcation and buckling phenomena and to formulate methods capable of dealing with geometrically non-linear structural behaviour. Once the general concept of stiffness degradation and the various post-buckling possibilities are understood, the course addresses the specific problem of column and beam design, taking account of initial imperfections, coexistent end-moments, residual stresses and material inelasticity.

**Elastic Theory (8L) (Dr F Cirak)**

- Asymmetric beams; principal axes;
- Shear centre; torsion and warping of open-sections;
- Virtual work;
- Grillages;
- Differential equation of beam (Macaulay);
- Reciprocal theorem and influence lines;
- Beams on elastic foundations;
- Catenary.

**Stability and Buckling (8L) (Dr A McRobie)**

- Fundamentals of buckling and stability: total potential energy approach and direct equilibrium approach;
- Classification of instabilities into snap-through tpe and bifurcation type;
- Eigenvalues and eigenvectors of stiffness matrix;
- Buckling of elastic structures; approximate estimates of buckling load; Rayleigh quotient;
- Lateral buckling of columns: Euler strut, imperfections, Southwell plot, beam-columns, stability coefficients, buckling of frames;
- Elasto-plastic buckling: tangent-modulus, double-modulus, Shanley's analysis;
- Design of columns;
- Lateral-torsional buckling of beams.

## Coursework

**Buckling Elastic and Inelastic**

<u>Learning objectives</u>:

- Understand the difference between *stable* and *unstable* buckling.
- Appreciate the circumstances in which a "classical" buckling calculation gives a useful estimate of the buckling strength of a structure, and those in which it does not.
- Be able to cite examples of structures for which the buckling load is both significantly less than the

prediction of "classical" theory, and the postbuckling behaviour is highly *unstable*.
- Be aware of the "classical" buckling formulae for bars (including the "tangent-modulus" formula), simple plates and cylindrical shells.

Practical information:

- Signup on http://to.eng.cam.ac.uk/teaching/apps/cuedle/index.php?context=3D4 [2].

Full Technical Report:

Students will have the option to submit a Full Technical Report.

## Booklists

Please see the Booklist for Part IIA Courses [3] for references for this module.

## Examination Guidelines

Please refer to Form & conduct of the examinations [4].

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**Links**
[1] mailto:fc286@cam.ac.uk
[2] http://to.eng.cam.ac.uk/teaching/apps/cuedle/index.php?context=3D4
[3] https://www.vle.cam.ac.uk/mod/book/view.php?id=364091&chapterid=46601
[4] https://teaching.eng.cam.ac.uk/content/form-conduct-examinations