**Appendix-**

**DEPARTMENT OF CIVIL ENGINEERING**
**INDIAN INSTITUTE OF TECHNOLOGY ROORKEE**

Program Code: **18** **M. Tech. (Geotechnical Engineering)**
Department: **CE** **Civil Engineering**
Year: **I**

| Teaching Scheme | | | | | Contact Hours/Week | | | Exam Duration | | Relative Weight (%) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| S. No. | Subject Code | Course Title | Subject Area | Credits | L | T | P | Theory | Practical | CWS | PRS | MTE | ETE | PRE |
| **Semester- I (Autumn)** | | | | | | | | | | | | | | |
| 1. | CEN-521 | Advanced Numerical Analysis | PCC | 4 | 3 | - | 2 | 3 | - | 15 | 25 | 20 | 40 | - |
| 2. | CEN-522 | Advanced Soil Mechanics | PCC | 4 | 3 | 1 | 2/2 | 3 | - | 20 | 20 | 20 | 40 | - |
| 3. | CEN-523 | Engineering Behaviour of Rocks | PCC | 4 | 3 | 1 | 2/2 | 3 | - | 20 | 20 | 20 | 40 | - |
| 4 | CEN-524 | Soil Dynamics and Machine Foundations | PCC | 4 | 3 | 1 | - | 3 | - | 25 | - | 25 | 50 | - |
| 5. | CEN-542 | Continuum Mechanics | PCC | 4 | 3 | 1 | - | 3 | - | 25 | - | 25 | 50 | - |
| | | Total | | 20 | 12 | 3 | 4 | | | | | | | |
| | | | | | | | | | | | | | | |
| **Semester-II (Spring)** | | | | | | | | | | | | | | |
| 1. | CEN-700 | Seminar | SEM | 2 | 0 | 0 | 2 | - | - | - | - | - | 100 | - |
| 2. | | Programme Elective-I | PEC | 4 | - | - | - | - | - | - | - | - | - | - |
| 3. | | Programme Elective-II | PEC | 4 | - | - | - | - | - | - | - | - | - | - |
| 4. | | Programme Elective-III | PEC | 4 | - | - | - | - | - | - | - | - | - | - |
| 5. | | Programme Elective-IV | PEC | 4 | - | - | - | - | - | - | - | - | - | - |
| | | Total | | 18 | | | | | | | | | | |

**DEPARTMENT OF CIVIL ENGINEERING**
**INDIAN INSTITUTE OF TECHNOLOGY ROORKEE**

Program Code: **18** **M. Tech. (Geotechnical Engineering)**
Department: **CE** **Civil Engineering**
Year: **II**

| Teaching Scheme | | | | | Contact Hours/Week | | | Exam Duration | | Relative Weight (%) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **S. No.** | **Subject Code** | **Course Title** | **Subject Area** | **Credits** | **L** | **T** | **P** | **Theory** | **Practical** | **CWS** | **PRS** | **MTE** | **ETE** | **PRE** |
| **Semester- I (Autumn)** | | | | | | | | | | | | | | |
| 1. | CEN-701A | Dissertation Stage–I (to be continued next semester) | DIS | 12 | - | - | - | - | - | - | - | - | 100 | - |
| | | Total | | 12 | | | | | | | | | | |
| **Note: Students can take 1 or 2 audit courses as advised by the supervisor, if required.** | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | |
| **Semester-II (Spring)** | | | | | | | | | | | | | | |
| 1. | CEN-701B | Dissertation Stage–II (contd. From III semester) | DIS | 18 | - | - | - | - | - | - | - | - | 100 | - |
| | | Total | | 18 | | | | | | | | | | |

| **Summary** | | | | |
|---|---|---|---|---|
| Semester | 1 | 2 | 3 | 4 |
| **Semester-wise Total Credits** | **20** | **18** | **12** | **18** |
| **Total Credits** | **68** | | | |

## Program Elective Courses (Geotechnical Engineering)

| Teaching Scheme | | | | | Contact Hours/Week | | | Exam Duration | | Relative Weight (%) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| S. No. | Subject Code | Course Title | Subject Area | Credits | L | T | P | Theory | Practical | CWS | PRS | MTE | ETE | PRE |
| 1. | CEN-621 | Advanced Geotechnical Exploration and Testing | PEC | 4 | 3 | 1 | - | 3 | - | 25 | - | 25 | 50 | - |
| 2. | CEN-622 | Advanced Foundation Engineering | PEC | 4 | 3 | 1 | 2/2 | 3 | - | 20 | 20 | 20 | 40 | - |
| 3. | CEN-623 | Stability Analysis of Slopes | PEC | 4 | 3 | 1 | - | 3 | - | 25 | - | 25 | 50 | - |
| 4. | CEN-624 | Design of Under-Ground Excavations | PEC | 4 | 3 | 1 | - | 3 | - | 25 | - | 25 | 50 | - |
| 5. | CEN-625 | Ground Improvement Engineering | PEC | 4 | 3 | 1 | - | 3 | - | 25 | - | 25 | 50 | - |
| 6. | CEN-626 | Foundations on Weak Rocks | PEC | 4 | 3 | 1 | - | 3 | - | 25 | - | 25 | 50 | - |
| 7. | CEN-627 | Landslide Analysis and Control | PEC | 4 | 3 | 1 | - | 3 | - | 25 | - | 25 | 50 | - |
| 8. | CEN-628 | Constitutive Modeling of Geological Materials | PEC | 4 | 3 | 1 | - | 3 | - | 25 | - | 25 | 50 | - |
| 9. | CEN-545 | Finite Element Analysis | PEC | 4 | 3 | - | 2 | 3 | - | 15 | 25 | 20 | 40 | - |
| 10. | CEN-650 | Design of Bridge Sub-structure | PEC | 4 | 3 | - | 2 | 3 | - | 15 | 25 | 20 | 40 | - |

# INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPTT/CENTRE : **Department of Civil Engineering**

1. Subject Code : **CEN-521** Course Title : **Advanced Numerical Analysis**
2. Contact Hours : **L: 3 T : 0 P: 2**
3. Examination Duration (Hrs) : **Theory : 3 Practical : 0**
4. Relative Weight : **CWS : 15 PRS: 25 MTE: 20 ETE: 40 PRE: 0**
5. Credits : **04** 6. Semester: **Autumn** 7. Subject Area : **PCC**
8. Pre-requisite: **Nil**
9. Objective of Course: To impart knowledge of various numerical techniques to solve the problems of geotechnical engineering.

