Seismic Performance of Tall Building with RC Floating Columns and Shear Wall

[1] Siddhant R. Pol*, [2] Dr. S. P. Patil, [3] Dr. R. M. Desai
[1] Department of Civil Engineering, Sanjay Ghodawat University, *A/P Atigre, Kolhapur, Maharashtra 416118, INDIA*
[2] Department of Civil Engineering, Sanjay Ghodawat University, *A/P Atigre, Kolhapur, Maharashtra 416118, INDIA*
[3] Department of Civil Engineering, Sanjay Ghodawat University *A/P Atigre, Kolhapur, Maharashtra 416118, INDIA*

Abstract

This study presents a comprehensive seismic evaluation of tall reinforced concrete buildings featuring floating columns, with and without shear walls, using ETABS 2019 and design criteria per IS 1893 (Part 1):2016. Three structural models were analyzed a standard framed building, one with first-floor floating columns, and a configuration combining floating columns with strategically placed shear walls. Utilizing both response spectrum and pushover methods, results demonstrate that the introduction of floating columns significantly increases the fundamental period, story drift, and lateral displacement, and concentrates axial forces on the underlying conventional columns as reported in prior studies highlighting irregular structural behaviors under seismic loading. Conversely, incorporation of shear walls markedly enhances lateral stiffness (by up to ~70%), substantially mitigating displacements and drifts compared to the floating-column-only model, aligning with documented stiffness improvements in similar configurations. Pushover analysis consistently yields higher base shear values than linear dynamic estimates. While all models attain performance points, the floating-column-plus-shear-wall model approaches Immediate Occupancy or Life Safety levels, whereas the others correspond more closely to Life Safety or Collapse Prevention thresholds, contingent on detailing and material quality. These findings underscore that although floating columns may reduce dead load, pairing them with shear walls can substantially restore seismic resilience in tall RC buildings.

Keywords: ETABS, Floating column, Nonlinear analysis, Pushover curve, Shear wall, Tall Building.

1. INTRODUCTION

Many urban multi-storey buildings feature an open first floor to accommodate parking, lobbies, or halls, leading to architectural irregularities that significantly influence seismic behavior. Introducing floating columns vertical members that rest on transfer beams rather than extending to the foundation creates discontinuities in load paths, which heighten fundamental periods, story drifts, and lateral displacements under seismic loading. To mitigate these adverse effects, shear walls vertical, stiff structural elements designed to resist lateral forces are often incorporated to enhance rigidity and promote uniform strength distribution. This study evaluates three configurations a conventional frame, a frame with floating columns, and a combined floating-column-plus-shear-wall system using response spectrum analysis in ETABS in accordance with IS 1893 (Part 1) 2016. Key responses examined include natural period, story displacement, drift, and base shear to assess the relative effectiveness of shear walls in restoring seismic resilience to irregular tall RC structures.

Several studies have highlighted the notable impact of tall building with floating column on the seismic behavior of RC frames. Lina et.al (2020) This study introduces an innovative seismic-risk mitigation system that integrates base isolation with Earthquake Early Warning (EEW) signals. The system utilizes electromagnetic shear keys to lock and release the base isolator based on EEW signals or on-site accelerometer data, enhancing vibration isolation effectiveness. Kazeminezhada et.al (2020) This study introduces a smart seismic-risk mitigation concept that combines base isolation with an Earthquake Early Warning (EEW) system: under normal conditions shear keys lock the isolator; upon EEW or sensor alert, the isolator is released and then re-locked when shaking stops, maximizing vibration isolation effectiveness. Laboratory-scale shake-table tests on a six-story frame using historical earthquake records confirm that this adaptive system substantially reduces seismic responses compared to conventional base isolation. Nakamura and Okada (2019) This review examines seismic isolation and response control methods employed in buildings to enhance earthquake resilience. It highlights three types of laminated rubber bearings and three damping devices: steel hysteretic, viscoelastic, and viscous fluid dampers. These techniques aim to safeguard both structural integrity and occupant safety. The effectiveness of these methods has been validated through shaking table tests, structural health monitoring, and earthquake response analyses. Cancellara and Angelis (2019) This review examines seismic isolation and response control methods employed in buildings to enhance earthquake resilience. It highlights three types of laminated rubber bearings and three damping devices: steel hysteretic, viscoelastic, and viscous fluid dampers. These techniques aim to safeguard both structural integrity and occupant safety. The effectiveness of these methods has been validated through shaking table tests, structural health monitoring, and earthquake response analyses. Kumara et.al (2019) This review evaluates the seismic performance of special concentric X-braced frames in 6-, 9-, 12-, and 15-story buildings, with tension bracings designed for 100%, 70%, and 60% of base shear. The Demand-to-Capacity Ratio (DCR) was varied 0.4 0.7 for beams and columns, and 0.6 0.9 for bracings and nonlinear pushover analyses were conducted to assess frame strength and ductility. Results indicate that column DCR values of 0.4 0.5 paired with bracing DCR of 0.8 0.9 yield optimal performance, while frames designed for 60% base shear during major seismic events maintain acceptable displacement levels

