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Parametric Evaluation of Building Height Effects on Seismic Code Compliance of RC Special Moment Frames Using OpenSeesPy

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ABSTRACT

This study presents a parametric evaluation of building-height effects on the global seismic response and initial code-compliance indicators of reinforced concrete Special Moment Frames (RC-SMFs). The work is limited to linear response-spectrum analysis and global screening checks; nonlinear static analysis, non liner time-history analysis, and detailed SNI 2847 member design are outside the present scope. Three OpenSeesPy-based three dimensional models with 6, 9, and 12 stories were developed using the same structural plan, maximum analytical beam span of 9.5 m, Jakarta soft-soil seismic demand, and SNI 1726:2019 design parameters. The novelty of the study is an integrated OpenSeesPy parametric workflow that evaluates modal regularity, modal participating mass ratio, base-shear scaling, design drift, torsional response, and P-Delta stability in one SNI-oriented assessment process. The results show a regular modal sequence for all models, with Mode 1 and Mode 2 dominated by X- and Y- translation and, Mode 3 governed by torsion. As the number of stories increases, the fundamental period increases from 0.365 s to 0.537 s and 0.689 s, while the equivalent lateral force base shear increases from 7,918.73 kN to 11,878.09 kN and 15,837.45 kN. The maximum design drift increases with building height but remains far below the 2.0% allowable limit, while torsion ratios and P-Delta coefficients remain low. Thus, the adopted RC-SMF configuration satisfies the selected linear global screening checks, although final acceptance still requires nonlinear assessment and detailed member design.

INTRODUCTION

Seismic design of reinforced concrete buildings requires a clear understanding of how structural height influences dynamic behavior, lateral deformation, torsional response, and overall code compliance. In earthquake-prone regions, an increase in the number of stories generally leads to a longer fundamental period, larger lateral displacement, and greater sensitivity to inter-story drift and second-order effects. These responses are particularly important for reinforced concrete Special Moment Frames (RC-SMFs), which rely on ductile beam-column mechanisms to dissipate seismic energy. Therefore, the evaluation of building-height effects is relevant not only to estimating structural demand but also to ensuring that the selected frame configuration remains consistent with seismic design requirements.

In the Indonesian design context, seismic-resistant buildings must comply with the provisions of SNI 1726:2019, including response spectrum analysis, modal participation mass requirements, base shear scaling, drift limitation, torsional response control, and P-Delta stability checks. For RC-SMF systems, the seismic force-resisting mechanism must also be supported by appropriate detailing requirements in accordance with reinforced concrete design provisions. Although commercial structural software is widely used in engineering practice, open-source computational platforms such as OpenSeesPy provide an alternative framework for transparent numerical modeling, reproducible analysis, and systematic parametric studies. Through script-based modeling, assumptions regarding geometry, mass distribution, stiffness, boundary conditions, diaphragm constraints, modal classification, and seismic response checks can be explicitly defined and modified.

Previous studies on the seismic response of moment-resisting frames have generally shown that building height significantly influences the fundamental period, base shear distribution, lateral displacement, and inter-story drift demand (Fardis, 2001; Llanos & Delgadillo, 2025). In addition to height effects, structural irregularities such as non-uniform plan geometry, asymmetric stiffness distribution, and long-span framing systems may substantially modify a building's dynamic characteristics (Anil K. Chopra, 2017; Varum Humberto et al., 2022). These irregularities can alter the sequence of dominant vibration modes, redistribute modal mass participation, and increase susceptibility to torsional response under seismic excitation (Calvi et al., 2008; Khosravi Larijani & Tehrani, 2024; Tsegay, 2019). As a result, the interaction between building height and structural irregularity represents an important aspect of structural dynamics that may not be adequately captured by conventional displacement- or drift-based evaluations alone (Filippou & Taucer, 1996). Although OpenSeesPy provides a versatile open-source platform for advanced structural modeling and seismic assessment, its application to systematically evaluates the combined influence of building height on modal characteristics, mass participation ratios, torsional behavior, and seismic code-compliance parameters remains relatively limited (Frank McKenna, 2011; Ibarra et al., 2005; Mazzoni et al., 2007; Yan & Xie, 2025; Zhu et al., 2018). However, many practical studies tend to focus only on a single building configuration or evaluate drift response without sufficiently discussing modal regularity, torsional behavior, modal mass participation, and base shear scaling as an integrated code-compliance process (Blasi et al., 2024; Khosravi Larijani & Tehrani, 2024; Krawinkler & Seneviratna, 1998). In addition, for buildings with irregular plan grids or long-span beam arrangements, the relationship among structural height, modal sequence, and lateral performance should be examined carefully (Khosravi Larijani & Tehrani, 2024). A structure may satisfy drift limits but still exhibit undesirable modal behavior or torsional sensitivity if its stiffness distribution is not properly controlled (Chen et al., 2026; Haselton et al., 2011; Moehle, 2015).

