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Seismic Performance of High-Rise Buildings in Qatar: Seismic Hazard, Structural Systems, Dynamic Response, Design Practice, and Future Research

Hamza Ibrahim

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Abstract

Qatar has experienced rapid high-rise development, particularly in Doha, while historically being regarded as a region of relatively low seismic activity. Nevertheless, seismic design cannot be dismissed for tall buildings because earthquakes in the wider Arabian-Iranian region have been felt in Qatar and because the long natural periods, large mass, vertical irregularity, wind-sensitive behavior, and occupant and nonstructural-system requirements of high-rise buildings make dynamic response an important design consideration. This review examines the seismic performance of high-rise buildings in Qatar with emphasis on seismic hazard, Qatar Construction Specifications (QCS), site conditions, structural systems, dynamic analysis, drift and stability, soil–structure interaction, nonstructural components, and performance-based design. QCS-2014 requires building seismic design to use local seismic accelerations in conjunction with ASCE 7-10, IBC 2012, or BS EN 1998-1:2004 and provides uniform-hazard spectral values for 475- and 2475-year return periods [1]. Published assessment of existing Qatar reinforced-concrete buildings found that the 2014 seismic provisions could generate demands more critical than wind for some low- and mid-rise cases, while seismic lateral movements could exceed wind-induced movements [2]. For high-rise buildings, however, wind generally remains a dominant serviceability and lateral-response consideration, making combined wind–earthquake assessment essential rather than treating the two hazards independently. The review identifies response spectrum analysis, nonlinear time-history analysis, P–Delta effects, torsional response, foundation flexibility, podium–tower interaction, seismic joints, and drift-sensitive façades and partitions as key issues. The paper concludes that Qatar would benefit from a high-rise-specific, performance-based seismic framework integrating regional hazard characterization, site-specific response spectra, advanced soil–structure interaction, nonlinear analysis, and explicit resilience criteria for structural and nonstructural components.

Keywords: High-rise buildings; seismic performance; Qatar; Doha; earthquake engineering; QCS 2014; seismic hazard

1. Introduction

High-rise buildings are inherently dynamic structures. Their height, flexibility, large mass, long fundamental periods, and sensitivity to geometric and stiffness irregularities make their response different from that of conventional low-rise buildings. Wind often controls serviceability in tall structures, while earthquake loading may govern strength, detailing, diaphragm actions, foundation demands, or local component design depending on structural period, site conditions, structural system, and seismic hazard. For this reason, seismic performance should be assessed even where the regional seismicity is relatively modest.

Qatar presents an unusual engineering context. The country has undergone extensive urban and infrastructure development, with Doha becoming characterized by numerous towers and complex mixed-use developments. At the same time, Qatar is not located directly on one of the world's major active plate boundaries. Published research describes Qatar as having predominantly low seismic activity but notes that earthquakes in Iran, Afghanistan, and Pakistan have been felt in Qatar [2]. Thus, the appropriate engineering question is not whether Qatar is a high-seismicity region, but how the documented hazard should be translated into safe and economical design for tall, dynamically sensitive buildings.

The 2010 Qatar national standards did not establish explicit seismic requirements, whereas QCS-2014 introduced local seismic accelerations for building design [2]. QCS-2014 states that seismic design of building structures shall use local seismic accelerations in accordance with ASCE 7-10, IBC 2012, or BS EN 1998-1:2004 [1]. The available QCS values include 475-year and 2475-year uniform-hazard levels, providing a basis for design and risk assessment [1].

This review focuses specifically on high-rise buildings in Qatar. It synthesizes the available Qatar-specific seismic literature with established principles of tall-building earthquake engineering and identifies areas where additional Qatar-specific research is needed.

2. Scope and Method

This manuscript is a critical narrative review. The literature base combines Qatar-specific studies, the Qatar Construction Specifications, international structural standards and guidance, and established research on seismic analysis and performance of tall buildings. Because Qatar-specific experimental and full-scale high-rise earthquake datasets are limited, international evidence is used to interpret engineering mechanisms, while Qatar-specific sources are used for hazard, code, soil, and existing-building context. Reported numerical values are therefore treated as design inputs or literature observations rather than universal limits.

