Curriculum

M.Tech (Computer Aided Structural Engineering)

Semester – I						
	Code	**Course**	**L**	**T**	**P**	**Credits**
1	CE 5101	Numerical Methods Using Programing	2	0	2	3
2	CE 5102	Applied Elasticity and Plasticity	3	0	0	3
3	CE 5103	Computational Structural Dynamics	3	0	2	4
4	CE 5104	Analysis of Framed Structures	3	0	0	3
5	CE 5105	Computer Aided Reinforced Concrete Design	3	0	0	3
6	CE 5106	Python Programing	0	0	2	1
7	CE 5107	Building Visualization	0	0	2	1
		Total Credits	14	0	8	**18**
Semester – II						
	Code	**Course**	**L**	**T**	**P**	**Credits**
8	CE 5201	Infrastructural Health Monitoring	2	0	2	3
9	CE 5202	Programming Finite Element Method	3	0	2	4
10	CE 5203	Advanced Cementitious Composites	3	0	0	3
11	CE 5204	Computer Aided Steel Design	3	0	0	3
12	CE 5205	Analysis of Foundations & Soil Structure Interaction	2	0	0	2
13	CE 5xxx	Departmental Elective-I	3	0	0	3
14	CE 5xxx	Open Elective	3	0	0	3
		Total Credits	19	0	4	**21**
Semester-III						
	Code	**Course**	**L**	**T**	**P**	**Credits**
14	CE 5108	Capstone Project on Software Development	0	0	4	2
15	CE 5xxx	Department Elective-II	3	0	0	3
16	CE 5109	Industry Internship				2
17	CE 5110	Industry Seminars				0
18		Masters Thesis				4
		Total Credits				**11**
Semester-IV						
	Code	**Course**	**L**	**T**	**P**	**Credits**
19		Masters Thesis			0	12
		Total Credits				**12**

Total Credits for the M.Tech. Program = 18 + 21 +11+12 = **62**

M.Tech Course Descriptions

CE 5101 (2-0-2)

Numerical Methods using Programming

Module 1

Approximation in numerical computation: Truncation and rounding errors, Fixed and floating-point arithmetic, Propagation of errors and corresponding programming.

Module 2

Interpolation: Newton forward/backward interpolation, Lagrange's and Newton's divided difference Interpolation and corresponding programming.

Module 3

Numerical integration: Trapezoidal rule, Simpson's 1/3 rule, Expression for corresponding error terms and corresponding programming.

Module 4

Numerical solution of a system of linear equations: Gauss elimination method, Matrix inversion, LU Factorization method, Gauss-Seidel iterative method and corresponding programming.

Module 5

Numerical solution of Algebraic equation: Bisection method, Regula-Falsi method, Newton-Raphson method and corresponding programming.

Module 6

Numerical solution of ordinary differential equation: Euler's method, Runge-Kutta methods, Predictor-Corrector Methods and Finite Difference method and corresponding programming.

Lab

The course is accompanied by a two-hour lab every week which will involve development of computer programs for topics covered in all four modules. Specifically, detailed MATLAB programs will be developed for a) Numerical integration by Trapezoidal and Simpson's rule b) Gauss-Siedel iteration method c) Various matrix operations and their use as sub-routines.

Textbooks

1. Epperson, J. F. (2013). *An introduction to numerical methods and analysis*. John Wiley & Sons.
2. Atkinson, K. E. (2008). *An introduction to numerical analysis*. John Wiley & Sons.
3. Beu, T. A. (2014). *Introduction to numerical programming: a practical guide for scientists and engineers using Python and C/C++*. CRC Press.
4. Stoer, J., & Bulirsch, R. (2013). *Introduction to numerical analysis* (Vol. 12). Springer Science & Business Media.

CE 5102 (3-0-0)

Applied Elasticity and Plasticity

Module 1: Tensor Algebra and Kinematics of Continuum

- Introduction and mathematical preliminaries: Indicial notation and Einstein summation convention; Tensor Algebra; Transformation of tensors.
- Kinematics of a continuum: Analysis of deformation; Material and Spatial description; Displacement and strain field: Strain-displacement relationship, strain at a point, Principal strains; Rate of deformation and vorticity tensors; Compatibility conditions.

Module 2: Stress Tensor and Equilibrium

- The stress field: Stress vector, stress tensor, and Cauchy's formula; Transformations of stress components and principal stresses; Principal stresses and Planes.
- Equations of equilibrium in 3D state, Generalized Hooke's law for anisotropic material, stress-strain relationship for isotropic and orthotropic materials.

Module 3: Formulation of Boundary Value Problems

- Formulation of boundary value problems in elasticity: Equilibrium, compatibility, formulation in Cartesian and Polar coordinates; plane-stress, plane-strain and axisymmetric approximations; Boundary conditions.
- Bending of beams; Formulation of Euler-Bernoulli and Timoshenko beams; Straight beams and asymmetrical bending; Shear center or center of flexure;
- Shear stresses in thin-walled open sections: Shear centre; Shear centers for channel, I-sections and few others.
- Bending stresses due to unsymmetrical bending of angle sections; few other sections.

Module 4: Solutions to Boundary Value Problems

- Torsion on prismatic bars: Saint Venant's theory; Prandtl analogy; Torsion of circular, elliptical, triangular and rectangular bars; Torsion of a bar of narrow rectangular cross-section.
- Torsion of thin walled tubes; multi-celled closed sections - Torsion of rolled sections; H-section, Channel-section and angle section.
- Solution of boundary value problems in elasticity: Airy stress function; Plane stress and plane strain problems.

Module 5: Introduction to Plasticity

- Introduction to the non-linear elasticity and the theory of plasticity (rate independent); uni-axial plasticity and stress-strain curves; Decomposition of strain; Yield criterion and failure theories, Loading conditions.
- Associated and non-associated flow rules, isotropic and kinematic hardening.

The homework for module 3 and module 4, although containing analytical solutions, will require coding to visualize the solution and perform parametric study. Most of the practical formulations would require FE or numerical solutions.

Text Books

- Martin H. Sadd; Theory of elasticity, Academic press, 4th edition, Elsevier.
- S. Timoshenko and J.N. Goodier; Theory of elasticity, McGraw Hill Publications.
- Lubliner, J. (2008). *Plasticity theory*. Courier Corporation.

Reference Books

- J.N. Reddy; An Introduction to continuum mechanics (2nd Edition), Cambridge University Press.
- A. J. M. Spencer; Continuum Mechanics, Dover Publications, Minneola, New York, First Edition (2004).
- N. Chandramouli; Continuum Mechanics, Yes Dee Publishing Pvt. Ltd.
- L.S. Srinath; Advanced Mechanics of Solids, Tata McGraw Hill Edcucation Pvt Ltd., ISBN-10: 0070702608.
- A.F. Bower; Applied Mechanics of Solids, url: http://solidmechanics.org/ CRC Press; 1st Edition (October 5, 2009), ISBN-10: 1439802475.
- Ugural and Fenster; Applied Mechanics of Materials and Applied Elasticity, Prentice Hall Pearson Education.

