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Seismic Performance Evaluation and Mitigation Strategies for Reinforced Concrete Buildings with Floating Columns: A Critical State-of-the-Art Review

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ABSTRACT

Modern urban buildings frequently eliminate ground-floor or intermediate columns to accommodate open stilt parking, grand entrance lobbies, and pillar-free commercial halls. These terminated members, known as floating columns, rest on horizontal flexural transfer girders instead of continuing directly down to the foundation. While floating columns carry routine gravity loads adequately, they break the natural vertical load path and create severe stiffness discontinuities. During strong earthquake shaking, this disruption triggers shear force singularities, large inter-storey drift spikes, and dangerous soft-storey collapse mechanisms. This review synthesizes findings from twenty peer-reviewed studies and recent pushover research on a ten-storey reinforced concrete building conducted at Dr. Subhash University. We examine how column positions—specifically corner, exterior edge, and central interior bays—alter dynamic lateral drift, torsional coupling, and plastic hinge progressions. Standard equivalent static calculations fail to capture these localized force concentrations, making nonlinear static pushover and dynamic response spectrum procedures essential. Integrating continuous reinforced concrete shear walls reduces roof displacements by up to 85% and drift ratios by 70%, while structural steel X-bracing achieves 68% drift reduction with minimal weight penalty. Persistent research voids, including near-fault velocity pulses and the scarcity of physical shake-table validation, are highlighted alongside five actionable design rules aligned with Indian Standard codes IS 1893:2016 and IS 13920:2016.

Keywords: Capacity Spectrum Method, Floating Columns, IS 13920:2016, IS 1893:2016, Nonlinear Pushover Analysis, RC Shear Walls, Soft-Storey Collapse, Steel X-Bracing, Transfer Girders, Vertical Irregularity.

Structural Mechanics of Discontinuous Load Paths

Urban real estate development in seismically active regions places heavy demands on building floor space. Municipal bylaws often mandate on-site vehicular parking, prompting designers to clear out ground floors for parking stilts, driveways, and retail foyers. To meet these spatial targets, structural engineers frequently terminate columns at lower floors, allowing upper storeys to bear on horizontal beams known as transfer girders. While this framing arrangement satisfies architectural plans, it introduces a severe structural conflict under lateral earthquake ground shaking.

In a conventional building frame, vertical columns extend uninterrupted from the roof straight to the foundation footings. Lateral inertial shears generated by seismic ground accelerations flow downward through floors and columns smoothly, maintaining continuous moment equilibrium. In contrast, a floating column terminates abruptly in mid-air. Its full vertical gravity load and overturning compression are dumped as a heavy, concentrated point load directly onto a transfer girder. This forces the transfer girder to act in intense flexure and transverse shear, deflecting downward and rotating the joint.

At the junction where the floating column meets the transfer girder, a sharp stress singularity develops. The sudden transition from pure axial compression in the column into high bending moments and shear stresses in the girder creates localized cracking. More critically, removing lower columns causes an abrupt loss of lateral stiffness at the transfer level. The storey stiffness of the open floor drops well below 70% of the storey above, forming a classic soft-storey. Under dynamic cyclic ground shaking, lateral displacements concentrate almost entirely in this flexible storey, while the stiffer upper block sways as a rigid box. Post-earthquake reconnaissance from the 2001 Bhuj earthquake in Gujarat, the 1999 Chi-Chi earthquake in Taiwan, and the 2023 Kahramanmaraş earthquakes in Turkey documented pancake collapses and joint shearing in buildings featuring open stilt floors and floating columns.

