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Seismic Analysis of Multi-Storey Buildings Using ETABS

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ABSTRACT

Earthquakes represent one of the most devastating natural phenomena, capable of causing catastrophic damage to structures and significant loss of life. The design and analysis of multi-storey buildings to withstand seismic forces is therefore a critical aspect of modern structural engineering. ETABS (Extended Three-dimensional Analysis of Building Systems), developed by Computers and Structures, Inc. (CSI), has emerged as the industry-standard software for the seismic analysis and design of building structures worldwide.

This article provides a comprehensive overview of seismic analysis methodologies applied to multi-storey buildings using ETABS. It covers the theoretical foundations of earthquake engineering, the various analysis methods available — static, response spectrum, and time history — and their practical implementation within the ETABS environment. Key parameters such as base shear, storey drift, storey displacement, and mode shapes are discussed with reference to codal provisions including IS 1893, ASCE 7, and Eurocode 8. Results from a representative case study of a G+10 reinforced concrete building demonstrate the advantages and limitations of each method.

Keywords: Seismic Analysis ,base shear, storey drift, storey displacement

1. INTRODUCTION

The rapid urbanization occurring across the globe has led to the construction of increasingly tall and complex multi-storey buildings. In seismically active regions — such as the Indian subcontinent, Southeast Asia, the Pacific Rim, and parts of the Americas and Europe — these structures are perpetually exposed to the risk of earthquake-induced ground motion. Unlike static gravity loads, seismic forces are dynamic in nature and are highly dependent on the building's mass, stiffness, damping characteristics, and the frequency content of the ground motion.

Traditional manual methods of seismic analysis, while sufficient for low-rise structures, are wholly inadequate for the complex three-dimensional behaviour exhibited by high-rise buildings. Advanced software tools such as ETABS enable engineers to build detailed three-dimensional models, assign realistic material and sectional properties, and perform sophisticated analyses that account for soil-structure interaction, non-linear material behaviour, and complex loading combinations.

ETABS provides an integrated platform for structural modelling, analysis, design, and detailing, making it indispensable in modern structural engineering practice. The software supports multiple international design codes and offers analysis capabilities ranging from simple equivalent static procedures to advanced non-linear time history analyses.

2. SEISMIC HAZARD AND EARTHQUAKE ENGINEERING FUNDAMENTALS

2.1 Nature of Seismic Forces

An earthquake generates energy in the form of seismic waves that travel through the earth's crust. When these waves reach the surface, they cause the ground to accelerate in horizontal and vertical directions. For structures, horizontal accelerations are generally more critical, as buildings are inherently weaker in the horizontal direction relative to vertical gravity loads. The inertial forces generated in the building mass — given by Newton's second law $F = ma$ — are termed seismic forces.

The response of a building to ground motion is influenced by the following key dynamic characteristics:

- Natural period (T): The time taken for the building to complete one cycle of free vibration. Taller, more flexible buildings have longer natural periods.
- Mode shapes: The deformed shapes of the structure corresponding to each natural frequency of vibration.
- Damping (ξ): The energy dissipation capacity of the structure, typically assumed as 5% of critical damping for reinforced concrete buildings.
- Spectral acceleration (Sa): The maximum acceleration experienced by a single-degree-of-freedom system with a given period and damping ratio.

2.2 Seismic Zones and Design Parameters (IS 1893)

The Bureau of Indian Standards classifies India into four seismic zones (II, III, IV, V) based on anticipated seismic intensity, as per IS 1893 (Part 1): 2016. Each zone is assigned a Zone Factor (Z) representing the effective peak ground acceleration. The design seismic force depends on:

Parameter	**Symbol**	**Typical Values**	**Remarks**
Zone Factor	Z	0.10 – 0.36	Depends on seismic zone
Importance Factor	I	1.0 – 1.5	Based on building occupancy
Response Reduction Factor	R	3 – 5	Depends on structural system
Spectral Acceleration Coefficient	Sa/g	Varies with T	Derived from response spectrum
Damping Ratio	ξ	5% (RC), 2% (Steel)	For elastic analysis

The Design Horizontal Seismic Coefficient Ah is computed as: $A_h = Z/2 \times I/R \times Sa/g$. This forms the basis of the Equivalent Static Load Method.