CE 5103 (3-0-2)

Computational Structural Dynamics

UNIT-I

Theory of Vibrations: Introduction –Elements of a vibratory system – degrees of freedom-continuous systems –lumped mass idealization –Oscillatory motion –Simple harmonic motion – pictorial representation of S.H.M - free vibrations of single degree of Freedom (SDOF) systems – undamped and Damped –Critical damping – Logarithmic decrement –Forced vibrations of SDOF systems-Harmonic excitation – Dynamic magnification factor- Bandwidth.

Programming: Simple pendulum for different lengths and initial conditions

UNIT-II

Single degree of Freedom System: Formulation and solutions of the equation of motion - free Vibration response –response to harmonic, periodic, Impulsive and general Dynamic loading – Duhamel integral.

Programming: Response of SDOF with and without damping, Harmonic loading

UNIT-III

Multi Degree of Freedom System: selection of the degree of freedom –Evaluation of structural property matrices-Formulation of the MDOF equations of motion – Undamped free vibrations-Solution of Eigen value problem for natural frequencies and mode shapes- Analysis of dynamic response –Normal coordinates –Uncoupled equations of motion –Orthogonal properties of normal modes-mode superposition procedure.

Programming: Response of MDOF with and without damping, Harmonic loading

UNIT-IV

Practical vibration analysis: Stodola method- Fundamental mode analysis –analysis of second and higher modes –Holzer‟s method –basic procedure –transfer matrix procedure

Programming: Eigen Value problem and Modal analysis

UNIT-V

Introduction to Earthquake analysis: Introduction –Excitation by rigid base translation – Lumped mass approach -SDOF and MDOF system- I.S code methods of analysis.

Programming: Response of SDOF subjected to Earthquake ground motion

REFERENCE BOOKS:

- A.K.Chopra, “Structural Dynamics for Earthquake Engineering”, Pearson Publications
- Dynamics of Structures With MATLAB Applications by Ashok K Jain
- Dynamics of structures by Clough & Penziem
- Structural dynamics by Mario Paz
- I.S:1893(latest) “Code of practice for earthquakes resistant design of structures”

CE 5104 (3-0-0)

Analysis of Framed Structures

Module I: Matrix Analysis of Framed Structures
Introduction, direct stiffness method, complete, member stiffness matrices, formation of joint stiffness matrix, formation of load vector, computer programming

Module II: Additional Topics in Stiffness Method
Bandwidth, Elastic Supports, Inclined Supports, Hinges in Framed Structures, Static Condensation, Substructuring

Module III: Seismic Analysis of Framed Structures
IS 1893:2016 Guidelines for Seismic Analysis of structures, Equivalent static method for frame analysis-Base shear and storey shear, Response history analysis under support excited vibration, Response spectrum analysis, modal mass, modal participation factors, modal combination rules using absolute sum, SRSS and CQC method.

Module IV: Wind Analysis of Framed Structures
IS 875-Part III: 2015 Guidelines for Wind Analysis of structures, Basic and Design Wind Speed, Various factors for wind speed, Wind Pressure and Forces, Static analysis for Wind loads, Dynamic wind analysis, effect of terrain.

Module V: Analysis of elastic instability and second order effects
Effects of axial force on flexural stiffness, Solution by slope deflection method, Solution by matrix method

Programming using MATLAB and Analysis using STAAD Pro

1. Formulation of Direct Stiffness matrix for a Plane Frame
2. Analysis of Framed structure subjected to Seismic Loads
3. Analysis of Framed Structure subjected to Wind Loads
4. Computer programming using static condensation, substructuring and bandwidth

TEXT BOOKS:

- Advanced Structural Analysis by Devdas Menon, Narosa Publishing House, Reprint Edition, 2019
- Matrix Analysis of Structures by Asslam Kassimali, Brooks/ Cole Publishing Co., USA 1999.
- Structural Analysis: A Unified Classical and matrix Approach by Amin Ghali, Adam M Neville and Tom G Brown, Sixth Edition, 2007, Chapman &Hall.
- Earthquake Resistant Design of Structures by Agarwal, P. and Shrikhande, M., Prentice-Hall of India, 2006

REFERENCE BOOKS:

- Matrix Analysis of Framed Structures by William, W. & Gere J.M., CBS Publishers & Distributers, 1986.
- Introduction to Matrix Methods of Structural Analysis by Harold C. Martin, McGraw Hill. Inc. 1966.
- IS 1893:2016- S 1893 (Part 1): 2016. Indian Standard. Criteria for Earthquake Resistant Design. Of Structures. Part 1 General Provisions And Buildings
- IS 875: Part 3: 2015. Design Loads (Other than Earthquake) for Buildings and Structures - Code of Practice Part 3 Wind Loads (Third Revision)

CE 5105 (3-0-0)

Computer Aided Reinforced Concrete Design

Module I: Introduction to Reinforced Concrete Design and Types of Limit States:
Basics for the design of RC members. Limit States-Collapse and Serviceability.
Introduction to International Standards for RC design
Estimation of Crack Width: **S**hort term deflection and long-term deflection, estimation of crack width

Module II: Yield Line Theory for Slabs: Yield line analysis for slabs: Upper bound and lower bound theorems – yield line criterion – Virtual work and equilibrium methods of analysis for square and circular slabs with simple and continuous end conditions.

Module III: Design of RC Deep Beams and Flat slabs: Steps for designing of Deep Beams, Design by IS 456, Checking for Local Failures, Detailing of Deep Beams

Flat slabs: Direct design method – Distribution of moments in column strips and middle strip-moment and shear transfer from slabs to columns – Shear in Flat Slabs-Check for one way and two-way shears – Introduction to Equivalent frame method. Limitations of Direct design method, Distribution of moments in column strips and middle strip.

Module IV: Design of Elevated Water Tank: Types of elevated water tanks, Structural elements of elevated tanks, Intz Tank-Forces acting on Intz tank, Design principles, Steps for designing Intz tank, Foundation for Intz tank, Detailing of Intz tank

Module V: Earthquake Resistant Design of Reinforced Concrete Structures: Principles of earthquake resistant deign of RC members; Causes of failure of RCC structures, case studies. Concept of ductility, Ductile design- Beams, columns, joints, strong columns and weak beams concept. Design and detailing of beam column joint, Design and detailing of RC shear wall.

