Certificate in Civil Structural Engineering

Engineering Mathematics

Scalar – a quantity described by magnitude alone, such as temperature or mass. In structural analysis, scalars are used to represent loads, material properties, and coefficients in equations. Example: A dead load of $2.5\,KN/m^2$ is a scalar value applied uniformly over a slab.

Vector – a quantity possessing both magnitude and direction. Forces, displacements, and velocities are vectors. In two-dimensional problems a vector is often expressed as (Fx, Fy) or (ux, uy). Example: A horizontal wind pressure of 1.2 KN acting eastward is represented as vector $(1.2, 0)$.

Matrix – a rectangular array of numbers organized in rows and columns. Matrices are fundamental for representing systems of linear equations, stiffness relations, and transformation operations. The stiffness matrix [K] of a beam element relates nodal forces to nodal displacements: $[F] = [K]\{d\}$.

Determinant – a scalar value derived from a square matrix that indicates whether the matrix is invertible. If $\det([K]) = 0$, the structure is singular, implying mechanisms or instability. In practice, checking the determinant of a global stiffness matrix helps identify modeling errors.

Eigenvalue – a scalar λ that satisfies the equation $[A] - \lambda[I] = 0$ for a square matrix [A]. In vibration analysis, eigenvalues correspond to natural frequencies squared. Example: For a simple spring-mass system, the eigenvalue $\lambda = k/m$ yields the natural frequency $\omega = \sqrt{\lambda}$.

Eigenvector – a non-zero vector v that satisfies $[A]v = \lambda v$. In structural dynamics, eigenvectors describe mode shapes, indicating relative displacement patterns of members at each natural frequency.

Stress – internal force per unit area within a material, denoted σ. Types include normal stress ($\sigma = P/A$) and shear stress ($\tau = V/A$). Stress analysis determines whether a member will yield or fail under applied loads. Example: A steel rod subjected to tensile load 50 kN and cross-section $100\,mm^2$ experiences $\sigma = 500\,MPa$.

Strain – deformation per unit length, expressed as $\varepsilon = \Delta L/L$. In linear elastic materials, stress and strain are related by Hooke’s law: $\Sigma = E\varepsilon$, where E is Young’s modulus. Strain gauges measure ε to monitor structural health.

Hooke’s Law – a linear relationship between stress and strain for elastic materials, $\sigma = E\varepsilon$. It provides the basis for calculating deflections and stresses in beams, columns, and frames.

Bending Moment – the algebraic sum of moments about a section in a beam, represented as M. Positive bending moments cause compression at the top fibers and tension at the bottom. The flexural formula $M = \sigma \cdot I/c$ links moment, stress, moment of inertia I, and distance c from the neutral axis.

Shear Force – the internal force parallel to a beam’s cross-section, denoted V. Shear forces are calculated by taking the derivative of the bending moment diagram: $V = dM/dx$.

Moment of Inertia – a geometric property I that quantifies a cross-section's resistance to bending. For a rectangular section of width b and depth h, $I = b\,h^3/12$ about the centroidal axis. Larger I reduces deflection under a given load.

Section Modulus – defined as $S = I/c$, where c is the distance from the neutral axis to the extreme fiber. Section modulus is used to check bending stress: $\Sigma = M/S$.

Deflection – the displacement of a point in a structure under load, often denoted δ. The Euler-Bernoulli beam equation $EI\, d^4w/dx^4 = q(x)$ relates bending stiffness EI to load distribution q(x). Classic examples include the deflection of a simply supported beam under uniform load: $\Delta max = 5wL^4/(384EI)$.

Compatibility – the requirement that deformations of connected members satisfy geometric continuity. In indeterminate structures, compatibility equations are combined with equilibrium to solve for internal forces.

Equilibrium – the condition that the sum of forces and moments equals zero. In static analysis, equilibrium equations $\Sigma Fx = 0$, $\Sigma Fy = 0$, $\Sigma Mz = 0$ are the starting point for determining reactions and internal forces.

Statically Determinate – a structure where the number of unknown reactions equals the number of independent equilibrium equations. A simply supported beam is determinate; a fixed-fixed beam is indeterminate.