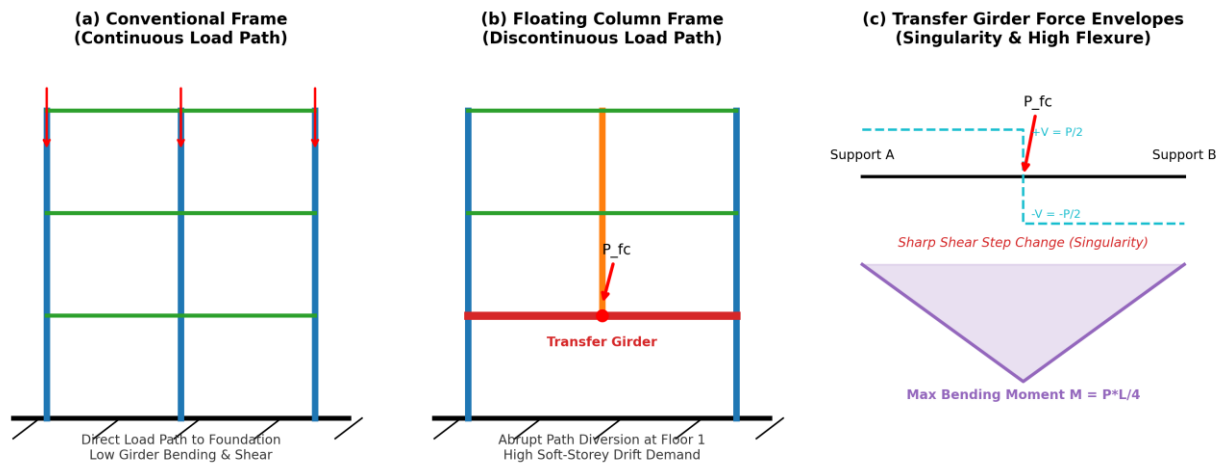


Fig. 1 - Comparison of structural load transfer mechanisms: (a) Conventional RC frame with continuous vertical load paths; (b) Floating column frame showing abrupt load diversion through a transfer girder; (c) Internal bending moment and shear force envelopes.

Regulatory Codes, Standards, and Safety Thresholds

Building codes worldwide recognize vertical stiffness and strength discontinuities as major seismic hazards. In India, seismic design is governed by three primary standards: IS 1893 (Part 1):2016 for earthquake forces, IS 456:2000 for reinforced concrete, and IS 13920:2016 for ductile detailing. Together, these standards establish strict limits to prevent brittle collapse in discontinuous frames.

Under IS 1893:2016, India is divided into Seismic Zones II, III, IV, and V, with Zone Factors (Z) ranging from 0.10 to 0.36. The design horizontal seismic coefficient A_h depends on the Importance Factor (I), Response Reduction Factor ($R = 5.0$ for Special Moment Resisting Frames), and average spectral acceleration (S_a/g). Clause 7.1 and Table 6 classify floating columns as vertical geometric and stiffness irregularities. For irregular structures taller than 15 meters in Zones III through V, standard equivalent static calculations are explicitly forbidden; dynamic analysis is mandatory. Clause 7.11 also strictly caps the inter-storey drift ratio at 0.0040 (0.4% of storey height). Where an open ground storey exists without continuous shear walls, Clause 7.2.5 imposes a severe penalty: all columns and transfer beams in that storey must be designed for 2.5 times the moments and shear forces obtained from conventional linear analysis.

Design rules in IS 456:2000 classify transfer girders with span-to-depth ratios below 2.0 (for simple spans) or 2.5 (for continuous spans) as deep beams. Internal stresses in deep transfer girders do not follow straight-line beam bending; instead, compressive stress arches form directly between the column base and the lower supports. Nominal shear stress must stay below the concrete shear ceiling of $0.63 \cdot \sqrt{f_{ck}}$. In tandem, IS 13920:2016 dictates close seismic hoop spacing (not exceeding 100 mm or $d/4$) and 135-degree cross-ties with ten-diameter anchorage extensions. To safeguard overall stability, the Strong-Column Weak-Beam criterion requires the sum of column nominal flexural strengths at beam-column joints to exceed beam flexural strengths by at least 40% ($\sum M_c / \sum M_b \geq 1.4$). This hierarchy prevents hinge mechanisms from locking into supporting columns before beams yield.

Table 1 - Regulatory codes, standards, and safety thresholds for vertically irregular structures.

Standard / Regulatory Code	Clause / Reference	Governing Parameter	Mandatory Threshold / Codal Requirement	Structural Engineering Objective
IS 1893 (Part 1):2016	Clause 7.1 & Table 6	Vertical Irregularity	Mandatory Dynamic Analysis (RSA/THA) if $H > 15$ m in Zone III–V	Prevents inaccurate linear static force estimation
IS 1893 (Part 1):2016	Clause 7.11	Inter-Storey Drift	Drift ratio limit: $\Delta_i / h_i \leq 0.0040$ under design lateral load	Protects non-structural infill and limits P-Delta collapse
IS 1893 (Part 1):2016	Clause 7.2.5	Soft-Storey Framing	2.5x multiplier on calculated column/beam moments and shears	Compensates for severe stiffness and strength deficiency
IS 456:2000	Clause 29 & Annex G	Transfer Girder Depth	Deep beam check if $L/D \leq 2.0$ (simple) or ≤ 2.5 (continuous)	Controls nonlinear internal strut-and-tie shear flow
IS 13920:2016	Clause 7.2 & 7.4	Confinement & SCWB	$\sum(M_c)/\sum(M_b) \geq 1.4$; hoop spacing $s \leq 100$ mm with 135° ties	Enforces beam hinge yielding before brittle column failure

Standard / Regulatory Code	Clause / Reference	Governing Parameter	Mandatory Threshold / Codal Requirement	Structural Engineering Objective
ATC-40 / FEMA-356	Chapter 8 / 11	Performance Levels	Immediate Occupancy (IO), Life Safety (LS), Collapse Prevention (CP)	Benchmarks nonlinear plastic rotation under MCE demand

Spatial Layouts, Storey Distributions, and Torsional Behavior

A building's vulnerability to earthquakes depends heavily on where floating columns are situated in the floor plan and across storeys. In single-level stilt buildings, columns are cut off at the ground floor to create clear vehicle bays, leaving the base entirely unbraced while upper floors remain stiffened by masonry walls. In multi-level podium buildings, floating columns terminate on transfer girders at intermediate levels—such as the third or fifth floor. When floating columns are staggered across multiple upper floors, their gravity and dynamic loads accumulate downwards onto lower transfer beams, compounding shear demands.