Narjabadifam et.al (2019) This study investigates the seismic performance of base-isolated buildings with 3, 7, and 11 storey steel and RC frames under near- and far-field ground motions using nonlinear time-history analysis across 84 models, examining base shears, story displacements, and accelerations. Results reveal that while isolation effectiveness strongly depends on superstructure mass and stiffness, isolation damping plays a more significant role, and Friction Pendulum Systems (FPS) outperform High-Damping Rubber Bearings (HRB), particularly under near-field excitations. Kun Ye et.al (2019) This study introduces a Direct Displacement–Based Design (DDBD) procedure for base-isolated buildings using lead rubber bearings, incorporating a 2-degree-of-freedom equivalent model to relate displacement targets to structural parameters via modal and response-spectrum analyses. Numerical validation, including nonlinear time-history simulations, confirms that this method is straightforward, reliable, and effectively meets predefined displacement thresholds, offering improved design efficiency compared to existing approaches. Khana (2019) This study compares the seismic performance of an 8-storey structure equipped with three passive isolators High Damping Rubber Bearing (HDRB, 13%), Low Damping Rubber Bearing (LDRB, 3%), and Lead Core Rubber Bearing (LCRB, 25%) using MATLAB state-space modeling under near-field and far-field earthquakes to evaluate global drift, inter-story drift, and acceleration transmissibility. Results indicate that dynamic response significantly depends on excitation source, prompting designers to tailor isolator damping or use hybrid dampers to minimize both deformation and transmissibility ratios. Guneyisi (2018) This review assesses the seismic performance of five and ten storey steel moment-resisting frames comprising OMF, IMF, and SMF types using friction dampers (FDs), base isolation with lead rubber bearings (LRBs), and their hybrid combination. Nonlinear time-history simulations demonstrate that coupling FDs with LRBs markedly improves seismic resilience by reducing structural damage and satisfying serviceability limits more effectively than either strategy alone. Jumoad et.al (2018) This study evaluated the seismic performance of a ten-story RC hospital building designed per the 2015 National Structural Code of the Philippines using time-history analysis in Kantan software. Results showed that base isolation significantly reduced structural responses, with interstory drift, shear force, and acceleration reductions of up to 77%, confirming the effectiveness of lead dampers in dissipating seismic energy. Patil, and Sangle (2015) This review compares the seismic performance of various bracing systems MRFs, CBFs, VBFs, XBFs, and ZBFs in 15- to 35 story high-rise steel buildings using nonlinear static pushover analysis. Results indicate that CBF, VBF, and ZBF systems notably enhance structural performance in terms of story displacement, drift, base shear, and performance point, outperforming traditional moment-resisting frames.

Floating columns are vertical elements that rest on beams instead of starting from the foundation, causing concentrated loads transferred horizontally to the supporting beams and columns below, which must be strengthened accordingly. Shear walls are vertical structural elements designed to resist lateral forces like seismic or wind loads, typically spanning from the ground to the top of a building, and are essential in high-rise constructions to reduce lateral displacements. These walls act as stiffeners, transferring horizontal loads safely to the foundation, especially when there is a significant offset between the building's center of gravity and the load. Shear walls are often thick reinforced.

2. METHODOLOGY FOR STUDY

2.1 Non-linear modelling

The reinforced concrete (RC) frame is modeled using two-node finite elements to represent beams and columns. To incorporate material nonlinearity, the lumped plasticity approach is used, where nonlinear hinges are defined at the ends of the members to simulate localized plastic deformations. Flexural hinges are modeled as deformation-controlled, while shear hinges are treated as force-controlled elements. For columns, flexural hinges with coupled degrees of freedom (P-M2-M3) are defined to account for the interaction between axial force and biaxial bending moments. In the case of beams, uncoupled M3 hinges are assigned, considering bending about the major axis only. The Auto Hinge feature in Etabs is used to automatically assign hinge properties to RC members based on standard performance criteria and anticipated plastic behavior.