Programming using MS Excel and Design using STAAD Pro & Detailing using RCDC:

5. Design of Singly and Doubly Reinforced Beams
6. Design of Continuous Beams
7. Design of Flat slabs
8. Design of Deep beams
9. Design of Intz Tank
10. EQRD of Beams and Columns

TEXT BOOKS:

- Reinforced concrete design by S. Unnikrishna Pillai & Menon, Tata Mc. Graw Hill, 2nd Edition, 2004
- Advanced Reinforced Concrete Design – P.C. Varghese, Prentice Hall of India, 2008
- Prestressed Concrete by N. Krishna Raju, Tata Mc. Graw Hill, 6th Edition, 2018

- Earthquake Resistant Design of Structures by Agarwal, P. and Shrikhande, M., Prentice-Hall of India, 2006

REFERENCE BOOKS:

- Reinforced concrete design by Kennath Leet, Tata Mc. Graw-Hill International, editions, 2nd edition, 1991.
- Design of Reinforced concrete structures by N.Subramanian, Oxford University Press
- Reinforced Concrete Structures by Park and Paulay, John Willey Publishers.
- Design of concrete structures – Arthus H. Nilson, David Darwin, and Chorles W. Dolar, Tata Mc. Graw-Hill, 3rd Edition, 2005.
- Limit state theory and design of reinforced concrete by Dr. S.R. Karve and Dr. V.L. Shah, Standard Publishers, Pune, 3rd Edition, 1994.
- IS: 456: 2000, Code of Practice for Plane and Reinforced Cement Concrete,
- IS 1893:2016- S 1893 (Part 1): 2016. Indian Standard. Criteria for Earthquake Resistant Design. Of Structures. Part 1 General Provisions and Buildings
- IS 13920: 2016. Ductile Design and Detailing of Reinforced Concrete Structures Subjected to Seismic Forces - Code of Practice (First Revision)
- IS 3370: Part 1 and 2: 2021. Concrete Structures for Retaining Aqueous Liquids - Code of Practice: Part 1 General Requirements, Part 2 Plain and Reinforced Concrete Structures
- Standard, British. "Eurocode 2: Design of concrete structures—." Part 1-1: General rules and rules for buildings (2004): 230.
- ACI Committee. "Building code requirements for structural concrete (ACI 318-08) and commentary." American Concrete Institute, 2008.

CE 5106 (0-0-2)
Python Programming

The Python Programming Laboratory comprises of a hands-on training session (two lab hours per week) on basic programming modules. The programming lab course will cover Control and Evaluations, Data Aggregates, Functions and Modules, Classes, Objects, and Exceptions.

Module-1

- Basic Introduction to Python Language Computers
- The Basic Constructs: Variables, Logical and Arithmetic Operations

Module-2

- List Basics
- Conditionals
- Iterative Loops – while and for loops
- Handling exceptions
- Modules

Module-3

- Functions and Recursions
- List Comprehensions, Sets, Tuples and Dictionaries
- Glimpses of Algorithms

Module-4

- OOP Basics

Module-5

- Plotting and Graphics – Matplotlib (Python Library)

Module-6

- Numpy / Scipy (Python Data Science Library)
- Pandas / Flask (Python Data Science Library)

Lab Sessions: Weekly (2 hrs)

Weeks 1 & 2: Introduction to the Spyder IDE / Jupyter Note Book. Working on basic I/O's, expressions, statements and calculations using operators.

Week 3: More complicated calculations. Importing math module. Usage of exceptions.

Week 4: Programs with more complicated logic. If, else and elif blocks. Logic illustration through flowcharts. Try – Catch blocks.

Week 5: Programs with While Loop and For Loop.

Week 6: Programs using Lists. More complex problems using conditionals, loops and lists.

Week 7: Programming with Functions. Usage of recursions.

Week 8: Using random module. More complex functions with Lists. Sorting. Algorithmic analysis of complexity of Sorting.

Week 9: Working on Matrices. Algorithmic complexities of different operations (add, multiply) on Matrices.

Week 10: Modules – creating, exploring and using modules.

Week 11: Plotting in Python: example programs. (Matplotlib)

Week 12: Programs on Tuples, Sets and Dictionaries.

Week 13: Programs in OOP.

Week 14: Application specific exercising on Python Libraries. (Numpy / Scipy / Pandas / Flask)

Week 15: Case Studies / Applications / Projects

Websites:

- www.python.org
- www.pythonlearn.com (also has a good ebook)
- http://introtopython.org/contents.html
- https://www.continuum.io/downloads

Quick reference (follow lectures and labs)

- Python in Easy Steps – Mike McGrath
- Fundamentals of Python – Lambert and Juneja

Textbooks

1. Lutz, M. (2001). *Programming python*, O'Reilly Media, Inc.
2. Chun, W. (2001). *Core python programming* (Vol. 1). Prentice Hall Professional.
3. Zelle, J. M. (2004). *Python programming: an introduction to computer science*. Franklin, Beedle & Associates, Inc..

CE 5107 (0-0-2)
Building Visualization

The Building Visualization Laboratory comprises of a hands-on computer training session (two lab hours per week) on various aspects of structural modelling, 3D visualization and simulation. The topics covered in the lab are as under -

Lab Sessions:

- Building Visualization using 2D drawings (actual site drawings)
- Introduction to BIM: History and dimensions
  Lab: Autodesk Revit Interface
- BIM tools, new workflow of construction planning and management
  Lab: Hands-on 3D Modelling in Revit
- BIM LoD discussions with case studies
  Lab: Hands-on Development of a new project in Revit
- BIM and Project delivery
  Lab: Hands-on 3D visualization, Rendering and walkthrough
- BIM Scheduling and 4D simulation
  Lab: Hands-on Model based scheduling
- BIM based Model checking
  Lab: Hands-on Model based cost estimation
- Integrated Project delivery with case studies
  Lab: Hands-on 4D Simulation using (MS Project / Navisworks)

Textbooks

1. Kirby, L., Krygiel, E., & Kim, M. (2017). *Mastering Autodesk Revit 2018*. John Wiley & Sons.

   Omura, G. (2011). *Mastering AutoCAD 2010 and AutoCAD LT 2010*. John Wiley & Sons.

CE 5201 (2-0-2)

Infrastructural Health Monitoring

Module 1:

Introduction to structural health monitoring, its need and necessity (case studies related to failures), Factors affecting Health of Structures, Causes of Distress, Regular Maintenance, components of SHM and challenges, various sensing technologies, hardware and software requirements etc

Module 2:

Low frequency SHM techniques: Local and Global vibrations, Modal and structural parameters, model updating, data evaluation and assessment, Method based on modal frequency/shape/damping, Curvature and flexibility method, Modal strain energy method, Sensitivity method, Baseline-free method, Cross-correlation method

Module 3:

High frequency SHM techniques: working principles of smart materials used as sensors and actuators, different sensors and its application, Electro mechanical impedance technique, wave propagation method,

Module 4:

Field Application: Challenges for practical applications of sensors, data acquisition, filtering, evaluation and assessment

Module 5:

Application of AI in SHM: Image processing, Artificial neural network, time series models

Textbooks and References

1. Ewins, D. J. (2000), Modal Testing: Theory, Practice and Applications, 2nd edition, Research Studies Press Ltd., Baldock.

2. Inman, D. J., Farrar, C.R., Steffan, V. and Lopes, V. (2005), Damage Prognosis -For Aerospace, Civil and Mechanical Systems, John Wiley & Sons, Ltd., Chichester, UK.