10. Details of Course:

| S. No. | Contents | Contact Hours |
|---|---|---|
| 1. | Introduction, roots of a non-linear equation and roots of a polynomial of $n^{th}$ degree [incremental search method, method of successive approximations, Newton's method, bisection method, secant method, Müller's method, synthetic division, Bairstow's method] and convergence study | 10 |
| 3. | Solution of (non-homogeneous) linear algebraic equations, review of matrix algebra, Gauss elimination method, Cholesky's decomposition method, householder method, Gauss-Siedal iterative method | 06 |
| 4. | Solution of non-linear algebraic equations, method of successive approximation, Newton's method, modified Newton – Raphson method, secant method | 04 |
| 5. | Eigen values and Eigen vectors, reduction of generalized Eigen value problem to the standard Eigen value problem, methods for obtaining Eigen values and Eigen vectors [polynomial method, vector iteration method, Mises power method, Jacobi method] | 08 |
| 6. | Time marching schemes for solution of problems in time domain, numerical integration (2 – D) [Newton – Cotes method, Gauss – Legendre method] | 04 |
| 7. | Solution of ordinary and partial differential equations, Euler's method, Runge – Kutta method, finite difference method, applications to problems of beam and plates on elastic foundation, Laplacian equation, consolidation equation, laterally loaded piles etc | 10 |
| | **Total** | **42** |

List of Practicals:

1. Development of algorithms/codes by considering different methods for: roots of equations
2. Solution of simultaneous equation (linear-nonlinear),
3. Eigen value and Eigen vectors
4. Numerical integration
5. Solution of differential equation

11. Suggested Books:

| S. No. | Name of Authors/Books/Publishers | Year of Publication/ Reprint |
|---|---|---|
| 1. | Chapra, S. C. and Canale R. P., "Numerical Methods for Engineers", Tata McGraw hill | 2003 |
| 2. | Carnahan, B., Luther, H. A. and Wilkes, J. O., "Applied Numerical Methods", John Wiley | 1969 |
| 3. | Heath, M. T. ,"Scientific Computing : An Introductory Survey", McGraw hill | 1997 |
| 4. | Douglas Faires, J. and Richard Burden, "Numerical Methods", Thomson | 2003 |
| 5. | Rajasekaran, S., "Numerical Methods in Science and Engineering", S. Chand | 1999 |

# INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPTT/CENTRE : **Department of Civil Engineering**

1. Subject Code : **CEN-522** Course Title : **Advanced Soil Mechanics**
2. Contact Hours : **L: 3 T : 1 P: 2/2**
3. Examination Duration (Hrs) : **Theory : 3 Practical : 0**
4. Relative Weight : **CWS :20 PRS: 20 MTE: 20 ETE: 40 PRE: 0**
5. Credits : **04** 6. Semester: **Autumn** 7. Subject Area : **PCC**
8. Pre-requisite: **Nil**
9. Objective of Course : To give advanced knowledge of mechanics governing the behaviour of soils to students so that they are able to understand the behaviour of foundations and structures constructed in/on them.

10. Details of Course :

| S. No. | Contents | Contact Hours |
|---|---|---|
| 1. | Fundamental aspects of soil mechanics, characteristics of soil, particulate nature, weight volume relationship | 02 |
| 2. | Flow of water through soils, permeability, flownets | 02 |
| 3. | Theory of elasticity, few aspects of elasticity, plane stress and plane strain problems | 05 |
| 4. | Pore water pressure, undrained loading, determination of pore water pressure parameters | 05 |
| 5. | Consolidation, Terzaghi's 1-D consolidation theory, layered soils, time dependent loading, 2-D problems, 3-D consolidation (axisymmetric problems, vertical drains), creep/secondary consolidation and basic of rheological models | 09 |
| 6. | Shear strength, stresses in soils, Mohr's circle, stress paths, UU, CU, CD tests, drained and undrained stress-strain relationships and shear strength | 09 |
| 7. | Critical state theory, normal consolidation line, critical state line, Roscoe surface, Hvorslev surface, no tension line | 04 |
| 8. | Constitutive laws for soils | 06 |
| | **Total** | **42** |

List of Practicals:

1. Determination of relative density
2. Vane shear test
3. Consolidation tests
4. Direct shear and tri-axial compression test – UU, CU, CD tests
5. Influence of strain rate
6. Stress path testing etc.

11. Suggested Books:

| S. No. | Name of Authors/Books/Publishers | Year of Publication/ Reprint |
|---|---|---|
| 1. | Das, Braja, M., "Advanced Soil Mechanics", Taylor & Francis | 1983 |
| 2. | Lambe, T. William and Whitman, Robert V., "Soil Mechanics", John Wiley. | 2000 |
| 3. | Craig, R.F., "Soil Mechanics", Chapman & Hall. | 1993 |
| 4. | Suklje, L., "Rheological Aspects of Soil Mechanics", John Wiley. | 1969 |
| 5. | Terzaghi, K. and Peck, R.B., "Soil Mechanics in Engineering Practice", John Wiley. | 1967 |
| 6. | Davis, R.O. and Selvadurai, E.P.S. "Elasticity and Geomechanics", Cambridge University Press. | 1995 |

# INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPTT/CENTRE : **Department of Civil Engineering**

1. Subject Code : **CEN-523** Course Title : **Engineering Behaviour of Rocks**
2. Contact Hours : **L: 3 T : 1 P: 2/2**
3. Examination Duration (Hrs) : **Theory : 3 Practical : 0**
4. Relative Weight : **CWS :20 PRS: 20 MTE: 20 ETE: 40 PRE: 0**
5. Credits : **04** 6. Semester: **Autumn** 7. Subject Area : **PCC**
8. Pre-requisite: **Nil**
9. Objective of Course : To impart to students the knowledge of the basic mechanics which governs the behaviour of rocks and rock masses so that they can understand the mechanics of structures constructed in/on them.