Statically Indeterminate – a structure requiring additional compatibility conditions beyond equilibrium to solve for internal forces. The degree of indeterminacy equals the number of extra unknowns.

Superposition – a principle stating that the response caused by multiple loads is the sum of the responses caused by each load applied separately. Superposition simplifies analysis of linear systems.

Boundary Condition – constraints imposed on a structural model, such as supports or prescribed displacements. Correctly specifying boundary conditions is essential for accurate finite element solutions.

Partial Differential Equation (PDE) – an equation involving partial derivatives of an unknown function of several variables. In structural mechanics, the governing PDE for elastic solids is Navier's equation: $M\nabla^2 u + (\lambda + \mu)\nabla(\nabla\cdot u) = 0$, where u is the displacement vector and λ, μ are Lamé constants.

Ordinary Differential Equation (ODE) – an equation containing derivatives of a single-variable function. Beam deflection equations are ODEs; for example, $EI\, d^4w/dx^4 = q(x)$ is a fourth-order ODE.

Initial Condition – values of a function and its derivatives at a starting point, required for solving ODEs. In time-dependent structural dynamics, initial displacement and velocity are specified.

Series Solution – representing a function as an infinite sum of terms, such as a Taylor or Fourier series. Series solutions are useful for approximating complex functions in analytical calculations.

Fourier Series – a representation of a periodic function as a sum of sine and cosine terms. In heat transfer analysis of slabs, Fourier series express temperature distribution over time.

Laplace Transform – an integral transform converting a time-domain function into a complex frequency domain. It simplifies solving linear ODEs with constant coefficients, particularly for transient structural response.

Inverse Laplace Transform – the operation that retrieves the original time-domain function from its Laplace domain representation.

Characteristic Equation – an algebraic equation obtained from a differential equation's homogeneous part, whose roots determine the solution's form. For a second-order ODE $m\,d^2x/dt^2 + c\,dx/dt + k\,x = 0$, the characteristic equation is $m\,r^2 + c\,r + k = 0$.

Natural Frequency – the frequency at which a system vibrates when disturbed from equilibrium and allowed to oscillate freely. It is calculated from eigenvalues: $\Omega n = \sqrt{\lambda n}$.

Damping – a mechanism that dissipates vibrational energy, reducing amplitude over time. Common damping models include viscous damping ($c \cdot dx/dt$) and structural damping (fraction of critical damping).

Modal Analysis – a technique that decomposes a structure's dynamic response into contributions from its mode shapes and natural frequencies. It is widely used in earthquake engineering to assess seismic performance.

Finite Difference Method (FDM) – a numerical technique that approximates derivatives by differences between function values at discrete points. FDM is applied to solve ODEs and PDEs for beam deflection and heat conduction.

Finite Element Method (FEM) – a powerful numerical approach that discretizes a continuum into elements connected at nodes. FEM converts governing differential equations into a system of algebraic equations $[K]\{d\} = \{F\}$.

Element – the smallest subdivision in FEM, characterized by shape functions, material properties, and degrees of freedom. Common element types include 1-D beam, 2-D plane stress, and 3-D solid elements.

Node – a point in the FEM mesh where degrees of freedom are defined. Nodal values represent displacements, rotations, or temperatures.

Shape Function – a set of interpolation functions that describe how field variables vary within an element. For a linear 2-node beam element, the shape functions $N1 = 1 - x/L$ and $N2 = x/L$ approximate axial displacement.

Assembly – the process of combining individual element matrices into a global stiffness matrix. Proper assembly ensures continuity of displacements across element interfaces.

Boundary Value Problem – a differential equation together with conditions specified at the boundaries of the domain. Beam deflection under prescribed end supports is a classic boundary value problem.

Convergence – the property that a numerical solution approaches the exact solution as the discretization is refined (e.G., Mesh size reduced). Convergence studies verify the reliability of FEM results.

Mesh – the collection of elements and nodes that discretize the geometry. Mesh quality influences solution accuracy; aspects include element shape, size, and aspect ratio.