This study addresses these issues by developing a parametric evaluation of RC-SMF buildings across three heights: 6-, 9-, and 12-story models. All models were developed using the same structural plan: a maximum analytical beam span of 9.5 m, a 3.0 m story height, a 130 mm slab thickness, 350 mm × 700 mm primary beams, and 250 mm × 600 mm secondary beams. The secondary beams were considered as part of the gravity framing layout, while the lateral response was evaluated through the primary RC-SMF system. The models were assigned Jakarta soft-soil seismic parameters with Seismic Design Category D, response modification factor R = 8.0, deflection amplification factor Cd = 5.5, and overstrength factor $\Omega 0$ = 3.0 (SNI 1726:2019). This consistent modeling framework allows the effect of building height to be isolated and more clearly compared.

The evaluation focuses on several important seismic response indicators. First, the modal characteristics are examined to verify whether the first two modes are dominated by translational responses in the principal horizontal directions and whether the third mode is governed by torsional response (SNI 1726:2019, 2019; Calvi et al., 2008; Paulay & Priestley, 1992). This check is important because a regular modal sequence indicates a balanced distribution of lateral stiffness and limited modal coupling. Second, the cumulative modal participating mass ratio is assessed to ensure that the selected number of modes sufficiently represents the dynamic response of each model. Third, the response-spectrum base shear is compared with the equivalent lateral force minimum to confirm the required scaling. Finally, story shear, average displacement, design inter-story drift, torsion ratio, and P-Delta stability coefficient are compared among the three building heights (Paulay & Priestley, 1992).

The main objective of this study is to evaluate how increasing the number of stories from 6 to 9 and 12 affects modal regularity, lateral displacement, drift demand, torsional response, P-Delta stability, and response-spectrum-based code compliance of RC-SMF buildings. The research gap addressed in this study is the limited integration of modal regularity, modal mass participation, base-shear scaling, drift, torsion, and P-Delta checks into a single OpenSeesPy-based parametric workflow for RC-SMF buildings designed in accordance with SNI 1726:2019. The study also aims to demonstrate how an OpenSeesPy-based workflow can be used to perform a transparent and reproducible parametric evaluation of building-height effects. The expected contribution of this research is a practical computational framework for preliminary seismic assessment of RC-SMF buildings on soft-soil sites subject to high seismic demand. The scope is limited to global linear response-spectrum checks; therefore, the results should be interpreted as an initial code-compliance screening rather than a complete nonlinear performance evaluation or final member-design verification.

RESEARCH METHODS

The study was conducted using three-dimensional OpenSeesPy models of RC special-moment-frame buildings, with the occupancy function designated as a hotel in accordance with local and international load standards (ASCE/SEI 7-22, SNI 1727:2020). The objective of the modeling framework was to investigate the influence of building height on the seismic response of RC moment-frame structures while maintaining consistency in the remaining design and analysis parameters.

A parametric approach was adopted, with the number of stories as the primary variable. Three building configurations were considered: 6-, 9-, and 12-story buildings, corresponding to total building heights of 18 m, 27 m, and 36 m, respectively. The story height was fixed at 3.0 m for all levels to eliminate the influence of vertical geometric variations. All models employed the same plan geometry, gridline layout, and framing configuration to ensure that differences in structural response were primarily associated with building height. The maximum analytical span of the primary beams was limited to 9.5 m, and the resulting maximum span obtained from the models was 9.0 m, satisfying the intended span-control target in all cases.

The site condition was assumed to represent Jakarta soft soil with Site Class SE. The lateral-force-resisting system consisted of RC special moment-resisting frames with a response modification factor of R = 8.0, a deflection amplification factor of $C_d = 5.5$, an overstrength factor of $\Omega_0 = 3.0$, and an importance factor of $I_e = 1.0$. The design spectral accelerations adopted in the study were $S_{DS} = 0.67g$ and $S_{D1} = 0.63g$ (SNI 1726:2019). These parameters were used to provide a consistent basis for evaluating relative seismic response trends across the investigated building heights. For practical applications, seismic design parameters should be verified using official hazard maps, site-specific geotechnical investigations, and the requirements of (SNI 1726:2019) and related code provisions.

