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Earthquake-Resistant Design of Reinforced Concrete Buildings

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ABSTRACT: Earthquake-resistant design of reinforced concrete buildings aims to protect human life, control structural and non-structural damage, and prevent collapse during severe seismic events. Earthquake forces differ from ordinary gravity loads because they are dynamic, cyclic and strongly influenced by structural mass, stiffness, ductility, configuration and soil conditions. This article examines the fundamental principles, analysis methods and detailing requirements used in the seismic design of reinforced concrete buildings. It adopts a conceptual and technical review methodology based on established structural-engineering literature and major design standards, including IS 1893 (Part 1): 2016, IS 13920: 2016, IS 456: 2000, ASCE/SEI 7 and ACI 318. The study discusses seismic load estimation, structural regularity, load paths, moment-resisting frames, shear walls, dual systems, capacity design and ductile detailing. Particular attention is given to the strong-column–weak-beam principle, confinement of concrete, beam-column joints, lap-splice locations, shear design, diaphragm action and foundation interaction. The review finds that adequate member strength alone cannot ensure earthquake safety. Buildings require a regular structural configuration, controlled drift, sufficient deformation capacity and carefully detailed connections. Soft storeys, short columns, floating columns, torsional irregularity and poor reinforcement anchorage significantly increase vulnerability. Nonlinear analysis and performance-based design provide more realistic assessments for irregular, important and tall structures. The article concludes that effective seismic resistance results from the coordinated application of architectural planning, structural analysis, ductile detailing, quality construction and periodic inspection. Code compliance should be treated as a minimum requirement and must be supported by competent engineering judgment and site-specific evaluation.

1. Introduction

Earthquakes generate ground motion that causes buildings to accelerate. Because a building possesses mass, this acceleration produces inertia forces within its structural system. These forces reverse direction repeatedly and may subject beams, columns, walls, joints and foundations to severe cyclic demands.

Reinforced concrete is widely used because it offers strength, durability, fire resistance and flexibility in architectural form. However, poorly designed reinforced concrete buildings can fail in a brittle manner during earthquakes. Typical failures include column shear failure, beam-column joint damage, loss of reinforcement anchorage, soft-storey collapse, torsional response and pounding between adjacent buildings.

It is neither economically practical nor technically necessary to design ordinary buildings to remain completely undamaged during every possible earthquake. Modern seismic codes generally follow a performance philosophy:

- Minor earthquakes should cause little or no structural damage.
- Moderate earthquakes may cause repairable damage.
- Severe earthquakes may cause substantial damage, but collapse should be prevented.

Earthquake-resistant design therefore emphasizes ductility and energy dissipation in addition to strength. A ductile structure can undergo large deformations while maintaining adequate load-carrying capacity. This provides occupants with time to evacuate and reduces the likelihood of sudden collapse.

The seismic performance of a building begins with its configuration. A regular, continuous and well-balanced structure is generally safer than an irregular building that depends on complicated analytical calculations to redistribute seismic forces. Structural analysis and reinforcement detailing must then ensure that the selected system behaves as intended.

2. Objectives of the Study

The main objectives of this article are:

1. To explain the behaviour of reinforced concrete buildings during earthquakes.
2. To discuss the fundamental principles of earthquake-resistant design.
3. To examine seismic-force estimation and analysis methods.
4. To compare major lateral-force-resisting systems.
5. To explain ductile reinforcement detailing.
6. To identify common structural irregularities and failure mechanisms.
7. To examine the role of foundations, soil and non-structural components.
8. To recommend measures for improving the seismic safety of reinforced concrete buildings.

3. Research Methodology

This article uses a descriptive, conceptual and technical review methodology. It synthesizes principles from seismic-design standards, engineering books, research publications and earthquake reconnaissance findings.

The principal technical references include:

- IS 1893 (Part 1): 2016
- IS 13920: 2016
- IS 456: 2000
- IS 4326: 2013
- IS 15988: 2013
- ACI 318
- ASCE/SEI 7
- FEMA seismic-design guidance
- Established research on ductile reinforced concrete structures

The article does not present a design for a particular building. Numerical design parameters must be selected according to the applicable edition of the governing code, project location, soil investigation and structural system.

4. Nature of Earthquake Loading

Earthquake ground motion may contain three translational and three rotational components. Building analysis usually gives primary consideration to horizontal ground motion because ordinary buildings are generally more flexible laterally than vertically.