Refinement – the act of increasing mesh density in regions of high stress gradients or where higher precision is required. Adaptive refinement algorithms automate this process based on error estimates.

Error Estimate – an assessment of the difference between the numerical solution and the exact solution. Techniques such as the Zienkiewicz-Zhu estimator provide quantitative error measures.

Stiffness Matrix – a matrix that relates nodal forces to nodal displacements for an element. For a 2-node axial bar, the stiffness matrix is (AE/L)[[1, -1],[-1, 1]].

Mass Matrix – a matrix representing inertial properties of an element. In dynamic analysis, consistent mass matrices distribute mass according to shape functions, while lumped mass matrices concentrate mass at nodes.

Damping Matrix – a matrix that models energy dissipation. Rayleigh damping expresses the damping matrix as a linear combination of the stiffness and mass matrices: $[C] = \alpha[M] + \beta[K]$.

Load Vector – the collection of external forces applied at nodes. In FEM, the load vector {F} is assembled from contributions of distributed loads, point loads, and prescribed forces.

Boundary Condition Enforcement – the technique of modifying the global system to incorporate supports or constraints, often by zeroing rows/columns and inserting prescribed values.

Eigenvalue Problem – in structural dynamics, solving $[K] - \omega^2[M] = 0$ yields natural frequencies (ω) and mode shapes (eigenvectors).

Modal Superposition – a method that expresses the dynamic response as a sum of modal contributions, each scaled by a participation factor.

Time Integration – numerical schemes that advance the solution of dynamic equations through time. Common methods include the explicit central difference and the implicit Newmark-β algorithms.

Explicit Method – a time integration technique where the state at the next step is computed directly from known quantities at the current step. It is conditionally stable and requires small time steps.

Implicit Method – a scheme where the next state is obtained by solving a set of equations that involve both current and future values. It is unconditionally stable for many problems, allowing larger time steps.

Stability – the attribute of a numerical method that prevents the growth of errors. For explicit schemes, the Courant-Friedrichs-Lewy (CFL) condition governs permissible time step size.

Consistency – the property that the truncation error of a numerical method tends to zero as the discretization parameters ($\Delta x, \Delta t$) approach zero.

Accuracy – the closeness of a numerical solution to the exact solution. Accuracy depends on both consistency and stability, as summarized by the Lax equivalence theorem.

Newton-Raphson Method – an iterative technique for solving non-linear algebraic equations. In FEM, it linearizes the equilibrium equations at each iteration: $[K_T]\{\Delta d\} = \{R\}$, where $[K_T]$ is the tangent stiffness matrix and $\{R\}$ the residual force vector.

Tangent Stiffness Matrix – the derivative of the internal force vector with respect to nodal displacements, reflecting the instantaneous stiffness of a non-linear structure.

Geometric Nonlinearity – non-linear behavior arising from large deformations that alter the structure's geometry, affecting stiffness. Examples include buckling of slender columns and post-yield behavior of frames.

Material Nonlinearity – non-linear response due to material behavior, such as plasticity, cracking, or strain hardening. Constitutive models like the von Mises yield criterion describe such effects.

Plasticity – the permanent deformation that occurs once a material's yield stress is exceeded. In structural analysis, plastic hinge formation is critical for assessing ultimate load capacity.

Yield Criterion – a mathematical condition that defines the onset of plastic deformation. Common criteria include von Mises and Tresca for isotropic metals.

Hardening – the increase in stress required to continue plastic deformation. Isotropic hardening assumes uniform expansion of the yield surface, while kinematic hardening translates it in stress space.

Stress Concentration – localized increase in stress due to geometric discontinuities such as holes, notches, or sudden changes in cross-section. Stress concentration factors (K_t) quantify the amplification.

Factor of Safety – the ratio of a structure's capacity to the applied demand, ensuring reliability under uncertainties. It is computed as allowable stress divided by calculated stress, or as ultimate load divided by design load.

Load Combination – a set of loads applied simultaneously according to code-specified factors, reflecting realistic loading scenarios. Typical combinations include dead + live, dead + live + wind, and seismic load factors.