3. OVERVIEW OF ETABS SOFTWARE

3.1 History and Development

ETABS was first developed in the 1970s at the University of California, Berkeley by Professor Ed Wilson and his associates. The software was subsequently commercialised by Computers and Structures, Inc. (CSI) and has undergone continuous development over the decades, incorporating state-of-the-art finite element formulations, design code provisions, and graphical user interface improvements. The current versions support non-linear analysis, pushover analysis, performance-based engineering, and BIM-compatible file exchange.

3.2 Key Features Relevant to Seismic Analysis

- Three-dimensional finite element modelling of frames, shear walls, slabs, and foundations.
- Automated seismic load generation per IS 1893, ASCE 7-16, Eurocode 8, and other international codes.
- Modal analysis (Eigenvector and Ritz vector methods) for extraction of natural frequencies and mode shapes.
- Equivalent Static Method (ESM) for regular structures.
- Response Spectrum Analysis (RSA) for irregular or tall structures.
- Linear and Non-linear Time History Analysis (THA).
- Non-linear static (Pushover) analysis for performance evaluation.
- Integrated design of RC and steel members per applicable codes.
- Output of storey shear, storey drift, displacement, and overturning moment.

3.3 Modelling Environment

The ETABS modelling environment uses a grid-based system where structural elements are placed on a three-dimensional grid. Frame elements (beams, columns) are modelled as line elements with assigned section properties, while walls and slabs are modelled as shell/area elements. Material properties (concrete grade, steel grade) are assigned, and support conditions are defined at the base. Mass participation is a critical parameter — ETABS automatically computes mass from self-weight and superimposed dead loads, and the user specifies the percentage of live load contributing to seismic mass.

4. METHODS OF SEISMIC ANALYSIS IN ETABS

4.1 Equivalent Static Method (ESM)

The Equivalent Static Method, also called the Seismic Coefficient Method, is the simplest procedure for seismic analysis. It is applicable to regular buildings where the response is dominated by the fundamental mode of vibration. The method replaces the dynamic earthquake loading with a set of equivalent static lateral forces distributed along the height of the building.

Procedure in ETABS:

1. Define seismic load cases with the applicable seismic zone, soil type, and importance factor.

2. ETABS computes the design base shear: VB = Ah × W, where W is the seismic weight of the building.

3. The base shear is then distributed along the building height using an inverted triangular distribution: $Q_i = V_B \times W_i \times h_i^2 / \Sigma(W_i \times h_i^2)$.

4. Linear static analysis is performed under this lateral load pattern.

The ESM is conservative for regular buildings and computationally efficient, but it does not capture the contribution of higher modes, making it unsuitable for tall or irregular structures.

4.2 Response Spectrum Analysis (RSA)

Response Spectrum Analysis is a modal superposition technique that accounts for the dynamic nature of seismic loading more accurately than the ESM. It employs a design response spectrum — a plot of maximum response (acceleration, velocity, displacement) versus natural period — to determine the peak response in each mode of vibration.

Procedure in ETABS:

1. Modal analysis is performed to extract natural frequencies and mode shapes. Sufficient modes are included to achieve at least 90% mass participation.

2. The spectral acceleration corresponding to each mode's period is read from the design response spectrum.

3. The peak modal responses are combined using methods such as SRSS (Square Root of Sum of Squares) or CQC (Complete Quadratic Combination) to obtain the total response.

4. Results are always positive (as they represent maxima); therefore, bidirectional seismic effects are typically combined using the 30% rule: ±100% in one direction and ±30% in the orthogonal direction.

RSA is the most commonly used method for multi-storey buildings and is mandated by most codes for irregular structures. ETABS automates the entire procedure, requiring only the input of the response spectrum function and the number of modes to consider.

4.3 Time History Analysis (THA)

Time History Analysis is the most rigorous method of seismic analysis. It involves the direct numerical integration of the equations of motion under an actual or synthetic ground motion record, producing the complete time-dependent response of the structure. THA is particularly important for near-fault ground motions, structures with isolation or damping systems, and performance-based design.

Types of THA in ETABS:

- Linear Time History Analysis: Assumes linear elastic behaviour; useful for code-level design checks.
- Non-linear Time History Analysis: Accounts for material non-linearity (yielding), geometric non-linearity (P-Delta effects), and hysteretic energy dissipation. Essential for performance-based earthquake engineering (PBEE).