Primary beams were modeled with uniform 350 mm × 700 mm sections, while 250 mm × 600 mm secondary beams were included for gravity framing, floor-load transfer, and seismic mass calculation, but not as primary lateral-resisting members. The OpenSeesPy models were idealized as three-dimensional linear-elastic frame models using gross elastic section properties; therefore, nonlinear concrete and steel material models and cracked-section stiffness modifiers were not activated at this preliminary screening stage. Column bases were fixed, and rigid-diaphragm constraints were assigned at each floor. Column sizes were adjusted with building height to represent practical, preliminary code-compliant layouts rather than a constant-section sensitivity study. Model reasonableness was assessed using modal sequence, modal mass participation, RSA base-shear scaling, and fundamental-period comparison against empirical SNI/ASCE trends.

By maintaining identical plan geometry, structural configuration, material assumptions, and seismic input parameters, the adopted modeling approach enables a direct assessment of the influence of building height on the dynamic characteristics and seismic performance of RC special moment-resisting frame buildings. The plan geometry and member-size configuration adopted in the analytical models are summarized in Figure 1.

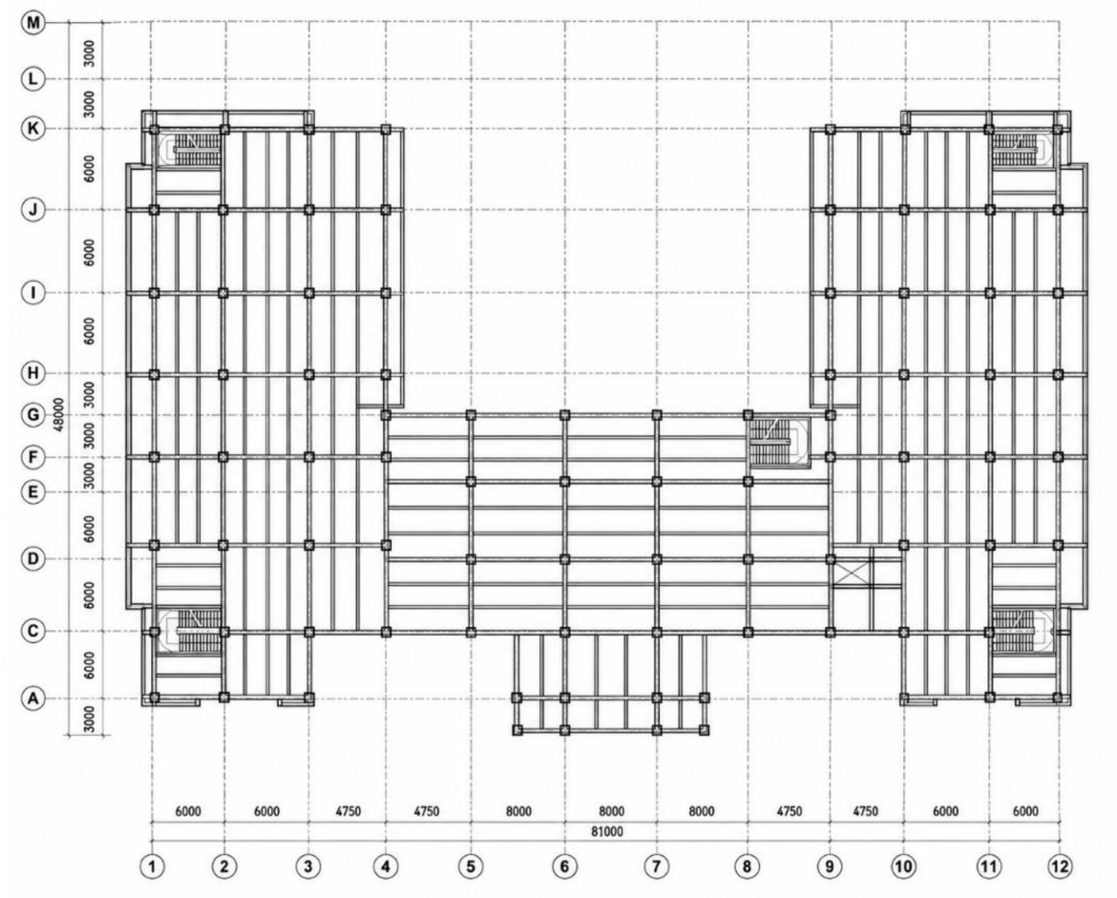

Figure 1. Structural plan and member-size schedule for the 6-story, 9-story, and 12-story models