The inertia force developed in a mass can be represented by Newton's second law:

$$F = ma$$

Where:

- F = inertia force
- m = structural mass
- a = ground-induced acceleration

A heavier building develops greater inertia force for the same acceleration. Reducing unnecessary seismic mass can therefore reduce structural demand.

Earthquake response also depends on the natural period of vibration:

$$T = 2\pi \sqrt{\frac{m}{k}}$$

Where:

- T = natural period
- m = effective mass
- k = lateral stiffness

Increasing stiffness generally reduces the period but does not always reduce seismic force, because the response depends on the shape of the design spectrum. Engineers must balance strength, stiffness and ductility rather than maximizing only one property.

5. Fundamental Seismic-Design Principles

5.1 Continuous load path

Seismic forces must travel through floors and roofs into frames or walls and then into the foundation and soil. Every connection along this path must possess sufficient strength and deformation capacity.

5.2 Structural regularity

Regular buildings generally distribute seismic demands more predictably. Sudden changes in mass, stiffness, strength or geometry create concentrations of force and deformation.

5.3 Adequate lateral stiffness

The building must have sufficient stiffness to control storey displacement, non-structural damage and instability.

5.4 Ductility

Members and connections should deform beyond initial yielding without sudden loss of strength.

5.5 Redundancy

Multiple load-resisting elements provide alternative load paths if one element is damaged.

5.6 Energy dissipation

Properly detailed yielding regions dissipate earthquake energy through stable cyclic behaviour.

5.7 Capacity design

Brittle failure modes should be prevented by making them stronger than the intended ductile mechanisms.

5.8 Foundation compatibility

The superstructure and foundation should form a consistent load-resisting system appropriate for the soil conditions.

6. Performance Objectives

Earthquake level	Expected structural performance	Typical acceptable condition
Frequent or minor earthquake	Operational	Negligible structural damage
Moderate earthquake	Immediate occupancy or damage control	Limited and repairable damage
Design-basis earthquake	Life safety	Significant damage but adequate stability
Maximum considered earthquake	Collapse prevention	Severe damage without global collapse

Exact performance definitions depend on the applicable code or performance-based methodology. Essential facilities may require stricter objectives than ordinary residential or commercial buildings.

7. Seismic Weight and Base Shear

In equivalent static analysis, the total design lateral force is represented by base shear.

Under IS 1893 terminology:

$$V_B = A_h W$$

Where:

- V_B = design seismic base shear
- A_h = design horizontal seismic coefficient
- W = seismic weight of the building

The design horizontal coefficient may be expressed as:

$$A_h = \frac{Z}{2} \frac{I}{R} \frac{S_a}{g}$$

Where:

- Z = seismic-zone factor
- I = importance factor
- R = response-reduction factor
- S_a/g = spectral acceleration coefficient
- g = acceleration due to gravity

The base shear is distributed vertically according to the applicable code expression, typically considering storey seismic weight and height.

A common general form is:

$$Q_i = V_B \left(\frac{W_i h_i^k}{\sum_{j=1}^n W_j h_j^k} \right)$$

Where:

- Q_i = lateral force at level i
- W_i = seismic weight at level i
- h_i = height of level i
- k = code-specified distribution exponent
- n = number of storeys

Upper storeys usually attract larger lateral forces because of their greater height.

8. Seismic Analysis Methods

8.1 Equivalent static analysis

The dynamic effect of an earthquake is represented by an equivalent set of horizontal static forces. This method is most appropriate for regular and relatively low-rise buildings within code limitations.

8.2 Response-spectrum analysis

The building is analysed in different vibration modes. Modal responses are combined using an accepted statistical method such as SRSS or CQC. Response-spectrum analysis is commonly used for multistorey and irregular structures.

8.3 Linear time-history analysis

The structure is subjected to selected or generated ground-motion records while assuming essentially linear structural behaviour. Records must be appropriately selected, scaled and applied.

8.4 Nonlinear static analysis

Commonly called pushover analysis, this method applies increasing lateral load to estimate yielding, deformation capacity and probable failure mechanisms.

8.5 Nonlinear time-history analysis

The structure's inelastic response is calculated under earthquake records. It can provide detailed information but requires reliable material models, ground-motion selection and specialist judgment.