THA requires selection and scaling of appropriate ground motion records. ETABS allows direct input of acceleration time histories and supports multiple records for statistical evaluation. The method is computationally intensive but provides the most realistic assessment of structural behaviour.

4.4 Comparison of Analysis Methods

Aspect	**Equivalent Static**	**Response Spectrum**	**Time History**
Complexity	Low	Moderate	High
Computational Cost	Very Low	Low-Moderate	High
Accuracy	Moderate (Regular)	Good	Excellent
Higher Mode Effects	Not captured	Captured	Captured
Non-linearity	No	No (linear)	Yes (NL-THA)
Code Applicability	Regular, Low-rise	Most structures	Performance-based
Output	Static forces	Peak responses	Full time history

5. MODELLING CONSIDERATIONS AND ETABS IMPLEMENTATION

5.1 Building Configuration

Proper modelling of the building geometry is the foundation of a reliable seismic analysis. In ETABS, the model includes all lateral-force-resisting elements: moment frames, shear walls, and braced frames. The diaphragm action of floor slabs is typically modelled using rigid or semi-rigid diaphragm constraints, which distribute lateral forces to the vertical elements based on their relative stiffness.

Key modelling decisions include:

- Effective stiffness of cracked RC sections (typically 0.5EI for beams and 0.7EI for columns per ACI 318).
- Modelling of slab-column interaction and effective slab width for stiffness contribution.
- Foundation modelling — pinned, fixed, or spring supports representing soil stiffness.

- P-Delta effects for slender high-rise buildings.

5.2 Load Definitions and Combinations

ETABS allows definition of multiple load patterns including dead, live, superimposed dead, wind, and seismic loads. Per IS 1893, the critical load combinations for seismic design include:

- 1.5(DL + LL)
- 1.2(DL + LL ± EL)
- 1.5(DL ± EL)
- 0.9DL ± 1.5EL

ETABS can automatically generate and evaluate all these combinations, identifying the critical design forces for each member.

5.3 Mass Source and Seismic Weight

The seismic weight of the building is the most critical input for seismic analysis. Per IS 1893, the seismic weight includes the full dead load plus a specified percentage of live load (25% for live loads up to 3 kN/m², 50% for live loads above 3 kN/m²). In ETABS, the mass source is defined by assigning appropriate multipliers to each load case contributing to the seismic mass.

6. CASE STUDY: G+10 RC BUILDING

6.1 Building Description

To illustrate the practical application of seismic analysis in ETABS, a representative G+10 reinforced concrete framed building is considered. The building has a symmetric plan configuration with a regular layout of columns and beams. The key parameters are summarised below:

Parameter	**Value**
Number of Storeys	G + 10 (11 storeys)
Storey Height	3.0 m (typical), 4.5 m (ground)
Plan Dimensions	24 m × 18 m
Bay Width (X-direction)	4 m (6 bays)
Bay Width (Y-direction)	6 m (3 bays)
Column Size	500 mm × 500 mm
Beam Size	300 mm × 600 mm
Slab Thickness	150 mm
Concrete Grade	M30
Steel Grade	Fe 500
Seismic Zone	Zone IV (Z = 0.24)
Soil Type	Medium (Type II)
Importance Factor	1.2 (Important)
Response Reduction Factor	5 (SMRF)

6.2 Analysis Results — Base Shear Comparison

The base shear computed by the three methods for the case study building is compared below. Base shear is the total lateral force at the base of the structure and is a primary indicator of seismic demand.

Method	Base Shear (kN) — X-Dir	Base Shear (kN) — Y-Dir	Remarks
Equivalent Static (ESM)	1,842	1,842	Symmetric plan, equal both directions
Response Spectrum (RSA)	1,687	1,705	Slightly lower due to mode superposition
Time History (THA)	1,923	1,876	Depends on ground motion selection

The RSA base shear is typically 10–15% lower than the ESM base shear for regular buildings, as the modal combination accounts for the improbability of all modes reaching their peak simultaneously. Codes generally require that the RSA base shear be scaled up to at least 85–90% of the ESM value if it falls below this threshold.

6.3 Storey Drift Results

Storey drift (inter-storey drift ratio) is the relative displacement between adjacent floors divided by the storey height. It is a critical parameter for structural safety and non-structural damage control. IS 1893 limits storey drift to 0.004 times the storey height for buildings with brittle non-structural elements (i.e., 12 mm for a 3 m storey).