2.2 Nonlinear Seismic Analysis of Structure

Nonlinear static (pushover) analysis is a simplified yet effective method for evaluating the inelastic seismic performance of reinforced concrete (RC) frame structures. In this method, gradually increasing lateral loads are applied to the structure to examine its behavior beyond the elastic range. The key outcome is a capacity curve that represents the relationship between base shear and roof displacement. Pushover analysis helps identify critical structural vulnerabilities, potential failure mechanisms, and overall deformation capacity. It also provides essential insights into strength capacity, stiffness degradation, and ductility. With these results, engineers can assess whether the structure meets specific performance objectives, such as Life Safety (LS) or Collapse Prevention (CP). The analysis continues until the structure either reaches a predefined target displacement or fails. Although more complex nonlinear dynamic analyses are available, pushover analysis offers a less intricate approach that still effectively evaluates seismic performance.

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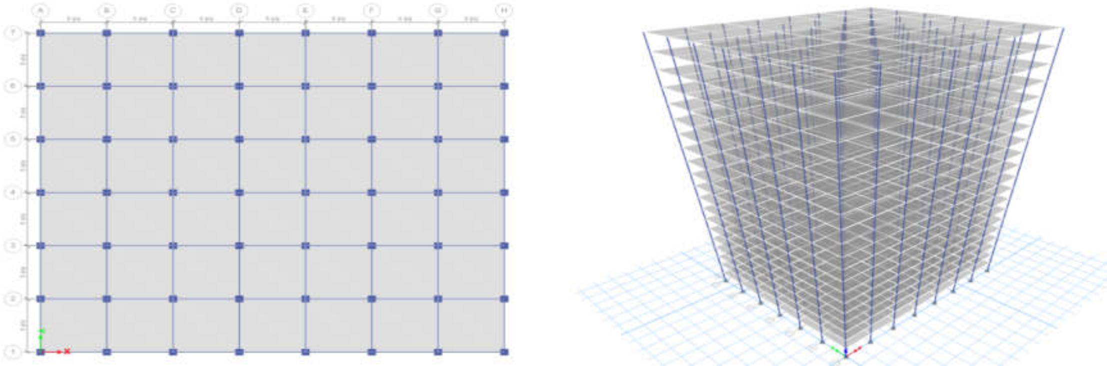
3 Structure Modelling and Analysis

3.1 RC Frame Model Geometry and Structural Design

In this study, a high-rise reinforced concrete (RC) frame structure with 20 stories (G+20) and an overall height of 64 meters is modeled and analyzed. The building has a rectangular plan area of 1050 m², with plan dimensions of 35 m × 30 m. The structural components consist of columns measuring 600 mm × 600 mm, beams sized at 300 mm × 450 mm, and slabs with a thickness of 150 mm. The materials used include M25 grade concrete and Fe415 grade steel. The structure is located in Seismic Zone V, considering an importance factor of 1.0, a response reduction factor of 5, and medium-type soil (Type II) as per IS 1893 guidelines. The unit weight of concrete is taken as 25 kN/m³. The detailed structural model, including the plan, elevation, is illustrated in figure 1.



(a) **(b)**

Figure 1. *(a) Plan; (b) Elevation*

Three high-rise structural models were developed to evaluate the effects of vertical irregularities and lateral load–resisting elements on seismic performance:

Model M1 (Baseline RC Frame)

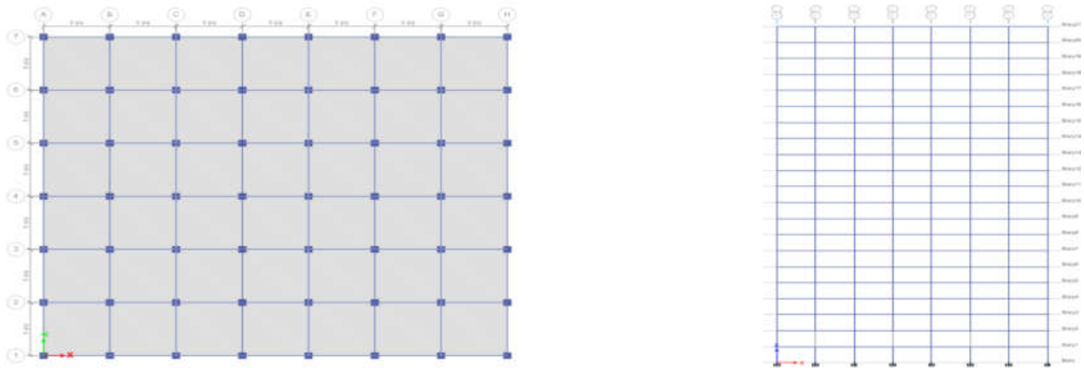
- A conventional reinforced-concrete (RC) moment-resisting frame building with 20 stories above grade (G+20).
- Regular geometry and uniform mass distribution; no special vertical irregularities or supplementary lateral elements.