Four primary plan positions appear throughout the literature: Corner Floating Columns (CFC), Outer Edge Floating Columns (OFC), Interior Center Floating Columns (IFC), and Multiple Combined Floating Columns. Corner columns are by far the most hazardous. Making an exterior corner column float strips stiffness from the building's outer perimeter, shifting the Center of Rigidity (CR) away from the Center of Mass (CM). This offset creates dynamic eccentricity (ed). When ground shaking strikes, the base shear V_b exerts an intense twisting moment ($T = V_b * ed$), causing severe torsional rotation and driving high drift concentrations in outer columns.

Outer edge floating columns also trigger noticeable torsional rotation, though less extreme than corner columns. In contrast, central interior floating columns preserve peripheral framing symmetry, keeping dynamic eccentricity near zero. The challenge with center columns is heavy concentrated gravity load, which demands deep transfer girders and substantial shear reinforcement. When floating columns are placed in irregularly shaped floor plans—such as L-shaped, T-shaped, or U-shaped buildings—re-entrant corners create amplified stress concentrations that lead to early concrete cracking.

Computational Modeling and Seismic Analysis Procedures

Simulating the seismic response of buildings with floating columns requires computational tools that capture localized stress gradients and progressive damage. A review of twenty benchmark studies reveals that CSI ETABS is the most widely adopted platform (used in 65% of papers), followed by Bentley STAAD.Pro (20%), CSI SAP2000 (10%), and CSI Detail (5%). ETABS is especially popular because it models thick plate shell elements, automated rigid diaphragms, and nonlinear plastic hinges directly within a building-focused workflow.

Engineers apply four main analytical procedures to these structures: Equivalent Static Analysis (ESA), Linear Dynamic Response Spectrum Analysis (RSA), Nonlinear Static Pushover Analysis (NSP), and Dynamic Time-History Analysis (THA). Equivalent static analysis simplifies earthquake loading into a linear inverted-triangular lateral force distribution. While simple, ESA assumes a regular structure oscillating in its fundamental mode. In a floating column building, localized stiffness loss causes higher modes to dominate, meaning ESA consistently underestimates lateral drift and transfer girder stresses.

Response Spectrum Analysis improves on static methods by combining multiple dynamic mode shapes through the Complete Quadratic Combination (CQC) rule. However, RSA remains a linear-elastic method and cannot predict how concrete cracks, yields, or redistributes forces during intense shaking. Nonlinear Static Pushover Analysis addresses this limitation by applying monotonic lateral loads in small steps until the structure pushes into deep inelastic deformation. Plastic hinges are assigned to beams and columns following FEMA-356 and ASCE 41-17 standards. Using the ATC-40 Capacity Spectrum Method, the building's base shear versus roof displacement capacity curve is overlaid onto the seismic demand spectrum in Acceleration-Displacement Response Spectrum (ADRS) format to determine the structural performance point.

For critical infrastructure, Nonlinear Dynamic Time-History Analysis applies actual earthquake acceleration records step-by-step. Recent investigations also incorporate Soil-Structure Interaction (SSI). Modeling flexible foundation soil with Winkler springs shows that foundation rocking elongates the natural period and increases lateral roof drift by 18% to 25% over fixed-base assumptions.

Seismic Response Metrics and Observed Damage Patterns

Evaluating research on a G+10 reinforced concrete building model highlights how floating columns degrade key structural metrics. Four framing models were analyzed: a baseline continuous frame (NFC), a center floating column model (IFC), an exterior edge model (OFC), and a corner model (CFC). In all cases, floating columns significantly magnified lateral storey displacement and drift.

Under Seismic Zone III response spectrum loading, the regular frame had a maximum roof displacement of 40.2 mm. Moving the floating column to the center increased roof displacement to 48.9 mm (+21.6%). Placing it at the outer edge pushed displacement to 57.8 mm (+43.8%), while the corner configuration reached 64.9 mm—a 61.4% increase. More alarming is the inter-storey drift ratio at the ground-level transfer floor. While the regular building maintained a drift ratio of 0.0018 (comfortably below the IS 1893:2016 limit of 0.0040), the edge and corner floating column models spiked to

0.0048 and 0.0062 respectively. This sudden drift jump violates codal safety limits by more than 50% and creates severe second-order P-Delta overturning hazards.

