School of Science and Engineering

Office of Graduate Studies

Master of Science

Earthquake Engineering

Academic Program

Fall 2011

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1. Introduction

From the point of view of civil engineers, earthquake is the most challenging environmental condition that a structure might to withstand during its life time. Although the occurrence of intensive earthquakes during the structure life time is rare, a standard design must consider its effects appropriately. Earthquake Engineering is a field of civil engineering dealing with this importance. An earthquake engineer is responsible to analyze the structures under seismic loads and propose a safe and economic design.

For the students admitted in Earthquake Engineering program, two plans are offered; the M.Sc. Thesis Plan, and the M.Sc. Course Plan. The M.Sc. Thesis Plan is designed for those students with an interest in research prior to entering the earthquake engineering profession. The M.Sc. Thesis Plan involves course work leading to the completion and defense of a master's thesis. The M.Sc. Course Plan only involves coursework. The students of either plan must complete thirty-four units of courses for graduation.

Graduates of the program will receive the degree of Master of Science in Earthquake Engineering from Sharif University of Technology, International Campus, Kish Island.

2. Program in a Glance

Duration of Program: 2 years (4 semesters)

Course Requirements:

i) **Thesis plan:** 32+2†
   a. Compulsory: 120
   b. Elective: 12
   c. Seminar: 2
   d. Thesis: 6

ii) **Course plan:** 32+2†
   a. Compulsory: 12
   b. Elective: 18
   c. Seminar: 2

†Note: Since the program is offered in English, Master students studying in either plans are required to pass 2 credit hours “Advanced Technical English”.

Note: ***This document serves as a guide only. To comply with the rules students must refer to the graduate office and ask for the up-to-date program and regulations.***

3. Course Requirements

The program is defined in terms of two levels of courses, compulsory and elective courses. *Compulsory* courses and some *Elective* courses are listed in Table 1 and 2, respectively.

Table 1. Compulsory courses

Course No.	Course Title	Credit hrs.
53014	Advanced Engineering Mathematics	3
53153	Dynamics of Structures	3
53165	Advanced Earthquake Engineering	3
53166	Design of Earthquake Resistant Structures	3

Table 2. Elective courses

Course No.	Course Title	Credit hrs.
53133	Theory of Plates and Shells	3
53151	Stability of Structures	3
53117	Fracture Mechanics	3
53147	Finite Element Method II	3
53118	Inelastic Analysis of Structures	3
53148	Numerical Methods in Structural Analysis	3
53142	Theory of Plasticity	3
53149	Finite Element Method I	3
53135	Mechanics of Composite Materials	3
53144	Continuum Mechanics	3
53251	Bridge Design	3
53195	Design Optimization	3
53138	Theory of Elasticity	3
58192	Advanced Engineering Mathematics II	3
53162	Dynamics of Structures II	3

4. Suggested 2-Years Course Selection

- **M.Sc. Thesis Plan**

1st Semester			**2nd Semester**		
Course No.	Course Title	Credit hrs.	Course No.	Course Title	Credit hrs.
53014	Adv. Eng. Math	3	53166	Dsgn. Equake Resist. Struc.	3
53153	Dynamics of Structures	3	-	Elective course	3
53165	Adv. Earthquake Eng.	3	-	Elective course	3
50621	Adv. Technical English	2	53850	Seminar	2
		11			11

3rd Semester			**4th Semester**		
Course No.	Course Title	Credit hrs.	Course No.	Course Title	Credit hrs.
-	Elective course	3	53910	Research II	3
-	Elective course	3			3
53920	Research I	3			
		9			

- **M.Sc. Course Plan**

1st Semester			**2nd semester**		
Course No.	Course Title	Credit hrs.	Course No.	Course Title	Credit hrs.
53014	Adv. Eng. Math	3	53165	Adv. Earthquake Eng.	3
53153	Dynamics of Structures	3	53166	Dsn. Equake Resistant Struc.	3
			-	Elective course	3
50621	Adv. Technical English	2	53850	Seminar	2
		8			11

3rd Semester			**4th semester**		
Course No.	Course Title	Credit hrs.	Course No.	Course Title	Credit hrs.
-	Elective course	3	-	Elective course	3
-	Elective course	3	-	Elective course	3
-	Elective course	3			6
		9			

5. Research Areas

- Numerical Analysis
- Risk Analysis
- Earthquake Engineering
- Active and Passive Controls
- Performance Based Design
- Retrofitting of Structures

6. Research Laboratories

- Concrete Laboratory
- Corrosion Laboratory

7. Course Syllabus

The following contains the recent course syllabus for the M.Sc. program in Earthquake Engineering.