Design Load – the load magnitude used for structural design, derived from load combinations and safety factors.

Service Load – the actual loads that a structure experiences during normal use, typically lower than design loads.

Buckling – the sudden lateral deflection of a compression member when its load exceeds a critical value. Euler's formula for the critical load of a pin-ended column is $Pcr = \pi^2 EI/(KL)^2$, where K is the effective length factor.

Effective Length Factor – a coefficient K that accounts for end conditions in buckling calculations. For a fixed-pinned column, $K \approx 0.699$.

Lateral-Torsional Buckling – instability mode of beams subjected to bending about the strong axis, coupled with torsional deformation. The critical moment Mcr depends on shear center location, warping stiffness, and lateral restraints.

Shear Center – the point in a cross-section through which a transverse load must pass to produce no twisting. For symmetrical I-sections, the shear center coincides with the centroid; for asymmetrical sections, it may lie outside the material.

Warping – out-of-plane deformation of a beam's cross-section during torsion. Warping stiffness contributes to the overall torsional rigidity, especially in thin-walled sections.

Torsion – twisting action caused by torque about the longitudinal axis of a member. The torsional constant J governs the relationship $\tau = T \cdot r/J$, where τ is shear stress, T is torque, and r is radial distance.

Thin-Walled Section – a cross-section whose wall thickness is small compared to other dimensions, allowing simplifications such as the Bredt-Bath theorem for torsion.

Bredt-Bath Theorem – a principle stating that the torsional shear flow q in a thin-walled closed section is constant and equal to $T/(2A_m)$, where A_m is the median area enclosed by the wall.

Shear Flow – the rate of shear force per unit length along a beam's cross-section, denoted q. It is used in the analysis of thin-walled members under shear and torsion.

Shear Center – (repeated for emphasis) the location where applied shear does not cause twisting; essential for accurate shear flow calculations.

Stress Resultant – an integrated quantity such as axial force, shear force, bending moment, or torsional moment, obtained by integrating stress distribution over the cross-section.

Sectional Property – geometric attributes of a cross-section, including area, moment of inertia, radius of gyration, and torsional constant.

Radius of Gyration – defined as $r = \sqrt{I/A}$, representing the distribution of area about an axis. It is used in slenderness calculations for columns.

Slenderness Ratio – the ratio of member length to its radius of gyration, $\lambda = L/r$. High slenderness indicates susceptibility to buckling; design codes prescribe limits on λ for different materials.

Euler-Bernoulli Beam Theory – a classical theory assuming plane sections remain plane and normal to the deformed axis, neglecting shear deformation. It provides the differential equation $EI\, d^4w/dx^4 = q(x)$.

Timoshenko Beam Theory – an enhanced beam model that includes shear deformation and rotational inertia, improving accuracy for short, deep beams. The governing equations couple bending curvature and shear strain.

Shear Deformation – the distortion of a beam's cross-section due to transverse shear, significant when depth-to-length ratio exceeds 1/10.

Rotational Inertia – resistance of a beam to angular acceleration, incorporated in Timoshenko theory through the term $I\rho\, d^2\theta/dt^2$.

Plate – a flat, two-dimensional structural element with thickness much smaller than its planar dimensions. Plate theory extends beam theory to two dimensions, incorporating bending in both directions.

Kirchhoff-Love Plate Theory – a classical plate model assuming normals to the mid-surface remain straight and perpendicular after deformation, neglecting transverse shear.

Mindlin-Reissner Plate Theory – a refined plate theory that accounts for transverse shear deformation, improving predictions for thick plates.

Plate Bending Equation – a fourth-order PDE: $D\nabla^4 w = q$, where $D = Eh^3/[12(1 - \nu^2)]$ is the flexural rigidity, w is deflection, and q is the transverse load.

Membrane Action – in shell structures, the in-plane forces that carry loads without significant bending. Membrane behavior dominates in thin shells under uniform pressure.

Shell – a curved structural element that can carry loads through membrane and bending actions. Shell analysis involves coupling of curvature, membrane stresses, and bending moments.