The geometric configuration and member-size schedule for the three parametric RC-SMF models are summarized in Table 1. The three models are 6-, 9-, and 12-story structures with the identical structural design, floor height, slab thickness, beam arrangement, and maximum analytical span limit. All models had the same primary beams, but the column diameters were varied with building height to provide appropriate global stiffness, drift control, and preliminary strong-column weak-beam capacity. This setup enables assessment of the effects of building height on modal behavior, base shear demand, drift response, torsional response, and P-Delta stability under the same modeling assumptions.

Tabel 1. Parametric model and member-size configuration

Model	Height	Primary / secondary beam	C1 column schedule	C2 column schedule
6-story	18 m	350x700 mm / 250x600 mm	S1-S2: 700x700; S3-S4: 650x650; S5-S6: 600x600	S1-S2: 900x900; S3-S4: 850x850; S5-S6: 800x800
9-story	27 m	350x700 mm / 250x600 mm	S1-S2: 800x800; S3-S4: 750x750; S5-S6: 700x700; S7-S8: 650x650; S9: 600x600	S1-S2: 1000x1000; S3-S4: 950x950; S5-S6: 900x900; S7-S8: 850x850; S9: 800x800
12-story	36 m	350x700 mm / 250x600 mm	S1-S2: 950x950; S3-S4: 900x900; S5-S6: 850x850; S7-S8: 800x800; S9-S10: 750x750; S11-S12: 700x700	S1-S2: 1150x1150; S3-S4: 1100x1100; S5-S6: 1050x1050; S7-S8: 1000x1000; S9-S10: 950x950; S11-S12: 900x900

For each model, eigenvalue analysis was performed to identify the first three dominant modes. The intended modal sequence was translation in the X direction, translation in the Y direction, and torsional rotation about the vertical axis. Modal participating mass ratios were calculated for both principal horizontal directions. Response-spectrum results were scaled to the equivalent-static base-shear minimum. Story responses were evaluated using design drift, torsion ratio, and P-Delta stability coefficient as expressed in Equations (1) to (3).

$$\delta_x = \frac{C_d \delta_{xe}}{I_e} \tag{1}$$

$$Torsion\ ratio = \frac{\delta_{max}}{\delta_{Avg}} \tag{2}$$

$$\theta = \frac{P_x\, \Delta I_e}{V_x h_{sx} C_d} \tag{3}$$

where δ_x is the design displacement at level x, δ_{xe} is the elastic displacement obtained from the response-spectrum analysis, C_d is the deflection amplification factor,θ is the stability coefficient for P-Delta effects, I_e is the importance factor, P_x is the cumulative gravity load above the story, V_x is the story shear, and h_{sx} is the story height. The torsion ratio was defined as the ratio of the maximum to the average floor displacement at the same level.

RESULTS AND DISCUSSION

The ratios of the masses participating in the first three modes are shown in Table 2. In all models, the first mode was dominated by X translation, the second by Y translation, and the third by torsional rotation. This modal sequence reveals that the structural models exhibited dynamic regularity as the number of tales increased. The fundamental period increased from 0.365 s for the 6-story model to 0.689 s for the 12-story model, consistent with the predicted increase in flexibility with height.

Tabel 2. Modal period, modal character, and participating mass ratio

Model	Mode 1	Mode 2	Mode 3	Mass X	Mass Y
6-story	0.365 s / X-trans	0.360 s / Y-trans	0.350 s / RZ-torsion	97.22%	97.22%
9-story	0.537 s / X-trans	0.526 s / Y-trans	0.513 s / RZ-torsion	97.79%	97.79%
12-story	0.689 s / X-trans	0.672 s / Y-trans	0.658 s / RZ-torsion	98.14%	98.14%

The first three modal periods of the 6-story, 9-story, and 12-story models are compared in Figure 2. The results show a consistent increase in modal period with building height, indicating the expected reduction in lateral stiffness for taller structures. Mode 1 and Mode 2 remain dominated by translational responses in the X and Y directions, respectively, while Mode 3 is governed by torsional response about the vertical axis. The relatively close values of the first and second modal periods suggest balanced lateral stiffness in both principal directions, whereas the stable identification of the third mode as torsional confirms that the models maintain a regular modal sequence across all height variations.