Course Title : **ADVANCED TECHNICAL ENGLISH**
Course Number : **50621**
Field : **-**
Credits : **2**
Prerequisite : **N.A.**

Course Objective

- To learn writing technical articles: Journal paper, Proposal, Report and Thesis
- To learn technical presentations: Conference and Poster presentations
- To practice oral presentation

Tentative Outline

- Why witting a paper?
- Research Papers
- Paper's structures: abstract, introduction, literature review
- Paper's structures: evidence, methodology, conclusion, references and appendices
- Proposal writing
- Thesis writing
- Oral presentation: slide preparation, opening, sequence and answer the questions

Text Book: D. Soles, *The Academic Essay*, 2nd edition, Studymates, 2005, UK.

References and Supplementary Readings:

- J. Wyrick, *Steps to Writing Well*, 10th edition, Thomson Wadsworth, 2008, USA

Course Title : **SEMINAR**
Course Number : **53850**
Field : **Structural Engineering, Earthquake Engineering**
Credits : **2**
Prerequisite : **2nd semester standing**

Course Objective

- To prepare students to present a full seminar.
- Guide students through selection of good primary journal articles suitable for a seminar presentation.
- Guide students through proper presentation of data for a seminar.
- Help students develop a good speaking style suitable for a broad scientific audience

Tentative Outline

1. **Paper Summary:** Guidelines will be presented for preparing a paper summary.
    a. Each student will submit one paper summary according to guidelines provided. The selected article must be from **peer-reviewed** scientific publications.
2. **Slide preparation:** An overview of techniques for creating slides suitable for technical presentation will be given.
    a. **Data Slides:** Each student will prepare two slides that demonstrate their ability to present scientific information using Microsoft Office PowerPoint.
3. **Presentations:** develop necessary skills to effectively communicate with a broad audience, discuss techniques for presenting technical data, and rules and etiquettes that must be observed:
    a. **Introduction.** Each student will prepare and present an eight to ten-minute seminar presentation that is an overview of the introductory material needed to provide adequate background for their research topic.
    b. **Methods and Results.** Each student will prepare and present an eight to ten-minute presentation of the methods and research from the primary references that were submitted as part of the topic selection. Each presentation must include and integrate data from **two** peer-reviewed research articles.
    c. **Discussion, Conclusions and Acknowledgments.** Each student will prepare and present an eight-ten-minute presentation that discusses the results presented and provides overall conclusions about the research articles reviewed in the results presentations.
    d. **Full Seminar.** Each student will submit their revised set of PowerPoint slides to be used for their presentation. Students will give a 20-min seminar presentation
4. **Attendance.** Each student is required to attend all seminars.

Text Book: None

References and Supplementary Readings: None

Course Title : **THEORY OF PLATES AND SHELLS**
Course Number : **53133**
Field : **Structural Engineering, Earthquake Engineering**
Credits : **3**
Prerequisite : **N.A.**

Course Objective:

This course deals with the mechanics of thin plates and shells using the classical theories. Exact, approximate, and numerical approaches are utilized to solve various engineering problems of practical importance.

Tentative Outline

5. Classical small deflection theories of thin plates
6. Circular plates
7. Series solution (Navier's and Levi's methods)
8. Energy and variational methods
9. Numerical solution of plate problems (Finite Difference Method)
10. Plates of various geometrical shapes
11. Anisotropic Plates
12. Buckling of plates
13. Free vibration of Plates
14. Membrane theory of thin shells

Text Book: A.C. Ugural, *Stresses in Plates and Shells*, 2nd edition, McGraw-Hill, New York, 1999.

References and Supplementary Readings:

- S.P. Timoshenko and S. Woinkowsky-Krieger, *Theory of Plates and Shells*, 2nd edition, McGraw-Hill, New York, 1987.

- R. Szilard, *Theories and Applications of Plate Analysis: Classical, Numerical and Engineering Methods*, John Wiley & Sons, Hoboken, New Jersey, 2004.

- E. Ventsel and T. Krauthammer, *Thin Plates and Shells: Theory, Analysis and Applications*, Marcel Dekker, New York, 2001.