3. Soh, C. K, Yang Y. W. and Bhalla S. (2012), Smart Materials in Structural Health Monitoring, Control and Bio – mechanics, Springer, ISBN: 978-3-642-24462-9 (Print) 978-3-642-24463-6 (Online).

4. Hixon, E.L. (1988), “Mechanical Impedance”, Shock and Vibration Handbook, edited by C. M. Harris, 3rd ed., Mc Graw Hill Book Co., New York, pp. 10.1-10.46.

5. Ikeda, T. (1990), Fundamentals of Piezoelectricity, Oxford University Press, Oxford.

6. Bhalla, S., Moharana, S., Talakokula, V., & Kaur, N. (2016). *Piezoelectric materials: applications in SHM, energy harvesting and biomechanics*. John Wiley & Sons.

7. Farrar, C. R., & Worden, K. (2012). *Structural health monitoring: a machine learning perspective*. John Wiley & Sons.

CE 5202 (3-0-2)

Programming Finite Element Method

UNIT-I
Computer Strategies: Introduction –Computer Strategies - Applications Software – Array Features – MPI Libraries - Visualizations.

UNIT-II
Spatial Discretization by Finite Elements: Introduction – Rod element – Rod Stiffness Matrix – Rod Mass Matrix, Beam element – Beam Stiffness matrix – Beam Mass Matrix, Beam on Elastic foundation, Two Dimensional Elements – Plane Stress – Plane Strain, Three Dimensional – Plate Bending.

UNIT-III
Programming Finite Element Computations: Local coordinates for Quadrilateral Elements-Numerical Integration – Analytical Integration, Local coordinates for Triangular Elements, Multi-Element Assemblies, Incorporation of Boundary conditions, Programming using Building Blocks, Solution of Equilibrium Equations, Evaluation of Eigen values and Eigen vectors

UNIT-IV
Static Equilibrium of Structures: Axially loaded elastic rod using 2-node rod elements, 2d and 3D analysis of truss, 2D and 3D Beam deformation, Stability of elastic beams using 2 node beam element.

UNIT-V
Static Equilibrium of Linear Elastic Solids: Plane axisymmetric strain analysis of a rectangular elastic solid using 3, 6, 10 and 15 node right angled triangles and 4,8 node rectangular quadrilaterals. Plane non-axisymmetric strain analysis, Three dimensional strain analysis using 8, 14 and 20 node brick hexahedra. Generating ABAQUS UMAT files.

UNIT-VI
Material Non-linearity: Introduction, Stress-strain behavior, stress invariants, Failure criteria, Viscoelasticity.

Programming using Python

a. 2D and 3D Truss
b. 2D and 3D Beams
c. 2D and 3D Plates
d. Material Nonlinearity
e. Temperature Induced Rod

REFERENCE BOOKS:

- Smith, I. M., Griffiths, D. V., & Margetts, L. (2013). Programming the finite element method. John Wiley & Sons.
- Finite Elements Methods in Engineering by Tirupati. R. Chandrnpatla and Ashok
- D. Belegundu – Pearson Education Publications.
- Finite Element analysis – Theory & Programming by C.S.Krishna Murthy- Tata Mc Graw Hill

CE 5203 (3-0-0)

Advanced Cementitious Composites

Module 1: Hydration of Cements and Aggregates

Portland Cement: Chemical composition; Hydration of cement compounds; Pores in hydrated cement paste;

Types of cements; Reactivity and filler effect of pozzolana;

Aggregate: Influence of size, shape and surface texture of aggregate; Interfacial transition zone; Grading of Aggregate; Particle packing using EMMA* software.

Module 2: Green State Characteristics

Green State Characteristics: Segregation and bleeding; plastic shrinkage; workability, pumpability and flowability of concrete; concreting in hot and cold weather;

Use of chemical admixtures in enhancing the properties of concrete.

Module 3: Microstructure, Strength and Durability

Microstructure of concrete: Microstructure of hydrated cement paste, aggregate and interfacial transition zone from SEM; Microstructure of Pore space from SEM and MIP. Strength of Concrete;

Durability of concrete: Water permeability, Carbonation and Sulphate attack; Corrosion of steel in concrete

Module 4: Fiber-reinforced Concrete

Fiber Reinforced Concrete (FRC): Types of fibers and their properties; Effect of fiber orientation; Mechanics of fiber pull-out (fiber-matrix interaction); Constitutive response; Influence on workability; Design FRC mixes; Mechanical performance of FRC.

Fiber Reinforced Plastic (FRP) as structural repairs: types; mechanics of load-transfer;

Module 5: 3D printable Concrete

Brief Introduction to additive manufacturing: FDM, powder bed and Inkjet printers; Bio-mimicking; structural optimization;

Design mix for concrete 3D printing: Requirements; Rheology of fresh concrete; Thixotropic nature of concrete; Hardened properties; Influence of print parameters;

Text Books:

1. Neville, A. M., ‘Properties of Concrete,’ Pitman Publishing, Inc., MA, 1981

2. Mehta, P. K., and Monteiro, P. J. M., ‘Concrete: Microstructure, Properties, and Materials,’ Fourth Edition (Indian Edition), McGraw Hill, 2014.

3. Singh, H. (2016). Steel fiber reinforced concrete: behavior, modelling and design. Springer.

4. Relevant research papers in the areas of FRC and 3D printing.

CE 5204 (3-0-0)

Computer Aided Steel Design

Module I: Review of Structural Steel and Design of Moment-Resisting Connections

Mechanical properties of steel, cold working and strain hardening; Philosophy, concept and methods of design of steel structures; Types frames and structural forms; Brief-review of member and simple connection designs.

Moment-resisting connections: - Connections Subjected to Eccentric Shear – Bolted Framed Connections- Bolted Seat Connections – Bolted Bracket Connections. Bolted Moment Connections – Welded Framed Connections – Welded Bracket Connections.

Introduction to various Steel Design Codes and Standards – IS 800, CSA S16, AISC 341, EN 1993. Limit State Design Philosophy, Various Limit States, Working Stress Design Philosophy

Module II: Design of Beam-Column

Beam-column design: General Behavior of Beam-columns; Equivalent Moment Factor; Nominal Strength-Instability in the Plane of Bending; Beam-columns Subjected to Tension and Bending; Design of Eccentrically Loaded Base Plates

Module III: Design of Plate and Gantry Girder

Design of Plate Girder: Preliminary Design Procedure; Web Panel Subjected to Shear; Local Buckling; Behavior of Transverse Web Stiffeners; Design using IS 800: 2007; Welding of Girder Components; Proportioning of the Section. Introduction to S-N Curves and Fatigue Design

Design of Gantry Girder: Loading Considerations; Maximum Load Effects; Fatigue Effects; Selection of Gantry Girder; Design.