Analysis method	Appropriate application	Main limitation
Equivalent static	Regular low- to medium-rise buildings	Limited representation of higher modes
Response spectrum	Multistorey and moderately irregular buildings	Provides combined peak response rather than time sequence
Linear time history	Detailed elastic-response assessment	Does not directly model inelastic damage
Pushover analysis	Performance and capacity evaluation	Limited for complex higher-mode response
Nonlinear time history	Important, tall or highly irregular structures	High modelling and computational demands

9. Structural Configuration

Good seismic performance begins with architectural and structural planning.

9.1 Plan regularity

A compact and approximately symmetrical plan reduces torsional response. L-shaped, T-shaped, U-shaped and highly elongated plans may experience stress concentration and differential movement.

Irregular plans can be improved by:

- Providing seismic separation joints
- Arranging walls symmetrically
- Maintaining balanced stiffness
- Using clear diaphragm load paths
- Avoiding large eccentricities

9.2 Vertical regularity

Stiffness, strength and mass should change gradually over the building height. Sudden discontinuities concentrate drift and damage.

9.3 Separation between buildings

Adjacent buildings may vibrate out of phase and collide. Adequate seismic separation should be provided according to calculated displacement demands and code requirements.

9.4 Uniform distribution of mass

Heavy equipment, water tanks and storage areas should be considered carefully. Large mass concentrations at upper levels can increase seismic demand.

10. Lateral-Force-Resisting Systems

10.1 Moment-resisting frames

Moment frames resist lateral forces through bending and shear in beams, columns and joints. They provide architectural flexibility and ductility but may experience comparatively large lateral drift.

10.2 Reinforced concrete shear walls

Shear walls provide high lateral stiffness and strength. They are effective for controlling drift in medium- and high-rise buildings. Wall location is important because eccentric placement can produce torsion.

10.3 Dual systems

A dual system combines moment frames and shear walls. The walls provide stiffness, while the frames provide redundancy and additional deformation capacity.

10.4 Core-wall systems

Walls around lifts and staircases can form a central core. The core must be arranged and connected so that it does not create excessive torsional eccentricity.

Structural system	Major advantage	Principal concern
Moment-resisting frame	Flexibility and ductility	Higher storey drift
Shear-wall system	High stiffness and strength	Foundation forces and wall-placement sensitivity
Dual system	Balanced stiffness and redundancy	Proper distribution of forces between systems
Coupled shear walls	Efficient tall-building response	Detailing of coupling beams
Core-wall system	Functional integration with service core	Torsion when the core is eccentric
Base-isolated system	Reduces force transmitted to superstructure	Cost, displacement and maintenance requirements

11. Ductility and Energy Dissipation

Ductility is the ability to sustain substantial inelastic deformation without major loss of resistance.

Displacement ductility may be expressed as:

$$\mu_{\Delta} = \frac{\Delta_u}{\Delta_y}$$

Where:

- μ_{Δ} = displacement ductility
- Δ_u = ultimate displacement
- Δ_y = displacement at yield

A ductile building can dissipate energy through repeated yielding. This ability justifies the use of response-reduction factors in design. However, designers must not select a high response-reduction factor unless the structural system is detailed to provide the associated ductility.

Concrete is strong in compression but weak and relatively brittle in tension. Reinforcement and confinement are therefore necessary to provide stable cyclic performance.

12. Capacity Design

Capacity design intentionally selects where yielding should occur and prevents undesirable brittle mechanisms.

A desirable mechanism generally permits beam-end yielding while columns and joints remain comparatively protected. This is commonly known as the strong-column–weak-beam principle.

A simplified requirement can be written as:

$$\sum M_{Rc} > \gamma \sum M_{Rb}$$

Where:

- $\sum M_{Rc}$ = sum of column moment capacities at a joint
- $\sum M_{Rb}$ = sum of beam moment capacities at the joint
- γ = code-required capacity factor

The exact code expression and factor must be applied according to the governing standard.

The principle reduces the likelihood of a storey mechanism in which columns at one level yield simultaneously and cause collapse.

Capacity design also requires:

- Shear strength greater than shear generated by probable flexural capacity
- Strong beam-column joints
- Secure reinforcement anchorage
- Protected columns
- Controlled location of plastic hinges

13. Ductile Detailing of Beams

Beams in ductile moment frames should develop stable flexural yielding without premature shear or anchorage failure.