Course Title : **STABILITY OF STRUCTURES**
Course Number : **53151**
Field : **Structural Engineering, Earthquake Engineering**
Credits : **3**
Prerequisite : **N.A.**

Course Objective:

This course deals with the stability concept of various structures including simple rigid bar-spring models, isolated columns, beam-columns, frames, and thin plates. Both methods of equilibrium and energy are considered to obtain stability criteria. The inelastic stability of columns is discussed and some applicable numerical procedures are also addressed. An introduction to dynamic methods is provided.

Tentative Outline

1. Introduction to stability
2. Mechanical stability models
3. Buckling of elastic columns
4. Beam-columns
5. Stability of Frames
6. Torsional buckling of columns
7. Lateral-torsional buckling of beams
8. Inelastic column buckling
9. Buckling of thin plates

Text Book: F. Chen, and E.M. Lui, *Structural Stability: Theory and Implementation*, Elsevier, 1987**.**

References and Supplementary Readings:

- M.R. Horne, and W. Merchant, *The Stability of Frames*, Pergamon Press, 1965.
- S.P. Timoshenko, and J.M. Gere, *Theory of Elastic Stability*, 2nd Edition, McGraw-Hill, 1985.
- Z.P. Bazant, and L. Cedolin, *Stability of Structures: Elastic, Inelastic, Fracture, and Damage Theories*, Dover Publications, 2003.
- G.J. Simitses, and D.H. Hodges, *Fundamentals of Structural Stability*, Elsevier, 2006.
- Chajes, Principles of Structural Stability Theory, Prentice-Hall, Englewood Cliffs, NJ, 1974.

Course Title : **CONTINUUM MECHANICS**
Course Number : **53144**
Field : **Structural Engineering, Earthquake Engineering**
Credits : **3**
Prerequisite : **N.A.**

Course Objective:

Tentative Outline

1. Concept of continuous media, Indicial notation, Summation convention, Cartesian tensors, Transformation laws, Gauss and Green Theorems, Quotient rule
2. Analysis of stress in a continuum: stress vector, stress tensor, stress quadric, stress invariants, stress deviators
3. Analysis of Deformation in a continuum: Lagrangian description, Eulerian description, strain tensor, finite and infinitesimal strains, Lagrangian and Eulerian components of displacement, strain quadrics, strain invariants, strain deviators
4. Compatibility equations, Basic physical laws of continuum motion: conservation of mass, conservation of energy, conservation of linear and angular momentum, Thermodynamic laws, kinetic equation.
5. Application to solids: Linear elasticity: Constitutive equation, strain energy function, principle of superposition, anisotropic and isotropic solids, Navier equations, Beltrami Mitchel equations, Helmholdz decomposition
6. Thermo elasticity: constitutive relations;
7. Viscoelasticity: constitutive relations
8. Plasticity: constitutive relation .
9. Application to fluids: Fluid stress and fluid pressure, equations of continuity, equations of motion, Newtonian and Stoksian fluids

Text Book: Fredrick and T.S. Chang, *Continuum Mechanics*, Scientific Publishers, Cambridge, 1972.

References and Supplementary Readings:

- M. Lai, D. Rubin, E. Krempl, *Introduction to Continuum Mechanics*, 3rd edition, Pergamon Press, 1993.

Course Title	**: BRIDGE DESIGN**
Course Number	**: 53251**
Field	**: Structural Engineering, Earthquake Engineering**
Credits	**: 3**
Prerequisite	**: N.A.**

Course Objective:

Familiarizing with classical and modern methods of designing bridges and excelling at designing slab and reinforced concrete T-Beam bridges using conventional methods.

Tentative Outline

1. **Introduction:** types of bridges, historical background, aesthetic and architectural aspects, conceptual design
2. **Material and Properties:** types of materials used in bridge construction including masonry, concrete and steel and their mechanical properties
3. **Loads on Bridges:** dead loads, live loads, dynamic effect of vehicles, longitudinal forces, centrifugal forces, wind loads, earthquake forces, stream flow pressure, floating ice pressure, loading combinations (according to Iranian standard code for design of bridges and AASHTO)
4. **Influence Lines:** definition, influence lines for beam reactions, shear and moment, influence lines for trusses, influence lines for floor systems, influence lines for indeterminate beams, applications of influence lines, shear and moment envelops
5. **Allowable Stress Design Method:** bending of rectangular sections with tension reinforcement only, bending of rectangular sections with tension and compression reinforcements, bending of T-Sections with tension reinforcements, shear
6. **Ultimate Stress Design:** bending of rectangular and T-Sections, shear
7. **Floor Structural Systems:** one-element, two-element, three-element and four element deck systems
8. **Design of Slab Bridges:** economic span length, determination of slab thickness, design of longitudinal reinforcement, design of transverse reinforcement, effective width
9. **Design of Two-element Deck Systems:** economic span length, design of concrete slab including the determination of slab thickness, design of the main and transverse reinforcements, design of reinforced concrete T-Beams
10. **Analysis and Design Bridges using Softwares:** Modeling, loading, interpretations of results, design