Model M2 (Floating–Column Configuration)

- Identical to M1 except for the introduction of floating columns at the first-floor level.
- These floating columns create a discontinuity between ground and first floor, resulting in a vertical irregularity and altered load path that significantly affects stiffness and story drift response under seismic loads.

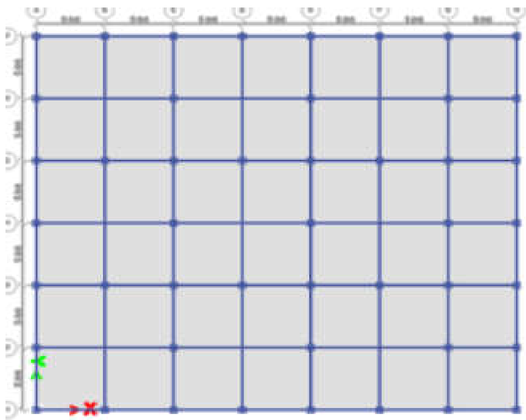
Model M3 (RC Frame with Corner Shear Walls)

- Based on the M1 frame, augmented with RC shear walls located at the four building corners.
- These shear walls act as lateral load–resisting elements, enhancing stiffness, reducing inter-story drift, and improving overall seismic stability compared to the baseline frame.

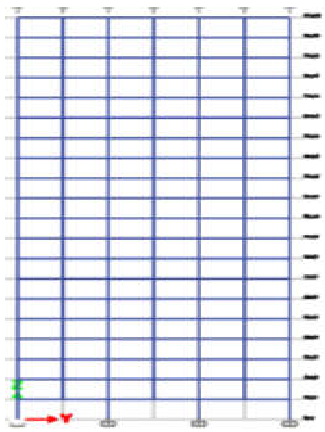


(a) Plan (b) Elevation

Model M1 (Baseline RC Frame)

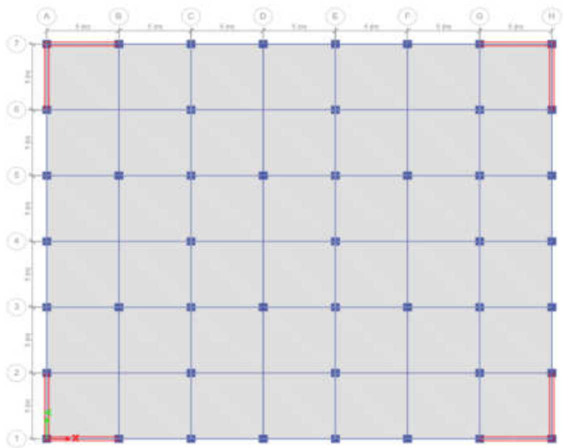


(c) Plan

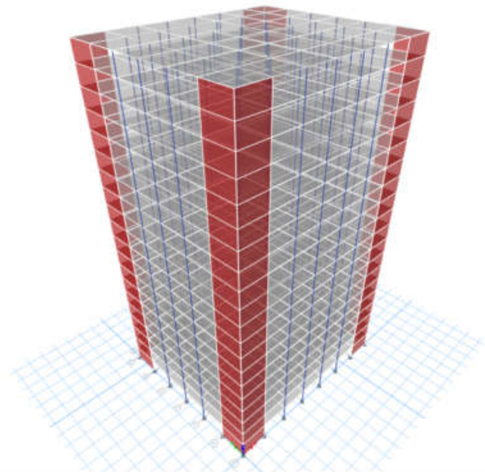


(d) Elevation

Model M2 (Floating–Column Configuration)



(e) Plan



(f) Elevation

Model M3 (RC Frame with Corner Shear Walls)