10. Details of Course :

| S. No. | Contents | Contact Hours |
|---|---|---|
| 1. | Introduction, definitions, development of rock mechanics, activities and applications of rock mechanics and rock engineering | 3 |
| 2. | Properties of intact rocks, types of specimens for testing-,uniaxial compressive strength tests- tolerance limits and requirements, preparation of specimens , factors affecting UCS, modes of failures, stress strain curves, post failure behaviour | 6 |
| 3. | Tensile strength, direct methods, indirect methods, miscellaneous methods | 2 |
| 4. | Shear tests, single shear test, double shear test, punch test, direct shear test, oblique shear test, triaxial strength of rocks - triaxial strength test, Coulomb's theory, Mohr envelopes and p-q plots | 4 |
| 5. | Strength criteria for intact rocks, rock strength criteria by Coulomb-Navier, Griffith's (1924), Mcclintock and Walsh (1962), empirical failure criteria by Bieniawski (1974), Hoek and Brown (1980), Ramamurthy (1993), Singh and Singh (2005) | 8 |
| 6. | Classification of intact rocks, geological classification, geotechnical classification, classification of jointed rocks, Terzaghi (1946), Deere (1968), RQD, RMR, Q-systems, BGD, $J_f$ concept, RMI, GSI, strength behaviour of jointed rocks, scale effect, classification approaches | 8 |
| 7. | Deformational behaviour of jointed rocks, definitions, computation of modulus of deformation through RMR, Q, GSI and $J_f$, constitutive modeling | 7 |
| 8. | Flow through jointed rock mass, hydraulic conductivity and flow nets, ground water flow in fractured rocks, measurement of water pressure, field tests | 4 |
| | **Total** | **42** |

List of Practicals:

1. Physical properties
2. Uniaxial compression test
3. Brazilian test
4. Point load strength index test
5. Triaxial compression test
6. Oblique shear test
7. Sonic wave velocity
8. Permeability test
9. Field shear test
10. Schmidt hammer test.

11. Suggested Books

| S. No. | Name of Authors/Books/Publishers | Year of Publication / Reprint |
|---|---|---|
| 1. | Hudson, J.A. and Harrison, John P., "Engineering Rock Mechanics- An Introduction to the Principles", Elsevier. | 2000 |
| 2. | Jaeger, J.C. and Cook, N.G.W., "Fundamentals of Rock Mechanics", Mathew & Co. Ltd. | 1979 |
| 3. | Singh, B. and Goel, R.K., "Rock Mass Classification- A Practical Engineering Approach", Elsevier. | 2006 |
| 4. | Hoek, E., "Practical Rock Engineering", Rock Science. | 2000 |
| 5. | Ramamurthy, T., "Engineering in Rocks", PHI Learning Pvt. Ltd. | 2008 |

# INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPTT/CENTRE : **Department of Civil Engineering**

1. Subject Code : **CEN-524** Course Title : **Soil Dynamics and Machine Foundations**
2. Contact Hours : **L: 3 T : 1 P: 0**
3. Examination Duration (Hrs) : **Theory : 3 Practical : 0**
4. Relative Weight : **CWS :25 PRS: 0 MTE: 25 ETE: 50 PRE: 0**
5. Credits : **04** 6. Semester: **Autumn** 7. Subject Area : **PCC**
8. Pre-requisite: **Nil**

9. Objective of Course : To impart to students the basic knowledge in theory of vibrations and behaviour of soils under dynamic loads so that foundations for various types of machines could be designed.

10. Details of Course :

| S. No. | Contents | Contact Hours |
|---|---|---|
| 1. | Theory of vibrations, single, two and multiple degree of freedom systems, vibration isolation, vibration absorbers, vibration measuring instruments | 10 |
| 2. | Strength characteristics, factors affecting, philosophy of design of equipments, studies by dynamic tri-axial and oscillatory shear equipments | 06 |
| 3. | Liquefaction, mechanism, factors affecting, studies by dynamic tri-axial testing, oscillatory shear box, shake table and blast tests, assessment of liquefaction potential | 06 |
| 4. | Dynamic earth pressure, analytical and graphical methods, displacement analysis of retaining walls, seismic stability of slopes : modified Swedish circle and Taylor's method, concept of yield acceleration and evaluation of displacement of embankment | 06 |
| 5. | Machine foundations, types and basic requirements, analysis and design of foundations for reciprocating and impact type machines, introduction to the design of T.G. Foundations | 06 |
| 6. | Determination of dynamic elastic constants, various methods including block resonance tests, cyclic plate load tests, wave propagation tests, oscillatory shear box test, soil liquefaction test | 08 |
| | **Total** | **42** |

11. Suggested Books

| S. No. | Name of Authors/Books/Publishers | Year of Publication/ Reprint |
|---|---|---|
| 1. | Das, B.M., "Fundamentals of Soil Dynamics", Elsevier. | 1983 |
| 2. | Steven Kramer, "Geotechnical Earthquake Engineering", Pearson. | 2008 |
| 3. | Prakash, S., "Soil Dynamics", McGraw Hill. | 1981 |
| 4. | Kameswara Rao, N.S.V., "Vibration Analysis and Foundation Dynamics", Wheeler. | 1998 |
| 5. | Saran, S., "Soil Dynamics and Machine Foundations", Galgotia. | 2006 |

# INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPTT/CENTRE : **Department of Civil Engineering**

1. Subject Code : **CEN-542** Course Title : **Continuum Mechanics**
2. Contact Hours : **L: 3** **T : 1** **P: 0**
3. Examination Duration (Hrs) : **Theory : 3** **Practical : 0**
4. Relative Weight : **CWS :25** **PRS: 0** **MTE: 25** **ETE: 50** **PRE: 0**
5. Credits : **04** 6. Semester: **Spring** 7. Subject Area : **PEC**
8. Pre-requisite: **Nil**

9. Objective of Course : To impart to students the basic knowledge in theory of vibrations and behaviour of soils under dynamic loads so that foundations for various types of machines could be designed.