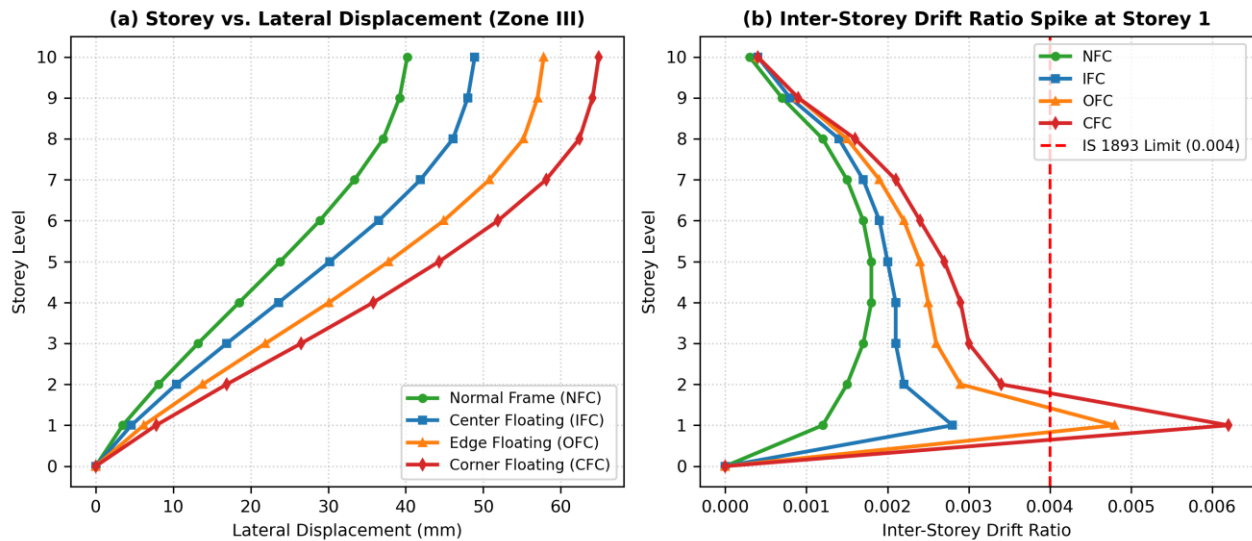


Fig. 2 - Seismic response profiles for G+10 building configurations: (a) Lateral storey displacement across height; (b) Inter-storey drift ratio profiles showing the severe drift spike at Storey 1 compared with the IS 1893:2016 limit of 0.004.

Table 2 - Seismic response metrics and code compliance comparison for G+10 RC building configurations.

Configuration Model	Floating Column Position	Roof Displacement (mm)	Max Inter-Storey Drift	Codal Drift Compliance	Natural Period (s)	Transfer Hinge State
Normal Frame (NFC)	None (Continuous Columns)	40.2 mm (Baseline)	0.0018 (Uniform across height)	Fully Compliant (Below 0.0040)	0.82 s	Elastic / Minor IO
Center Floating (IFC)	Storey 1 Interior Bay (C3)	48.9 mm (+21.6%)	0.0028 (Moderate transfer peak)	Compliant (Margin: 30%)	0.94 s (+14.6%)	IO transitioning to LS
Edge Floating (OFC)	Storey 1 Exterior Bay (B1)	57.8 mm (+43.8%)	0.0048 (Spike at Storey 1)	Non-Compliant (+20% violation)	1.05 s (+28.0%)	Life Safety (LS)
Corner Floating (CFC)	Storey 1 Corner Bay (A1)	64.9 mm (+61.4%)	0.0062 (Severe transfer spike)	Dangerous Violation (+55%)	1.13 s (+37.8%)	Collapse Prevention (CP)

Dynamic base shear behaves counter-intuitively. Eliminating columns from lower storeys reduces the building's total dead weight, which lowers static base shear calculated from formula $V_b = A_h * W$. At the same time, the loss of lateral stiffness lengthens the building's fundamental natural period (T) by 25% to 38% (increasing from 0.82 s in NFC to 1.13 s in CFC). Because earthquake response spectra slope downward at longer periods, dynamic spectral acceleration drops, reducing dynamic base shear by 12% to 24%. While a smaller base shear might appear favorable at first glance, it reflects a dangerous loss of frame stiffness, not improved safety.

Under pushover analysis, the sequence of plastic hinge formation reveals serious structural flaws. In a conventional frame, ductile hinges form gradually in floor beams while columns stay elastic. In the floating column frame, hinges yield prematurely in the transfer girders and stilt columns at low drift levels. These critical transfer hinges rapidly degrade from Immediate Occupancy (IO) to Collapse Prevention (CP) states while upper-level beams remain undamaged, completely reversing the desired Strong-Column Weak-Beam design hierarchy.