Figure 2. *Models plan and elevation*

4 Result

4.1 Time Period

The seismic response of the three examined structural configurations M1 (simple RC frame), M2 (RC frame with floating columns), and M3 (RC frame with floating columns augmented by shear walls) reveals distinct differences in fundamental natural periods. According to the response spectrum analysis, the bare-frame model (M1) exhibits a time period of 4.409 s, which slightly decreases to 4.438 s upon introducing floating columns (M2), indicating a minor increase in system flexibility. However, the introduction of shear walls alongside floating columns (M3) significantly reduces the time period to 3.501 s, reflecting a marked increase in overall lateral stiffness. The reduction in period by approximately 1.0 s relative to M2 underscores the effectiveness of shear-wall integration in mitigating the detrimental flexibility introduced by floating-column discontinuities. These findings align with established studies showing that shear-wall systems not only bolster lateral resistance but also substantially reduce fundamental time periods, thereby improving seismic performance

Table 1. *fundamental time period*

Sr. no	Model	Time
1	Model -1	4.409
2	Model -2	4.438
3	Model -3	3.501

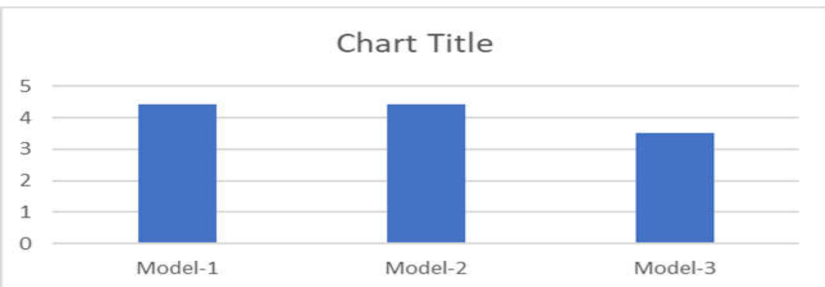


Figure 3. *fundamental time period*

4.2 Storey Displacement

The lateral displacement profile for the three structural models (M-1: simple RC frame, M-2: frame with floating columns, and M-3: frame with floating columns plus shear walls) shows systematic variations across the 20-storey height. At the roof (20th storey), M-1 exhibits a displacement of 0.011 m, which slightly increases to 0.012 m in M-2 indicating added flexibility from the floating-column configuration while M-3, incorporating shear walls, reduces roof drift back to 0.010 m. This trend continues down the elevation: at mid-height (e.g., storeys 10–15), both M-1 and M-2 maintain drifts in the 0.008–0.010 m range, whereas M-3 consistently lowers displacements to 0.004–0.007 m. Toward the base (storeys 1–5), M-1 and M-2 show similar drifts between 0.0004–0.004 m, while M-3 further diminishes these to 0.00008–0.001 m. Across all elevations, the inclusion of floating columns slightly increases displacements relative to the simple frame, but the integration of shear walls in M-3 notably suppresses drifts especially at the to demonstrating enhanced lateral stiffness and superior seismic performance relative to both M-1 and M-2.

Table 2. *Storey Displacement* mm

Story no.	M-1	M-2	M-3
20	0.011	0.012	0.01
19	0.011	0.011	0.01
18	0.011	0.011	0.009
17	0.011	0.011	0.008
16	0.011	0.011	0.008
15	0.01	0.01	0.007
14	0.01	0.01	0.006
13	0.009	0.009	0.006
12	0.009	0.009	0.005
11	0.008	0.008	0.005
10	0.008	0.008	0.004
9	0.007	0.007	0.003
8	0.006	0.006	0.003
7	0.005	0.005	0.002
6	0.005	0.005	0.002
5	0.004	0.004	0.001
4	0.003	0.003	0.001
3	0.002	0.002	0.001
2	0.001	0.001	0.000264
1	0.000398	0.000452	8.17E-05
0	0	0	0