10. Details of Course :

| S. No. | Contents | Contact Hours |
|---|---|---|
| 1. | Vector and Tensors Algebra, Lineariziation and Directional Derivatives, Stress and Equilibrium, Analysis for Stresses, Translational and Rotational Equilibrium, Principal Stresses and Principal Planes in 3D, Stress Invariants, Cauchy and Kirchhoff Stress Tensor, Deviatoric and Volumetric Components, Work Conjugancy, Octahedral and von-Mises stresses. | |
| 2. | Kinematics, Linearized Kinematics, Strain Quadric of Cauchy, Principal Strains, Invariants, Equations of Compatibility, Finite Deformation, Material (Lagrangian) and Spatial (Eulerian) Descriptions, Deformation Gradient, Polar Decomposition, Volume change, Distortional Component of Deformation Gradient, Area Change. | |
| 3. | Equations of Elasticity,Hooke's Law, Generalized Hooke's Law, Anisotropic, Orthotropic and Isotropic Elasticity Tensor, Plane Stress and Strain Problems, Airy Stress Functions for Two-Dimensional Problems, Airy Stress Function in Polar Coordinates, Isotropic Hyper elasticity, Three-Dimensional Elasticity. | |
| 4. | Elasto-Plastic Behavior of Material, Elasto-Plastic Formulations, Material Yield Criteria- von Mises, Tresca, Mohr-coulomb, Ducker-Pager, Isotropic and Kinematic Hardening, Normality Principle, Plastic Flow Rule, Plastic Potential, Elasto-Plastic Stress-Strain Relations, Prandtl-Rauss Equations, Levy-Mises Relations, Hardening Modulus, Generalized Elasto-Plastic Stress-Strain Relations | |
| | **Total** | **42** |

11. Suggested Books:

| S. No. | Name of Authors/Books/Publishers | Year of Publication/ Reprint |
|---|---|---|
| 1. | Finite element analysis in Geotechnical Engineering theory, By David M Potts and Lidija Zdravkovic, Thomas Telford | 1999 |
| 2. | Mechanics of Materials and Interfaces: The Disturbed State Concept, By C S Desai, CRC Press LLC | 2000 |
| 3. | Mechanics of Geomaterial Interfaces, By A.P.S. Selvadurai, M.J. Boulon, Elsevier | 1995 |

**INDIAN INSTITUTE OF TECHNOLOGY ROORKEE**

NAME OF DEPTT/CENTRE : **Department of Civil Engineering**

1. Subject Code : **CEN-545** Course Title : **Finite Element Analysis**
2. Contact Hours : **L: 3** **T : 0** **P: 2**
3. Examination Duration (Hrs) : **Theory : 3** **Practical : 0**
4. Relative Weightage : **CWS : 15** **PRS: 25** **MTE: 20** **ETE: 40** **PRE: 0**
5. Credits : **04** 6. Semester: **Spring** 7. Subject Area : **PCC**
8. Pre-requisite: **Nil**
9. Objective: To introduce the concept of domain discretisation and a variational framework of the equations of mechanics. Application of these methodologies to a wide range of engineering problems and connection with the laws of continua.

10. Details of Course:

| S. No. | Contents | Contact Hours |
|---|---|---|
| 1. | Basic Concepts, Discretization; Displacement, Force and Hybrid Models | 02 |
| 2. | Interpolation Functions for General Element Formulations: Compatibility and Completeness, Polynomial Forms: One Dimensional Elements, Geometric Isotropy, Triangular Elements, Rectangular Elements, Three Dimensional Elements, Isoperimetric Formulations, Axisymmetric Elements; Numerical Integration. | 08 |
| 3. | Applications in Solid Mechanics: Plane Stress/Strain: FE Formulation: CST, LST; Stiffness Matrix, Load Matrix Formation Rectangular Element Isoparametric Formulation: Plate Elements and Shell Elements, Three Dimensional Elements FE Formulation: Axisymmetric Stress Analysis, Torsion, Interface Elements, Infinite Elements | 08 |
| 4. | Application in Structural Dynamics and Vibrations: Mass (Consistent and Diagonal) and Damping Matrices; Modal Analysis, Time History Analysis, Explicit Direct Integration/ Implicit Direct Integration and Mixed Methods. | 06 |
| 5. | Introduction to Nonlinear Problems: Geometric and Material (Elasto-plastic), Solution Methods: Newton Ralphson Method, Modified Newton-Ralphson Method, Arc Method, A Problem of Geometric Nonlinearity. | 08 |
| 6. | Stationary Principles, Rayleigh Ritz Method and Interpolation; Weighted Residual Methods and Variational Methods, Numerical Errors and Convergence | 06 |
| | **Total** | **42** |

11. Suggested Books:

| S. No. | Name of Authors/Books/Publishers | Year of Publication/ Reprint |
|---|---|---|
| 1. | David Hutton, “Fundamentals of Finite Element Analysis”, Tata McGraw Hill | 2005 |
| 2. | R. D. Cook, Malkus and Plesha, “Concepts and Applications of Finite Element Analysis”, 3rd Ed., John Wiley. | 1989 |
| 3. | T. J. R. Hughes, “The Finite Element Method : Linear Static and Dynamic Analysis”, Prentice Hall. | 1987 |
| 4. | Klaus Juergen Bathe, “Finite Element Procedures”, Prentice Hall of India. | 2003 |
| 5. | O. C. Zienkiewicz., R. L. Taylor & J. Z. Zhu., “The Finite Element Method Its Basis & Fundamentals”, Elsivier Publications. | 2007 |

# INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPTT/CENTRE : **Department of Civil Engineering**

1. Subject Code : **CEN**-621 Course Title : **Advanced Geotechnical Exploration and Testing**
2. Contact Hours : **L: 3 T : 1 P: 0**
3. Examination Duration (Hrs) : **Theory : 3 Practical : 0**
4. Relative Weight : **CWS :25 PRS: 0 MTE: 25 ETE: 50 PRE: 0**
5. Credits : **04** 6. Semester: **Spring** 7. Subject Area : **PEC**
8. Pre-requisite: **Nil**
9. Objective : To impart knowledge of advanced methods of testing of geological materials like soil, rocks and rock masses
10. Details of Course :