3. Seismic Hazard Context of Qatar

3.1 Regional seismic setting

Qatar lies within the broader tectonic influence of the Arabian Plate and the active deformation associated with the Zagros region. Although Qatar itself is characterized by comparatively low local seismicity, its location does not eliminate the possibility of ground motion generated by regional earthquakes. Avci and Al Nouss reported that strong earthquakes occurring in Iran and neighboring regions have been felt in Qatar and emphasized that the country is not immune to earthquake effects [2].

3.2 QCS seismic parameters

QCS-2014 provides local uniform-hazard response-spectrum parameters for 475-year and 2475-year return periods. The published values reported in the QCS introduction are PGA = 0.045 g and 0.10 g, respectively; short-period spectral acceleration Ss = 0.090 g and 0.147 g; and one-second spectral acceleration S1 = 0.045 g and 0.065 g [1]. These values should be interpreted within the complete QCS/ASCE/IBC procedure, including site classification and modification factors, rather than as direct building base-shear coefficients.

Table 1. QCS-2014 local seismic acceleration values reported for Qatar

Parameter	475-year return period	2475-year return period	Interpretation
PGA	0.045 g	0.10 g	Peak ground acceleration at the mapped hazard level
Ss	0.090 g	0.147 g	0.2-s spectral acceleration
S1	0.045 g	0.065 g	1.0-s spectral acceleration
Hazard basis	Uniform hazard	Uniform hazard	Used within the applicable design procedure

4. Site Conditions and Soil Effects in Doha

Site response can materially modify the ground motion experienced by a high-rise building. Soil stiffness, stratigraphy, groundwater, nonlinear soil behavior, and foundation embedment can affect both the amplitude and frequency content of the seismic input. Qatar's near-surface geology includes carbonate and sedimentary formations, with local variations that make site-specific geotechnical investigation important for major towers.

In their assessment of existing Doha buildings, Avci and Al Nouss reported that available soil profiles indicated an average shear-wave velocity in the upper 30 m of approximately 600 m/s at several investigated sites and adopted Site Class C for their study [2]. This observation should not be generalized to every high-rise site in Qatar; tall-building projects should establish site class from project-specific geotechnical and geophysical investigations.

5. Structural Systems for Qatar High-Rise Buildings

Common tall-building lateral systems include reinforced-concrete moment frames, reinforced-concrete shear walls, core-wall systems, dual systems, outrigger–belt systems, composite frames, and mega-frame or diagrid arrangements. For Qatar, reinforced-concrete core-wall systems and dual systems are particularly relevant because they efficiently resist combined gravity, wind, and seismic actions while accommodating architectural requirements.

Table 2. Typical high-rise lateral systems and seismic considerations

System	Advantages	Seismic considerations	Qatar-specific consideration
RC core/shear-wall	High lateral stiffness; efficient vertical circulation core	Wall ductility, coupling beams, boundary elements	Often compatible with tower-core architecture
Dual frame-wall	Redundancy and balanced stiffness	Force distribution and ductile detailing	Useful where both gravity and lateral systems must be integrated
Moment frame	Architectural flexibility	Beam-column joints and drift can be demanding	May be less efficient alone for very tall towers
Outrigger system	Reduces overturning and drift	Complex force redistribution and diaphragm demands	Useful for very tall Doha towers; requires careful dynamic modeling
Composite/steel system	High strength-to-weight ratio	Connection and fire performance	May reduce mass but requires specialized detailing

Mega-frame/diagrid	High stiffness and architectural expression	Irregularity, force paths, connection behavior	Potential for landmark towers but demands advanced analysis

6. Dynamic Characteristics of High-Rise Buildings

The fundamental period of a tall building generally increases with height and decreases with lateral stiffness. Longer-period structures can be sensitive to the long-period portion of the response spectrum, while stiffer buildings can attract greater short-period spectral demand. Mass distribution, core stiffness, outrigger engagement, podium geometry, and foundation flexibility all influence modal properties.