Module IV: Design of Industrial Buildings and Trusses

Analysis and Design of Industrial Buildings: Dead loads, live loads and wind loads on roofs. Design wind speed and pressure, wind pressure on roofs; wind effect on cladding and louvers; Design of angular roof truss, tubular truss, truss for a railway platform. Design of purlins for roofs, design of built up purlins, design of knee braced trusses and stanchions. Design of bracings.

Types of truss bridges, component parts of a truss bridge, economic proportions of trusses, self-weight of truss girders, design of bridge compression members, tension members; wind load on truss girder bridges; wind effect on top lateral bracing; bottom lateral bracing; portal Bracing; sway bracing;

Module V: Earthquake Resistant Design of Steel Structures

Introduction to Design of Dissipative Structures, Seismic Design of Moment Resisting Frames, Seismic Design of Concentrically Braced Frames, Seismic Design of Eccentrically Braced Frames, Seismic Design of Composite Steel Concrete Structures, Design Examples.

Programming using MATLAB, Python and Macros in MS Excel:

Design of Simple and Moment resisting connections; Design of plate girders; Design of truss bridges;

Text Books

- N. Subramanian; *Design of Steel Structures*, Oxford University Press 2016. ISBN-13:978-0-19-946091-5.
- Design Steel Structures Volume – II, Dr. Ramachandra & Vivendra Gehlot, Scientific Publishers Journals Department.
- Graham W. Owen and Brian D. Cheal; *Structural Steelwork Connections*, Butterworth-Heinemann (August 1, 1989), ISBN-10: 0408012145

Reference Books

- S. Duggal; *Limit State Design of Steel Structures*, Mc Graw Hill Education, 5th Edition. ISBN-10 9351343499.
- Abi O. Aghayere; *Structural Steel Design: A Practice Oriented Approach,* Pearson eISBN: 9781282660656 (ebook available).

CE 5205
Analysis of Foundations & Soil Structure Interaction
(2-0-0)

Module 1: Functions and requisites of a foundation - Different types - Choice of foundation type – shallow foundation- load carrying capacity-settlement. Types of deep foundation – Types of pile foundations- Factor governing choice of type of pile –Choice of pile materials.

Module 2: Load carrying capacity of piles by static formulae- Introduction: IS code method- Piles in cohesive and cohesionless soils – Piles in layered cohesive and cohesionless soils – Settlement of single pile – Piles bearing on rock – Piles in fill and Negative skin friction.

Module 3: Group action in piled foundations: Introduction- Minimum spacing of piles- group efficiency- Estimation of group bearing capacity- Effect of pile arrangement- Effect on pile groups of installation methods- precaution against heave effect in pile group-Settlement of pile Group-Reduce differential settlement in pile group.

Module 4: Soil-Foundation Interaction: Introduction to soil-foundation interaction problems, Soil behaviour, Foundation behaviour, Interface behaviour, Scope of soil foundation interaction analysis, soil response models, Winkler, Elastic continuum, Two parameter elastic models, Elastic plastic behaviour, Time dependent behaviour. Beam on Elastic Foundation- Soil Models: Infinite beam, Two parameters, Isotropic elastic half space, Analysis of beams of finite length, Classification of finite beams in relation to their stiffness.

Module 5: Laterally Loaded Pile: Load deflection prediction for laterally loaded piles, Subgrade reaction and elastic analysis, Interaction analysis, Pile-raft system, Solutions through influence charts.

Reference books:

1. J.E. Bowles, "Foundation Analysis and Design", McGraw Hill, 1996.
2. Braja M. Das., "Principles of Foundation Engineering", Thomson Asia Pte, 1987, London Ltd., Singapore, 2005, A viewpoint publication.
3. P.C. Varghese, "Foundation Engineering", Prentice-Hall of India, New Delhi, 2005.
4. Selva durai, A. P. S, Elastic Analysis of Soil-Foundation Interaction, Elsevier, 1979. Poulos, H. G., and Davis, E. H., Pile Foundation Analysis and Design, John Wiley, 1980

CE 5021 (3-0-0)
Bridge Engineering

UNIT –I

Introduction: Types of bridges - Materials of construction - Codes of practice (Railway and Highway Bridges) - Aesthetics - Loading standards (IRC, RDSO, AASHTO) - Recent developments box girder bridges - Historical bridges (in India and overseas). Planning and layout of bridges: Hydraulic design - Geological and geotechnical considerations - Design aids - Computer software's - Expert systems.

UNIT – II

Concrete bridges: Bridge deck and approach slabs - Slab design methods - Design of bridge deck systems - Slab-beam systems (Guyon-Massonet and Hendry Jaeger methods) - Box girder systems - Analysis and design - Detailing of box girder systems. Seismic resistant design provisions

UNIT – III

Steel and composite bridges: Introduction to composite bridges - Advantages and disadvantages - Orthotropic decks - Box girders - Composite steel-concrete bridges - Analysis and design - Truss bridges.

UNIT-IV

Sub-structure: Piers - Columns and towers - Analysis and design - Shallow and deep foundations - Caissons - Abutments and retaining walls. Bridge appurtenances: Expansion joints - Design of joints - Types and functions of bearings - Design of elastomeric bearings - Railings - Drainage system - Lighting.

UNIT-V

Long span bridges: Design principles of continuous box girders - Curved and skew bridges - Cable stayed and suspension bridges - Seismic resistant design - Seismic isolation and damping devices. Construction techniques: Cast in-situ - Prefabricated - Incremental launching - Free cantilever construction.
Inspection - Maintenance and rehabilitation - Current design and construction practices.

Software: STAAD Pro / MIDAS

References:

1. Wai-Fah Chen Lian Duan, "Bridge Engineering Handbook", CRC Press, USA, 2000.
2. R.M. Barker and J.A. Puckett, “Design of Highway Bridges”, John Wiley & Sons, New York, 1997.
3. P.P. Xanthakos, "Theory and Design of Bridges", John Wiley & Sons, New York, 1994.
4. D.J. Victor, “Essentials of Bridge Engineering,” Oxford & IBH Publishing, New Delhi, 2001.
5. N. Krishna Raju, “Design of Bridges,” Oxford & IBH Publishing, New Delhi, 1998.
6. T.R. Jagadeesh and M.A. Jayaram, “Design of Bridge Structures,” Prentice-Hall of India, New Delhi, 2006.
7. AASHTO (1999). “AASHTO LRFD Bridge Design Specifications, 1999 Interim”, American Association of State Highway and Transportation Officials, Washington, D.C

8. IRC (1999). “IRC 83-1999: Standard Specifications and Code of Practice for Road Bridges, Section IX – Bearings”, Indian Roads Congress, New Delhi.
9. IRC (2000). “IRC 6-2000: Standard Specifications and Code of Practice for Road Bridges, Section II – Loads and Stresses”, Indian Roads Congress, New Delhi.

CE 5022 (3-0-0)
Tall Buildings

Module-I: Introduction: Evolution of tall buildings – Classification of Buildings – Low-rise, medium-rise, Highrise – Ordinary framed buildings & Shear-wall buildings –Behaviour of buildings under lateral loads like Wind loads, Earthquake loads & Blast loads – Basic structural & functional design requirements – Strength, Stiffness & Stability.

