The Hong Kong Polytechnic University

Subject Description Form

Subject Code	CSE6010
Subject Title	Nonlinear Finite Element Analysis of Structures
Credit Value	3
Level	6
Pre-requisite / Co-requisite/ Exclusion	Students should possess a basic understanding of elasticity, plasticity, and linear finite element analysis of structures from first courses on these topics or through self-learning.
Objectives	This subject is intended to: (a) Expose students to common geometrically and materially nonlinear phenomena of civil engineering structures; (b) Equip students with a good understanding of plasticity-based constitutive modelling for steel and other materials; and (c) Provide students with a good knowledge of the concepts and techniques of the finite element method as employed in the nonlinear numerical analysis of structures under static and dynamic loads.
Intended Learning Outcomes	Upon completion of the subject, students will be able to: (a) Develop finite element models for static and dynamic problems; (b) Explain clearly the stress-strain-strength of metals and concrete, and their constitutive modeling; (c) Explain clearly geometric nonlinearity and its modelling techniques; (d) Conduct reliable and efficient static or dynamic nonlinear finite element analyses using a general-purpose package by making informed choices of element types, boundary conditions, constitutive models, solution procedures, etc.; (e) Interpret and evaluate results from nonlinear finite element analyses in a sensible manner.
Subject Synopsis/ Indicative Syllabus	This subject covers the following aspects: 1. <u>Review of fundamental concepts of finite element method</u> Finite element formulation by Weighted Residual Method; Iso-parametric formulation, Numerical integration; Solution by frontal solver; Solution of eigenvalue problems; Method of sub-space iterations; Types of elements. 2. <u>Geometric nonlinearity</u> Finite element vs stability function; Element with initial imperfection for second-order analysis; Newton Raphson Method; Displacement control method for tracing of equilibrium path; Snap-through and snap-back buckling. Second-order direct analysis applied to structural

design.

3. Material nonlinearity and constitutive models for metals

   Elastic-plastic behavior of metals; Yield surfaces; Flow theory of plasticity; Associated versus non-associated plasticity; Tresca model; Von Mises model; Incremental stress-strain relationships; Tangent stiffness matrix; Brief introduction to finite element programs for solids.

4. Constitutive models for concrete

   Elastic-plastic behavior of concrete; Yield surfaces for concrete; Rate effects; Drucker-Prager model; Mohr-Coulomb model; Plastic-damage model.

5. Dynamic nonlinear analysis of structures

   Linear dynamics: Equations of motion; Mass matrix (lumped mass, consistent mass); Damping matrix (Rayleigh damping and modal damping); Central difference method; Newmark's method. Nonlinear dynamics: Incremental equations of motion; Computational errors. Seismic analysis: Ground motion; Seismic equations of motion; Response spectrum; Ductility demand; Capacity spectrum; Incremental dynamic analysis.

Teaching/Learning Methodology

The subject is delivered mainly through lectures focused on the theory and techniques of nonlinear finite element analysis of structures. The lectures need to be supplemented by substantial self-study after class by students of reference materials recommended by subject lecturers.

Students need to each complete a set of assignments on small numerical modeling problems. Each student also needs to undertake a numerical modeling project using a general-purpose finite element package. These modeling exercises will provide students with hands-on experience and opportunities to put theory into practice.

Assessment Methods in Alignment with Intended Learning Outcomes

Specific assessment methods/tasks	% weighting	Intended subject learning outcomes to be assessed (Please tick as appropriate)					
		a	b	c	d	e	
1. Assignments	30%	✓	✓	✓	✓		
2. Project report	30%				✓	✓	
3. Quiz	20%	✓	✓	✓			
4. Oral Examination	20%				✓	✓	
Total	100 %						

Explanation of the appropriateness of the assessment methods in assessing the intended learning outcomes:

The assignments are used mainly to assess the mastery of skills for developing finite element models [learning outcome (a)], for explaining material and

	geometric nonlinearity [learning outcomes (b) and (c)] and for conducting nonlinear finite element analysis using a general-purpose finite element package [learning outcome (d)]. The in-class quizzes are used to assess learning outcomes (a), (b) and (c). The numerical modeling project, requiring the integration of skills to solve a more sophisticated physical problem using a general-purpose FE package, is an assessment that covers learning outcomes (d), and (e). The oral examination, consisting of the oral presentation of a project and a question & answer session, is for the assessment of learning outcomes (d) and (e).

Student Study Effort Expected

Class contact:	
▪ Lectures	39 Hrs.
▪ Examination	
Other student study effort:	
▪ Reading of reference materials	26 Hrs.
▪ Assignments on small modeling problems	30 Hrs.
▪ Numerical modeling project	40 Hrs.
Total student study effort	135 Hrs.

Reading List and References

1. Books

Bhatti, M. A. (2006). Advanced topics in finite element analysis of structures: with Mathematica and Matlab Computations. John Wiley & Sons, Inc. New York.

Barbero, E.J. (2013) Finite element analysis of composite materials using ABAQUS, CRC Press/Taylor & Francis Group.

Chen, W.F. and Han, D.J. (1988). Plasticity for structural engineers. Springer-Verlag, New York.

Chopra, A.K. (2001) Dynamics of structures: theory and applications to earthquake engineering, Prentice Hall.

Clough, R.W. and Penzien, J. (1993) Dynamics of structures. McGraw-Hill Education.

Cook, R.D. (1995) Finite element modeling for stress analysis, John Wiley & Sons.

De Borst, R., Crisfield, M.A., Remmers, J.J.C. and Verhoosel, C.V. (2012) Nonlinear finite element analysis of solids and structures, 2nd edition, Wiley.

Guven, I. (2006) The finite element method and applications in engineering using ANSYS, Springer.

Khennane, A. (2013) Introduction to finite element analysis using MATLAB and ABAQUS, CRC Press/Taylor & Francis Group.

Kythe, P. and Wei, D. (2004) An introduction to linear and nonlinear finite element analysis: a computation approach, Birkhauser Publisher.

Reedy, J.N. (2004) An introduction to nonlinear finite element analysis. Oxford University Press.

Smith, I.M. and Griffiths D.V. (1988), Programming the finite element method, John Wiley, 3rd edition.

Zienkiewicz, O.C. (1977) The finite element method, 3rd edition, McGraw-Hill.

2. Finite Element Software Available in the CEE Computer Room

ANSYS, from ANSYS Inc, Pittsburgh, USA.
ABAQUS FEA, from Dassault Systèmes Simulia Corp, Rhode Island, USA.
NIDA, Nonlinear Integrated Design and Analysis, PolyU.