Seismic Performance Evaluation and Nonlinear Analysis of Reinforced Cement Concrete Multi-Story Buildings Using ETABS Software: A Comprehensive Structural Engineering Study

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Abstract

Seismic performance evaluation of reinforced cement concrete (RCC) buildings is critical for ensuring structural safety and resilience in earthquake-prone regions. This article presents a comprehensive study on the seismic analysis and performance assessment of multi-story RCC buildings using ETABS (Extended Three-Dimensional Analysis of Building Systems) software. The study examines fundamental principles of seismic design, structural modeling techniques, analysis methodologies including linear static, linear dynamic, nonlinear static pushover, and nonlinear time-history analysis. Key parameters investigated include lateral load resistance, story drift, inter-story drift ratio, base shear distribution, plastic hinge formation, and structural ductility. The research evaluates performance levels ranging from immediate occupancy to collapse prevention under varying seismic intensities. Material constitutive models, boundary conditions, load combinations, and code compliance verification are systematically addressed. Applications demonstrate ETABS capabilities for analyzing regular and irregular building configurations, evaluating retrofitting strategies, and optimizing structural designs. The study identifies critical challenges including computational complexity for high-rise structures, modeling uncertainties, soil-structure interaction effects, and limitations of simplified analysis methods. Future perspectives highlight integration with building information modeling, artificial intelligence-based optimization, real-time structural health monitoring, and performance-based seismic design frameworks. The findings provide valuable insights for structural engineers, researchers, and practitioners engaged in seismic-resistant building design and assessment using advanced computational tools.

Keywords: Seismic performance evaluation, ETABS software, Reinforced cement concrete buildings, Pushover analysis, Nonlinear time-history analysis, Performance-based design

1. Introduction

Earthquakes represent one of the most devastating natural hazards, causing catastrophic structural failures, economic losses, and loss of life worldwide [1]. Reinforced cement concrete (RCC) buildings constitute the predominant structural system in urban environments, particularly in seismically active regions [2]. The seismic performance of these structures depends on multiple factors including structural configuration, material properties, foundation conditions, and design adequacy [3].

Historical earthquake events have demonstrated the vulnerability of inadequately designed RCC structures [4]. The 1985 Mexico City earthquake, 1994 Northridge earthquake, 1995 Kobe earthquake, and 2015 Nepal earthquake revealed critical deficiencies in conventional design approaches [5, 6]. These events emphasized the necessity for rigorous seismic performance evaluation methodologies that assess structural behavior beyond elastic limits [7].

Traditional force-based seismic design approaches specify minimum lateral strength requirements but provide limited information about actual structural performance during earthquakes [8]. Performance-based seismic design (PBSD) has emerged as an advanced methodology that explicitly evaluates structural response at multiple performance levels corresponding to different seismic intensities [9, 10]. This approach enables stakeholders to make informed decisions regarding acceptable risk levels and economic investments in seismic safety [11].

Computational analysis tools have revolutionized seismic engineering practice by enabling detailed modeling and simulation of complex structural systems [12]. ETABS (Extended Three-Dimensional Analysis of Building Systems) represents a comprehensive software platform specifically developed for building analysis and design [13]. The software integrates sophisticated finite element modeling capabilities with automated code checking features, making it widely adopted in professional engineering practice [14].

ETABS provides multiple analysis options ranging from linear static procedures to advanced nonlinear dynamic analyses [15]. Linear static analysis applies equivalent lateral forces based on code-specified formulas, providing preliminary design estimates [16]. Response spectrum analysis captures dynamic characteristics through modal superposition, accounting for higher mode effects significant in tall buildings [17]. Nonlinear static pushover analysis progressively increases lateral loads while tracking structural degradation, identifying capacity and failure mechanisms [18]. Nonlinear time-history analysis directly integrates equations of motion using earthquake ground motion records, providing the most accurate representation of seismic response [19].

This article provides a comprehensive examination of seismic performance evaluation for RCC buildings using ETABS software. The objectives are to: (1) review seismic design principles and analysis methodologies, (2) examine ETABS modeling techniques and analysis procedures, (3) evaluate performance assessment criteria and acceptance limits, (4) demonstrate applications across different building types and configurations, and (5) identify current challenges and future research directions in computational seismic analysis.