Lateral Load Resisting Systems and Structural Retrofitting

Because floating columns interrupt the direct vertical path of forces, mitigating their seismic risk requires adding dedicated lateral-force resisting elements that restore stiffness and energy dissipation. Research across literature focuses on four main interventions: reinforced concrete shear walls, structural steel bracing, transfer girder strengthening, and column section enlargement.

Reinforced concrete shear walls provide the highest lateral stiffness. Acting as stiff vertical cantilevers, continuous shear walls attract 75% to 90% of total seismic storey shear away from the flexible frame. This relieves stilt columns and transfer girders of large lateral shears, allowing them to carry primarily axial gravity loads. Studies show that placing L-shaped shear walls at exterior corners is most effective because it increases the building's torsional radius of gyration, neutralizing the eccentricity caused by corner floating columns. Overall, continuous shear walls reduce roof displacements by up to 84.6% and inter-storey drifts by 71.5%, bringing performance well within IS 1893:2016 limits.

Where architectural plans require open perimeter walls for driveways or display windows, structural steel bracing offers a practical alternative. Steel braces form a triangular truss mechanism that resists lateral loads through axial tension and compression rather than portal bending. Steel X-bracing achieves a 68.2% reduction in lateral displacement and a 62.0% cut in inter-storey drift, while adding less than 5% to the total structural dead weight. Chevron (inverted-V) bracing performs moderately well (58.5% displacement reduction) but tends to induce secondary vertical bending in beams when compressive braces buckle.

Transfer girders themselves can be strengthened using external post-tensioning tendons, steel haunch brackets at column junctions, or thickened concrete cross-sections. Steel haunch brackets shorten the effective girder span and absorb high corner shear stresses. While enlarging lower column dimensions improves member capacity, it only reduces overall drift by 32% to 37%, proving less effective than shear walls or steel bracing.

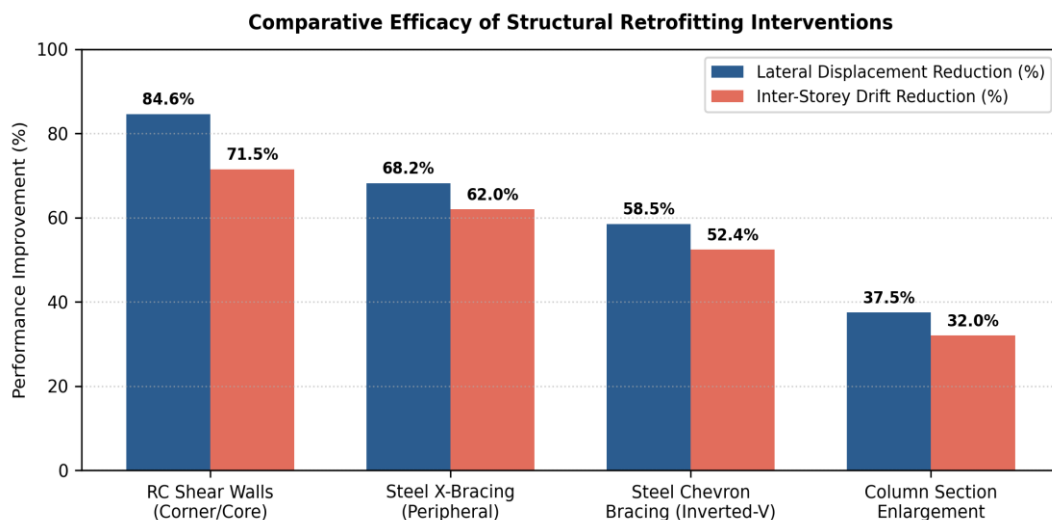
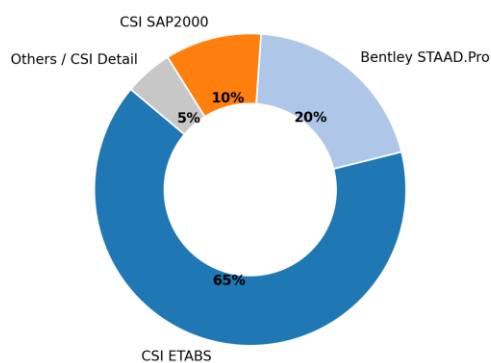


Fig. 3 - Comparative effectiveness of structural retrofitting systems in reducing lateral displacement and inter-storey drift.

Comparative Synthesis and Meta-Analysis of Benchmark Literature

To provide a broad perspective on current knowledge, twenty peer-reviewed research papers investigating floating columns were analyzed. The surveyed buildings range in height from low-rise G+3 frames up to high-rise G+18 structures across Seismic Zones III, IV, and V. Over the last decade, analytical methodology has evolved significantly: early studies (2014–2016) relied primarily on linear equivalent static and response spectrum methods, whereas recent investigations (2020–2026) emphasize nonlinear static pushover and dynamic time-history analyses to examine plastic hinge sequences and energy dissipation.