Text Books:

- C.P. Heins and D.A. Firmage, Design of Modern Highway Steel Bridges, John Wiley & Sons
- C.P. Heins & R.A. Lawrie, Design of Modern Highway Concrete Bridges, John Wiley & Sons

References and Supplementary Readings:

- M.J.N. Priestly, F. Seible, and G.M. Calvi, *Seismic Design and Retrofit of Bridges*, John Wiley & Sons
- AASHTO, *Standard Specification for Highway Bridges*, 12th Edition, 1992.
- AASHTO, *Standard Specification for Highway Bridges*, 17th Edition, 2002.

Course Title : **THEORY OF ELASTICITY**
Course Number : **53138**
Field : **Structural Engineering, Earthquake Engineering**
Credits : **3**
Prerequisite : **N.A.**

Course Objective

Getting familiar with the basics of theory of elasticity and its application in solving engineering problems

Tentative Outline

1. **Cartesian coordinates:** transformation of coordinates, index notation, vectors, tensors, relation between δ and ε, divergence and gradient of a vector field, dyadic operations
2. **Stress:** surface, internal and body forces, traction components on arbitrary surfaces, relation between traction vector and stress tensor, equilibrium equations
3. **Strain:** infinitesimal strain and rotation, shear strain
4. **Constitutive equations for linearly elastic bodies:** generalized Hook's law for isotropic materials, Lame's constants, hyperelastic materials, elastic symmetry
5. **Boundary value problems:** formulation in terms of displacement, Cauchi-Navier equations, formulation in terms of stress
6. **Compatibility equations:** incompatibility tensor and its physical implications
7. **Plane strain and plane stress:** compatibility conditions in terms of stress components, Airy's stress function, bi-harmonic equations
8. **Solution to various problems:** hollow cylinder under internal and external pressure, composite cylinder under external pressure, declination, dislocation, disturbance in tension field using a circular hole, modeling cracks using dislocation…

Text Book: Timoshenko and Goodier, *Theory of Elasticity*, 3rd edition, McGraw-Hill

References and Supplementary Readings:

- Sokolinkoff, *Mathematical Theory of Elasticity*, McGraw-Hill
- Timoshenko and Goodier, *Theory of Elasticity*, Third edition, McGraw-Hill
- Little, *Elasticity*, Prentice Hall
- Fung, *Foundations of Solid Mechanics*, Prentice Hall

Course Title : **MECHSNICS OF COMPOSITE MATERIALS**
Course Number : **53135**
Field : **Structural Engineering, Earthquake Engineering**
Credits : **3**
Prerequisite : **N.A.**

Course Objective

Tentative Outline

1. Basic Concepts
2. Elastic Behavior and Strength of Unidirectional Laminates
3. Elastic Behavior of Multidirectional laminates
4. Hydrothermal Effects
5. Stress and Failure Analysis of Laminates
6. Experimental Methods

Text Book: I.M. Daniel, and O. Ishai, *Engineering Mechanics of Composite Materials*, Oxford University Press, 1994

Course Title : **SEISMIC DESIGN OF BULDING STRUCTURES**
Course Number : **53166**
Field : **Structural Engineering, Earthquake Engineering**
Credits : **3**
Prerequisite : **Dynamics of Structures**

Course Objective

Tentative Outline

1. **Seismic Design Requirements**
   Ground Motion, Importance Factor, Seismic Design Category, Structural Design Basic, Structural Systems, Diaphragm Flexibility, Irregular and Regular Classification, Redundancy, Seismic Load Effects and Combinations, Over strength Factor, Drift and Deformation.
2. **Concrete Structures**
   General Requirements, Materials, Ordinary Moment Frames, Intermediate Moment Frames, Special Moment Frames, Joints, Precast Concrete, Special Structural Wall and Coupling Beams, Foundations.
3. **Steel Structures**
   General Requirements, Materials, Connections, Special Moment Frames, Intermediate Moment Frame, Special Concentrically Braced Frame , Ordinary Concentrically Braced Frames, Eccentrically Braced Frames, Buckling-Restrained Braced Frames, Special Plate Shear Walls, Composite Structural Steel and Reinforced Concrete Buildings.