| S. No. | Contents | Contact Hours |
|---|---|---|
| 1. | **Pressure Meter Testing of Soils and Weak Rocks:** Menard pressure meter equipment, Probe calibration and corrections, Limit pressure, Creep pressure, Tests in soils and weak rocks, Interpretation of test data, Pressure meter modulus of soils & weak rocks | 05 |
| 2. | **Dilatometer Testing of Soils:** Equipment and procedure of testing, Interpretation of test data, Geotechnical parameters of clay- OCR, $k_0$, un-drained shear strength, soil stiffness, coefficient of consolidation, Geotechnical parameters of clay- friction angle, state parameter, soil stiffness,<br>Application to problems of settlement of shallow foundations, laterally loaded piles, soil liquefaction etc. | 05 |
| 3. | **Stress Path Testing of Soils:** Influence of stress history on behavior of soils, Stress paths for hydrostatic compression (HC), Direct shear (DS), Conventional tri-axial compression (CTC), Conventional tri-axial extension (CTE), True tri-axial compression (TTC), drained and un-drained situations, analysis and interpretation of test data on NC and OC clays | 07 |
| 4. | **Post Failure Testing of Rocks:** Servo-controlled uni-axial and tri-axial testing of different rock types, effect of confining pressure, brittle-ductile transition, effect of L/D ratio, Cyclic testing of rock cores, analysis and interpretation of test data | 06 |
| 5. | **Electrical Resistivity Methods:** Principle, Resistivity of soils and rocks, Resistivity Technique- Wenner and Schlumberger arrangements, Electrical Soundings, Methods of electrical resistivity profiling, Analysis and interpretation of field test data | 07 |
| 8. | **In-situ shear Strength of Jointed Rocks:** Equipment and test procedure, interpretation for peak and residual strength of rock mass | 02 |
| 6. | **Measurement of In-situ Stresses in Rocks:** Flat jack technique, Hydro-fracturing method | 04 |
| 7. | **In-situ Deformation Modulus of Jointed Rocks :** Goodman Jack test, Plate jacking test, Plate jacking test down the drill hole, radial jacking test etc., interpretation of test data. | 06 |
| | **Total** | **42** |

List of Practicals :

1. Pressure meter testing of soils during boring and its variation with depth
2. Stress path testing of soils under hydro-static compression
3. Stress path testing of soils in conventional tr-axial compression
4. Stress path testing of soils under true tr-axial compression
5. Servo-controlled uni-axial testing of rock specimens
6. Servo-controlled tri-axial testing of rock specimens
7. Demonstration of electrical resistivity profiling method
8. Demonstration of Goodman jack test for deformation modulus of rocks

11. Suggested Books :

| S. No. | Name of Authors/Books/Publishers | Year of Publication/ Reprint |
|---|---|---|
| 1. | Singh Alam, "Soil Engineering in Theory and Practice", Asia Pub. House. | 1981 |
| 2. | Atkinson, J.H., Bransby, P.L., " The Mechanics of Soils- An Introduction to Critical State Soil Mechanics", McGraw Hill Book Co., UK. | 1978 |
| 3. | Schnaid, F., " In Situ Testing in Geomechanics", Taylor and Francis. | 2009 |
| 4. | Hudson, J. A., Harrison, J. P., "Engineering Rock Mechanics", Pergamon Press | 1997 |
| 5. | Ramamurthy, T., " Engineering in Rocks for Slopes, Foundations and Tunnels", Prentice Hall. | 2007 |

# INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPTT/CENTRE : **Department of Civil Engineering**

1. Subject Code : **CEN-622** Course Title : **Advanced Foundation Engineering**
2. Contact Hours : **L: 3 T : 1 P: 2/2**
3. Examination Duration (Hrs) : **Theory : 3 Practical : 0**
4. Relative Weight : **CWS :20 PRS: 20 MTE: 20 ETE: 40 PRE: 0**
5. Credits : **04** 6. Semester: **Spring** 7. Subject Area : **PEC**
8. Pre-requisite: **Nil**

9. Objective of Course: To impart knowledge of methods of analysis and design of various foundations.

10. Details of Course :

| S. No. | Contents | Contact Hours |
|---|---|---|
| 1. | Planning of soil exploration for different projects, methods of subsurface exploration, methods of borings along with various penetration tests | 05 |
| 2. | Shallow foundations, requirements for satisfactory performance of foundations, methods of estimating bearing capacity, settlements of footings and rafts, proportioning of foundations using field test data, IS codes, pressure – settlement characteristics from constitutive laws | 06 |
| 3. | Pile foundations, methods of estimating load transfer of piles, settlements of pile foundations, pile group capacity and settlement, laterally loaded piles, pile load tests, analytical estimation of load- settlement behaviour of piles, proportioning of pile foundations, lateral and uplift capacity of piles | 06 |
| 4. | Well foundation, IS and IRC codal provisions, elastic theory and ultimate resistance methods | 05 |
| 5. | Tunnels and arching in soils, pressure computations around tunnels | 04 |
| 6. | Open cuts, sheeting and bracing systems in shallow and deep open cuts in different soil types | 06 |
| 7. | Coffer dams, various types, analysis and design | 03 |
| 8. | Foundations under uplifting loads | 04 |
| 9. | Soil-structure interaction | 03 |
| | **Total** | **42** |

List of Practicals:

1. Exploratory borings by different methods including auger boring
2. Wash boring
3. Percussion drilling and rotary drilling etc. followed by - planning of soil exploration for different projects,
4. Standard penetration tests
5. Dynamic cone penetration tests
6. Static cone penetration tests
7. Plate load tests
8. Load tests on piles

11. Suggested Books:

| S. No. | Name of Authors/Books/Publishers | Year of Publication/ Reprint |
|---|---|---|
| 1. | Bowles, Joseph E., "Foundation Analysis and Design", Mc-Graw Hill. | 1996 |
| 2. | Das, Braja M., "Principles of Foundation Engineering", PWS Publishing. | 1998 |
| 3. | Som, N, N. and Das S. C., "Theory and Practice of Foundation Design", Prentice Hall. | 2003 |
| 4. | Poulos, H. G. and Davis, F. H., "Pile Foundation Analysis and Design", Wiley and Sons. | 1980 |
| 5. | Saran, S., "Analysis and Design of Substructures", Oxford and IBH. | 2006 |

# INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPTT/CENTRE : **Department of Civil Engineering**

1. Subject Code : **CEN-623** Course Title : **Stability Analysis of Slopes**
2. Contact Hours : **L: 3** **T : 1** **P: 0**
3. Examination Duration (Hrs) : **Theory : 3** **Practical : 0**
4. Relative Weight : **CWS :25** **PRS: 0** **MTE: 25** **ETE: 50** **PRE: 0**
5. Credits : **04** 6. Semester: **Spring** 7. Subject Area : **PEC**
8. Pre-requisite: **Nil**

9. Objective of Course : Landslides is a very common phenomenon in hilly regions and results in loss of life and property. The course is designed to identify various modes of failures and study their safety aspects including provision of remedial measures.