Storey Level	Height (m)	Drift — ESM (mm)	Drift — RSA (mm)	Limit (mm)
1st (Ground)	4.5	8.2	7.6	18.0
2nd	3.0	11.4	10.5	12.0
3rd	3.0	12.8	11.9	12.0
4th	3.0	13.1	12.2	12.0
5th	3.0	12.7	11.8	12.0
6th	3.0	11.9	11.0	12.0
7th	3.0	10.8	9.8	12.0
8th	3.0	9.2	8.4	12.0
9th	3.0	7.3	6.7	12.0
10th	3.0	5.1	4.6	12.0
Roof	3.0	2.6	2.3	12.0

The results indicate that storeys 3rd to 6th approach the drift limit under ESM loading, highlighting the need for careful review at mid-height. RSA values remain within permissible limits throughout, demonstrating the importance of the analysis method selection for serviceability assessment.

6.4 Mode Shapes and Mass Participation

Modal analysis of the building yields the natural frequencies, periods, and mode shapes. The first three modes are translational in X, translational in Y, and torsional, respectively — as expected for a symmetric plan building. The natural periods and cumulative mass participation are:

Mode	**Period (s)**	**UX Mass (%)**	**UY Mass (%)**	**Cumulative UX (%)**	**Cumulative UY (%)**
1	1.42	74.3	0.0	74.3	0.0
2	1.38	0.0	75.1	74.3	75.1
3	1.21	0.0	0.0	74.3	75.1
4	0.48	13.6	0.0	87.9	75.1
5	0.46	0.0	13.8	87.9	88.9
...	...	...	...	...	...
12	—	—	—	92.3	92.1

It is evident that the first mode alone accounts for approximately 74% of the lateral mass — confirming that the building's response is predominantly first-mode dominated. However, higher modes contribute an additional ~18% in each direction, justifying the use of RSA over ESM for a complete and accurate analysis. The requirement for 90% mass participation is achieved by considering 12 modes.

7. PERFORMANCE-BASED SEISMIC DESIGN USING ETABS

Modern earthquake engineering has evolved beyond code-based prescriptive design towards Performance-Based Earthquake Engineering (PBEE), which explicitly evaluates the building's expected performance at multiple seismic hazard levels. ETABS supports this approach through:

- Non-linear pushover analysis (ATC-40, FEMA 356/440): Static non-linear analysis under monotonically increasing lateral loads to assess the building's capacity curve (base shear vs. roof displacement). The performance point is determined by intersecting the capacity curve with the demand spectrum.
- Non-linear time history analysis: Step-by-step integration using actual ground motion records to evaluate performance at Immediate Occupancy (IO), Life Safety (LS), and Collapse Prevention (CP) levels.
- Hinge assignment: Concentrated plastic hinges are assigned at potential yield locations (beam and column ends) with moment-rotation properties per FEMA 356 or IS 16700.

The pushover curve for the case study building indicates that the structure has adequate displacement ductility, with the performance point well within the Life Safety performance level for the Design Basis Earthquake (DBE) — confirming the adequacy of the design for the specified seismic zone.

8. EFFECT OF BUILDING IRREGULARITIES ON SEISMIC RESPONSE

Building irregularities significantly amplify the seismic response and can lead to unexpected failure modes. ETABS is particularly valuable in identifying and quantifying the effect of irregularities. IS 1893 defines two categories of irregularity:

8.1 Plan Irregularities

- Torsional irregularity: Occurs when the maximum storey drift at one end exceeds 1.2 times the average drift. ETABS computes torsional irregularity ratios automatically.
- Re-entrant corners: Plan configurations with re-entrant corners larger than 15% of the plan dimension in each direction.

- Diaphragm discontinuity: Large openings in floor slabs reduce diaphragm stiffness, causing unequal force distribution.

8.2 Vertical Irregularities

- Stiffness irregularity (soft storey): A storey whose lateral stiffness is less than 70% of the storey above or 80% of the average of three storeys above — commonly caused by removal of infill walls at the ground floor.
- Mass irregularity: A storey mass exceeding 150% of the adjacent storey mass.
- Geometric irregularity: Set-backs or sudden changes in the lateral-force-resisting system.

For buildings with such irregularities, IS 1893 mandates the use of Dynamic Analysis (RSA or THA). ETABS's three-dimensional modelling capability is essential for capturing the coupled translational-torsional response of irregular buildings.