Curvature – the geometric measure of how a shell deviates from a plane, expressed as 1/R where R is the radius of curvature.

Gaussian Curvature – product of principal curvatures, indicating whether a surface is convex, concave, or saddle shaped.

Principal Curvature – the maximum and minimum curvatures at a point on a surface, governing shell stiffness.

Laminate – a composite structure made of multiple layers (plies) with different orientations. Laminate theory predicts effective stiffness matrices (A, B, C) relating forces and moments to strains and curvatures.

Classical Laminate Theory – provides the ABD matrix, where A relates in-plane forces to mid-plane strains, B couples bending and stretching, and D relates moments to curvatures.

Ply – an individual layer within a composite laminate, characterized by thickness, material properties, and fiber orientation.

Fiber Orientation – the angle at which fibers are laid relative to reference axes, influencing anisotropic stiffness.

Orthotropic Material – a material with three mutually orthogonal axes of symmetry, each with distinct elastic properties. Wood and composite laminates are typical orthotropic materials.

Anisotropic Material – a material whose properties vary with direction in a more general manner than orthotropic.

Poisson's Ratio – the ratio $\nu = -\varepsilon_{lateral}/\varepsilon_{axial}$, describing the lateral contraction accompanying axial extension.

Shear Modulus – also called modulus of rigidity G, relating shear stress to shear strain: $\tau = G\gamma$.

Bulk Modulus – K, representing resistance to uniform volumetric compression: $\Delta P = K \cdot \Delta V/V$.

Thermal Expansion – the change in dimension per unit temperature change, α. Thermal strain $\varepsilon_T = \alpha\Delta T$ contributes to stress when restraints prevent free expansion.

Coefficient of Thermal Expansion – a material property indicating how much length changes with temperature.

Heat Conduction Equation – a PDE governing temperature distribution: $K\nabla^2 T + q = \rho c\, \partial T/\partial t$, where k is conductivity, q is internal heat generation, ρ is density, and c is specific heat.

Conduction – transfer of heat through a material due to temperature gradient.

Convection – heat transfer between a surface and a fluid, described by Newton's law $q = h(T_s - T_\infty)$, where h is the convection coefficient.

Radiation – emission of electromagnetic energy from a surface, modeled by the Stefan-Boltzmann law $q = \varepsilon\sigma(T^4 - T_s^4)$.

Thermal Stress – stress induced by restrained thermal expansion or contraction. In a fixed steel bar, temperature increase ΔT generates $\sigma = E\alpha\Delta T$.

Transient Analysis – analysis of structural response varying with time, such as seismic loading or impact events.

Steady-State Analysis – analysis where variables do not change with time; for heat conduction, the temperature field satisfies $\nabla^2 T = 0$.

Dynamic Amplification Factor – the ratio of dynamic response to static response, often expressed as $DAF = 1/(1 - (\omega/\omega_n)^2)$ for undamped systems.

Response Spectrum – a plot of maximum response (displacement, acceleration, or stress) versus natural frequency for a given ground motion, used in seismic design.

Seismic Load – forces generated by earthquake ground motions, represented by accelerograms or response spectra.

Base Shear – the total horizontal force transmitted to the foundation, calculated as $V_b = C_s \cdot W$, where C_s is the seismic coefficient and W is the building weight.

Story Drift – the relative horizontal displacement between consecutive floors, limited by codes to control damage.

Plastic Hinge – a localized region where a beam or column yields and undergoes plastic rotation, enabling redistribution of moments in collapse analysis.

Capacity Curve – a plot of base shear versus roof displacement, illustrating the nonlinear behavior of a structure under seismic loading.

P-Delta Effect – secondary moments induced by axial loads acting through displaced points, significant in tall structures.

Stability Analysis – evaluation of a structure's ability to maintain equilibrium under incremental loads, including buckling and P-Delta effects.

Load Path – the sequence of structural elements that transmit loads from the point of application to the foundation. Understanding load paths aids in efficient design.

Redundancy – the presence of additional load-carrying elements beyond those required for equilibrium, providing alternative paths in case of member failure.