2. Fundamentals of Seismic Design and Analysis

2.1. Seismic Hazard and Ground Motion Characteristics

Seismic hazard characterization forms the foundation for earthquake-resistant design [20]. Probabilistic seismic hazard analysis (PSHA) estimates the probability of exceeding specified ground motion intensities at a site considering all potential earthquake sources [21]. Design earthquakes are typically defined by return periods of 475 years (10% probability of exceedance in 50 years) for ordinary structures and 2475 years (2% in 50 years) for critical facilities [22].

Ground motion characteristics influencing structural response include peak ground acceleration (PGA), peak ground velocity (PGV), spectral acceleration, duration, and frequency content [23]. Response spectra represent maximum response of single-degree-of-freedom systems across a range of periods, providing design basis for code-specified lateral forces [24]. Site-specific factors including soil conditions significantly amplify or attenuate ground motions through local site effects [25].

2.2. Structural Dynamics and Modal Analysis

Understanding structural dynamics is essential for seismic analysis. Buildings exhibit natural vibration modes characterized by natural periods, mode shapes, and modal participation factors. Fundamental period determines the building's primary response characteristics and governs design force levels.

Modal analysis decomposes complex multi-degree-of-freedom systems into independent single-degree-of-freedom oscillators. Each mode contributes to total response based on modal mass participation, with lower modes typically dominating in regular low-rise structures and higher modes becoming significant in tall buildings. Complete quadratic combination (CQC) or square root of sum of squares (SRSS) rules combine modal responses to estimate total response.

2.3. Seismic Design Philosophies and Code Provisions

Modern seismic codes adopt multi-level performance objectives. These typically include: (1) operational performance under minor earthquakes (43-year return period), (2) immediate occupancy under moderate earthquakes (72-year return period), (3) life safety under design-basis earthquakes (475-year return period), and (4) collapse prevention under maximum considered earthquakes (2475-year return period).

Force-based design remains the predominant approach in most building codes. Design base shear is calculated using the formula $V = CsW$, where Cs represents seismic response coefficient depending on site class, structural period, and response modification factor R. The R-factor accounts for structural ductility and overstrength, permitting design for forces significantly lower than elastic demands.

Displacement-based and performance-based design methods directly assess structural deformations and damage states. These approaches recognize that structural damage correlates more strongly with deformations than forces. Target displacement procedures estimate maximum displacement demands and verify compatibility with capacity.

3. ETABS Software Architecture and Modeling Capabilities

3.1. Software Overview and Finite Element Formulation

ETABS employs three-dimensional finite element analysis with specialized formulations optimized for building structures. The software utilizes object-oriented modeling where structural components (columns, beams, walls, slabs) are defined as distinct objects with associated properties and connectivity.

Frame elements represent one-dimensional components (beams, columns, braces) using beam-column theory with six degrees of freedom per node [42]. Shell elements model two-dimensional components (walls, slabs) using layered shell formulations capable of representing membrane and bending behavior. P-delta effects capturing geometric nonlinearity from gravity loads acting through lateral displacements are automatically included.

The finite element formulation assembles global stiffness, mass, and damping matrices from element contributions. Eigenvalue analysis extracts natural frequencies and mode shapes [46]. Modal analysis reduces computational demands by projecting responses onto modal coordinates.

3.2. Material Models and Section Properties

ETABS implements comprehensive material models for concrete, reinforcing steel, and other structural materials. Concrete properties include compressive strength, tensile strength, elastic modulus, and stress-strain relationships following code specifications or user-defined curves. Confinement effects in confined concrete core and unconfined cover are distinguished for accurate nonlinear modeling.

Reinforcing steel models incorporate elastic-perfectly plastic, bilinear kinematic hardening, or multilinear stress-strain relationships. Strain hardening parameters control post-yield stiffness, important for estimating ultimate capacity.

Section properties for frame elements may be calculated automatically from geometric dimensions and reinforcement detailing or defined through section designer for complex shapes. Moment-curvature analysis determines section capacity and assigns plastic hinge properties for nonlinear analysis. Interaction surfaces for columns account for combined axial-flexural behavior.