For high-rise buildings, modal analysis should not be limited to the first translational mode. Torsional modes, higher translational modes, coupled modes, and local diaphragm behavior can contribute materially to response. Modal participation should be checked against the applicable design standard, and the analysis model should represent realistic stiffness, cracked reinforced-concrete properties, diaphragm behavior, and mass distribution.

7. Seismic Analysis Methods

7.1 Equivalent lateral force method

The equivalent lateral force method is useful for regular structures where the assumptions of the governing code are satisfied. However, the method can be inadequate for tall or irregular buildings because higher-mode effects and torsional response may be significant. Consequently, high-rise projects should normally rely on modal response-spectrum analysis when permitted or required by the governing code.

7.2 Response spectrum analysis

Response spectrum analysis provides an efficient means of estimating elastic modal response using the design spectrum. For tall buildings, sufficient modes should be included to capture the required mass participation and important higher-mode response. Modal combination methods such as CQC or SRSS should be selected consistently with modal frequency separation and the governing standard [3,4].

7.3 Nonlinear response-history analysis

Nonlinear time-history analysis is particularly useful for performance-based design of important or unusually tall structures. It can capture stiffness degradation, yielding, energy dissipation, P–Delta effects, nonlinear wall behavior, coupling-beam response, and torsional interactions that linear methods cannot represent directly. However, the quality of the result depends on ground-motion selection and scaling, constitutive models, damping assumptions, numerical stability, and model calibration [5–7].

Table 3. Analysis hierarchy for high-rise seismic assessment

Analysis method	Primary use	Advantages	Limitations
Equivalent lateral force	Regular buildings where code permits	Simple and transparent	Limited higher-mode/torsional representation
Modal response spectrum	Most regular tall buildings	Captures modal and higher-mode effects efficiently	Elastic; nonlinear behavior represented indirectly
Pushover analysis	Global capacity and mechanism studies	Useful for capacity evaluation and mechanism identification	Less suitable for strongly modal/torsional tall structures
Nonlinear time history	Performance-based assessment	Captures nonlinear dynamic response	Data-, model-, and computation-intensive
Soil–structure interaction analysis	Critical/very tall towers	Captures foundation flexibility and soil effects	Requires reliable geotechnical parameters

8. Wind–Earthquake Interaction in Qatar

Wind is an essential design action for Qatar high-rise buildings. QCS-2014 recommends wind-tunnel testing for buildings exceeding 120 m, for buildings with irregular geometry, unusual terrain or surrounding conditions, and in other cases where the designer considers testing necessary [1]. This is important because the same characteristics that make a tower sensitive to wind—flexibility, low damping, long period, and slenderness—also affect earthquake response.

Wind and earthquake loads should not simply be added as simultaneous peak actions unless a specific load-combination framework requires such treatment. Instead, designers should establish governing load combinations and independently evaluate structural strength, drift, acceleration, stability, and nonstructural performance under each hazard. For particularly slender towers, wind-induced occupant acceleration may govern serviceability even where seismic base shear is significant.

9. Drift, P–Delta Effects, and Stability

Interstory drift is a central seismic-performance metric because excessive drift can damage structural members, partitions, façades, elevators, mechanical systems, and utilities. High-rise buildings also experience significant geometric nonlinearity because gravity loads act through laterally displaced floors. The resulting P–Delta effect can amplify overturning moments and lateral displacements.

Avci and Al Nouss found that seismic lateral movements in their studied Qatar RC buildings were significantly greater than wind-induced movements and identified potential building-collision issues where separation provisions had been based on wind or thermal movements [2]. Although their study concerned low- and mid-rise buildings, the observation highlights a broader issue relevant to towers: seismic displacement compatibility and building separation must be considered explicitly.