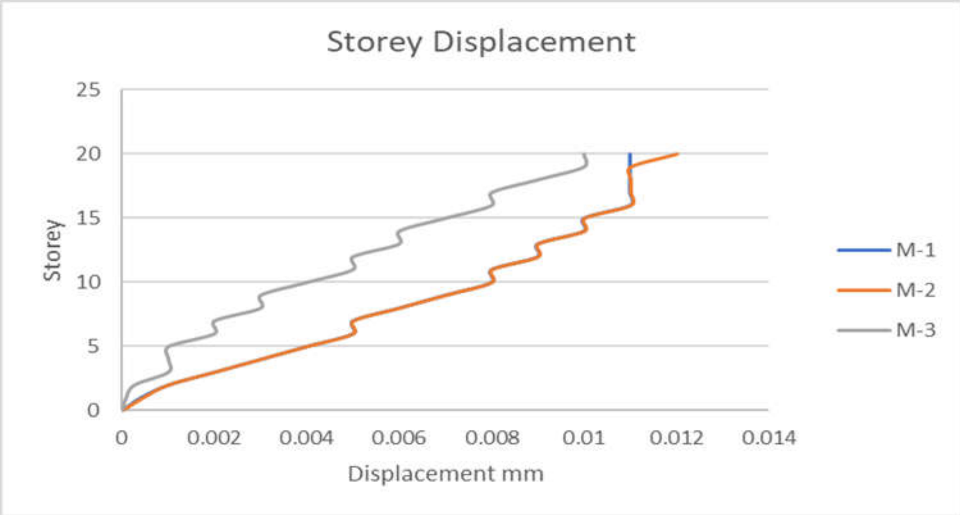


Figure 4. *Store Displacement*

4.3 Pushover Analysis

Pushover analysis is a nonlinear static procedure that incrementally applies predetermined lateral loads to a structural model, capturing its inelastic behavior and developing a capacity or pushover curve. This curve plots base shear against roof (control-node) displacement, effectively summarizing global stiffness degradation, yielding progression, and ductility. As the imposed lateral load rises, localized plastic hinges form at critical sections, prompting force redistribution and structural softening. The resulting pushover curve enables identification of key performance points elastic limit, yield point, ultimate capacity, and collapse initiation crucial for performance-based seismic assessment. By comparing the capacity curve with seismic demand spectra, engineers can determine the target displacement, performance point, and assess seismic adequacy in a simplified yet robust framework

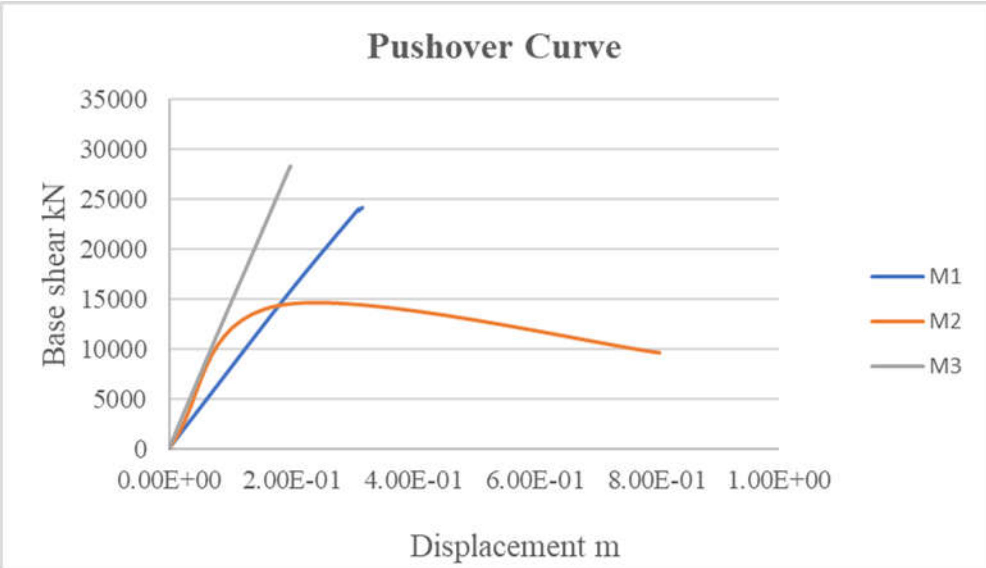


Figure 5. *pushover cure*

In comparing three reinforced-concrete (RC) frame configurations using pushover analysis, Model M2—featuring floating columns showed a much higher yield displacement (0.2824) but a dramatically reduced yield base shear (458.19 kN), indicating poor initial stiffness and significantly compromised lateral capacity; although its ultimate displacement climbed to 0.551 (higher than Model M1's 0.452), its ultimate base shear declined to 20,830.61 kN, and its ductility ratio of 1.95 was comparable to M1's 2.03, meaning M2, despite slightly greater ductility, remains vulnerable under seismic load due to low strength. In contrast, the simple RC frame (M1) provided a balanced combination of stiffness, strength and moderate ductility, while Model M3, which combined floating columns with shear walls, delivered the best seismic performance: the lowest yield displacement (0.0574), the highest yield base shear (8,199.35 kN), a relatively modest ultimate displacement of 0.349, the highest ultimate base shear of 28,348.34 kN, and an outstanding ductility ratio of 6.08—demonstrating that incorporating shear walls into floating-column structures substantially enhances stiffness, strength and energy dissipation capacity, effectively compensating for vertical irregularity and greatly improving seismic resilience.