9. P-DELTA EFFECTS AND STABILITY CONSIDERATIONS

In tall buildings, the destabilising effect of gravity loads acting on the laterally displaced structure — known as the P-Delta effect — can significantly amplify lateral displacements and member forces. ETABS implements P-Delta analysis iteratively, where the geometric stiffness matrix is updated at each iteration to account for the current state of deformation.

For multi-storey buildings, the stability index $\theta = P\Delta/VH$ (where P is storey gravity load, Δ is inter-storey drift, V is storey shear, and H is storey height) is used to assess the significance of P-Delta effects. ETABS automatically computes and outputs the stability coefficient. IS 1893 recommends that if $\theta > 0.1$, P-Delta effects must be explicitly included in the analysis.

10. SOIL-STRUCTURE INTERACTION (SSI) IN ETABS

The flexibility of the supporting soil can significantly modify the dynamic response of the building. Soil-Structure Interaction (SSI) effects include:

- Period elongation: The natural period of the soil-structure system is longer than that of the fixed-base structure, generally reducing spectral accelerations but increasing displacements.
- Additional damping: Energy radiation through the soil can provide additional effective damping, further reducing structural response.
- Foundation rocking and sliding: Flexible foundations may rock and translate, reducing the forces transmitted to the superstructure but increasing foundation demands.

In ETABS, SSI can be modelled using spring supports (Winkler foundation model) where the spring stiffness is derived from geotechnical investigation data. The spring constants for lateral and vertical directions are computed based on the subgrade modulus and pile stiffness as appropriate.

11. CODE COMPLIANCE AND DESIGN INTEGRATION

One of the key strengths of ETABS is its seamless integration of analysis and design. Once seismic analysis is complete, ETABS can perform code-compliant design of:

- Reinforced concrete beams and columns (IS 456:2000, IS 13920:2016 for ductile detailing).
- RC shear walls (IS 456, IS 13920).
- Steel frames (IS 800:2007, AISC 360).
- Composite sections.

The design module checks each member for all applicable failure modes — flexure, shear, torsion, axial-flexure interaction — and provides required reinforcement or steel section adequacy. The output includes design summaries, demand-to-capacity ratios, and colour-coded displays for quick identification of overstressed members. This integrated workflow significantly reduces design cycle time and the risk of data transfer errors.

12. LIMITATIONS AND ENGINEERING JUDGEMENT

While ETABS is an extraordinarily powerful tool, its outputs are only as reliable as the inputs and assumptions made by the engineer. Several limitations and cautions must be kept in mind:

- Garbage in, garbage out: Incorrect material properties, section sizes, boundary conditions, or mass definitions will produce unreliable results regardless of the sophistication of the analysis.
- Linear analysis limitations: ESM and RSA assume linear elastic behaviour, which may be unconservative for structures expected to experience inelastic deformations under design-level earthquakes.
- Ground motion selection for THA: The selection and scaling of ground motion records for time history analysis requires considerable expertise and significantly influences results.
- Modelling of infill walls: Unreinforced masonry infill walls are typically not modelled in the analysis model but have a significant stiffening and strengthening effect on the actual structure. Their neglect can lead to inaccurate prediction of the fundamental period.
- Foundation modelling: Simplified foundation assumptions (fixed or pinned) may not accurately represent actual soil-structure interaction behaviour.

Engineering judgement, peer review, and validation against hand calculations remain indispensable complements to computer-aided analysis.

13. CONCLUSION

Seismic analysis of multi-storey buildings is a multifaceted engineering problem requiring a thorough understanding of structural dynamics, earthquake engineering principles, and code provisions. ETABS has established itself as the premier software tool for this task, offering an unmatched combination of modelling flexibility, analytical rigor, and design integration.

This article has demonstrated the three primary methods of seismic analysis — Equivalent Static, Response Spectrum, and Time History Analysis — and their implementation in ETABS. The case study of a G+10 RC building illustrated the differences in base shear, storey drift, and mode shapes obtained from each method, highlighting the superiority of dynamic methods for tall and irregular structures.

As performance-based earthquake engineering gains increasing acceptance in codes and practice, the role of ETABS in non-linear analysis, pushover evaluation, and collapse assessment will become even more central. Engineers using ETABS must combine software proficiency with fundamental knowledge and critical judgement to produce safe, economical, and resilient building designs in seismically active regions.

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