Chapter 41: Design as per the Codes

Introduction

Designing earthquake-resistant structures is a critical part of civil engineering in seismically active regions. Indian codes such as **IS 1893 (Part 1): 2016** and **IS 13920: 2016** play a vital role in standardizing procedures for earthquake-resistant design. These codes provide guidelines for analyzing, designing, and detailing buildings and structures to withstand seismic forces with acceptable levels of safety and serviceability.

This chapter discusses the philosophy of seismic design, important clauses of Indian codes, code-based seismic design procedures, and ductile detailing as prescribed by IS codes. The objective is to enable engineers to ensure that structures not only remain standing during strong ground motions but also prevent collapse and save lives.

41.1 Philosophy of Earthquake Resistant Design

- **Performance Objective**: To ensure safety against collapse and limit damage under design earthquake.
- **Basic Assumptions**:
  - Earthquake forces are random in nature.
  - Structures must have adequate ductility, strength, and stiffness.
  - Some damage is acceptable under strong earthquakes, but collapse must be prevented.
- **Design Levels**:
  - **Operational Level Earthquake (OLE)** – frequent, low-intensity events; minimal or no damage.
  - **Design Basis Earthquake (DBE)** – moderate earthquakes; acceptable damage, no collapse.
  - **Maximum Considered Earthquake (MCE)** – rare, very strong earthquakes; extensive damage allowed but collapse must be avoided.

41.2 Overview of Indian Seismic Codes

IS 1893 (Part 1): 2016 – ***Criteria for Earthquake Resistant Design of Structures***

- Applies to general buildings and includes seismic zoning, seismic coefficients, and design spectrum.
- Provides method for calculating base shear and its distribution.

IS 13920: 2016 – ***Ductile Detailing of Reinforced Concrete Structures Subjected to Seismic Forces***

- Mandatory for buildings in seismic zones III, IV, and V.
- Prescribes detailing methods that enhance ductility and energy dissipation capacity.

41.3 Seismic Zoning and Zone Factor (Z)

- India is divided into four seismic zones: II, III, IV, V.
- Each zone has a **Zone Factor (Z)**:
  - Zone II: Z = 0.10
  - Zone III: Z = 0.16
  - Zone IV: Z = 0.24
  - Zone V: Z = 0.36
- Zone factor represents the effective peak ground acceleration (PGA).

41.4 Importance Factor (I)

- Accounts for the significance of structure.
- Example:
  - Hospitals, schools: I = 1.5
  - Residential buildings: I = 1.0

41.5 Response Reduction Factor (R)

- Represents inherent ductility and overstrength of the structure.
- Varies from 3 to 5 depending on structural system and detailing.
- Higher the R, lower the design seismic forces.

Structural System	R value
Ordinary RC Moment Frame	3
Ductile RC Moment Frame	5
Steel Frame with Bracings	4–5

41.6 Fundamental Natural Period (T)

- Required to calculate design base shear.
- For moment-resisting frames:

$$T = 0.075 \times h^{0.75}$$

- For other structures:

$$T = 0.09 \times \frac{h}{\sqrt{d}}$$

Where, h = height of the building (m) d = base dimension of building (m) in the direction of lateral force

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41.7 Design Seismic Base Shear (Vb)

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

Where,

- Z = Zone factor
- I = Importance factor
- R = Response reduction factor
- S_a/g = Spectral acceleration coefficient
- W = Seismic weight of the building

41.8 Vertical Distribution of Base Shear

- Total base shear is distributed along the height of the building using:

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

Where, Q_i = Lateral force at level i W_i = Seismic weight at level i h_i = Height of level i from base

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41.9 Design Spectrum as per IS 1893

- Provides the variation of spectral acceleration S_a/g with time period T.
- Depends on type of soil:
  - Hard soil
  - Medium soil
  - Soft soil
- Helps estimate peak forces for dynamic analysis.

41.10 Equivalent Static Method of Analysis

- Used for regular buildings up to 15m height in Zone IV and V or up to 40m in other zones.
- Involves base shear calculation and distribution.
- Simple and widely used method.

41.11 Dynamic Analysis: Response Spectrum Method

- Required for irregular or tall buildings.
- Steps:
  - Modal analysis using structure's mode shapes and frequencies.
  - Combine modal responses using SRSS or CQC methods.

41.12 Ductile Detailing as per IS 13920: 2016

a) Beam Detailing

- Minimum and maximum reinforcement limits.
- Anchorage length for bars.
- Hinge zone length and confinement reinforcement.

b) Column Detailing

- Strong column–weak beam concept.
- Transverse reinforcement and spacing.

- Lap splices at mid-height.

c) Beam–Column Joints

- Adequate confinement with closed ties or hoops.
- Shear strength requirements.

d) Shear Walls

- Boundary elements for confinement.
- Distributed vertical reinforcement.
- Special detailing for openings and curtailments.