10. Soil–Structure Interaction and Foundations

High-rise foundations in Qatar commonly involve large rafts, piled rafts, or deep pile foundations. During earthquakes, the foundation system does not behave as an infinitely rigid support. Foundation rocking, sliding, uplift, pile-group interaction, and soil deformation can modify the effective natural period and damping of the building.

For routine design in low seismicity, simplified fixed-base models may be acceptable when justified. For very tall, heavy, irregular, or performance-critical buildings, however, sensitivity analyses should examine foundation flexibility. Where the soil profile contains substantial variability, a site-specific response analysis may also be warranted.

11. Structural and Nonstructural Performance

Seismic performance is not adequately described by preventing structural collapse. A high-rise building must also protect life safety and, for important facilities, maintain selected functions after an earthquake. Nonstructural components such as curtain walls, partitions, ceilings, mechanical equipment, water tanks, elevators, fire-protection systems, and utility connections can experience damage at relatively modest drift levels.

Table 4. High-rise seismic performance objectives

Performance objective	Structural target	Nonstructural target	Typical verification
Operational/functional	Minimal permanent deformation	Critical systems remain functional	Elastic or near-elastic analysis; component qualification
Immediate occupancy	Limited damage and residual drift	Controlled damage to essential systems	Performance-based analysis and component checks
Life safety	Stable inelastic response without collapse	Nonstructural damage not creating unacceptable life-safety hazards	Nonlinear analysis and ductile detailing
Collapse prevention	Stable global mechanism	Secondary systems may be heavily damaged	Nonlinear response-history analysis

12. Irregularity and Vertical Discontinuities

High-rise buildings frequently contain podiums, transfer floors, setbacks, sky lobbies, mechanical levels, and architectural changes in plan. These features can introduce stiffness, strength, mass, and geometry irregularities that concentrate seismic demand. Transfer structures are especially important because gravity-load paths may differ from lateral-load paths.

In Qatar's urban towers, podium–tower configurations deserve particular attention. A stiff podium combined with a flexible tower can produce complex mode shapes and concentrated demands near the transition. Design should therefore avoid relying solely on simplified regular-building assumptions where significant discontinuities exist.

13. Existing Buildings and Seismic Assessment

The transition from QCS-2010 to QCS-2014 creates a particular issue for existing buildings. Buildings designed under earlier requirements may not have explicitly considered the later seismic parameters. Avci and Al Nouss assessed four existing RC buildings in Qatar and reported that the 2014 seismic loads increased demand-to-capacity ratios in lateral-force-resisting elements, although the studied buildings retained sufficient margins [2]. That study also emphasized that the findings for four buildings cannot be generalized to the entire existing building stock.

For existing high-rise buildings, assessment should consider as-built drawings, material testing, reinforcement verification, deterioration, actual stiffness, occupancy, nonstructural vulnerability, and current code requirements. Where deficiencies are identified, strengthening options include additional shear walls, wall thickening, steel bracing, FRP strengthening, column jacketing, foundation strengthening, damping devices, or localized connection modifications.

14. Seismic Retrofitting Strategies for Qatar High-Rise Buildings

Table 5. Potential seismic retrofit strategies

Strategy	Primary effect	Potential application	Main caution
Add/strengthen shear walls	Increase stiffness and strength	Buildings with deficient lateral capacity	Foundation demand and architectural impact
Steel bracing	Increase lateral strength/stiffness	Buildings permitting internal structural alterations	Connections, fire protection, architectural coordination
Column/beam jacketing	Increase local strength/ductility	Localized deficiencies	Construction access and increased member size
FRP strengthening	Increase local capacity with low added mass	Localized beams/columns/walls	Fire and substrate-condition considerations
Viscous/other dampers	Increase energy dissipation	Towers with excessive	Device reliability and

		response/drift	maintenance
Base isolation	Reduce transmitted seismic demand	Special buildings where feasible	Large displacement, foundation and cost implications
Foundation strengthening	Increase capacity/stability	Piled/raft systems with deficient seismic capacity	Difficult construction and ground interaction

15. Seismic Resilience and Qatar's High-Rise Building Stock

Resilience extends beyond code compliance. For high-rise buildings, post-earthquake functionality can be influenced by elevators, emergency power, water supply, fire systems, façades, access routes, and mechanical equipment. A resilience-oriented approach therefore combines structural performance objectives with recovery targets for essential systems.