10. Details of Course :

| S. No. | Contents | Contact Hours |
|---|---|---|
| 1. | Introduction, classification of natural slopes and excavation failures, slope stability – mechanics of slope failure, failure modes | 04 |
| 2. | Collection and analysis of geological data, field survey and testing, graphical presentation of geological data and evaluation of potential slope problems | 06 |
| 3. | Seepage analysis, in-situ permeability tests, two dimensional flow – Laplace equation and it's solution, graphical method, determination of phreatic line, flow nets in homogeneous and zoned earth dams under steady seepage and draw-down conditions, seepage control in earth dams, influence of seepage on slope stability | 06 |
| 4. | Soil slopes, infinite slope, method of slices, friction circle methods etc., Bishop's modified method, Bishop's rigorous method, Janbu's method, Morgenstern and Price, Spencer's method, stability analysis of dam body during steady seepage | 08 |
| 5. | Rock slopes, methods of slope stability analysis, plane failure, wedge failure, over toppling failure, Hoek & Bray's charts, three dimensional wedge analysis, seismic considerations, computer programs, use of non-linear failure criterion in rock slope stability analysis | 10 |
| 6. | Strengthening measures, stabilization of slopes by drainage methods, surface and subsurface drainage, use of synthetic filters, retaining walls, stabilization and strengthening of slopes, shotcreting, rock bolting and rock anchoring | 06 |
| 7. | Instrumentation and monitoring of slopes, slope movements, warning devices, maintenance of slopes | 02 |
| | **Total** | **42** |

11. Suggested Books:

| S. No. | Name of Authors/Books/Publisher | Year of Publication/ Reprint |
|---|---|---|
| 1. | Hoek, E. and Bray, J.W., "Rock Slope Engineering" Institution of Mining Engineering. | 1981 |
| 2. | Giani, G.P., "Rock Slope Stability Analysis", A A Balkema. | 1992 |
| 3. | Wyllie Duncan C and Christofer W Mah," Rock Slope Engineering" Spon Press, Taylor and Francis Group. | 2004 |
| 4. | Singh, B. and Goel, R.K.,"Software for Engineering Control of Landslides and Tunneling Hazards", A A Balkema. | 2002 |
| 5. | Harr M.E.," Ground Water and Seepage", McGraw Hill. | 1962 |
| 6. | Chowdhary Robin and Chowdhary Indrajit , "Geotechnical Slope Analysis", CRC Press. | 2009 |

# INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPTT/CENTRE : **Department of Civil Engineering**

1. Subject Code : **CEN-624** Course Title : **Design of Underground Excavations**
2. Contact Hours : **L: 3 T : 1 P: 0**
3. Examination Duration (Hrs) : **Theory : 3 Practical : 0**
4. Relative Weight : **CWS :25 PRS: 0 MTE: 25 ETE: 50 PRE: 0**
5. Credits : **04** 6. Semester: **Spring** 7. Subject Area : **PEC**
8. Pre-requisite: **Nil**
9. Objective of Course : To impart knowledge of methods of analysis and design of underground excavations in rocks and jointed rock masses for hydro-power projects and large underground storages for various purposes.

10. Details of Course :

| S. No. | Contents | Contact Hours |
|---|---|---|
| 1. | Introduction, planning of and exploration for various underground construction projects | 04 |
| 2. | Stereographic projection method, principle and its application in underground excavation design | 04 |
| 3. | Elastic stress distribution around tunnels, stress distribution for different shapes and under different in-situ stress conditions, Greenspan method, design principles, multiple openings, openings in laminated rocks, elasto-plastic analysis of tunnels, Daemen's theory | 08 |
| 4. | Application of rock mass classification systems, ground conditions in tunneling, analysis of underground openings in squeezing and swelling ground, empirical methods, estimation of elastic modulus and modulus of deformation of rocks; uni-axial jacking / plate jacking tests, radial jacking and Goodman jacking tests, long term behaviour of tunnels and caverns, New Austrian Tunneling Method (NATM), Norwegian Tunneling Method (NTM), construction dewatering | 09 |
| 5. | Rock mass-tunnel support interaction analysis, ground response and support reaction curves, Ladanyi's elasto-plastic analysis of tunnels, design of various support systems including concrete and shotcrete linings, steel sets, rock bolting and rock anchoring, combined support systems, estimation of load carrying capacity of rock bolts | 08 |
| 6. | In-situ stress, flat jack, hydraulic fracturing and over coring techniques and USBM type drill hole deformation gauge, single and multi-point bore hole extensometers, load cells, pressure cells, etc | 05 |
| 7. | Instrumentation and monitoring of underground excavations, during and after construction, various case studies | 04 |
| | **Total** | **42** |

11. Suggested Books:

| S. No. | Name of Authors /Books/Publishers | Year of Publication / Reprint |
|---|---|---|
| 1. | Hoek, E and and Brown, E. T.," Underground Excavations in Rocks", Institute of Mining Engineering. | 1983 |
| 2. | Obert, L. and Duvall, W.I., "Rock Mechanics and Design of Structures in Rocks", John Wiley. | 1967 |
| 3. | Singh, B. and Goel, R.K.,"Rock Mass Classification- A Practical Engineering Approach", Elsevier. | 2006 |
| 4. | Singh, B. and Goel, R.K., "Tunnelling in Weak Rocks", Elsevier. | 2006 |
| 5. | Ramamurthy, T., "Engineering in Rocks", PHI Learning. | 2008 |

# INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPTT/CENTRE : **Department of Civil Engineering**

1. Subject Code : **CEN-625** Course Title : **Ground Improvement Engineering**
2. Contact Hours : **L: 3 T : 1 P: 0**
3. Examination Duration (Hrs) : **Theory : 3 Practical : 0**
4. Relative Weight : **CWS :25 PRS: 0 MTE: 25 ETE: 50 PRE: 0**
5. Credits : **04** 6. Semester: **Spring** 7. Subject Area : **PEC**
8. Pre-requisite: **Nil**

9. Objective of Course: To apprise the students about treatment of poor soil conditions for development activities and tell them about state of art in this area by case studies.