5 Conclusion

- Structure which having floating column will reduce dead load of structure.
- Story drift is decreasing with increasing height of structure in every model.

- Maximum story drift and displacement values are increasing for floating column.
- As the transfer of load of floating columns to conventional columns because of that axial forces are increasing in conventional columns.
- In comparison to buildings without floating columns, it has been discovered that displacement is higher in buildings with floating columns.
- Providing shear wall will give up to 70 % more strength and stability to the structure. Displacement in shear wall model will be lesser as compare to other structure.
- Installation of shear wall in having lesser height won't be as of economic note.
- Base shear is much higher in pushover analysis than linear analysis.
- The regular RC structure is the most flexible. And structure with only floating column and with floating column + shear walls are much stiffer, likely due to addition of shear walls and floating column.
- Structure with floating column + shear walls (M3) is slightly stiffer than M2, based on slightly shorter periods.
- These changes would result in improved seismic performance (less displacement during earthquakes) but possibly higher acceleration responses.
- All three cases found performance points, suggesting that the structures can survive expected earthquakes but with varying damage levels.
- M 3 is closest to life safety or immediate occupancy performance level, while M 2 and M 1 could correspond to life safety or collapse prevention, depending on detailing and material behavior.

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AUTHOR CONTRIBUTIONS

Siddhant R. Pol: Performed the analysis, modeling, and drafted the manuscript.
Dr. S. P. Patil: Supervised the project and validated the results.
Dr. R. M. Desai: Contributed to review and editing.
All authors reviewed and approved the final manuscript.

REFERENCES

Braga, F., & Laterza, M. (2004). Field testing of a low-rise base-isolated building. Engineering Structures, 26(14), 1997–2003. https://doi.org/10.1016/j.engstruct.2004.06.004

Cancellara, D., & De Angelis, F. (2019). Dynamic assessment of base isolation systems for irregular in-plan structures: Response spectrum analysis vs nonlinear analysis. Engineering Structures, 190, 58–78 https://doi.org/10.1016/j.engstruct.2019.03.018

Charmpis, D. C., Komodromos, P., & Phocas, M. C. (2012). Optimized earthquake response of multi-storey buildings with seismic isolation at various elevations. Earthquake Engineering & Structural Dynamics, 41(5), 755–773. https://doi.org/10.1002/eqe.1167

Choi, H., Kim, W.-B., & Lee, S. J. (2003). A method of calculating the non-linear seismic response of a building braced with viscoelastic dampers. Journal of Earthquake Engineering, 7(4), 485–503. https://doi.org/10.1080/13632460305620

Dubey, S. K. D., & Kute, S. Y. (2013). Experimental investigation on the ultimate strength of partially infilled and steel-braced reinforced concrete frames. International Journal of Advanced Structural Engineering, 5(4), 259–272. https://doi.org/10.1007/s40091-013-0025-7

Erduran, E., Dao, N. D., & Ryan, K. L. (2010). Comparative response assessment of minimally compliant low-rise conventional and base-isolated steel frames. Earthquake Engineering & Structural Dynamics, 39(1), 59–74. https://doi.org/10.1002/eqe.944

Gavin, H. P., & Nigbor, R. L. (2012). Performance of the base-isolated Christchurch Women's Hospital in Darfield (2010) and Christchurch (2011) earthquakes. In Proceedings of the 20th Analysis & Computation Specialty Conference. ASCE.

Guneyisi, E. M., & Deringol, A. H. (2018). Seismic response of friction-damped and base-isolated frames considering serviceability limit state. Journal of Constructional Steel Research, 147, 1–12. https://doi.org/10.1016/j.jcsr.2018.04.007

Hwang, J. S., & Ku, S. W. (1997). Analytical modeling of high damping rubber bearings. Journal of Structural Engineering, 123(2), 238–246.
https://doi.org/10.1061/(ASCE)0733-9445(1997)123:2(238)

Jangid, R. S. (2007). Optimum lead rubber isolation bearings for near-fault motions. Engineering Structures, 29(11), 3007–3016.
https://doi.org/10.1016/j.engstruct.2007.05.003

Kalantari, S. M., Naderpour, H., & Hoseini Vaez, S. R. (2008). Investigation of base-isolator type selection on seismic behavior of structures including story drifts and plastic hinge formation. In 14th World Conference on Earthquake Engineering, Beijing, China.