Module-II: Lateral load resisting elements: Frames, Rigid frames, braced frames, infilled frames, shear walls, coupled shear walls, wall – frames, tubulars, cores, futrigger - braced and hybrid mega system. Structural behaviour of Shear walls – Approaches of analysis – Elastic continuum approach & Discrete approach —Choice of System for a Building:

Module-III: Bluff body aerodynamics; aero-elastic phenomena; wind directionality effects; structural response and design considerations; standard provisions for wind loading.

Module-IV: Codal provisions, asiesmic design of structures; dynamic analysis; effect of torsion; design of stack like structures; earthquake forces in tall buildings. Shear in buildings; need and location of shear walls in tall buildings; analysis and design of shear walls.

Module-V: Matrix oriented methods of design of tall buildings; design of pile and raft foundation for tall buildings – Available Software's for analysis of tall buildings.

Programming using MATLAB/MS Excel and Analysis & Design using ETABS/STAAD Pro.

TEXTBOOKS:

1. Design of Tall Buildings by Taranath B., McGraw Hill.

REFERENCES

- Reinforced Concrete Design of Tall Buildings by Bungales. Taranath, CRC Press.
- Analysis of Shear Walled Buildings by S. M. A. Kazimi& R. Chandra, Tor-steel Research Foundation, Calcutta, India.
- Analysis of Framed Structures by Gere & Weaver
- Design of Building Structures by Wolfgang Schuller, Prentice Hall

CE 5023 (3-0-0)
Fracture Mechanics of Concrete Structures

Module-I: Introduction and Linear Elastic Fracture Mechanics

Study of cracks in concrete- Types and causes of cracks in concrete due to moisture, thermal, creep, shrinkage, chemical reaction, and elastic deformation. Principles Of Linear Elastic Fracture Mechanics (LEFM)- Griffith and Irwin theory of brittle fracture, Modes of fracture, Stress Intensity factor (SIF)- Three Point bend beams and other cases, Crack opening, Strain Energy Release Rate (SERR), plastic zone at crack tip, Measurement of SIF for metallic materials

Module-II: Non-Linear Fracture Mechanics

Crack Tip Opening Displacement (CTOD) and Crack Mouth Opening Displacement (CMOD), J-Integral, Fracture resistance (R-curve), Measurement of J-R curves and CTOD for metallic materials

Module-III: Introduction to Fracture Mechanics of Concrete

Need for fracture in concrete, Application of LEFM and NLFM to concrete, Various NLFM models, Constituents and microstructure of concrete, fracture process zone, toughening mechanisms, brittleness and size effect of concrete, determination of tension softening response of concrete, Size-dependent (RILEM) and Size-independent fracture energy, characteristic length.

Module-IV: Application of Fracture Mechanics to Plain and Reinforced Concrete Structures

Concrete pipes, concrete gravity dams, concrete pavements, time-dependent crack growth of large concrete dams, nuclear containers, tanks, spalling of concrete due to fire exposure, Fracture behavior of special concretes (fiber reinforced concrete, self-compacting concrete, UHPC, UHSC, UHPFRC, HSC, AAB, etc.), case studies

Module-V: Numerical analysis of fracture of concrete

Concrete Damage Plasticity model, Cohesive Zone model, XFEM for crack simulation

Programming using MATLAB and Simulations using ABAQUS.

Textbooks (T):

1. Prashant Kumar, “Elements of Fracture Mechanics”, First Edition, Tata McGraw Hill, India, 2009.
2. Karihaloo, B. L, “Fracture mechanics and structural concrete”, Harlow, Essex, England: New York: Longman Scientific & Technical; Wiley, 1995.

Reference Books (R):

1. S.P. Shah, Stuart E. Swartz, Chengsheng Ouyang, “Fracture Mechanics of Concrete: Applications of Fracture Mechanics to Concrete, Rock and Other Quasi-Brittle Materials”, Wiley, 1995.
2. Indian Standard: SP-25:1984-Handbook for causes and prevention of cracks in buildings.
3. P.C.Verghese, Advanced Reinforced Concrete Design, Prentice Hall India, 2nd Edition, 2005
4. N. Krishna Raju, Advanced Reinforced Concrete Design, CBS Publishers, 2012
5. IS 456:2000- Plain and Reinforced Concrete - Code of Practice

CE 5024 (3-0-0)

Forensic Structural Engineering

MOOCS course (Ref. TU Delft)

https://online-learning.tudelft.nl/courses/forensic-engineering-learning-from-failures/

Module 1: Introduction to Forensic Engineering

You will learn what Forensic Engineering is and why it is important. Furthermore, you will be introduced to basic concepts such as lifecycles of constructed facilities, failure, and damage.

Module 2: The Forensic Engineering Investigation

You will learn the basic steps of a Forensic Engineering process and how the TU Delft mind-set can help to perform these steps in a factual, reliable and systematic way.

Module 3*: Case from Civil Engineering

You will learn about various structural failure mechanisms and you will practice setting hypotheses for structural failures.

Module 4*: Case from Aerospace Engineering

You will learn about the failure mechanism fatigue in airplanes and how you can test to see whether this occurred.

Module 5*: Case from Biomechanical Engineering

You will learn about contamination of medical instruments and how technical and procedural aspects play a role.

Module 6: Course debriefing

In this week, the outcomes of the different cases from Modules 3-5 are revealed. Best practices and tips for the future are discussed and some results and contributions from participants are put in the spotlight!

**Modules 3-5 will be offered at the same time, to allow students to choose or prioritize their preferred module(s) based on their main areas of interest.*

CE 5025 (3-0-0)

Prestressed Concrete Design

Module 1

Materials for prestressed concrete and prestressing systems High strength concrete and high tensile steel – tensioning devices – pretensioning systems – post tensioning systems.

Module 2

Analysis of prestress and bending stresses Analysis of prestress – resultant stresses at a sector – pressure line or thrust line and internal resisting couple – concept of load balancing – losses of prestress – deflection of beams.

Module 3

Strength of prestressed concrete sections in flexure, shear and torsion Types of flexural failure – strain compatibility method – IS code procedure – design for limit state of shear and torsion.

Module 4

Design of prestressed concrete beams and slabs Transfer of prestress in pre tensioned and post tensioned members – design of anchorage zone reinforcement – design of simple beams – cable profiles – design of slabs.

Module 5

Design of tension and compression members – Tanks, pipes and poles – Partial prestressing – Definition, methods of achieving partial prestressing, merits and demerits of partial prestressing.

