Chapter 34: Design Earthquake

Introduction

In earthquake-resistant design, it is neither feasible nor economical to design structures for the maximum possible ground motion. Instead, engineers design for a *design earthquake*, which represents the ground motion level that structures are expected to safely withstand with limited damage. The concept of the design earthquake is central to seismic design and building codes. It encapsulates expected seismic intensities, site conditions, and probability of occurrence, thereby ensuring safety, serviceability, and cost-effectiveness in structural design. This chapter delves into the principles and parameters involved in defining a design earthquake, as well as its use in practical seismic analysis and design.

34.1 Seismic Hazard and Design Earthquake

34.1.1 Types of Seismic Hazards

- **Ground Shaking**: The most common and destructive hazard.
- **Surface Rupture**: Displacement along a fault that reaches the earth's surface.
- **Liquefaction**: Loss of soil strength due to intense shaking.
- **Landslides**: Triggered in hilly or unstable slopes during quakes.
- **Tsunamis**: Seismic sea waves caused by undersea earthquakes.

34.1.2 Seismic Hazard Analysis

There are two main approaches to hazard analysis:

- **Deterministic Seismic Hazard Analysis (DSHA)**: Considers the largest possible earthquake from a known fault, ignoring the probability of occurrence.
- **Probabilistic Seismic Hazard Analysis (PSHA)**: Incorporates uncertainties in size, location, and occurrence frequency of earthquakes, and provides a probabilistic estimate of ground motion.

34.2 Design Basis Earthquake (DBE) and Maximum Considered Earthquake (MCE)

34.2.1 Maximum Considered Earthquake (MCE)

- Represents the most severe ground motion that could occur at a site.
- Used to evaluate *collapse prevention* level in performance-based design.
- Typically associated with a probability of exceedance of 2% in 50 years (return period ≈ 2500 years).

34.2.2 Design Basis Earthquake (DBE)

- Ground motion level for which a structure is designed to remain operational or suffer only minor damage.
- Associated with 10% probability of exceedance in 50 years (return period ≈ 475 years).
- DBE = 2/3 × MCE, as per IS 1893:2016 provisions for regular structures.

34.3 Seismic Zoning and Zoning Maps

34.3.1 Seismic Zones in India

- India is divided into four seismic zones: II, III, IV, and V (Zone I was removed in IS 1893:2002).
- Zone II: Least severe; Zone V: Most severe.

34.3.2 Zone Factor (Z)

- Represents the peak ground acceleration (PGA) for MCE.
- Values in IS 1893 (Part 1):
    - Zone II: Z = 0.10
    - Zone III: Z = 0.16
    - Zone IV: Z = 0.24
    - Zone V: Z = 0.36

34.4 Site Effects and Importance of Local Soil

34.4.1 Soil Amplification

- Ground shaking intensity depends on local geology.

- Soft soil sites amplify motion compared to rock sites.

34.4.2 Site Classification (as per IS 1893)

- **Type I (Rock/Hard Soil)**: Vs > 760 m/s
- **Type II (Medium Soil)**: 360 < Vs ≤ 760 m/s
- **Type III (Soft Soil)**: Vs ≤ 360 m/s

34.4.3 Importance Factor (I)

- Multiplier to account for importance/use of structure.
- Values (IS 1893):
  - Ordinary buildings: I = 1.0
  - Hospitals, schools, emergency buildings: I = 1.5

34.5 Response Spectra for Design

34.5.1 Design Response Spectrum

- Represents maximum response of a single-degree-of-freedom (SDOF) system to ground motion.
- Used to derive design forces for different structural systems.

34.5.2 Parameters of Spectrum

- **Spectral Acceleration (Sa/g)**: Depends on time period (T), damping, soil type.
- **Damping ratio**: Usually 5% for design.
- **Peak values occur at low-to-moderate periods.**

34.5.3 IS Code Spectrum (IS 1893:2016)

- Normalized for PGA (Z/2 × I/R × Sa/g).
- Separate spectra for each soil type provided.
- Site-specific spectra needed for important/irregular buildings in Zone IV & V.

34.6 Design Seismic Base Shear

34.6.1 Formula (IS 1893)

$$V_b = \frac{Z}{2} \cdot \frac{I}{R} \cdot S_a / g \cdot W$$

Where:

- V_b: Design base shear
- Z: Zone factor
- I: Importance factor
- R: Response reduction factor
- S_a / g: Spectral acceleration
- W: Seismic weight of the building

34.6.2 Seismic Weight (W)

- Includes dead load and applicable portions of imposed load.
- Water tanks, parapets, mechanical equipment, etc., are included as per code.

34.7 Vertical Distribution of Base Shear

34.7.1 Lateral Force at Each Storey (IS 1893)

$$Q_i = V_b \cdot \frac{W_i h_i^2}{\sum W_i h_i^2}$$

Where:

- Q_i: Lateral force at floor i
- W_i: Seismic weight of floor i
- h_i: Height of floor i from base

34.7.2 Storey Shear and Overturning Moment

- Storey shear: Sum of lateral forces above the level.
- Overturning moment: Based on lateral forces and vertical distances.

34.8 Time History and Site-Specific Ground Motion

34.8.1 When Required

- Critical/irregular structures
- High seismic zones
- Large industrial, nuclear, or lifeline structures

34.8.2 Ground Motion Selection

- Real, recorded earthquake data scaled to match DBE.
- Simulated synthetic ground motions can also be used.