Important requirements include:

- Continuous longitudinal reinforcement
- Adequate positive and negative moment capacity
- Proper anchorage into beam-column joints
- Closely spaced transverse reinforcement near potential plastic hinges
- Avoidance of lap splices in critical yielding zones
- Shear design based on probable end moments
- Adequate rotation capacity
- Appropriate limits on reinforcement ratio

Excessive tension reinforcement can cause concrete compression failure before sufficient steel yielding occurs. A balanced ductile design allows longitudinal reinforcement to yield before brittle concrete crushing or shear failure.

14. Ductile Detailing of Columns

Columns carry gravity loads while resisting earthquake-induced bending and shear. Their failure can threaten the stability of an entire building.

Key detailing principles include:

- Adequate column dimensions
- Strong-column–weak-beam proportioning
- Closely spaced transverse reinforcement in confinement regions
- Cross-ties and properly anchored hoops
- Lap splices away from potential plastic-hinge regions
- Adequate splice confinement
- Shear strength based on capacity-design actions
- Consideration of axial load and biaxial bending

Confinement reinforcement delays buckling of longitudinal bars, restrains the concrete core and improves deformation capacity.

15. Beam-Column Joints

Beam-column joints transfer forces among connected members. They experience high shear stress and complex bond demands during cyclic loading.

Joint failure is dangerous because it may prevent beams and columns from developing their intended capacities.

Effective joint design requires:

- Proper anchorage of beam reinforcement
- Adequate transverse reinforcement
- Sufficient joint dimensions
- Control of joint shear stress
- Continuity of column reinforcement

- Prevention of bond deterioration
- Avoidance of congested and unconstructible detailing

Exterior and corner joints require special attention because reinforcement anchorage space is more limited than in interior joints.

16. Shear Walls and Boundary Elements

Shear walls resist overturning moment, shear and axial forces. Their behaviour depends on wall aspect ratio, thickness, reinforcement and boundary detailing.

Slender walls generally behave in flexure, while squat walls may be dominated by shear.

Important design considerations include:

- Continuous wall alignment to the foundation
- Symmetrical placement where possible
- Adequate vertical and horizontal reinforcement
- Confinement of highly compressed boundary regions
- Design of coupling beams
- Control of openings
- Prevention of brittle shear failure
- Foundation design for overturning forces

Discontinuing a shear wall at an intermediate storey can create a serious vertical irregularity. Transfer systems beneath walls must be designed for large and uncertain force demands.

17. Common Seismic Irregularities

Irregularity	Effect on seismic behaviour	Recommended response
Soft storey	Concentration of drift and column damage	Provide walls, bracing or adequately designed frames
Weak storey	Insufficient lateral strength	Increase member and system strength
Torsional irregularity	Unequal displacement across floor plan	Balance mass and stiffness
Floating column	Discontinuous vertical load path	Avoid or design transfer system carefully
Setback	Sudden change in mass and stiffness	Perform dynamic analysis and strengthen transition
Short column	High shear demand and brittle failure	Avoid partial restraint or design for amplified shear
Re-entrant corner	Stress concentration and diaphragm demand	Provide separation or strengthened collectors
Heavy upper storey	Increased inertia and overturning	Reduce mass and verify dynamic response
Discontinuous shear wall	Force concentration at transfer level	Continue walls to foundation where possible
Open ground storey	Major stiffness discontinuity	Explicitly design for amplified demands

18. Soft-Storey Behaviour

Open ground storeys are common in buildings used for parking or commercial space. Upper floors may contain masonry infill walls, while the ground floor remains open. This creates a large difference in stiffness.

During an earthquake, lateral displacement concentrates in the flexible storey. Ground-storey columns may experience severe bending and shear, leading to a storey-collapse mechanism.

Mitigation measures include:

- Reinforced concrete shear walls
- Properly designed moment frames
- Enlarged columns
- Structural bracing
- Accurate modelling of infill effects
- Capacity-based column and foundation design

Merely increasing column reinforcement without addressing overall stiffness distribution may be insufficient.

19. Short-Column Effect

A short column occurs when part of a column's clear height is restricted by masonry walls, ramps, stair landings or level differences. Because short columns are stiffer, they attract greater shear forces.

For columns subjected to similar displacement:

$$V \propto \frac{1}{L^3}$$

Where:

- V = attracted shear force
- L = effective deformable height

A substantial reduction in effective height can sharply increase shear demand. Short-column formation should preferably be avoided. Where unavoidable, the column must be designed and detailed for the amplified force.