Reliability – the probability that a structure will perform its intended function without failure over a specified period. Reliability analysis incorporates statistical variations in loads and material properties.

Probability Distribution – a function describing the likelihood of different values of a random variable, such as load intensity or material strength.

Monte Carlo Simulation – a computational technique that uses random sampling to estimate the probability of structural performance metrics.

Safety Index – a numerical measure of reliability, often expressed as the number of standard deviations between mean capacity and demand.

Optimization – the process of finding the most efficient design, balancing cost, weight, and performance. Common methods include gradient-based algorithms and genetic algorithms.

Design Variable – a parameter that can be altered during optimization, such as cross-section dimensions, material grade, or reinforcement layout.

Constraint – a condition that must be satisfied in an optimization problem, such as stress limits or displacement limits.

Objective Function – the quantity to be minimized or maximized, for example total material cost or structural weight.

Sensitivity Analysis – assessment of how small changes in design variables affect the objective function or constraints, guiding optimization direction.

Gradient – the vector of partial derivatives of the objective function with respect to design variables, indicating the steepest ascent or descent.

Finite Element Software – computer programs that implement FEM, such as SAP2000, ANSYS, ABAQUS, or OpenSees. Familiarity with user interfaces, model setup, and result interpretation is essential for civil engineers.

Pre-Processor – the stage where geometry, material properties, loads, and boundary conditions are defined before solving.

Solver – the computational engine that assembles matrices, applies numerical methods, and obtains solutions for displacements, forces, and stresses.

Post-Processor – the stage where results are visualized, extracted, and interpreted, including contour plots, deformed shapes, and reaction diagrams.

Convergence Criterion – a numerical threshold that determines when iterative solutions have sufficiently satisfied equilibrium, e.G., Residual force norm below 1×10^{-6} kN.

Non-Linear Solver – algorithms that handle material and geometric non-linearity, typically using Newton-Raphson iterations with line search or arc-length control.

Arc-Length Method – a technique that controls the progression of load steps along the equilibrium path, enabling tracing of post-peak behavior in snap-through problems.

Load Step – a discrete increment of applied load in a non-linear analysis, allowing the structure to follow the equilibrium path gradually.

Incremental–Iterative Procedure – the combination of load stepping (incremental) and solving at each step (iterative) to achieve equilibrium.

Force Method – a structural analysis approach that solves for unknown forces using compatibility conditions, often applied in indeterminate trusses.

Displacement Method – also known as the stiffness method, solves for unknown displacements first, then derives forces. The finite element approach is a displacement method.

Flexibility Matrix – the inverse of the stiffness matrix, relating forces to displacements in the force method.

Compatibility Equation – an expression ensuring that deformations of connected members are consistent, essential for solving indeterminate structures.

Redundancy Removal – the process of eliminating extra unknowns by applying compatibility, reducing a statically indeterminate structure to a determinate one.

Castigliano's Theorem – states that the partial derivative of the total strain energy with respect to a load gives the displacement in the direction of that load: $\Delta = \partial U / \partial P$. Widely used for displacement calculation in complex structures.

Strain Energy – the energy stored in a deformed elastic body, expressed as $U = \frac{1}{2}\int \sigma \cdot \varepsilon \, dV$. Strain energy concepts underpin many analytical methods, including the virtual work principle.

Virtual Work – the principle that the external virtual work equals internal virtual work for any admissible virtual displacement. It provides a basis for deriving equilibrium equations and compatibility conditions.

Principle of Minimum Potential Energy – asserts that among all admissible displacement fields, the actual displacement minimizes the total potential energy. This principle underlies the Ritz and Galerkin methods for approximate solutions.

Ritz Method – an approximate solution technique that assumes a displacement shape function with unknown coefficients, then applies the minimum potential energy principle to solve for those coefficients.

Galerkin Method – similar to the Ritz method, but the weighting functions are chosen to be the same as the assumed shape functions, leading to a symmetric system of equations.

Weighted Residual Method – a family of methods (including Galerkin) that minimize the residual of the governing differential equation weighted by chosen functions.