(a) FEA Software Adoption in 20 Benchmark Studies



(b) Seismic Analysis Method Distribution

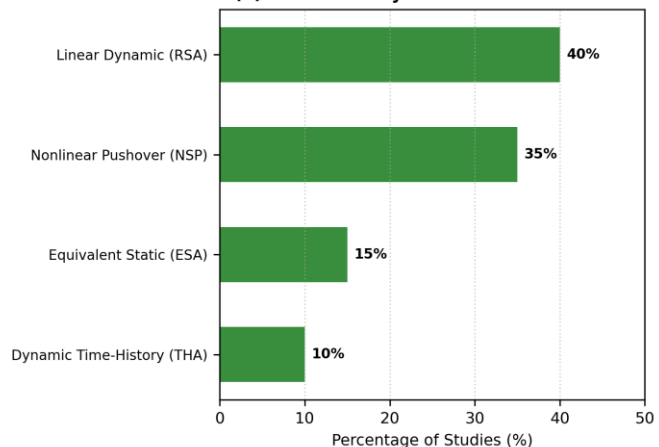


Fig. 4 - Literature trend analysis across 20 benchmark studies: (a) Finite element software adoption share; (b) Distribution of seismic analysis procedures.

Table 3 - Meta-analysis and comprehensive synthesis of 20 benchmark studies on floating columns (2014–2026).

Author(s) & Year	Building Height	Software	Methodology	Evaluated Layouts	Retrofit Solution	Core Research Findings
Lingampally & Veerupakshi (2022)	G+10 RC	ETABS 2018	Linear Dynamic RSA	Corner, Edge, Center FC	Positioning	Corner FC produced highest drift; center location minimized dynamic eccentricity.
Subhashini et al. (2022)	G+7 RC	ETABS	RSA (Zones III–V)	Ground stilt floating columns	Shear Wall vs Bracing	Shear walls reduced displacement by 85% and drift by 70%, outperforming bracings.
Tom et al. (2022)	G+6 RC	ETABS	Static & Dynamic RSA	Conventional vs. Stilt FC	Transfer beam sizing	FC increased displacement by 12.5% and decreased static base shear by 51.4%.
RaghuNandan et al. (2020)	Multi-storey	ETABS 2015	Nonlinear Pushover	Normal, Corner, Edge	IFC, Capacity curves	FC reduced seismic capacity; plastic hinges initiated prematurely at corner FC.
Patange et al. (2023)	Multi-storey	ETABS / STAAD	3D Finite Element	Two different floor positions	Joint detailing	FC amplified support reactions and moments; confirmed close software agreement.
Patil et al. (2025)	Multi-storey	ETABS	Response Spectrum	Conventional vs. Stilt FC	Transfer girder depth	FC amplified storey drift by 48% and displacement by 37.5%; ductile detailing vital.
Varma & Bhalchandra (2016)	G+3 RC	ETABS 2015	Nonlinear Pushover	Regular vs. Floating column	Performance point	FC reduced global lateral capacity and initiated early plastic hinge yielding.
Kulkarni et al. (2020)	Review Study	Literature	Analytical Review	Various reported layouts	Shear wall & bracing	Confirmed corner FC is most vulnerable; highlighted lack of experimental testing.
Mahajan & Gaud (2021)	G+18 RC	ETABS	RSA Dynamic	Irregular plan with FC	Corner L-shear walls	L-shaped corner shear walls restored symmetry and suppressed torsional drift.
Bhende & Kawde (2025)	Multi-storey	STAAD.Pro	Static & RSA	Regular vs. Floating columns	Member resizing	FC increased displacement by 45%; transfer girders require rigorous shear design.
Bhensdadia & Shah (2015)	G+4 RC	SAP2000	Nonlinear Pushover	Ground soft-storey with FC	Infill masonry struts	Soft-storey triggered sudden inter-storey drift failure before design base shear.
Shaik & Prashanth (2018)	G+5 RC	ETABS	Linear Dynamic RSA	Floating column frame	Steel X-bracing	Steel X-bracing reduced lateral displacement by 65% with minimal added mass.
Chandran & Antony (2015)	Multi-storey	ETABS	Comparative RSA	Regular vs. Irregular plans	Shear wall core	Re-entrant corners combined with FC doubled torsional moment demands.
Prakash et al. (2024)	G+11 RC	ETABS / Detail	Response Spectrum	Unsymmetrical plan with FC	Dual wall-frame	Integrated shear walls restored drift compliance under IS 1893:2016 limits.