34.9 Use of Design Earthquake in Structural Design

34.9.1 Linear Static Method

- For regular structures up to 15 m in Zone II/III.

34.9.2 Response Spectrum Method

- Preferred for most structures.
- Handles multiple modes of vibration.

34.9.3 Nonlinear Time History Analysis

- For special structures and performance-based design.
- Captures inelastic behavior and complex interactions.

34.10 Code Provisions and Revisions (IS 1893:2016)

34.10.1 Major Updates in IS 1893:2016

- Zone factor (Z) revised.
- Soil classification expanded.
- Response spectra refined for 5% damping.
- Irregularities and performance levels better defined.

34.10.2 Design Implications

- Emphasis on ductility and redundancy.
- Encourages site-specific studies for critical infrastructure.

34.11 Performance-Based Seismic Design (PBSD)

34.11.1 Concept and Need

- PBSD aims to design buildings not just to prevent collapse but to limit damage under various levels of seismic intensity.
- Goes beyond traditional force-based design by incorporating deformation and damage states.

34.11.2 Performance Levels

- **Operational**: No damage, continues functioning (e.g., hospitals).
- **Immediate Occupancy**: Minor non-structural damage, safe for occupancy.
- **Life Safety**: Moderate structural damage, life safety ensured.
- **Collapse Prevention**: Severe damage but no collapse; residual capacity.

34.11.3 Design Earthquakes for PBSD

- Two or more ground motion levels are considered:
    - **Service Level Earthquake (SLE)**: For operational/occupancy criteria.
    - **Design Basis Earthquake (DBE)**: For life safety.
    - **Maximum Considered Earthquake (MCE)**: For collapse prevention.

34.11.4 Nonlinear Analysis Requirements

- Use of pushover (static nonlinear) or time-history (dynamic nonlinear) analysis.
- Material inelasticity and element damage tracked explicitly.

34.12 Influence of Soil-Structure Interaction (SSI)

34.12.1 What is SSI?

- Interaction between structure, foundation, and the supporting soil during seismic shaking.
- Affects natural period, damping, and base shear.

34.12.2 SSI Effects

- **Flexible soils** increase displacement and period.
- **Stiff soils** reduce amplification but may increase base shear.

34.12.3 Considerations in Design

- Required for:
  - Tall buildings
  - Soft soil sites
  - Important/critical infrastructure

34.12.4 Code Provisions

- IS 1893 requires inclusion of SSI for:
  - Buildings on soft soil
  - Irregular or tall structures

34.13 Earthquake Design of Irregular Structures

34.13.1 Types of Irregularities (IS 1893:2016)

- **Plan Irregularities**:
  - Torsional, re-entrant corners, diaphragm discontinuity.
- **Vertical Irregularities**:
  - Mass, stiffness, or geometry discontinuities.

34.13.2 Challenges in Design

- Irregularities result in complex dynamic behavior and stress concentration zones.
- Require advanced analysis (e.g., dynamic response spectrum or time history).

34.13.3 Design Measures

- Avoid abrupt changes in stiffness or mass.
- Provide adequate lateral stiffness and ductility.
- Use dual systems (shear wall + moment frame) for redundancy.

34.14 Seismic Design of Non-Structural Elements

34.14.1 Importance

- Non-structural components (e.g., cladding, ceilings, piping) can cause injuries and economic losses.

34.14.2 Design Considerations

- Secure anchorage and bracing.
- Flexible connections for utilities and equipment.
- Design for drift compatibility.

34.14.3 Code Guidelines

- IS 1893 and NBC include requirements for critical equipment and life-safety elements.

34.15 Role of Ductility, Redundancy, and Overstrength

34.15.1 Ductility

- Ability of structural elements to undergo large inelastic deformations without significant strength loss.
- Ductile detailing ensures energy dissipation during strong shaking.

34.15.2 Redundancy

- Multiple load paths prevent progressive collapse.
- Frame and wall combinations enhance redundancy.

34.15.3 Overstrength

- Actual strength often exceeds design strength (due to material variation, detailing).
- Design must account for overstrength to prevent brittle failure in adjacent systems.

34.16 Retrofitting and Seismic Evaluation Based on Design Earthquake

34.16.1 Seismic Evaluation

- Assessment of existing buildings for performance under DBE and MCE.

- Identifies deficiencies in strength, stiffness, and ductility.

34.16.2 Retrofitting Techniques

- **Structural strengthening**: Jacketing, bracing, adding shear walls.
- **Base isolation**: Reduces energy input to the structure.
- **Energy dissipation devices**: Dampers to absorb seismic energy.

34.16.3 Prioritization

- Hospitals, schools, emergency facilities, heritage structures.

34.17 Earthquake Design Philosophy as per Indian Codes

34.17.1 Limit State Approach

- Ensures both:
  - No collapse under rare/intense earthquakes (MCE).
  - Limited damage under frequent/moderate earthquakes (DBE).

34.17.2 Indian Codes Referenced

- **IS 1893 (Part 1–5)**: Criteria for seismic design.
- **IS 13920**: Ductile detailing of reinforced concrete.
- **IS 4326**: Earthquake-resistant construction.
- **IS 13828**: Non-engineered buildings.

34.17.3 Design Approach Summary

- Use of response reduction factors (R).
- Ensure adequate detailing, anchorage, and continuity.
- Emphasis on simplicity, symmetry, and regularity in form.