Textbooks & References:

1. N. Krishna Raju, Prestressed concrete, Tata McGraw Hill, 2000
2. T.Y. Lin, Ned H. Burns, Design of Prestressed Concrete Structures, John Wiley & Sons, 2004.
3. P. Dayaratnam, Prestressed Concrete, Oxford & IBH,1982
4. R. Rajagopalan, Prestressed Concrete, Narosa publishers, 2004. 5. BIS codes (IS 1343)

CE 5026 (3-0-0)

Structural Reliability

Module 1

Introduction and Overview: Uncertainties in the Building Process, Errors and Classification of Errors, Possible Applications, Historical Perspective

Module 2

Random Variables: Basic Definitions, Properties of Probability Functions (CDF, PDF and PMF), Common Random Variables (Uniform, Normal, Lognormal, Gamma, Poisson), Interpretation of Test Data using Statistics, Conditional Probability

Functions of Random Variables: Linear functions of random variables and normal variables, product of lognormal random variables, nonlinear function of random variables, central limit theorem

Module 3

Simulation Techniques: Monte Carlo Methods, Latin Hypercube Sampling, Rosenblueth's 2K+1 Point Estimate Method

Structural Safety Analysis: Limit States - Definition of Failure, Limit State Functions, Reliability Index- General Definition, First Order Second Moment Reliability Index, Hasofer-Lind Reliability Index, Rackwitz-Fiessler Procedure, Reliability Analysis using Simulation

Module 4

Structural Load Models – Dead Load, Live Load for buildings and bridges, Environmental Loads (Wind, Earthquake and Snow Loads), Load Combinations

Models of Resistance – Parameters of Resistance, Steel Components, Reinforced and Prestressed Concrete Components, Wood Components

Module 5

Design Codes: Role of Code Development Procedure, Calibration of Partial Safety Factors for a Level 1 Code, Development of Bridge Design Code – Target Reliability Level, Load and Resistance Factors

Textbooks & References:

1. Andrzej S. Nowak and Kevin R. Collins, *Reliability of Structures*, 2nd Edition, CRC Press.
2. Melcher, R.E. *Structural Reliability: Analysis and Prediction*, John Wiley.
3. Ranganathan R. *Structural Reliability Analysis & Design*, 1st Edition, Jaico Publishing House.
4. Alfredo H-S. Ang and Wilson H. Tang *Probability Concepts in Engineering: Emphasis on Applications to Civil and Environmental Engineering*, 1st Edition, Wiley

CE 5027 (3-0-0)

Sustainable and Futuristic Construction Materials

Module 1:

Overview of different construction materials and their carbon foot print, Embodied and process energies of materials

Module 2:

Bamboo: Bamboo and its characteristics, bamboo resources and its potential in India, engineered bamboo for urban constructions,

Building with raw earth, stabilized earth and rammed earth

Module 3:

Alkaline activated systems and geopolymer concrete systems, Chemistry, material characteristics, strength and durability aspects and long term performance

Module 4:

Binary and ternary blended cement and concrete systems chemistry and material composition, strength short and long term, durability aspects

Module 5:

Life cycle assessment of sustainable materials, green certifications and other guidelines

Textbooks & References:

1. The Philosophy of Sustainable Design by Jason F. McLennan, Ecotone Publishing Co., 2004.
2. Green Building Fundamentals by Mike Montoya, Pearson, 2nd edition, 2010.
3. Sustainable Construction - Green Building Design and Delivery, by Charles J. Kibert, John Wiley & Sons, 2nd edition, 2008.
4. Sustainable Construction and Design by Regina Leffers, Prentice Hall, 2009.

CE 5028 (3-0-2)

Computer Aided Quantitative Techniques (4 credits)

Module 1 Linear programming: Formulation of linear programming problems, graphical solution, simplex method, Big-M method, sensitivity analysis

Module 2 Transportation and assignment problems: Transportation problem using northwest corner rule, least cost method, and Vogel's approximation method; transhipment problem; assignment problem; travelling salesman problem

Module 3 Decision analysis I: Goal programming, game theory, analytic hierarchy process, analytic network process

Module 4 Decision analysis II: Scoring model, technique of order preference by similarity to ideal solution, decision trees

Module 5 Multivariate data analysis: Examining data, factor analysis, cluster analysis, regression analysis, structural equation modelling

Computer Application and Software MS Excel, MATLAB, SPSS, AMOS, Super decision software

Text Books

- Hair, J. F., W. C. Black, B. J. Babin, and R. E. Anderson. 2014. Multivariate data analysis, London: Pearson.
- Vohra, N. D. 2009. Quantitative techniques in management. 4th edition, McGraw Hill Education.

CE 5029 (3-0-0)

Repair and Rehabilitation of Structures

Unit-1 Introduction

Maintenance: facets of maintenance, importance of maintenance, routine and preventive maintenance. Repair, retrofit and strengthening, need for rehabilitation of structures.

Cracks in R.C. buildings: Various cracks in reinforced concrete buildings, causes - Effects due to climate, temperature, Sustained elevated temperature, Corrosion - Effects of cover thickness

Strength and Durability of concrete: Quality assurance for concrete, strength, durability and thermal properties, Factors affecting durability of concrete, Corrosion of reinforcements in concrete, Carbonation, Chloride ingress, Alkali-silica reaction, Freeze-thaw effects, Chemical attack, Abrasion, erosion and cavitation, Weathering and efflorescence

Damages to masonry structures: Various damages to masonry structures and causes, Study of failures of buildings and lesson learnt, Role of quality control in construction as Preventive measures Maintenance of buildings.

Unit-2 Damage Diagnosis and Testing

Defects and deterioration in buildings: Survey and assessment of structural conditions in RCC structures. Damage/condition assessment and various methods (for quantification) for its evaluation, Visual inspection of Damage, Rapid Visual Screening (RVS) and ways to do RVS of damaged/deteriorated structures, Overview of health monitoring techniques.

Testing Techniques: Semi-destructive testing, Probe test, Pull out test, Chloride penetration test, Carbonation, Carbonation depth testing, Corrosion activity measurement;

Non-destructive testing: Non-destructive testing of concrete, NDT of connections in steel, Corrosion assessment in reinforcements in RCC elements and components in steel structures; Design principles, techniques and working mechanism various instruments used for NDT evaluations (for strength, durability etc.) like Rebound Hammer, Ultrasonic Pulse Velocity, impact echo etc.; Technology used in various advanced instruments like Imaging techniques, GPR, Thermography, Tomography etc.

Substrate preparation: Importance of substrate/surface preparation, General surface preparation methods and procedure, Reinforcing steel cleaning

Unit-3 Repair Materials

Materials for repairs, rehabilitation and retrofitting processes, Methods for repairs, rehabilitation and retrofitting including surface preparation, Various repair materials, applications of FRP as a repair material, Criteria for material selection, Methodology of selection, Health and safety precautions for handling and applications of repair materials;

Special mortars and concretes: Polymer Concrete and Mortar, Quick setting compounds;

Grouting materials: Gas forming grouts, Sulfo-aluminate grouts, Polymer grouts, Acrylate and Urethane grouts.

Bonding agents: Latex emulsions, Epoxy bonding agents.