20. Storey Drift and P-Delta Effects

Storey drift is the relative lateral displacement between consecutive floors:

$$\theta_i = \frac{\Delta_i - \Delta_{i-1}}{h_i}$$

Where:

- θ_i = storey-drift ratio
- Δ_i = displacement at storey i
- h_i = storey height

Excessive drift can damage columns, infill walls, partitions, glazing and service systems. It may also cause instability through second-order or P-Delta effects.

The additional moment is approximately:

$$M_{\Delta} = P\Delta$$

Where:

- P = gravity load
- Δ = lateral displacement

Tall or flexible buildings require explicit assessment of these effects.

21. Masonry Infill Walls

Masonry infill is often treated as non-structural, but it can substantially alter the stiffness and strength of reinforced concrete frames.

Infill walls may:

- Increase initial lateral stiffness
- Reduce the natural period
- Create torsional irregularity
- Produce short columns
- Transfer high forces to columns
- Fail out of plane
- Create an irregular open ground storey

Models should appropriately consider the presence and distribution of infill. Architectural walls should be detailed against out-of-plane collapse.

22. Diaphragms, Collectors and Connections

Floor and roof slabs act as diaphragms that transfer inertia forces to vertical elements. A diaphragm system includes:

- Slab
- Chords
- Collectors or drag members
- Connections to frames and walls

Large openings, irregular floor shapes and changes in wall alignment can interrupt the load path. Engineers should verify diaphragm strength, deformation and force transfer around openings.

Assuming rigid-diaphragm behaviour without examining actual geometry and stiffness can produce inaccurate force distribution.

23. Foundations and Soil Effects

Seismic design must consider the interaction between the building and supporting ground.

Important geotechnical hazards include:

- Soil amplification
- Liquefaction
- Lateral spreading
- Slope instability

- Settlement
- Fault-related ground deformation

Foundation systems may include isolated footings, combined footings, rafts or piles. The selected system must safely transfer gravity, shear and overturning forces.

Strong superstructures cannot provide adequate safety if foundations fail or the soil loses bearing capacity. Site-specific geotechnical investigations are therefore essential for significant structures and challenging ground conditions.

24. Non-Structural Components

Non-structural components can cause injury and major financial loss even when the structural frame remains stable.

These components include:

- Parapets
- Facade panels
- Partitions
- Ceilings
- Mechanical equipment
- Electrical systems
- Water tanks
- Piping
- Lifts
- Storage racks

They should be anchored and detailed to accommodate expected movement. Essential facilities require particular attention because failure of equipment may make the building unusable after an earthquake.

25. Construction Quality and Workmanship

Seismic performance depends on whether the design is constructed correctly. Common problems include:

- Incorrect bar placement
- Inadequate anchorage length
- Improper lap locations
- Missing transverse reinforcement
- Poor concrete compaction
- Honeycombing
- Weak construction joints
- Unauthorized structural alterations
- Incorrect material quality
- Congested reinforcement

Quality-control measures should include:

- Approved structural drawings
- Bar-bending schedules
- Material testing
- Reinforcement inspection
- Concrete cube testing
- Construction supervision
- Documentation of changes
- Structural audits at critical stages

Ductile details must be practical to construct. Excessive reinforcement congestion can prevent adequate concrete placement and create hidden defects.

26. Performance-Based Seismic Design

Prescriptive codes provide standardized minimum requirements. Performance-based seismic design goes further by explicitly evaluating expected behaviour under different earthquake intensities.

The process generally includes:

1. Defining performance objectives.
2. Characterizing seismic hazards.
3. Creating a nonlinear structural model.
4. Selecting and scaling ground motions.
5. Calculating demands.
6. Comparing demands with acceptance criteria.
7. Revising the structural system where necessary.

Performance-based design is particularly useful for:

- Tall buildings
- Essential facilities
- Irregular buildings
- Existing-building rehabilitation
- Structures using innovative systems
- Buildings requiring specific post-earthquake functionality

27. Base Isolation and Energy Dissipation

27.1 Base isolation

Base-isolation systems introduce flexible and energy-dissipating elements between the superstructure and foundation. The purpose is to increase the fundamental period and reduce force transmitted into the building.

Important considerations include:

- Isolator displacement
- Stability under vertical load
- Torsion
- Moat clearance
- Utility connections
- Fire and environmental protection
- Inspection and maintenance

27.2 Supplemental dampers

Viscous, friction and yielding dampers can dissipate earthquake energy and reduce structural response. Their effectiveness must be demonstrated through appropriate analysis and testing.