Text Book: F. Naeim, *The Seismic Design Handbook*, 2nd Edition, Springer, 2001.

References and Supplementary Readings:

- Y. Bozorgnia, *Erthquake Engineering: From Engineering Seismology to Performance-Based Engineering*, CRC Press, 2004.

Course Title : **DYNAMICS OF STRUCTURES**
Course Number : **53153**
Field : **Structural Engineering, Earthquake Engineering**
Credits : **3**
Prerequisite : **N.A.**

Course Objective

To provide students with a fundamental understanding of the theory of structural dynamics, as well as typical analytical and numerical methods and their practical applications.

Tentative Outline

Part I- Single-Degree- of – Freedom (SDF) Systems

1. **Equations of Motion and Free Vibration**
   Simple Structures,
   Mass-Spring- Damper System, Earthquake Excitation, Methods of Solutions of the Differential Equation, Undamped Free Vibration, Viscously Damped Free Vibration.
2. **Response to Harmonic and Arbitrary Excitations**
   Undamped Systems, Harmonic Vibration with Viscous Damping, Natural Frequency and Damping from Harmonic Tests, Unit Impulse, Arbitrary Force, Step Force, Ramped Force.
3. **Earthquake Response of Linear and Inelastic Systems**
   Earthquake Excitation, Response History and Spectrum, Pseudo-velocity, Pseudo-acceleration, Design Spectrum, Force- Deformation Relations, Reduction and Ductility Factors, Inelastic Design Spectrum.

Part II- Multi-Degree-of- Freedom (MDF) Systems

1. **Equation of Motion and Free Vibration**
   General Approach, Static Condensation, Natural Vibration Frequencies and Modes, Modal and Spectral Matrices, Orthogonality, Normalization, Undamped and Damped Systems.
2. **Dynamic Analysis and Response of Linear Systems**
   Model Analysis, Undamped and Damped Systems.
3. **Earthquake Analysis**
   Response History, Modal Analysis, Peak Response, Structural Dynamics in Building Codes.

Text Book: A.K. Chopra, *Dynamics of Structures*, 3rd edition, Prentice Hall, 2007.

References and Supplementary Readings:

- R. Clough, and J. Penzien, *Dynamics of Structures*, McGraw-Hill, 1975.
- J.L. Humar, *Dynamics of Structures*, Taylor & Francis, 2002.

Course Title : **INELASTIC ANALYSIS OF STRUCTURES**
Course Number : **53118**
Field : **Structural Engineering, Earthquake Engineering**
Credits : **3**
Prerequisite : **N.A.**

Course Objective

Tentative Outline

1. **Plastic Analysis**
   Plastic Moment, Plastic Hinge, Plastic Mechanism, Lower Bound Theorem, Upper Bound Theorem, Uniqueness Theorem, Beams and Frames, Virtual Work, Effect of Axial and Shear Forces, Moment-Rotation Capacity.

2. **Inelastic Analysis of Beam-Columns**
   General Behavior, Cross-Section Analysis for Moment-Curvature Relation, Numerical Methods, Inelastic and Elastic zones.

3. **Inelastic Analysis of Rigid Frames**
   P-delta Effects, Incremental finite Element Matrices, Inelastic Axial, Shear, Flexural, and Mixed Hinges, Solution Algorithms for Nonlinear Analysis, Nonlinear Dynamic Procedure, Pushover Analysis.

4. **Semi-Rigid Frames**
   Behavior and Modeling of Connections, Moment-Rotation Curves, Inelastic Analysis, Drift of Semi-Rigid Frames.