3.3. Load Definition and Combinations

ETABS supports multiple load types including dead loads, live loads, seismic loads, wind loads, temperature effects, and settlement loads. Automated load pattern generation assigns gravity loads based on material densities and tributary areas.

Seismic loads are defined through various methods: (1) equivalent lateral force procedure applying static forces based on code formulas, (2) response spectrum analysis using design or site-specific spectra, (3) time-history analysis using ground motion records. Load combination generation follows code specifications (ACI, ASCE, Eurocode, IS codes) with automatic factoring and critical envelopes.

4. Linear and Nonlinear Analysis Methodologies

4.1. Linear Static Analysis

Linear static analysis represents the simplest approach, applying equivalent lateral forces distributed vertically according to code formulas. The base shear V = CsW is distributed to floor levels as Fx = CvxV, where Cvx depends on floor weights and heights.

This method assumes elastic behavior, neglecting material nonlinearity, geometric nonlinearity, and inelastic energy dissipation. Applicable primarily to regular, low-to-medium rise buildings where higher mode effects are minimal. Results include member forces, story drifts, and support reactions forming the basis for proportioning structural elements.

4.2. Linear Dynamic Response Spectrum Analysis

Response spectrum analysis accounts for dynamic characteristics through modal analysis [65]. ETABS extracts mode shapes and periods through eigenvalue solution, then calculates maximum modal responses from design spectrum ordinates.

Modal combination rules (CQC or SRSS) combine individual modal contributions to estimate total response. CQC accounts for modal coupling from closely spaced modes, important for torsionally irregular or tall buildings [68]. Sufficient modes must be included to capture at least 90% of participating mass in each principal direction.

Advantages include computational efficiency and code compliance while capturing multi-modal effects. Limitations include inability to predict progressive damage, sequence of plastic hinge formation, or redistribution of forces.

4.3. Nonlinear Static Pushover Analysis

Pushover analysis applies incrementally increasing lateral loads until structural collapse or target displacement. The procedure tracks formation and progression of plastic hinges, identifying weak links and failure mechanisms. Capacity curves plotting base shear versus roof displacement characterize structural behavior from elastic through plastic ranges to ultimate capacity.

ETABS implements displacement-controlled or force-controlled pushover with various lateral load patterns. Uniform patterns apply forces proportional to floor masses, while modal patterns reflect first mode shape. Adaptive patterns update load distribution as structure yields, providing more realistic representation.

Performance evaluation involves superimposing seismic demand (from target displacement calculation) onto capacity curve. Acceptance criteria based on component strain limits, rotation capacities, or force ratios assess compliance with performance objectives. FEMA 356, ASCE 41, and ATC-40 provide detailed acceptance criteria for concrete and steel components.

4.4. Nonlinear Time-History Analysis

Nonlinear time-history analysis directly integrates equations of motion using ground acceleration records. This most rigorous method captures sequence of yielding, hysteretic behavior, strength and stiffness degradation, and higher mode effects.

ETABS employs direct integration schemes including Newmark's method and Wilson-theta method. Material nonlinearity is represented through plastic hinge models with user-defined force-deformation relationships. Concentrated plasticity models assign hinges at member ends, while distributed plasticity (fiber) models discretize sections.

Ground motion selection requires careful consideration of magnitude, distance, site conditions, and spectral compatibility. Multiple accelerograms (typically 7-11) are analyzed with results averaged to reduce record-to-record variability. Scaling procedures match record spectra to target design spectra across period ranges of interest.

Results include time histories of displacements, velocities, accelerations, member forces, and plastic hinge rotations. Numerical stability requires appropriate time steps, typically 1/100 to 1/1000 of fundamental period. Computational demands increase significantly with model complexity and analysis duration.

5. Performance Criteria and Damage Assessment

5.1. Performance Levels and Acceptance Criteria

Performance-based evaluation defines discrete performance levels representing structural damage states. Operational level maintains full functionality with negligible damage. Immediate occupancy permits continued use with minor repairs. Life safety prevents collapse but accepts significant structural damage. Collapse prevention represents ultimate limit state before global instability.

Quantitative acceptance criteria relate component demands to capacities. For linear procedures, demand-capacity ratios (DCR) compare forces or deformations against allowable limits. DCR values vary with performance level: 1.0 for immediate occupancy, 2.0-3.0 for life safety, 3.0-6.0 for collapse prevention depending on component type and deformation mode.