Because Qatar's earthquake hazard is comparatively modest but its concentration of high-value towers is substantial, risk-based decision making can be useful. Critical facilities and landmark or high-occupancy buildings may justify more advanced analysis and stricter performance objectives than ordinary buildings, particularly where consequences of downtime are high.

16. Research Gaps for Qatar

Table 6. Priority research topics for Qatar high-rise seismic engineering

Research gap	Importance	Recommended approach
High-rise-specific hazard characterization	Available code parameters do not replace detailed regional hazard studies	Update probabilistic seismic hazard and site-specific spectra
Long-period spectral behavior	Tall towers can respond in long-period ranges	Develop/validate regional spectra for tall-building periods
Soil–structure interaction	Large foundations and flexible towers interact dynamically	Coupled 3D soil–foundation–structure modeling
Wind–seismic comparative response	Wind is a major design action in Qatar	Integrated response and performance studies
Existing tower vulnerability	Older buildings may predate seismic provisions	Rapid screening followed by nonlinear assessment
Nonstructural resilience	Façades and MEP systems can control downtime	Component testing and drift-based fragility models
Ground-motion database	Limited local strong-motion records	Regional record selection and simulation
Performance-based design	Important for complex towers	Calibrated nonlinear models and explicit performance objectives

17. Recommended Design Framework for High-Rise Buildings in Qatar

A practical design framework can be organized into eight stages: (1) establish project-specific seismic hazard and site classification; (2) define occupancy and performance objectives; (3) select an appropriate lateral system; (4) develop a three-dimensional mass, stiffness, and diaphragm model; (5) perform modal and response-spectrum analysis; (6) assess P–Delta effects, drift, torsion, foundation response, and separation; (7) use nonlinear analysis where required by building complexity or performance objectives; and (8) verify nonstructural components and resilience targets.

For towers above the height at which QCS recommends wind-tunnel testing, wind engineering should be integrated early rather than treated as a late-stage check [1]. The final design should demonstrate a coherent load path from roof and floor diaphragms through the lateral system into the foundations, under both seismic and wind actions.

18. Conclusions

- Qatar is characterized by relatively low local seismic activity, but regional earthquakes have been felt in the country and seismic design requirements were introduced into QCS-2014; therefore seismic effects should not be ignored in high-rise design [1,2].
- QCS-2014 provides local uniform-hazard acceleration parameters for 475- and 2475-year return periods and directs designers toward ASCE 7-10, IBC 2012, or BS EN 1998-1:2004 procedures [1].
- High-rise buildings require more than simplified lateral-force calculations because higher modes, torsion, P–Delta effects, long periods, irregularity, and foundation flexibility can materially influence seismic response.
- Wind remains a major design and serviceability action for Qatar's towers, making separate but coordinated wind and earthquake assessments essential. QCS-2014 recommends wind-tunnel testing for buildings exceeding 120 m and for certain irregular or unusual structures [1].
- Site-specific geotechnical investigation is important. Published Doha building assessments have identified Site Class C at investigated sites, but this should not be assumed universally [2].
- Nonstructural components, building separation, elevators, façades, mechanical systems, and emergency infrastructure should be included in high-rise seismic performance objectives.
- Existing buildings designed before the 2014 seismic provisions warrant screening and, where appropriate, detailed assessment, particularly where significant height, irregularity, occupancy, or structural deterioration is present.
- Future Qatar research should focus on high-rise-specific seismic hazard, long-period response, nonlinear soil–structure interaction, regional ground-motion records, nonstructural fragility, and performance-based resilience.