Text Book:

References and Supplementary Readings:

Course Title : **FINITE ELEMENT METHOD I**
Course Number : **53149**
Field : **Structural Engineering, Earthquake Engineering**
Credits : **3**
Prerequisite : **N.A.**

Course Objective

Tentative Outline

Chapter 1. Fundamental concepts
Stress and equilibrium; Principle of virtual work for solid mechanics problems; Principle of minimum potential energy; Galerkin-weighted residual and variational approaches; Rayleigh-Ritz method for solid mechanics problems

Chapter 2. The concepts of finite element
Displacement based FE formulation; Strain-displacement and stress-strain relationships; The concepts of shape functions; Family of C-continuity (C0- and C1-continuities); One-dimensional finite element; Stiffness matrix and force vectors for truss and beam elements; Lagrangian and Hermitian polynomial shape functions; Assembly of global stiffness matrix and force vectors

Chapter 3. Finite elements for two-dimensional problems
The shape functions of triangular elements (linear and higher orders); The shape functions of rectangular elements (linear and higher orders); Stiffness matrix for plane stress/strain problems (triangular and rectangular elements);

Chapter 4. Finite elements for three-dimensional problems
The shape functions of tetrahedral elements (linear and higher orders); The shape functions of brick elements (linear and higher orders); Stiffness matrix for three-dimensional problems (tetrahedral and brick elements)

Chapter 5. Isoparametric elements and Numerical integration
Natural coordinates; Area coordinates; Volume coordinates; Serendipity elements; Curved and isoparametric elements; Jacobian matrix for isoparametric elements; Numerical integration for 1D, 2D and 3D problems; Newton-Cotes approach, Gauss integration points

Chapter 6. Finite elements for axisymmetric problems
The concept and element characteristics for axisymmetric problems; Stiffness matrix and load vectors

Chapter 7. Finite elements for plate bending problems
Mindlin theory of plate; A 12-degree-of-freedom rectangular element; Element shape functions and stiffness matrix

Chapter 8. Adaptive FEM strategy for linear problems
Error estimation; 'a-priori' and 'a-posteriori' estimates; Error norms (L2 and energy norms); Adaptive mesh refinement; h, p and h-p refinements; Adaptive mesh generator

Text Book: D. J. Dawe, *Matrix and Finite Element Displacement Analysis of Structures*, Oxford University Press, New York, 1984.

References and Supplementary Readings:

- O.C. Zienkiewicz, and R.L. Taylor, *The Finite Element Method*, Vol 1, McGraw-Hill, London, 2000.

Course Title : **FINITE ELEMENT METHOD II**
Course Number : **53147**
Field : **Structural Engineering, Earthquake Engineering**
Credits : **3**
Prerequisite : **53149**

Course Objective

Tentative Outline

Chapter 1. Review on linear FE analysis
Principle of virtual work; Principle of minimum potential energy; Galerkin-weighted residual and variational approaches; Rayleigh-Ritz method for solid mechanics problems; Shape functions; Isoparametric elements; Numerical integration.

Chapter 2. Finite elements in large deformations
Displacement based FE formulation for large deformation; Total and updated Lagrangian formulation; Strain-displacement relationships in large deformations; FE discretization in large deformation; Nonlinear iterative strategy for solution of nonlinear equilibrium equations; Newton-Raphson, Modified-Newton, and Quasi-Newton (Davidon and BFGS) approaches.

Chapter 3. Finite elements in nonlinear material behavior
Classical plasticity theory; Elasto-plastic constitutive matrix; Generalized plasticity theory; Single and double surface plasticity models; Numerical computation of material property matrix; Elastic predictor-plastic corrector algorithm; Integration of the constitutive relation.

Chapter 4. Finite element modeling of contact problems
Physical aspects of friction; Plasticity theory of friction; Modeling of friction; Stress-strain relationships; Continuum model of friction; Penalty and Lagrane techniques; Interface element formulation; Shape functions and stiffness matrix of 2D and 3D interface elements

Chapter 5. FE dynamic analysis
Dynamic equilibrium equations; Time domain discretization; Explicit time integration, Implicit time integration; Single-step method; Generalized Newmark approach.

Chapter 6. Adaptive FEM strategy for nonlinear problems
Error estimation; 'a-priori' and 'a-posteriori' estimates; L2 projection and SPR techniques; Error norms (L2 and energy norms); Adaptive mesh refinement; h, p and h-p refinements; Adaptive mesh generator; Mapping of variables; Error estimates and adaptive time stepping.

Chapter 7. Discontinuous Displacements and Localization
Causes of localization in solid mechanics; Governing equations of incompressible plasticity; Theory of Cosserat continuum; Adaptive strategy for discontinuous displacements; Error indicator, Adaptive mesh refinement; Element elongation.

Text Book: A.R. Khoei, *Computational Plasticity in Powder Forming Processes*, Elsevier, UK, 2005.