Author(s) & Year	Building Height	Software	Methodology	Evaluated Layouts	Retrofit Solution	Core Research Findings
Jagan & Visuvasam (2024)	Multi-storey	SAP2000	Nonlinear SSI + THA	Floating column on soil	Subgrade springs	Soil-structure interaction lengthened period and increased lateral drift by 22%.
Kumar et al. (2026)	G+9 RC	ETABS	RSA Dynamic	Corner vs. Center FC	Haunch girders	Corner FC amplified torsional drift; haunch girders reduced transfer shear by 28%.
Tijare & Varghese (2026)	Multi-storey	STAAD.Pro	Matrix Displacement	Multi-level floating floors	Transfer trusses	Multi-level FC caused cumulative load transfer, doubling lower girder moments.
Nanabala et al. (2014)	G+5 RC	SAP2000	Static & Pushover	Normal vs. Floating frame	Column jacketing	Floating column shifted plastic hinges to transfer beams, violating SCWB.
Rahman & Singla (2015)	Multi-storey	STAAD.Pro	Static & Dynamic	Various storey FC locations	Section enlargement	Displacement increased with storey height; ground-floor FC showed highest drift.
Hiba et al. (2021)	Multi-storey	ETABS	Dynamic RSA	Floating column frame	Chevron & X-bracing	X-bracing outperformed Chevron bracing, reducing storey drift by 62%.

Critical Research Gaps and Future Horizons

While computer modeling has expanded our understanding of floating columns, major gaps remain between numerical simulations and real-world physical behavior. Five critical areas warrant priority in future structural engineering research:

First, more than 90% of published studies focus exclusively on cast-in-place reinforced concrete frames. Concrete transfer girders carry a high self-weight, which adds substantial dead mass at upper floor levels and drives up seismic base shear. Replacing concrete transfer girders and columns with Steel-Concrete Composite (SCC) members—such as Concrete-Filled Steel Tubes (CFST) or encased steel girders—offers substantial benefits. CFST columns deliver superior axial capacity and ductility with compact cross-sections, satisfying Strong-Column Weak-Beam rules without eating into parking clearances. Combining composite girders with Light-Gauge Steel (LGS) framing on upper residential storeys can reduce tributary mass by 40% to 60%, directly lowering transfer girder forces.

Second, current pushover studies predominantly apply smooth far-field ground motion profiles. Near-fault earthquakes (within 10 to 15 km of a rupture) deliver powerful forward-directivity velocity pulses. These velocity pulses strike the building like a sudden dynamic impact, causing high strain-rate shear demands in transfer joints before forces can distribute smoothly throughout the frame. Nonlinear time-history investigations using pulse-like records are urgently needed to develop proper near-fault design factors.

Third, there is an acute lack of experimental test data. Almost all published conclusions rely purely on finite element simulations. Full-scale laboratory shake-table tests and cyclic testing of deep transfer girder-column joints are necessary to validate software hinge models and confirm actual shear-slip mechanisms under cyclic loading.

Fourth, most models assume idealized rigid foundations. In reality, soft clay or loose sand foundations undergo significant rocking. Nonlinear Soil-Structure Interaction (SSI) models that capture soil plasticity and foundation uplift must be integrated into standard practice. Finally, multi-hazard assessments evaluating combined earthquake shaking, high wind pressures, and fire exposure will provide a more complete picture of structural resilience.

Practical Engineering Protocol and Design Directives

To bridge the gap between academic findings and practical design office workflow, the synthesized literature supports five clear, mandatory design directives for practicing structural engineers:

Rule 1: Strict Prohibition of Corner and Edge Floating Columns in High Seismic Zones

Under no circumstances should Corner (CFC) or Outer Edge (OFC) floating columns be permitted in Seismic Zones IV and V. Their severe torsional eccentricity and high peripheral drift magnify collapse risks beyond acceptable engineering margins. In high-hazard zones, floating columns should be restricted exclusively to central interior bays where symmetry is preserved.

Rule 2: Spatial Hierarchy and Transfer Level Sizing

Where floating columns are architecturally unavoidable, they must be situated as low as possible in the elevation (preferably at the first floor) and supported on continuous, deep transfer girders designed with span-to-depth ratios $L/D \leq 2.5$. Multi-level staggered floating columns that transfer forces across successive storeys should be rejected.

Rule 3: Mandatory Dual Lateral Load Resisting Systems

Any building incorporating floating columns must integrate continuous reinforced concrete shear walls or structural steel X-bracing extending uninterrupted from roof to foundation. These lateral elements must be sized to resist at least 80% of total design lateral base shear, relieving the discontinuous frame of shear overloads.

Rule 4: Enhanced Capacity Design and Strict Ductile Detailing

In accordance with IS 1893:2016 Clause 7.2.5, transfer girders and stilt columns must be designed for 2.5 times the calculated linear forces unless continuous shear walls are provided. All transfer joints must satisfy IS 13920:2016 ductile requirements: confining hoop spacing not exceeding 100 mm, 135-degree seismic ties, side-face crack-control reinforcement, and Strong-Column Weak-Beam flexural strength ratios of $\sum M_c / \sum M_b \geq 1.4$.