Protective coatings: Protective coatings for Concrete and Steel, FRP sheets

Unit 4 Rehabilitation and Retrofitting:

Repair: Repair of structures distressed due to corrosion, fire, leakage and earthquakes

Various methods: Crack repair by Grouting, Routing and sealing, Stitching, Dry packing, Autogenous healing, Overlays, Repair to active cracks, Repair to dormant cracks; Epoxy injection, Shoring, Underpinning

Corrosion of embedded steel in concrete: Corrosion of embedded steel in concrete, Mechanism, Stages of corrosion damage, Repair of various corrosion damaged of structural elements (slab, beam and columns). Corrosion Protection Techniques – corrosion inhibitors, corrosion resistant steels, coatings to reinforcement, cathodic protection

Jacketing: Jacketing, Column jacketing, Beam jacketing, Beam Column joint jacketing, reinforced concrete jacketing, Steel jacketing, FRP jacketing.

Strengthening: Strengthening of structural elements, FRP rebars, Beam shear strengthening, Flexural strengthening; Strengthening of Earthquake-damaged buildings

Demolition Techniques: Engineered demolition methods, Case Studies

Textbooks

1. Repair and Protection of Concrete Structures, by Noel P.Mailvaganam, CRC Press,1991.
2. Concrete Repair and Maintenance Illustrated, by Peter.H.Emmons, Galgotia publications Pvt. Ltd., 2001.
3. Failures and Repair of Concrete Structures, by S.Champion, John Wiley and Sons, 1961.
4. Diagnosis and Treatment of Structures in Distress, by R.N.Raikar, published by R & D Centre of Structural Designers and Consultants Pvt.Ltd, Mumbai.

References

1. Handbook on Repair and Rehabilitation of RCC buildings, CPWD, Government of India.
2. Handbook on Seismic Retrofit of Buildings, A. Chakrabarti et.al., Narosa Publishing House, 2010.

CE 5030 (3-0-0)

Earthquake Resistant Design

Module 1: Introduction to Engineering Seismology

Introduction to Engineering Seismology, Earthquake phenomenon, cause of earthquakes; Faults; Plate tectonics Seismic waves; Terms associated with earthquakes; Magnitude/Intensity of an earthquake; Scales; Energy Released; Earthquake measuring instruments; Seismoscope, Seismograph; Characteristics of strong ground motions; Seismic zones of India.

Module 2: Principles of Earthquake Resistant Design

Introduction; Earthquake resistant building architecture; Functional Planning; Continuous load path; Overall form; simplicity and symmetry; elongated shapes; stiffness and strength; Horizontal and Vertical Members; Twisting of buildings; flexible buildings; framing systems; choice of construction materials - unconfined concrete; confined concrete; masonry; reinforcing steel.

Seismic design requirements; regular and irregular configurations; Vertical irregularities; Plan configuration problems; basic assumptions; design earthquake loads; basic load combinations; permissible stresses; seismic methods of analysis; factors in seismic analysis; equivalent lateral force method; dynamic analysis, response spectrum method; Time history method.

Strategies in the location of structural walls; sectional shapes; variations in elevation; cantilever walls without openings; Failure mechanism of non- structural elements; Effects of non-structural elements on structural system; Analysis of non-structural elements; Prevention of non-structural damage; Isolation of non-structures.

Module 3: Earthquake Resistant Design of Reinforced Concrete Structures

Principles of earthquake resistant deign of RC members; Structural models for RCC frame buildings; Seismic analysis of RCC structures; Seismic design methods; Lateral load resisting systems; Determination of design lateral forces; Equivalent lateral force procedure; Lateral distribution of base shear; Code based procedure for determination of design lateral loads - Infill walls. Seismic analysis procedure as per IS 1893 code - Equivalent static force method - Response spectrum method - Time history analysis - Mathematical modeling of multi-storey RCC buildings.

Module 4: Earthquake Resistant Design of Masonry Structures

Masonry Buildings: Introduction, Elastic properties of masonry assemblage; Categories of masonry buildings; Behaviour of unreinforced and reinforced masonry walls; Behaviour of walls; Box action and bands; Behaviour of infill walls; Improving seismic behaviour of masonry buildings; Load combinations and permissible stresses; Seismic design requirements; Lateral load analysis of masonry buildings. Seismic analysis and design of one-storey and two-storey masonry buildings.

Module 5: Ductility and Capacity Based Design

Introduction; Ductility; definition; Ductility relationships; Impact of Ductility; Requirements for Ductility; Assessment of Ductility; Factors affecting Ductility; Ductile detailing considerations as per IS 13920. Behaviour of beams, columns and joints in RC buildings during earthquakes; Vulnerability of open ground storey and short columns during earthquakes.

Capacity Based Design: Introduction to Capacity Design, Capacity Design for Beams and Columns; Structural Vibration Control, Base Isolation, Tuned Mass Dampers, Introduction to Performance Based Design of Buildings and Bridges, AASHTO Guide Specifications for LRFD Seismic Bridge Design, Case studies on Seismic Design of Bridges.

Textbooks

1. Dowrick, D. J. (2009). *Earthquake resistant design and risk reduction*. John Wiley & Sons.
2. Agrawal, P., & Shrikhande, M. (2006). *Earthquake resistant design of structures*. PHI Learning Pvt. Ltd.
3. Tomazevic, M. (1999). *Earthquake; resistant design of masonry buildings* (Vol. 1). World Scientific Ltd
4. Paulay, T., & Priestley, M. N. (1992). Seismic design of reinforced concrete and masonry buildings, Joh Wiley & Sons

Reference Codes

1. Bureau of Indian Standards (2016) *Criteria for Earthquake Resistant Design of Structures. IS 1893:2016*, New Delhi
2. Bureau of Indian Standards (2016) *Ductile detailing of concrete structures subjected to seismic force – Guidelines*, IS 13920:2016 New Delhi.
3. Bureau of Indian Standards (2016) *Earthquake Resistant Design and Construction of Buildings– Code of Practice*, IS 4326:2013 New Delhi.
4. AASHTO [American Association of State Highway and Transportation Officials] (2017) LRFD Bridge Design Specifications, 8h edition. AASHTO, Washington, DC
5. AASHTO (2015), Guide Specifications for LRFD Seismic Bridge Design, 2nd edition with 2012, 2014, and 2015 Interim Revisions, Washington, DC

CE 5108 (0-0-4)

Capstone Project on Software Development

In this project course, the students will work on development of a structural engineering software by programming using MATLAB / Python / C. The students will apply technical development skills and produce a deliverable that needs to be validated and evaluated. A presentation and detailed report are mandatory features of the course.

CE 5109

Industry Internship

Students complete a two-month summer internship in a reputed structural design consultancy firm. The course coordinator liaisons with the industry representative to monitor the progress of the student in carrying out the required design tasks. A presentation and detailed design report are mandatory features of the course.

CE 5110

Industry Seminars

Twelve lectures/talks are delivered by renowned experts from the structural engineering community/industry. The experts present their real-life designs implemented in practice and key challenges are discussed. Students present a detailed report on the basis of these lectures for submission to the department.