41.13 Design of Structural Walls and Frames

- Dual systems (shear walls + moment frames) require design for load sharing.
- Code specifies distribution of base shear among lateral force-resisting elements.

41.14 Capacity Design Principles

- **Hierarchy of Strength**: Plastic hinges should form in beams before columns.
- **Overstrength Factors**: Account for material and strength variation.

41.15 Special Considerations

- **Soft Storey Effect**: Avoid open ground storeys without adequate stiffness.
- **Torsional Irregularity**: Symmetry in plan is recommended.
- **Pounding**: Adequate separation between adjacent buildings.
- **Soil–Structure Interaction**: Foundation flexibility considered in dynamic analysis.

41.16 Detailing in Masonry and Steel Structures

Masonry:

- Use of horizontal bands at plinth, lintel, and roof levels.
- Reinforced concrete corner and junction elements.

Steel Structures:

- Bolted or welded connections with ductile behavior.
- Bracing systems must allow energy dissipation.

41.17 Seismic Design of Foundations

- **Types of Foundations** in seismic areas:
  - **Isolated Footings**
  - **Raft Foundations**
  - **Pile Foundations**
- **Design Considerations**:
  - Foundation must transfer seismic forces safely to ground.
  - Soil-structure interaction must be assessed.
  - Ensure no liquefaction in soil layers (especially in Zones IV and V).
  - Use of **plinth beams** and **tie beams** is mandatory for better stability.
- **Codal Provisions**:
  - IS 1893 (Part 1): Foundation design must consider seismic bearing capacity.
  - IS 2974: Guidelines for machine foundations (also applicable for seismic design).

41.18 Seismic Design of Water Tanks and Elevated Structures

- Governed by **IS 1893 (Part 2): 2014**.
- **Dynamic Analysis**:
  - **Staging** must be evaluated for stiffness and flexibility.
  - **Sloshing effect** of water considered in elevated tanks.
- **Design Forces**:
  - Hydrodynamic and impulsive pressures on tank walls.
  - Lateral forces on supporting structure.
- **Failure Modes**:
  - Staging collapse due to slenderness.
  - Uplift forces due to overturning moments.

41.19 Performance-Based Seismic Design (PBSD)

- A modern design philosophy beyond traditional force-based methods.
- **Levels of Performance**:
  - **Immediate Occupancy**
  - **Life Safety**
  - **Collapse Prevention**
- **Nonlinear analysis methods** such as:
  - Push-over analysis
  - Time history analysis
- Focus on **actual structural behavior**, energy dissipation, damage control, and resilience.

41.20 Retrofitting and Strengthening as per Codes

- Codal guidelines: **IS 13935: 2009** – *Seismic Evaluation, Repair and Strengthening of Masonry Buildings.*
- **Retrofitting Methods**:
  - Jacketing of columns and beams
  - Adding shear walls
  - Steel/FRP bracing
  - Base isolation (advanced retrofitting)
  - Shotcreting, epoxy injection for cracks
- **Structural Assessment Tools**:
  - Visual inspection
  - NDT (Non-destructive testing)
  - Linear/Non-linear static and dynamic analyses

41.21 Base Isolation and Seismic Dampers

- **Base Isolation**:
  - Devices placed between foundation and superstructure to reduce energy transfer.
  - Examples: Lead rubber bearings, elastomeric pads.
- **Seismic Dampers**:
  - Installed within structure to absorb seismic energy.
  - Types:

    * **Viscous Dampers**
    * **Friction Dampers**
    * **Tuned Mass Dampers (TMD)**

- Codal mention: Referenced in IS 1893 and advanced international standards (e.g., FEMA 356).

41.22 Quality Control and Construction Practices

- Proper construction is vital even if code-based design is done.
- **IS 4326: 1993** outlines good construction practices in seismic zones.
- **Checklist**:
  - Use of quality materials
  - Adequate curing and compaction
  - Supervision during reinforcement placement
  - Adherence to detailing provisions

41.23 Software Tools for Seismic Design

- Common tools used:
  - STAAD Pro
  - ETABS
  - SAP2000
  - ANSYS
- Used for:
  - Linear & nonlinear dynamic analysis
  - Modal analysis
  - Time history response
  - Seismic load combinations as per IS 1893

41.24 Case Studies and Code Application Examples

- **Bhuj Earthquake (2001)**: Importance of ductility and code compliance.
- **Nepal Earthquake (2015)**: Failure of unreinforced masonry and soft storey buildings.
- Lessons:
  - Structural irregularities increase vulnerability.

- Code compliance can significantly reduce fatalities.
- Retrofit and repair need to be implemented for existing buildings.