Khanna, B. L., Azeem, M., Usman, M., Farooq, S. H., Hanif, A., & Fawad, M. (2019). Effect of near and far field earthquakes on performance of various base isolation systems. Earthquake Engineering and Structural Dynamics.

Kumara, M. S., Senthilkumar, R., & Sourabha, L. (2019). Seismic performance of special concentric steel braced frames. Structural Engineering International, 29(3), 267–276.
https://doi.org/10.1080/10168664.2019.1606725

Lan, W., Ma, J., & Li, B. (2015). Seismic performance of steel–concrete composite structural walls with internal bracings. Engineering Structures, 92, 285–295.
https://doi.org/10.1016/j.engstruct.2015.04.040

Lin, Y.-S., Chan, R. W. K., & Tagawa, H. (2020). Earthquake early warning-enabled smart base isolation system. Smart Structures and Systems, 25(4), 453–468.
https://doi.org/10.12989/sss.2020.25.4.453

Maheri, M. R., & Sahebi, A. (1997). Use of steel bracing in reinforced concrete frames. Engineering Structures, 19(10), 811–818.
https://doi.org/10.1016/S0141-0296(96)00116-7

Mkrtycheva, O. V., Dzhinchvelashvili, G. A., & Bunova, A. A. (2014). Study of lead rubber bearings operation with varying height buildings at earthquake. Procedia Engineering, 91, 202–211.
https://doi.org/10.1016/j.proeng.2014.12.185

Nakamura, Y., & Okada, K. (2019). Review on seismic isolation and response control methods of buildings in Japan. Bulletin of Earthquake Engineering, 17(3), 1393–1424.
https://doi.org/10.1007/s10518-019-00606-w

Narjabadifam, P., Tiong, P. L. Y., & Mousavi Alanjagh, R. (2019). Effects of inherent structural characteristics on seismic performances of aseismically base-isolated buildings. Iranian Journal of Science and Technology, Transactions A: Civil Engineering, 43(3), 405–418.
https://doi.org/10.1007/s40996-019-00212-8

Panchal, D., & Purohit, S. (2013). Dynamic response control of a building model using bracings. Engineering Structures, 56, 145–154.
https://doi.org/10.1016/j.engstruct.2013.05.020

Patil, D. M., & Sangle, K. K. (2015). Seismic behaviour of different bracing systems in high-rise 2-D steel buildings. Engineering Structures, 89, 213–227.
https://doi.org/10.1016/j.engstruct.2014.12.033

Providakis, C. P. (2008). Effect of LRB isolators and supplemental viscous dampers on seismic isolated buildings under near-fault excitations. Engineering Structures, 30(7), 2103–2117.
https://doi.org/10.1016/j.engstruct.2008.01.015

Safarizkia, H. A., Kristiawan, S. A., & Basuki, A. (2013). Evaluation of the use of steel bracing to improve seismic performance of reinforced concrete building. Engineering Structures, 47, 729–742.
https://doi.org/10.1016/j.engstruct.2012.11.020

Samali, B., & Kwok, K. C. S. (1995). Use of viscoelastic dampers in reducing wind and earthquake induced motion of building structures. Engineering Structures, 17(9), 609–619.
https://doi.org/10.1016/0141-0296(94)00099-L

Shenton, H. W., & Lin, A. N. (1993). Relative performance of fixed-base and base-isolated concrete frames. Journal of Structural Engineering, 119(11), 3342–3360.
https://doi.org/10.1061/(ASCE)0733-9445(1993)119:11(3342)

Tremblay, R. (2002). Inelastic seismic response of steel bracing members. Engineering Structures, 24(5), 597–611.

https://doi.org/10.1016/S0141-0296(01)00112-2

Ye, K., Xiao, Y., & Hu, L. (2019). A direct displacement-based design procedure for base-isolated building structures with lead rubber bearings. Engineering Structures, 195, 115–126.
https://doi.org/10.1016/j.engstruct.2019.05.036

Youssef, M. A., & Ghaffarzadeh, H. (2007). Seismic performance of RC frames with concentric internal steel bracing. Engineering Structures, 29(10), 2571–2582.
https://doi.org/10.1016/j.engstruct.2006.11.009

Zhu, S., & Zhang, Y. (2008). Seismic analysis of concentrically braced frame systems with self-centering friction damping braces. Journal of Structural Engineering, 134(7), 1128–1136.
https://doi.org/10.1061/(ASCE)0733-9445(2008)134:7(1128)

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