References and Supplementary Readings

- D.R.J. Owen, and E. Hinton, *Finite Elements in Plasticity: Theory and Practice*, Pineridge Press, 1980.
- O.C. Zienkiewicz, and R.L. Taylor, *The Finite Element Method*, Vol. 2, McGraw-Hill, London, , 2000.

Course Title	**: DESIGN OPTIMIZATION**
Course Number	**: 53195**
Field	**: Structural Engineering, Earthquake Engineering**
Credits	**: 3**
Prerequisite	**: N.A.**

Course Objective

To understand optimization algorithms, to apply formal optimization techniques for optimal design, and to understand the commercial tools for design optimization

Tentative Outline

1. Introduction of design optimization, conventional versus optimal design, review of mathematical background (notations and concepts)
2. Formulating the problem, design variables, cost functions, constraint functions, and typical problems
3. Graphical problems, feasible region, infeasible region, solving graphical problem using MATLAB
4. Optimum design concepts, local and global minima/maxima, gradients, Hessian matrix Taylor expansion, single variable function, Taylor expansion, multivariable functions, Quadratic forms, optimality criteria, unconstraint optimal problems
5. Constraint optimal problems, Lagrange multipliers, KKT conditions
6. Linear programming methods
7. Unconstraint design optimization
8. Constraint design optimization
9. Introduction to genetic algorithm (GA)
10. Introduction to ant colony method (ACM)
11. Optimization using MATLAB

Text Book: J.S. Arora, *Introduction to Design Optimization*, 2nd edition, 2004.

References and Supplementary Readings:

- Venkataraman, *Applied Optimization with MATLAB Programming*, 2003

Course Title : **DYNAMICS OF STRUCTURES II**
Course Number : **53162**
Field : **Structural Engineering, Earthquake Engineering**
Credits : **3**
Prerequisite : **53153**

Course Objective

- To understand the limitations of linear dynamic analysis
- To familiarize students with advanced methods for dynamic analysis of continuous and nonlinear structures

Tentative Outline

1. Introduction and Overview on Multi-degrees of Freedom systems
   - Formulations
   - Evaluation of Structural Properties
     - Mass properties
     - Elastic properties
     - Damping properties
     - Loading properties
   - Step-by Step techniques
   - Static Condensation
   - Rayleigh, Improved Rayleigh, and some other approximated methods
   - Variational techniques
2. Non-linear dynamic analysis for SDF system
   - Time averaging method
   - Perturbation Technique
3. Distributed-Parameter Systems
   - Governing Differential Equation
   - Beam flexural
   - Analysis of un-damped free Vibrations
   - Orthogonally of continuous systems
   - Analysis of dynamic response
     - Un-damped cases with dynamic loads
     - Damped cases with dynamic loads
4. Introduction to some special topics (If time allows)

Text Book: A.K. Chopra, *Dynamics of Structures*, 3rd edition, Prentice Hall, 2007.

References and Supplementary Readings:

- R. Clough, and J. Penzien, *Dynamics of Structures*, McGraw-Hill, 1975.
- J.L. Humar, *Dynamics of Structures*, Taylor & Francis, 2002.

Course Title : **NUMERICAL METHODS IN STRUCTURAL ANALYSIS**
Course Number : **53148**
Field : **Structural Engineering, Earthquake Engineering**
Credits : **3**
Prerequisite : **N.A.**

Course Objective

To familiarize students with numerical methods for finding approximate solutions of static and dynamic problems encountered in civil engineering.

Tentative Outline

Introduction
Discussion on different Physical Problems
Discussion on Energy Methods and Lagrange Equation
- Examples on Static problems
- Examples on Dynamic problems

Discussion on "Discrete Element Model" (DEM)
- Application of DEM
- Implementation on beams and plates
- Examples on Static problems
- Examples on Dynamic problems

Introduction of Ritz, Galerkin, Lagrange Multiplier….Methods
Discussion on Timoshenko Beams
Discussion on Finite Differences Method (FDM)
- Numerical Method for elastic beams
- Numerical Method for elastic plates
- Examples on Static problems
- Examples on Dynamic problems

Discussion on the numerical solution of Differential Equations
- Initial Value Problems (IVP)
- Boundary Value Problems (BVP)
- Application Static and Dynamic problems in Civil Engineering

Text Book: Lecture notes

References and Supplementary Readings: None