Boundary Element Method (BEM) – a numerical technique that reduces the problem domain to its boundaries, useful for problems with infinite or semi-infinite domains, such as soil-structure interaction.

Soil-Structure Interaction – the mutual influence between a structure and the supporting ground, modeled using springs, springs-dashpots, or coupled FEM-BEM analyses.

Winkler Foundation – a simplified model representing the subgrade as a series of independent springs with stiffness k_s, relating vertical settlement w to pressure p: $P = k_s w$.

P-Y Curve – a nonlinear relationship between lateral soil resistance p and deflection y for pile foundations, used in dynamic pile analysis.

Dynamic Amplification – the increase in structural response due to inertial effects, quantified by the dynamic amplification factor or response spectrum.

Resonance – a condition where the frequency of external excitation matches a natural frequency, leading to large amplitude vibrations. Design strategies aim to avoid resonance through frequency separation or damping.

Frequency Separation – the practice of designing structural members so that their natural frequencies do not coincide with dominant excitation frequencies.

Damping Ratio – the ratio $\zeta = c/(2\sqrt{(km)})$, where c is the damping coefficient, k is stiffness, and m is mass. $Z = 0.05$ (5 %) Is typical for steel structures.

Critical Damping – the minimum damping needed to prevent oscillatory response, occurring when $\zeta = 1$.

Viscous Damping – a model where damping force is proportional to velocity, commonly used in time-domain dynamic analysis.

Structural Damping – energy dissipation due to internal friction, often represented as a fraction of critical damping.

Rayleigh Damping – a linear combination of mass and stiffness matrices to approximate frequency-dependent damping: $[C] = \alpha[M] + \beta[K]$.

Time-History Analysis – a direct integration method that computes structural response step-by-step using actual or synthetic ground motion records.

Synthetic Ground Motion – artificially generated accelerograms that match target response spectra, used when recorded data are unavailable.

Response Spectrum Analysis – a modal analysis method that uses the response spectrum to estimate maximum responses without performing full time-history simulations.

Modal Participation Factor – a coefficient that quantifies the contribution of each mode to the overall response, calculated from mode shapes and mass distribution.

Equivalent Static Method – a simplified seismic analysis approach that replaces dynamic effects with equivalent static forces, using base shear coefficients.

Capacity Design – a design philosophy that ensures plastic hinges form in predetermined locations, providing a stable collapse mechanism.

Performance-Based Design – an approach that defines target performance levels (e.G., Immediate occupancy, life safety) and designs structures to meet those criteria under specified seismic demands.

Design Spectrum – a code-provided plot of spectral displacement, velocity, or acceleration versus period, used to derive seismic forces for different structural types.

Code-Specified Load Factors – multipliers applied to basic loads to obtain design loads, such as 1.2 For dead load and 1.6 For live load in many building codes.

Load Path Redundancy – the presence of multiple pathways for load transfer, enhancing robustness against localized damage.

Robustness – the ability of a structure to withstand unforeseen events (e.G., Impact, blast) without disproportionate collapse.

Progressive Collapse – a failure mechanism where local damage leads to a cascade of failures, potentially resulting in total collapse.

Alternate Load Path – a secondary route for load transfer that activates when the primary path is compromised, essential for robust design.

Design for Constructability – the practice of shaping structural details to facilitate efficient fabrication, transportation, and erection.

Prestressing – a technique where steel tendons are tensioned before service loads, inducing compressive stresses that counteract tensile stresses from external loads.

Pre-Tensioned Concrete – tendons are tensioned before concrete casting, common in precast beam production.

Post-Tensioned Concrete – tendons are tensioned after concrete has hardened, allowing for larger spans and varying tendon profiles.

Cable – a flexible structural element that carries tension only, used in suspension bridges, cable-stayed bridges, and stay cables.

Euler Beam – a model for slender beams under axial compression, predicting buckling load based on end conditions and slenderness.

Tension-Only Element – a FEM element that can only carry tensile forces, useful for modeling cables and tendons.

Shear Wall – a vertical element that resists lateral loads through shear, providing stiffness and strength in building frames.