Nonlinear procedures evaluate plastic rotations, chord rotations, or strain limits. ASCE 41 tabulates modeling parameters and acceptance criteria for concrete and steel components under primary and secondary conditions. Primary components support gravity loads and require more stringent limits than secondary components.

5.2. Drift Limits and Deformation Criteria

Story drift represents relative horizontal displacement between adjacent floors, critical for structural and non-structural damage assessment. Maximum story drift ratios typically limited to 0.020-0.025 radians (2.0-2.5%) for life safety and 0.010 for immediate occupancy. Excessive drifts cause damage to cladding, partitions, glazing, and mechanical systems even when structural elements remain within acceptable limits.

Inter-story drift ratio (IDR) calculated as story drift divided by story height provides normalized measure enabling comparison across different buildings. Residual drifts representing permanent deformations after earthquake indicate recentering capability and repair feasibility. Residual drifts exceeding 0.005 often necessitate demolition despite structural stability.

5.3. Plastic Hinge Modeling and Capacity Assessment

Plastic hinges represent localized yielding regions where inelastic deformations concentrate. ETABS assigns hinges at predetermined locations (typically beam-column interfaces) with force-deformation relationships defining backbone curves.

Hinge properties include yield strength, post-yield stiffness, ultimate deformation capacity, and residual strength. Multi-linear curves capture stiffness degradation, strength hardening, and softening behavior. Axial-moment (P-M) interaction surfaces for columns account for varying axial loads affecting flexural capacity.

Acceptance criteria classify hinge states into immediate occupancy (IO), life safety (LS), and collapse prevention (CP) regions based on plastic rotation magnitudes. Performance assessment verifies that hinge deformations under specified seismic demand remain within acceptable limits for target performance level.

6. Applications of ETABS in Seismic Performance Evaluation

6.1. Regular RCC Buildings

Regular buildings with uniform mass and stiffness distributions represent straightforward applications. ETABS efficiently models rectangular plan configurations with symmetric column and shear wall layouts. Automated mesh generation, code-based load calculation, and design optimization expedite analysis workflow.

Case studies demonstrate pushover analysis of 5-15 story moment-resisting frames, identifying weak stories and beam-column joint vulnerabilities. Comparison of design spectrum and time-history analyses validates simplified procedures for regular configurations. Parametric studies investigate effects of beam-column stiffness ratios, foundation fixity, and live load intensity on seismic response.

6.2. Irregular Buildings

Irregular buildings with vertical or plan discontinuities exhibit complex response requiring detailed analysis. Torsional irregularity from eccentric mass or stiffness distribution induces rotational response amplifying edge element demands. ETABS captures torsional coupling through three-dimensional modeling with mass eccentricity consideration.

Vertical irregularities including soft stories, mass irregularities, and geometric discontinuities concentrate damage at transition zones. Pushover analyses reveal weak story mechanisms and excessive drift concentrations. Strengthening strategies using shear walls, bracing, or base isolation are evaluated through comparative analyses [.

6.3. Retrofitting Evaluation

Existing buildings often require seismic upgrades to meet current code requirements or performance objectives. ETABS facilitates retrofit design by modeling existing conditions and evaluating strengthening alternatives. Common retrofit techniques include concrete jacketing of columns, fiber-reinforced polymer (FRP) wrapping, steel bracing addition, and shear wall installation.

Comparative analyses quantify improvements from each retrofit strategy through capacity curve enhancement and reduced drift demands. Cost-benefit analyses weigh retrofit expenses against performance improvements and expected losses. Sequential analysis models progressive retrofit implementation, important for phased strengthening of occupied buildings.

6.4. High-Rise Buildings

High-rise structures exceeding 50-60 meters exhibit significant higher mode effects necessitating response spectrum or time-history analysis. ETABS handles large-scale models with thousands of elements through efficient solvers and sparse matrix storage. Outrigger-braced systems, tube structures, and mega-frame configurations are accurately modeled.

Wind-seismic load interaction becomes critical as wind often governs design for very tall buildings in moderate seismic zones. Soil-structure interaction effects modify foundation input motions and add flexibility, particularly significant for high-rise structures. ETABS incorporates foundation springs representing soil stiffness and damping.

