Engineering Tripos Part IIB, 4D17: Plate & Shell Structures, 2025-26

Leader

Professor K A Seffen [1]

Timing and Structure

Lent term. 14 lectures. Assessment: 100% Exam

Objectives

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

- understand the kinematical properties of curved surfaces;
- understand the load-carrying mechanisms for plates and shell structures;
- formulate the governing equations of deformation for small displacement behaviour;
- identify the benefits and limitations associated with closed-form solutions;
- appreciate the difference between stretching and bending effects in shells;
- appreciate the effects of geometrical non-linearity;
- be aware of the current state-of-the art in advanced shells;
- understand the nature of stability, instability and multistability in shells, and their practical exploitation.

Content

This module introduces the mechanics of plates and shells: thin-walled elastic surfaces that are important components of many structures and engineering devices. Key kinematical concepts are introduced for describing the initial and deformed shape of surface, either to make the description more succinct, or to reveal essential/invariant properties: these include the familiar Mohr's circle, surfaces of revolution, and the Gaussian curvature. The relationship between internal strains and external shape is revealed for conventional smooth elastic shells. The manufacture of traditional engineering shells is reviewed, and their constitutive response is formulated: more "advanced" shell materials are introduced, including smart materials. The imperatives of equilibrium, compatibility and Hooke's law are presented for deriving the final governing equations of deformation for circular and rectangular plates undergoing small displacements—a fraction of the thickness of shell. The distinction between bending and stretching responses of the shell is tackled through the membrane hypothesis and extended, first, to axisymmetrical pipe problems, and then to panel buckling under end-wise compression, which introduces geometrically non-linear behaviour. This is extended in cases of more compliant shells where displacements are expected to be much larger—of the order of the thickness, requiring more elaborate analysis techniques for tractable solutions: two approaches are presented, including an introduction of inextensibility theory. Finally, the behaviour and analysis of multistable shells are introduced: these show dramatic shape-changing properties, which may be exploited in novel "morphing" structures.

Geometry and kinematics of surfaces (4L)

- Properties of curves and surfaces: curvature and twist.
- Mohr's circle of curvature and twist.
- Kinematics of surfaces of revolution and circular plates.
- Gaussian curvature: extrinsic and intrinsic viewpoints, principal radii of curvature.
- Inextensibility of creased sheets: simple surface strain, Gauss' Theorema Egregium.
- Mixed/hierarchical kinematics: corrugated and compliant shells.

Materials (2L)

- Traditional engineering materials: metals, composites and natural materials, methods of manufacture, applications.
- Constitutive laws: bending and stretching generalised Hooke's laws, thermal effects.
- Bending and stretching strain energy densities.
- Advanced engineering materials: review of smart/actuating materials, applications.
- Natural shells: growth and bio-mimicry, constitutive laws.

Loading of shells: small displacement theories (3L)

- Bending of circular and rectangular plates: imperatives of equilibrium, Hooke's Law, and compatibility.
- Surfaces of revolution: membrane hypothesis and bending-stretching interaction in pipes.
- Two-surface idealisation and panel buckling.

Loading of shells: large displacement theories (3L)

- Non-linear methods: solutions by inspection and substitution; the lenticular plate.
- Inextensibility Theory.

Unloaded shells: multistability (2L)

- Applications.
- Analytical modelling: effects of material constitution, pre-stress, actuation and shape.

Booklists

Please see the Booklist for Group D 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.

IA2

Demonstrate creative and innovative ability in the synthesis of solutions and in formulating designs.

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.

P1

A thorough understanding of current practice and its limitations and some appreciation of likely new developments.

P3

Understanding of contexts in which engineering knowledge can be applied (e.g. operations and management, technology, development, etc).

US1

A comprehensive understanding of the scientific principles of own specialisation and related disciplines.

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:kas14@cam.ac.uk
[2] https://www.vle.cam.ac.uk/mod/book/view.php?id=364101&chapterid=52271
[3] https://teaching25-26.eng.cam.ac.uk/content/form-conduct-examinations
[4] https://teaching25-26.eng.cam.ac.uk/content/uk-spec