Braced Frame – a structural system where diagonal members (braces) connect columns and beams, enhancing lateral stiffness.

Moment-Resisting Frame – a frame that develops stiffness through rigid connections, allowing beams to act as continuous members and resisting overturning moments.

Semi-Rigid Connection – a connection that exhibits partial rotational stiffness, influencing frame behavior and requiring accurate modeling of connection properties.

Rigid Connection – a connection assumed to have infinite rotational stiffness, often idealized in analysis of moment frames.

Connection Design – the process of ensuring that joints between members can transmit forces and moments safely, accounting for welds, bolts, and bearing stresses.

Bolt – a mechanical fastener that transfers shear and tensile forces between connected members.

Weld – a metallurgical joining process that creates a continuous bond, capable of transmitting both shear and moment.

Bearing – a component that transfers loads between structural elements while allowing rotation or translation, such as bearing plates at column bases.

Foundation – the lower part of a structure that transfers loads to the ground, including shallow footings, deep piles, and mat foundations.

Shallow Footing – a spread footing placed near the ground surface, suitable for moderate loads and competent soils.

Deep Foundation – a foundation extending to deeper strata, such as driven piles, drilled shafts, or caissons, used when surface soils are inadequate.

Pile – a slender, elongated structural element driven or drilled into the ground to transfer loads through skin friction and end bearing.

End Bearing – the vertical reaction at the tip of a pile caused by contact with a firm stratum.

Skin Friction – the shear resistance along the surface of a pile due to interaction with surrounding soil.

Group Effect – the interaction among closely spaced piles, reducing the per-pile capacity compared to isolated piles.

Settlement – the vertical displacement of a foundation under load, which can be elastic (recoverable) or plastic (permanent).

Elastic Settlement – calculated using elastic theory, often expressed as $s = q \cdot B/(E_s)$, where B is footing width and E_s is soil modulus.

Plastic Settlement – occurs when soil yields, requiring limit equilibrium or numerical methods for prediction.

Ground Improvement – techniques such as compaction, grouting, or geosynthetics that enhance soil properties before construction.

Geotechnical Engineering – the branch of civil engineering dealing with soil and rock behavior, foundation design, and earthworks.

Slope Stability – the analysis of the potential for a soil or rock slope to fail, using methods like limit equilibrium, Bishop's simplified method, or finite element modeling.

Factor of Safety in Slope – the ratio of resisting forces to driving forces; a common target is $FS \geq 1.5$ For static conditions.

Retaining Wall – a vertical structure that holds back soil, designed for earth pressure, drainage, and stability.

Earth Pressure – the stress exerted by soil on a retaining wall, described by active (Ka), passive (Kp), and at-rest (Ko) coefficients.

Rankine Theory – a method for calculating active and passive earth pressures assuming planar failure surfaces and no wall friction.

Coulomb Theory – extends Rankine by including wall friction and inclination of failure planes.

Drainage – the provision of pathways for water to escape from behind a retaining wall, preventing hydrostatic pressure buildup.

Tie-Back – a ground anchor used to provide additional resistance to a retaining wall, typically installed at an angle into stable ground.

Seepage – the flow of water through porous media, which can cause erosion or uplift pressures in foundations.

Uplift – upward pressure exerted by groundwater or hydrostatic forces, requiring design measures such as drainage or counterweights.

Hydrostatic Pressure – pressure exerted by a fluid at rest, increasing linearly with depth: $P = \gamma h$, where γ is unit weight.

Dynamic Soil-Structure Interaction – the effect of soil damping and stiffness on structural vibration, influencing natural frequencies and response amplitudes.

Soil Damping – energy dissipation in soil due to hysteresis, often modeled as a viscous dashpot in foundation models.

Pile-Group Interaction – the combined effect of multiple piles on the overall stiffness and damping of a foundation system.

Design of Reinforced Concrete – the process of specifying concrete strength, reinforcement layout, and detailing to meet strength, serviceability, and durability criteria.

Concrete – a composite material composed of cement, aggregates, water, and admixtures, whose compressive strength develops over time.