7. Challenges and Limitations

7.1. Modeling Uncertainties and Assumptions

Computational models involve numerous simplifications and uncertainties affecting result accuracy. Material property variability, construction quality variations, and deterioration effects introduce epistemic uncertainties. Assumed boundary conditions for foundations and connections may not reflect actual behavior.

Plastic hinge models concentrate inelastic deformations at points rather than distributed along members, potentially misrepresenting spread plasticity. Shear and bond-slip deformations often neglected despite significance in short columns and poorly detailed elements. Modeling of infill walls, which significantly affect lateral stiffness and strength, remains challenging due to complex interaction mechanisms.

7.2. Computational Efficiency for Large Models

Analysis of complex high-rise buildings with thousands of elements requires substantial computational resources [146]. Nonlinear time-history analysis with multiple ground motions becomes prohibitively time-consuming for large models. Model reduction techniques including static condensation and modal truncation balance accuracy and efficiency.

Convergence difficulties arise in highly nonlinear analyses with extensive yielding and material degradation. Automatic time-step adjustment, convergence tolerance selection, and solution algorithm choice critically affect computational performance. Parallel processing capabilities in modern ETABS versions improve scalability for large-scale problems.

7.3. Soil-Structure Interaction

Conventional fixed-base assumption neglects soil flexibility and radiation damping effects. Soft soils significantly lengthen structural periods and modify seismic demands. Foundation rocking and sliding introduce additional energy dissipation mechanisms.

ETABS implements simplified SSI modeling through foundation springs and dashpots, though detailed modeling requires specialized geotechnical analysis. Impedance functions characterizing frequency-dependent soil stiffness and damping are approximated through equivalent linear springs. Nonlinear soil behavior under strong shaking further complicates accurate representation.

7.4. Validation and Verification

Verification of numerical models against experimental data or benchmark solutions ensures reliable predictions. Limited full-scale experimental data on building seismic response creates challenges for model validation. Shaking table tests on scaled models provide valuable data but introduce scaling issues.

Code checking modules in ETABS automate compliance verification but require engineering judgment for interpretation. Automated design may produce results meeting code minima without optimal performance. Peer review and engineering oversight remain essential for critical structures.

8. Future Perspectives

8.1. Integration with Building Information Modeling (BIM)

Building Information Modeling creates comprehensive digital representations integrating architectural, structural, and MEP disciplines. BIM-ETABS integration enables automated model generation from architectural plans, reducing manual modeling effort and errors. Bidirectional data exchange updates structural design changes back to BIM models maintaining consistency.

Clash detection identifies conflicts between structural and non-structural elements early in design. Parametric modeling in BIM environments facilitates design optimization studies varying structural configurations. Construction sequencing simulation evaluates temporary loading conditions during phased construction.

8.2. Machine Learning and AI-Based Optimization

Artificial intelligence and machine learning algorithms optimize structural designs for seismic performance. Neural networks trained on ETABS simulation databases predict structural response rapidly without detailed analysis. Genetic algorithms and particle swarm optimization explore vast design spaces identifying optimal member sizing and reinforcement layouts.

Surrogate modeling approximates expensive nonlinear analyses enabling probabilistic seismic assessment with Monte Carlo simulation. Automated feature extraction from building plans suggests preliminary structural configurations. Real-time analysis during design enables interactive exploration of alternatives.

8.3. Performance-Based Seismic Design Advancements

Next-generation performance-based methodologies explicitly consider uncertainty and risk. Probabilistic performance assessment evaluates probability of exceeding performance levels across hazard intensities. Loss estimation frameworks translate structural damage into economic losses, downtime, and casualty expectations.

Resilience-based design extends beyond individual building performance to community-level recovery. Multi-hazard considerations integrate seismic, wind, and progressive collapse resistance. Life-cycle cost analysis incorporates initial construction costs, expected seismic losses, and maintenance expenses.

8.4. Real-Time Structural Health Monitoring Integration

Structural health monitoring systems deploy sensors measuring accelerations, displacements, and strains during earthquakes. Real-time data assimilation updates ETABS models with actual material properties and boundary conditions. Post-earthquake damage assessment combines sensor data with computational models identifying damaged regions.