Rule 5: Compulsory Nonlinear Pushover Verification

Standard equivalent static calculations must never be used alone. For any building with floating columns, engineers must perform 3D Response Spectrum Analysis combined with Nonlinear Static Pushover Analysis to confirm that inter-storey drift ratios remain below 0.0040 and plastic hinges in transfer girders remain safely within Immediate Occupancy (IO) or Life Safety (LS) limits.

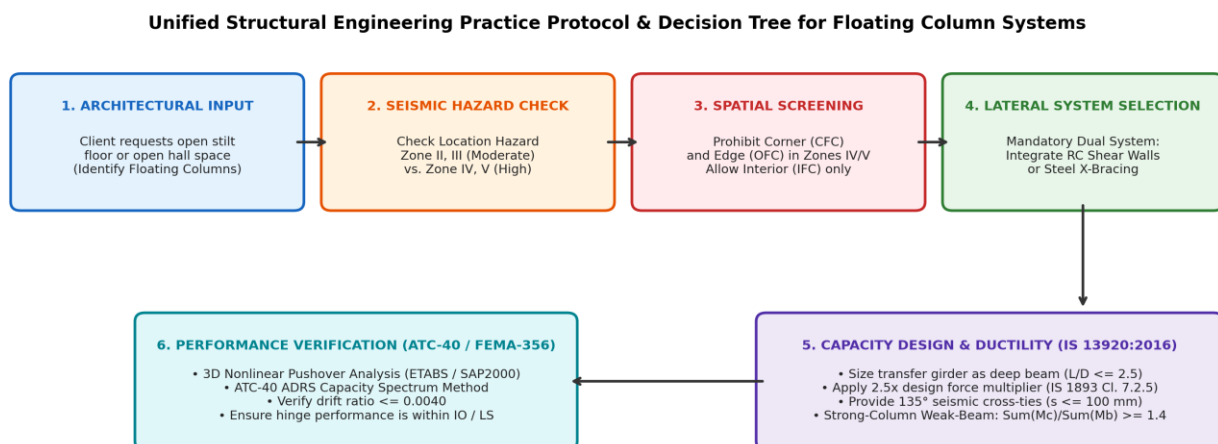


Fig. 5 - Practical structural engineering decision tree and design verification workflow for floating column building projects.

Concluding Remarks and Research Gaps

Concluding Remarks on Seismic Performance

Evaluating twenty benchmark studies alongside the G+10 reinforced concrete building model confirms that floating columns fundamentally compromise seismic safety by severing the continuous vertical load path. Eliminating lower-level columns forces transfer girders to carry heavy concentrated compressive forces through flexure and shear, creating localized stress singularities and an abrupt soft-storey stiffness drop. Under earthquake excitation, this discontinuity increases lateral roof displacement by up to 61.4% and causes inter-storey drift ratios at the ground transfer level to spike to 0.0062, severely exceeding the IS 1893:2016 safety threshold of 0.0040. Corner and exterior edge floating columns are especially hazardous because the asymmetrical loss of perimeter stiffness shifts the Center of Rigidity away from the Center of Mass, inducing intense dynamic torsional twisting ($T = Vb * ed$). Under nonlinear pushover analysis, plastic hinges yield prematurely in transfer girders and stilt columns from Immediate Occupancy to Collapse Prevention while upper-floor beams remain undamaged, directly inverting the Strong-Column Weak-Beam hierarchy ($\sum M_c / \sum M_b \geq 1.4$).

Incorporating continuous reinforced concrete shear walls or structural steel X-bracing successfully mitigates this vulnerability by absorbing 75% to 90% of total lateral shear, reducing displacement by up to 84.6% and drift by 71.5%.

Critical Research Gap Findings

Despite extensive computer simulation, five critical research gaps remain unaddressed across the published literature. First, over 90% of studies focus strictly on monolithic cast-in-place concrete, ignoring the potential of Steel-Concrete Composite (SCC) members—such as Concrete-Filled Steel Tube (CFST) columns and Light-Gauge Steel (LGS) superstructures—to cut structural dead weight by 40% to 60% and directly relieve transfer forces. Second, existing analyses rely almost exclusively on smooth far-field response spectra, overlooking near-fault forward-directivity velocity pulses that strike transfer joints as sudden dynamic impacts. Third, there is an acute empirical void: none of the benchmark studies provide physical shake-table validation or cyclic test data on full-scale transfer joints to verify software hinge models against actual concrete spalling and rebar buckling. Finally, standard practice continues to assume idealized rigid foundations, neglecting Soil-Structure Interaction (SSI) on soft cohesive soils where foundation rocking amplifies drift demands by an additional 18% to 25%, as well as multi-hazard interactions combining seismic ground motions with wind buffeting and blast loads.

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