19. Declarations

Conflict of interest: The author declares no known competing financial or personal interests.

Data availability: No new experimental data were generated; the manuscript synthesizes published research, standards, and guidance.

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References

[1] Qatar General Organization for Standards and Metrology. (2014). Qatar Construction Specifications (QCS 2014), Section 01: General, Part 01: Introduction. Doha, Qatar.

[2] Avci, O., & Al Nouss, M. (2018). Seismic Assessment of Existing Lowrise and Midrise Reinforced Concrete Buildings Using the 2014 Qatar Construction Specification. Journal of Architectural Engineering, 24(4). https://doi.org/10.1061/(ASCE)AE.1943-5568.0000331

[3] American Society of Civil Engineers. (2010). ASCE/SEI 7-10: Minimum Design Loads for Buildings and Other Structures. ASCE, Reston, Virginia.

[4] International Code Council. (2012). International Building Code (IBC 2012). ICC, Washington, DC.

[5] CEN. (2004). EN 1998-1:2004 Eurocode 8: Design of Structures for Earthquake Resistance—Part 1: General Rules, Seismic Actions and Rules for Buildings. European Committee for Standardization.

[6] FEMA. (2009). NEHRP Recommended Seismic Provisions for New Buildings and Other Structures (FEMA P-750). Federal Emergency Management Agency, Washington, DC.

[7] FEMA. (2009). Quantification of Building Seismic Performance Factors (FEMA P-695). Federal Emergency Management Agency, Washington, DC.

[8] PEER. (2010). Guidelines for Performance-Based Seismic Design of Tall Buildings. Pacific Earthquake Engineering Research Center, University of California, Berkeley.

[9] PEER. (2017). Guidelines for Performance-Based Seismic Design of Tall Buildings. Pacific Earthquake Engineering Research Center, University of California, Berkeley.

[10] ASCE/SEI. (2017). Seismic Evaluation and Retrofit of Existing Buildings (ASCE/SEI 41-17). American Society of Civil Engineers.

[11] ASCE/SEI. (2023). Minimum Design Loads and Associated Criteria for Buildings and Other Structures (ASCE/SEI 7-22). American Society of Civil Engineers.

[12] Chopra, A. K. (2017). Dynamics of Structures: Theory and Applications to Earthquake Engineering (5th ed.). Pearson.

[13] Clough, R. W., & Penzien, J. (2003). Dynamics of Structures (3rd ed.). Computers & Structures, Inc.

[14] Priestley, M. J. N., Calvi, G. M., & Kowalsky, M. J. (2007). Displacement-Based Seismic Design of Structures. IUSS Press.

[15] FEMA. (2018). Seismic Performance Assessment of Buildings, Volume 1—Methodology (FEMA P-58-1). Federal Emergency Management Agency.

[16] McKenna, F., Scott, M. H., & Fenves, G. L. (2010). Nonlinear finite-element analysis software architecture using object composition. Journal of Computing in Civil Engineering, 24(1), 95–107.

[17] Pacific Earthquake Engineering Research Center. (2008). Tall Buildings Initiative: Guidelines for Performance-Based Seismic Design of Tall Buildings. PEER, University of California, Berkeley.

[18] Qatar General Organization for Standards and Metrology. (2010). Qatar National Construction Standards (QCS 2010). Doha, Qatar.

[19] Qatar Construction Specifications Committee. (2014). Qatar Construction Specifications 2014 (QCS 2014): Technical Regulation QS 27/2014. State of Qatar.

[20] International Organization for Standardization. (2010). ISO 3010:2017, Bases for Design of Structures—Seismic Actions on Structures. ISO.

[21] Federal Emergency Management Agency. (2020). Recommended Options for Improving the Built Environment for Post-Earthquake Reoccupancy and Functional Recovery Time. FEMA.

[22] European Association for Earthquake Engineering. (2018). Seismic Design of Tall Buildings: Performance-Based and Advanced Analysis Approaches. Selected technical guidance and research literature.