

## Engineering Tripos Part IA, 1P2: Structures, 2017-18

### Lecturers

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### Timing and Structure

Weeks 1-8 Michaelmas term and weeks 3-8 Lent term. 24 lectures

### Aims

The aims of the course are to:

- Make students aware of the key role of structures in different branches of engineering.
- Illustrate the way in which structural engineers use the principles of structural mechanics to understand the behaviour of structures and so to design structures in order to meet specified requirements.
- Explain the importance of assumptions and hypotheses in the development of theory.
- Convince students of the important role of observation and experiment in the development of a proper theory of structures, and to provide practical examples of structural experiment, structural design and structural failure.
- Examine in detail certain simple structural forms, including triangulated frameworks, beams and cables; to understand how such structures carry applied loads, and how they deform under load, and how slender members may buckle.

### Objectives

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

- Describe, qualitatively, the way in which different kinds of structure (frameworks, beams, cables, pressure vessels, etc.) support the loads that are applied to them.
- Analyse the limiting equilibrium conditions of bodies in frictional contact.
- Explain and determine the shape of an inextensible cable subject to concentrated and distributed loads, as well as the tension distribution and support reactions.
- Determine the internal stress resultants at any section of a simple, statically determinate arch structure, and to find the maximum values of the stress resultants.
- Determine the axial force in any member of a statically determinate pin-jointed framework, making use of structural symmetry and of the principle of superposition when appropriate.
- Determine the displacement of any point of a pin-jointed framework subject to prescribed bar extensions.
- Understand the equation of virtual work for pin-jointed frameworks and how to choose appropriate equilibrium and compatible sets.
- Construct bending-moment and shearing-force diagrams for simple beam structures, and to explain the relationship between them.
- Explain curvature, and how it changes in an elastic beam when the bending moment changes.
- Explain and compute the geometry of deflection of an initially straight beam on account of curvature within it.
- Explain and compute the detailed distribution of bending stress in the cross-section of an elastic beam having a symmetrical cross-section, and sustaining a bending moment.
- Explain and compute the distribution of shearing stress in the cross-section of an elastic beam having a symmetrical cross-section, and sustaining a shearing force.
- Determine the buckling load of a column, and be able to approach the design of columns accounting for the

effects of yielding of the material and geometric imperfections.

## Content

### Introduction and Aims of the Course (1L)

#### 1. Equilibrium in Two Dimensions (3L)

- Forces, moments and couples (3) Sect 1/1-1/5, 1/7-2/5
- Resultants (3) Sect 2/6
- Free-body diagrams (3) Sect 3/1-3/2, 3/4
- Polygon of forces (3) Sect 2/6, 3/3
- Two-force problems (3) Sect 3/3
- Three-force problems (3) Sect 3/3
- Distributed forces: gravity (centre of mass), pressure and hydrostatic loads (centroid) (3) Sect 1/6, 5/1-5/3, 5/9
- Friction (3) Sect 6/1-6/3, 6/8

#### 2. Forces in Structures (4L)

##### 2.1 Calculation of Bar Forces in Statically Determinate Frameworks

- Triangulated frameworks, pin-jointed idealisation (3) Sect 4/1-4/2
- Method of joints (3) Sect 4/3
- Method of sections (3) Sect 4/4
- Superposition
- Symmetry
- Mechanisms and statically indeterminate frameworks
- Classification of two-dimensional structures

##### 2.2 Cables, Pressure Vessels, and Arches (4) Sect 5.1, 5.6, (7) Ch. 5

#### 3. Displacements in Pin-Jointed Frameworks (2L)

##### 3.1 Calculation of Bar Elongations

- Elastic stress-strain relationship (5) Sect 5.2, 5.3, 5.4
- Thermal strains (5) Sect 5.5

##### 3.3 Calculation of Displacements by Displacement Diagrams

- Assembly of an imperfect framework
- Displacements due to small bar elongations (5) Sect 2.3

#### 4. Principle of Virtual Work (2L)

- Particles and rigid bodies in two dimensions (3) Sect 7/3
- Reactions, bar forces and displacements in pin-jointed frameworks

#### 5. Equilibrium of Beams (2L)

- Introduction, hypotheses, sign conventions (5) Sect. 3.1, 3.2
- Distortion produced by internal forces
- Calculation of M, S, and T by analysis of free bodies (5) Sect. 3.2-3.4
- Differential relationships between q, S, and M (5) Sect. 3.5
- Construction of bending moment diagrams

- Statical indeterminacy
- Case study

## **6. Deflection of Straight Elastic Beams (2L)**

- Curvature and change of curvature, integration of curvature to find deflection (5) Sect. 8.1,8.2
- Deflection of elastic beams by integration (5) Sect. 8.3
- Deflection of elastic beams by superposition of deflection coefficients (5) Sect. 8.4

## **7. Stresses in Elastic Beams (5L)**

- Introduction, basic geometric concepts (5) Sect. 7.2
- Bending of beams with rectangular cross-section (5) Sect. 7.5
- Bending of beams with non-rectangular cross-section, centroid and second-moment of area
- Use of section tables
- Combined bending moment and axial force
- Bending stresses in composite beams, transformed section, bending of reinforced concrete beams
- Shear stresses in beams (5) Sect. 7.6

## **8. Buckling of Columns (3L)**

- Introduction, examples, hypotheses
- Euler column, fixed-end conditions, effective length (5) Sect. 9.4 (6) Sect 5.1
- Critical stress
- Imperfections (6) Sect 5.2
- Design of columns

## **REFERENCES**

- (1) GORDON, J.E. *STRUCTURES OR WHY THINGS DON'T FALL DOWN*
- (2) HEYMAN, J. *THE SCIENCE OF STRUCTURAL ENGINEERING*
- (3) MERIAM, J.L. & KRAIGE, L.G. *ENGINEERING MECHANICS. VOL. 1: STATICS*
- (4) FRENCH, M. *INVENTION AND EVOLUTION*
- (5) CRANDALL, S.H. DAHL, N.C. & LARDNER, T.J. *INTRODUCTION TO THE MECHANICS OF SOLIDS, with SI Units*
- (6) HEYMAN, J. *BASIC STRUCTURAL THEORY*
- (7) HEYMAN, J. *STRUCTURAL ANALYSIS: A HISTORICAL APPROACH*

## **Booklists**

Please see the [Booklist for Part IA 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.

**IA3**

Comprehend the broad picture and thus work with an appropriate level of detail.

**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.

**D1**

Wide knowledge and comprehensive understanding of design processes and methodologies and the ability to apply and adapt them in unfamiliar situations.

**D3**

Identify and manage cost drivers.

**D5**

Ensure fitness for purpose for all aspects of the problem including production, operation, maintenance and disposal.

**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.

**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.

**US4**

An awareness of developing technologies related to own specialisation.

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**Links**

[1] <mailto:mjd97@cam.ac.uk>, [sdg13@cam.ac.uk](mailto:sdg13@cam.ac.uk)

[2] <https://www.vle.cam.ac.uk/mod/book/view.php?id=364071&chapterid=41921>

[3] <https://teaching17-18.eng.cam.ac.uk/content/form-conduct-examinations>

[4] <https://teaching17-18.eng.cam.ac.uk/content/uk-spec>