These systems complement rather than replace sound structural configuration and detailing.

28. Assessment and Retrofitting of Existing Buildings

Many existing buildings were constructed before modern seismic provisions or without adequate engineering supervision.

Evaluation should examine:

- Structural drawings and material properties
- Load path
- Member dimensions
- Reinforcement detailing
- Soft and weak storeys
- Column shear capacity
- Joint strength
- Foundation condition
- Deterioration
- Unauthorized modifications

Retrofitting methods include:

- Reinforced concrete jacketing
- Steel jacketing
- Addition of shear walls
- Addition of bracing
- Fibre-reinforced polymer wrapping
- Foundation strengthening
- Diaphragm improvement
- Infill-wall strengthening
- Base isolation in specialized projects

A retrofit must consider the entire structural system. Strengthening one element may transfer larger forces to another vulnerable component.

29. Major Findings

The major findings are:

1. Earthquake-resistant design requires strength, stiffness, ductility and redundancy.
2. Regular configuration and continuous load paths significantly improve seismic performance.
3. Adequate member strength alone cannot prevent collapse if connections and joints are poorly detailed.
4. Capacity design helps ensure that ductile flexural yielding occurs before brittle shear or joint failure.
5. The strong-column–weak-beam principle reduces the probability of dangerous storey mechanisms.
6. Soft storeys, short columns and discontinuous vertical elements are major sources of vulnerability.
7. Shear walls effectively control lateral drift when they are properly distributed and continued to the foundation.
8. Masonry infill can substantially alter building response and should not be ignored indiscriminately.
9. Foundation and soil behaviour are integral parts of seismic safety.
10. Construction supervision is as important as structural calculations.

30. Recommendations

30.1 Integrate architecture and structural design

The lateral-force-resisting system should be selected during initial planning rather than added after the architectural layout is finalized.

30.2 Prefer regular structural configurations

Sudden changes in mass, stiffness, strength and geometry should be avoided wherever possible.

30.3 Follow ductile detailing standards

Reinforcement detailing should comply with the current applicable seismic and reinforced-concrete codes.

30.4 Prevent brittle failure

Shear, anchorage and joint capacities should exceed the demands associated with intended flexural yielding.

30.5 Use appropriate analysis

Dynamic or nonlinear analysis should be used where building height, irregularity, importance or code requirements make equivalent static analysis inadequate.

30.6 Control drift

Structural and non-structural drift limits should be checked under the required load combinations.

30.7 Conduct geotechnical investigation

Site response, liquefaction and foundation performance should be evaluated before final design.

30.8 Provide quality supervision

Critical reinforcement and concrete operations should be inspected and documented.

30.9 Protect non-structural components

Facades, partitions, equipment and services should be anchored for expected seismic movement.

30.10 Audit vulnerable existing buildings

Schools, hospitals, public buildings and densely occupied structures should receive priority for seismic evaluation and retrofitting.

31. Limitations and Future Research

This article presents general engineering principles and does not replace project-specific structural design. Seismic design values vary according to location, building type, structural system, soil and governing code.

Future research should examine:

- Low-damage reinforced concrete systems
- Self-centering structural components
- High-performance reinforcement
- Recycled and low-carbon concrete under cyclic loading
- AI-assisted structural optimization
- Digital twins for post-earthquake assessment
- Soil–structure interaction
- Seismic behaviour of irregular buildings
- Resilience-based design
- Affordable retrofitting methods
- Multi-hazard performance
- Automated construction-quality monitoring

32. Conclusion

Earthquake-resistant design of reinforced concrete buildings is based on the recognition that severe earthquakes may exceed the elastic resistance of an ordinary structure. The building must therefore possess controlled inelastic deformation capacity and a predictable mechanism of energy dissipation. Reliable seismic performance begins with a simple and regular configuration. It continues through accurate analysis, appropriate lateral-force-resisting systems, drift control, capacity design and ductile detailing. Beams, columns, joints, walls, diaphragms and foundations must operate as an integrated system. Soft storeys, floating columns, short columns, torsional irregularity and inadequate anchorage can create concentrated and brittle failures. These vulnerabilities should preferably be eliminated during planning rather than addressed only through additional calculations. Ultimately, earthquake safety depends on the complete construction process—from site investigation and architectural planning to reinforcement placement, concrete quality and long-term maintenance. Codes provide essential minimum requirements, but safe buildings also require professional competence, coordination and rigorous quality assurance.

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