10. Details of Course :

| S. No. | Contents | Contact Hours |
|---|---|---|
| 1. | Introduction, typical situations where ground improvement becomes necessary, historical review of methods adopted in practice, current status and the scope in the Indian context | 05 |
| 2. | Methods of ground improvement, mechanical compaction, dynamic compaction, impact loading, compaction by blasting, vibro-compaction; pre-compression, dynamic consolidation, design aspects of stone columns, use of admixtures, injection of grouts, design guidelines and quality control, design examples on preloading with sand drains, road designs with geosynthetics | 09 |
| 3. | Reinforced earth, basic mechanism, constituent materials and their selection; engineering applications – shallow foundations on reinforced earth, design of reinforced earth retaining walls, reinforced earth embankments structures, wall with reinforced backfill, analysis and design of shallow foundations on reinforced earth | 10 |
| 4. | Geotextiles, selection and engineering applications, design examples, stabilisation/improvement of ground using geomembranes, geocells, geonets, geosynthetic walls | 08 |
| 5. | Soil nailing, construction of underground structures, landslide controls, deep vertical cuts, contiguous piles | 04 |
| 6. | Problematic soils, use of ply soils, improvement of saline soils, improvement of black cotton soils | 06 |
| | **Total** | **42** |

11. Suggested Books:

| S. No. | Name of Authors/Books/Publisher | Year of Publication/ Reprint |
|---|---|---|
| 1. | Moseley, M. P. and Kirsch K.,"Ground Improvement", Spon press. | 2004 |
| 2. | Mittal, Satyendra, "Ground Improvement Engineering", Vikas publishing house | 2010 |
| 3. | Koerner, R.M., "Designing with Geosynthetics"' Prentice hall. | 1990 |
| 4. | Saran, S., "Reinforced Soil and Its Engineering Applications", I.K. international | 2005 |
| 5. | Rao, G.V., Geosynthetics – An Introduction, Sai Master geoenvironmental services. | 2007 |
| 6. | Jones, CJFP, "Earth Reinforcement and soil structure", Thomas Telford | 1996 |
| 7. | Shukla, S.K., Yin, Jian-Hua, "Fundamentals of Geosynthetic Engineering", Taylor & Francis. | 2006 |

# INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPTT/CENTRE : **Department of Civil Engineering**

1. Subject Code : **CEN-626** Course Title : **Foundations on Weak Rocks**
2. Contact Hours : **L: 3 T : 1 P: 0**
3. Examination Duration (Hrs) : **Theory : 3 Practical : 0**
4. Relative Weight : **CWS :25 PRS: 0 MTE: 25 ETE: 50 PRE: 0**
5. Credits : **04** 6. Semester: **Spring** 7. Subject Area : **PEC**
8. Pre-requisite: **Nil**
9. Objective of Course : This course is designed to impart knowledge for design of foundations of structures in hill regions and methods for treatment of weak foundations to make them stable.

10. Details of Course :

| S. No. | Contents | Contact Hours |
|---|---|---|
| 1. | Engineering properties of weak rocks, different rock mass classification systems, relative merits and demerits | 02 |
| 2. | Failure criteria for weak rocks, bi-linear Mohr-Coulomb failure criterion, Hoek and Brown criterion and modified Hoek and Brown failure criterion etc. | 02 |
| 3. | Effect of structural planes on rock foundations, possible modes of failure of foundations on rocks/ rock masses, determination of in-situ shear strength of rocks and rock masses | 04 |
| 4. | Requirements for satisfactory performance of foundations, bearing capacity of foundations on rocks and rock masses, allowable bearing pressure of rock foundations using a nonlinear failure criterion, monotonic and cyclic plate load tests | 07 |
| 5. | Pressure-settlement characteristics, effect of layering, anisotropy, heterogeneity and in-elasticity | 06 |
| 6. | Shallow foundations, shallow foundations on sloping ground, raft foundations, stilt foundations, foundations for suspension bridges, transmission line towers, framed buildings etc, treatment of foundations - open joints, solution cavities, weak seams | 08 |
| 7. | Piles in weak rocks, bearing capacity and settlement of piles, piles in stratified rock masses, field load tests on piles in weak rocks, behaviour of bored / driven piles in soft / weathered rocks, case studies | 06 |
| 8. | Dam foundations, stability analysis, 3D wedge analysis of abutments of arch dams, dam-foundation interaction problems, influence of discontinuities like faults, fault zones, shear zones, seams etc on stability of dams, seepage below dam foundations etc., treatment of dam foundations- shear keys, dental treatment of faults, seams, grouting of cavities, grout curtains, cable anchors etc | 07 |
| | **Total** | **42** |

11. Suggested Books:

| S. No. | Name of Authors/Books/Publisher | Year of Publication/ Reprint |
|---|---|---|
| 1. | Wyllie Duncan C.," Foundations on Rock: Engineering Practice", E&FN Spon, Taylor and Francis. | 2005 |
| 2. | Singh, B. and Goel, R.K.,"Rock Mass Classification- A Practical Engineering Approach", Elsevier . | 2006 |
| 3. | Hudson, J. A.(Chief Ed.), "Comprehensive Rock Engineering: Principles-Practice & Project," Vols. 1-5, Pergamon press. | 1993 |
| 4. | Hoek, E., "Practical Rock Engineering", Rock science. | 2000 |
| 5. | Ramamurthy, T., "Engineering in Rocks", PHI learning. | 2008 |

# INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPTT/CENTRE : **Department of Civil Engineering**

1. Subject Code : **CEN-627** Course Title : **Landslide Analysis and Control**
2. Contact Hours : **L: 3 T : 1 P: 0**
3. Examination Duration (Hrs) : **Theory : 3 Practical : 0**
4. Relative Weight : **CWS :25 PRS: 0 MTE: 25 ETE: 50 PRE: 0**
5. Credits : **04** 6. Semester: **Spring** 7. Subject Area : **PEC**
8. Pre-requisite: **Nil**

9. Objective : To impart knowledge of advanced methods of testing of geological materials like soil, rocks and rock masses