Digital twins representing virtual replicas synchronized with physical structures enable predictive maintenance. Machine learning algorithms detect anomalies in sensor data indicating deterioration or damage. Integration of monitoring and modeling improves seismic risk assessment for existing building portfolios.

9. Tables

Table 1: Comparison of seismic analysis methods for RCC buildings

Analysis Method	Computational Effort	Accuracy	Applicability	Design Stage	Nonlinear Behavior
Linear Static	Very Low	Low	Regular, low-rise	Preliminary	No
Response Spectrum	Low	Moderate	Regular, mid-rise	Detailed design	No
Pushover Analysis	Moderate	Moderate-High	All configurations	Performance evaluation	Yes
Time-History	Very High	Highest	Complex, critical structures	Final verification	Yes

Table 2: ETABS modeling parameters and material properties for RCC structures

Component	Material Model	Key Parameters	Typical Values	Nonlinear Behavior
Concrete	Mander confined/unconfined	f'c, Ec, εc	25-40 MPa, 22-32 GPa	Crushing, cracking
Rebar	Elastic-plastic with hardening	fy, Es, εsh	415-500 MPa, 200 GPa	Yielding, strain hardening
Beams	Frame elements with hinges	M3, M2 hinges	ASCE 41 defaults	Flexural yielding
Columns	Frame elements with P-M hinges	P-M2-M3 interaction	ASCE 41 defaults	Axial-flexural
Walls	Shell elements, layered	Thickness, reinforcement	150-300 mm	Shear, flexure

Table 3: Performance levels and acceptance criteria for RCC components (ASCE 41)

Performance Level	Story Drift Limit	Plastic Rotation (Beams)	Plastic Rotation (Columns)	Damage State	Functionality
Operational (O)	0.005	Elastic	Elastic	Negligible	Fully functional
Immediate Occupancy (IO)	0.010	0.010 rad	0.005 rad	Minor cracking	Continuous use
Life Safety (LS)	0.020	0.025 rad	0.015 rad	Major cracking, spalling	Not safe for occupancy
Collapse Prevention (CP)	0.033	0.050 rad	0.030 rad	Severe damage, near collapse	Prevent collapse only

Table 4: Advantages, limitations, and applications of ETABS for seismic analysis

Aspect	Advantages	Limitations	Typical Applications
Modeling	3D visualization, parametric input	Learning curve for complex features	All building types
Linear Analysis	Fast, code-compliant, automated	Doesn't capture yielding	Preliminary design
Nonlinear Analysis	Accurate performance prediction	Computationally intensive	Critical structures, retrofits
Design Integration	Automated code checking, optimization	Conservative automated design	Commercial projects
Documentation	Comprehensive reports, graphics	Manual interpretation needed	Engineering deliverables

9. Conclusion

Seismic performance evaluation using ETABS software represents a critical capability for earthquake-resistant building design and assessment. The comprehensive analysis methodologies ranging from linear static to nonlinear dynamic procedures enable engineers to evaluate structural behavior across multiple performance levels and seismic intensities.

ETABS provides powerful modeling capabilities including sophisticated material models, diverse element formulations, and automated code checking features. The software efficiently handles regular building configurations while accommodating complex irregular geometries and high-rise structures. Integration of linear and nonlinear analysis procedures enables progressive evaluation from preliminary design through detailed performance assessment.

Performance-based evaluation frameworks incorporated in ETABS facilitate explicit assessment of damage states and verification against multi-level performance objectives. Pushover analysis identifies capacity curves and failure mechanisms while time-history analysis captures realistic response including higher mode effects and hysteretic behavior.

Challenges persist including modeling uncertainties, computational demands for large-scale analyses, soil-structure interaction representation, and validation against experimental data. Continued development addresses these limitations through enhanced computational efficiency, improved material models, and integrated analysis-design workflows.

Future directions emphasize integration with BIM platforms, artificial intelligence-based optimization, advanced performance-based methodologies, and structural health monitoring systems. These developments will enhance seismic safety through more accurate predictions, optimized designs, and improved post-earthquake assessment capabilities.

