Engineering Tripos Part IIB, 4D2: Advanced Structural Design, 2021-22

Module Leader

Prof A McRobie [1]

Lecturers

Prof A McRobie and Prof W Baker [2]

Timing and Structure

Lent term. 16 lectures. Assessment: 100% coursework

Prerequisites

3D3 and 3D4 assumed

Aims

The aims of the course are to:

- Instil an intuitive approach to structural design.
- Introduce advanced concepts related to the design of structures.
- Introduce the concepts behind the tall building design.

Objectives

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

- Design a wide variety of structures which meet both aesthetic and efficiency criteria.
- Describe the relationship between form and force.
- Manipulate structural geometry or forces to improve the structural behaviour.
- Describe Airy stress functions and be able to design structures using them.
- Describe the relationship between states of self-stress and mechanisms.
- Design prestressable structures which contain mechanisms.
- Describe the load path and how to optimize it.
- Use Lagrange multipliers in constrained optimization problems in structural design.
- Understand the requirements for minimal total structural volume.
- Describe stiffness and stability from a geometrical perspective.
- Design gridshells, nets and tall buildings. Understand the unique behaviour of each.
- Intuitively understand structural behaviour so that visual design can occur.
- Describe the implications a structure's design has on the stakeholders.
- Describe the systems used in the design of tall buildings.

Content

Content and delivery will be largely provided by Prof Bill Baker. Prof Baker is the consulting partner at Skidmore Owings and Merrill in Chicago and Honorary Professor of this department. He is the world's leading structural engineer for the design of buildings and has been responsible for the design of many of the world's more iconic
buildings. Prof Baker will teach the skills needed to become a proficient structural designer. The course aims to inform students about powerful new design tools which are growing in popularity throughout industry, many of which have been developed by Prof Baker in collaboration with this department.

**Introduction to the course**

A short history of structures and architecture. The importance of geometry and design. Discussion of its wide-reaching impacts and implications.

**Graphic statics**

Relationship between the form and force. How to design structures so that the forces flow where the designer wants them to.

**Maxwell Load path theorem and how it relates to the total volume of structural material used.**

**Virtual work**

How it may be used to optimise the structural geometry, using Lagrange multipliers.

**Michell trusses**

Optimal structures and their behaviour.

**Airy stress functions and their application to truss design.**

To identify states of self-stress and mechanisms. The use of funiculars to include external loading.

**Mechanisms and states of self-stress**

The geometric relationship between mechanisms and states of self-stress, and the Maxwell-Calladine and Euler counts to obtain structurally sound trusses.

**Graphic kinematics**

How to consider mechanisms and stiffness. Tensegrity structures.

**Geometric stiffness and force density**

A short introduction to rigidity theory.

**Form finding for trusses, to optimise topology, shape and size for structure**

Discussion of the tools available.

**Equilibrium in 2D and 3D**

Discussion of the equilibrium conditions for structures in 2D and 3D. How we can use force density to solve linear problems to find the geometry.

**Geometry of surfaces**

How to consider surfaces, be it Airy stress functions or shells. Discussion of curvature, principal directions, and a soap-film analogy.

**Gridshells and cable nets**
How to design shells and gridshells using the Airy stress function and force density. The importance of obtaining planar faces and torsion free nodes. The design of tension structures, using prestress to stabilise mechanisms.

### Tall building design

The importance of wind loading, dynamics and seismic considerations.

### Tall building architecture including fire-safety and vertical transportation.

#### Coursework

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<th>Coursework</th>
<th>Format</th>
<th>Due date &amp; marks</th>
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<tbody>
<tr>
<td><strong>Coursework 1: Fundamental theory</strong></td>
<td>Individual/Group Report</td>
<td>day during term [XX/XX]</td>
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<tr>
<td>Answers to be submitted to a set of open-ended questions on theoretical topics.</td>
<td>[non] anonymously marked</td>
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<td>Learning objective:</td>
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<td><strong>Coursework 2: Design</strong></td>
<td>Individual/Group Report</td>
<td>date [XX/XX]</td>
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<td>Students will design an innovative structure using the tools developed in the course.</td>
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<td><strong>Coursework 3: Tall building analysis</strong></td>
<td>Individual/Group Report</td>
<td>date [XX/XX]</td>
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<td>Students will submit detailed calculations that encapsulate the structural mechanics underlying the design of an existing tall building.</td>
<td>[non] anonymously marked</td>
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<td>Learning objective:</td>
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#### Booklists

Please refer to the Booklist for Part IIB 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 [3].

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