10. Details of Course :

| S. No. | Contents | Contact Hours |
|---|---|---|
| 1. | Landslide hazard and risk | 03 |
| 2. | Landslides in earth systems | 03 |
| 3. | Earthquake and seismically induced landslides | 03 |
| 4. | Stability analysis soil and rock slopes | 03 |
| 5. | Rainfall analysis and rainfall induced landslides | 03 |
| 6 | Risk assessment | 03 |
| 7 | Landslide hazard zonations | 03 |
| 8 | Numerical modelling of landslides | 03 |
| 9 | Remote sensing techniques | 03 |
| 10 | Groundwater system analysis for landslides | 03 |
| 11 | Remediation techniques | 03 |
| 12 | Early warning systems | 03 |
| 12 | Disaster Mitigation | 03 |
| 14 | Sustainability and environmental issues | 03 |
| | **Total** | **42** |

11. Suggested Books :

| S. No. | Name of Authors/Books/Publishers | Year of Publication/ Reprint |
|---|---|---|
| 1. | **Landslides: Analysis and Control,** Volume 176 of Special report - Transportation Research Board, National Research Council, National Research Council (U.S.). Transportation Research Board | 1978 |
| 2. | Singh, B. and Goel, R.K., "Rock Mass Classification – A Practical Engineering Approach", Elsevier | 2006 |
| 3. | Hoek, E. and Bray, J.W., "Rock Slope Engineering", Institute of Mining Engg. | 1981 |
| 4. | Giani, G.P., "Rock Slope Stability Analysis", A.A. Balkema | 2002 |
| 5. | Singh, B. and Goel, R.K., "Software for Engineering Control of Landslide and Tunneling Hazards", A.A. Balkema | 2002 |
| 6. | Deoja, B., Dhital, M., Thapa, B., Wagner, A., "Mountain Risk Engineering Handbook", ISIMOD, Kathmandu | 2002 |

# INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NAME OF DEPTT/CENTRE : **Department of Civil Engineering**

1. Subject Code : **CEN-628** Course Title : **Constitutive Models for Geological Materials**
2. Contact Hours : **L: 3 T : 1 P: 0**
3. Examination Duration (Hrs) : **Theory : 3 Practical : 0**
4. Relative Weight : **CWS :25 PRS: 0 MTE: 25 ETE: 50 PRE: 0**
5. Credits : **04** 6. Semester: **Spring** 7. Subject Area : **PEC**
8. Pre-requisite: **Nil**
9. Objective of Course : To important knowledge in respect of various constitutive models for soil and rock involving stress-strain relationships.

10. Details of Course :

| S. No. | Contents | Contact Hours |
|---|---|---|
| 1. | Role of constitutive modeling | 02 |
| 2. | Importance of Laboratory Testing with Relation to Constitutive Modeling; | 02 |
| 3. | Elasticity: Linear, quasilinear, anisotropic; | 04 |
| 4. | Plasticity basics: Yield criteria, Flow rule, Plastic Potential, Hardening/ softening; | 06 |
| 5. | Rate Independent Plasticity: Mohr-Coulomb, Non-linear failure criteria, Drucker-Prager, and Cap models | 06 |
| 6. | Critical State Soil Mechanics: Critical state concept, Cam-clay models, | 06 |
| 7. | Constitutive model for rocks | 04 |
| 8. | Simulation of single element test using cam-clay: consolidation, drained and undrained triaxial test, | 04 |
| 9. | Stress-dilatancy theory | 02 |
| 10. | Work Hardening Plasticity Theory Formulation and implementation | 02 |
| 11. | Applications of Elasto-plastic models | 02 |
| 12. | Special Topics: Hypoelasticity-plasticity, Disturbed state concept | 02 |
| | **Total** | **42** |

11. Suggested Books:

| S. No. | Name of Authors/Books/Publishers | Year of Publication/ Reprint |
|---|---|---|
| 1. | Hicher and Shao, “Constitutive Modeling of Soils and Rocks”, John Wiley. | 2008 |
| 2. | N. Schofield and C. P. Wroth, “Critical State Soil Mechanics”, McGraw-Hill. | 1968 |
| 3. | C.S. Desai and H. J. Siriwardane, “Constitutive Laws for Engineering Materials with Emphasis on Geologic Materials”, Prentice-Hall, Inc., New Jersey. | 1984 |
| 4. | David M Potts and Lidija Zdravkovic, “Finite Element Analysis in Geotechnical Engineering Theory”, Thomas Telford. | 1999 |
| 5. | C.S. Desai, “Mechanics of Materials and Interfaces : The Disturbed State Concept”, CRC Press LLC. | 2000 |
| 6. | A.P.S. Selvadurai, M.J. Boulon, “Mechanics of Geomaterial Interfaces, Elsevier. | 1995 |

**INDIAN INSTITUTE OF TECHNOLOGY ROORKEE**

NAME OF DEPTT/CENTRE : **Department of Civil Engineering**

1. Subject Code : **CEN-650** Course Title : **Design of Bridge Substructures**
2. Contact Hours : **L: 3** **T : 0** **P: 2**
3. Examination Duration (Hrs) : **Theory : 3** **Practical : 0**
4. Relative Weight : **CWS : 15** **PRS: 25** **MTE: 20** **ETE: 40** **PRE: 0**
5. Credits : **4** 6. Semester: **Spring** 7. Subject Area : **PEC**
8. Pre-requisite: **Nil**

9. Objective: To introduce the behaviour and design of bridge substructures.

10. Details of Course:

| S. No. | Contents | Contact Hours |
|---|---|---|
| 1. | Hydraulic calculations related to bridge design | 04 |
| 2. | Analysis and design of piers and pier caps | 06 |
| 3. | Seismic restrainers | 01 |
| 4. | Analysis and design of abutments | 04 |
| 5. | Analysis and design of well foundations | 15 |
| 6. | Analysis and design of pile foundations | 12 |
| | **Total** | **42** |

11. Suggested Books:

| S. No. | Name of Authors/Books/Publishers | Year of Publication/ Reprint |
|---|---|---|
| 1. | Vijay Singh, “Wells and Cassions” Nem Chand & Sons. | 1981 |
| 2. | S. Saram, “Analysis and Design of Substructures”. | 2012 |
| 3. | Ponnuswamy, “Bridge Engineering”. | 1986 |
| 4. | D. J. Victor, “Essentials of Bridge Engineering”. | 2001 |
| 5. | Rakshit, “Design and Construction of Highway Bridges”. | 2004 |