ETABS remains an indispensable tool for structural engineers engaged in seismic-resistant building design, providing reliable analysis capabilities supporting safe, economical, and resilient construction in earthquake-prone regions.

10. References

1. Bilham R. The seismic future of cities. Bull Earthquake Eng. 2009;7(4):839-887.
2. Kam WY, Pampanin S, Elwood K. Seismic performance of reinforced concrete buildings in the 22 February Christchurch (Lyttelton) earthquake. Bull N Z Soc Earthq Eng. 2011;44(4):239-278.
3. Moehle J, Deierlein GG. A framework methodology for performance-based earthquake engineering. Proceedings of 13th World Conference on Earthquake Engineering; 2004 Aug 1-6; Vancouver, Canada.
4. Priestley MJN. Performance based seismic design. Bull N Z Soc Earthq Eng. 2000;33(3):325-346.
5. Goel RK, Chopra AK. Evaluation of modal and FEMA pushover analyses: SAC buildings. Earthquake Spectra. 2004;20(1):225-254.
6. Galasso C, Maddaloni G, Cosenza E. Uncertainty analysis of flexural overstrength for capacity design of RC beams. J Struct Eng. 2014;140(7):04014037.
7. Calvi GM, Sullivan TJ, Villani A. Conceptual seismic design of cable-stayed bridges. J Earthquake Eng. 2010;14(8):1139-1171.
8. Paulay T, Priestley MJN. Seismic design of reinforced concrete and masonry buildings. New York: John Wiley & Sons; 1992.
9. Federal Emergency Management Agency. FEMA 356. Prestandard and commentary for the seismic rehabilitation of buildings. Washington, DC: FEMA; 2000.
10. American Society of Civil Engineers. ASCE/SEI 41-17. Seismic evaluation and retrofit of existing buildings. Reston, VA: ASCE; 2017.
11. Porter KA. An overview of PEER's performance-based earthquake engineering methodology. Proceedings of 9th International Conference on Applications of Statistics and Probability in Civil Engineering; 2003.
12. Wilson EL. Three-dimensional static and dynamic analysis of structures. 3rd ed. Berkeley, CA: Computers and Structures Inc; 2002.
13. Computers and Structures Inc. ETABS integrated analysis, design and drafting of building systems. Berkeley, CA: CSI; 2021.
14. Habibullah A, Pyle S. Practical three dimensional nonlinear static pushover analysis. Structure Magazine. 1998;5:23-26.

15. Chopra AK, Goel RK. A modal pushover analysis procedure for estimating seismic demands for buildings. Earthquake Eng Struct Dyn. 2002;31(3):561-582.
16. American Society of Civil Engineers. ASCE/SEI 7-22. Minimum design loads and associated criteria for buildings and other structures. Reston, VA: ASCE; 2022.
17. Chopra AK. Dynamics of structures: theory and applications to earthquake engineering. 5th ed. Boston: Pearson; 2017.
18. Krawinkler H, Seneviratna GDPK. Pros and cons of a pushover analysis of seismic performance evaluation. Eng Struct. 1998;20(4-6):452-464.
19. Chopra AK, Chintanapakdee C. Comparing response of SDF systems to near-fault and far-fault earthquake motions in the context of spectral regions. Earthquake Eng Struct Dyn. 2001;30(12):1769-1789.
20. Cornell CA. Engineering seismic risk analysis. Bull Seismol Soc Am. 1968;58(5):1583-1606.
21. McGuire RK. Probabilistic seismic hazard analysis: early history. Earthquake Eng Struct Dyn. 2008;37(3):329-338.
22. Federal Emergency Management Agency. FEMA P-58. Seismic performance assessment of buildings. Washington, DC: FEMA; 2012.
23. Bommer JJ, Acevedo AB. The use of real earthquake accelerograms as input to dynamic analysis. J Earthquake Eng. 2004;8(1):43-91.
24. Newmark NM, Hall WJ. Earthquake spectra and design. Oakland, CA: Earthquake Engineering Research Institute; 1982.
25. Stewart JP, Chiou SJ, Bray JD, Graves RW, Abrahamson NA, Bozorgnia Y. Ground motion evaluation procedures for performance-based design. Soil Dyn Earthquake Eng. 2002;22(9-12):765-772.

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