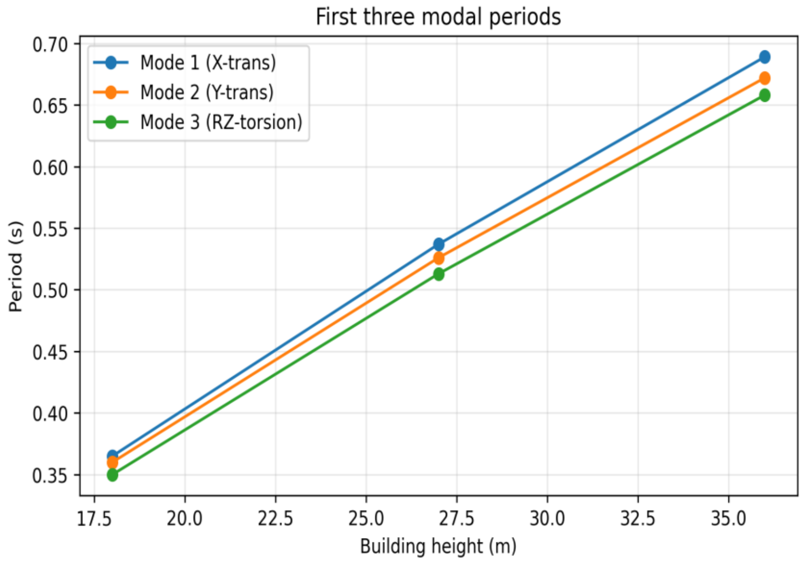

Figure 2. Variation of the first three modal periods with building height

The cumulative modal participation mass ratios in the X and Y directions for the 6-story, 9-story, and 12-story models are shown in Figure 3.

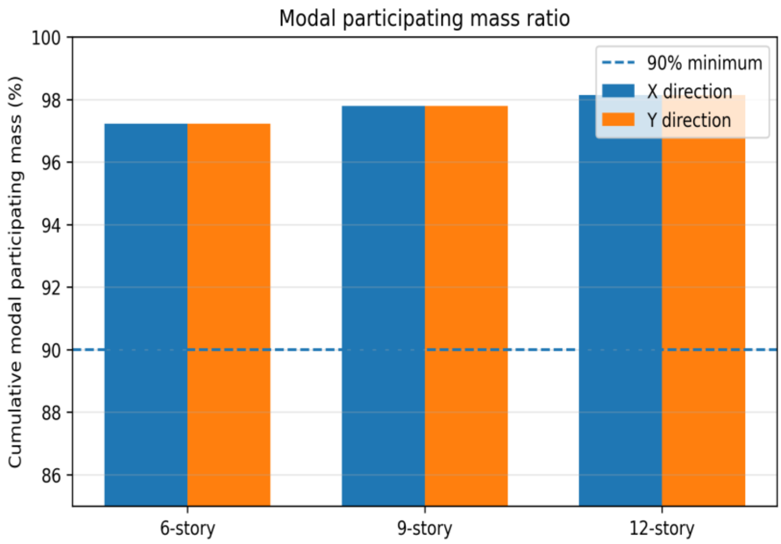

Figure 3. Cumulative modal participating mass ratios in X and Y directions

The cumulative modal participating mass ratios ranged from 97.22% to 98.14% in both horizontal directions. These values are higher than the 90% target used in the screening workflow and remain below 100%, indicating that the modal combination procedure captured the dominant dynamic response without the earlier numerical issue of exceeding the physical mass limit. The results also show that the modal participation values were stable across the three building heights.

Results of response-spectrum base-shear scaling are shown in Table 3. In all instances, the unscaled response-spectrum base shear was less than the equivalent-static minimum. Therefore, scaling factors were needed. The scale factors ranged from 1.273 to 1.316. The response-spectrum base shear, after scaling, agreed with the equivalent-static minimum in X and Y directions.

Tabel 3. Response-spectrum base-shear scaling against equivalent-static minimum

Model	Dir.	RSA before scale (kN)	Scale	ELF / RSA after scale (kN)
6-story	X	6,177.99	1.282	7,918.73
6-story	Y	6,220.09	1.273	7,918.73
9-story	X	9,143.11	1.299	11,878.09
9-story	Y	9,197.17	1.291	11,878.09
12-story	X	12,036.48	1.316	15,837.45
12-story	Y	12,109.30	1.308	15,837.45

The response-spectrum base shear vs minimum equivalent lateral force (ELF) for six, nine, and twelve-story models is illustrated in Figure 4. This is shown for all four directions.

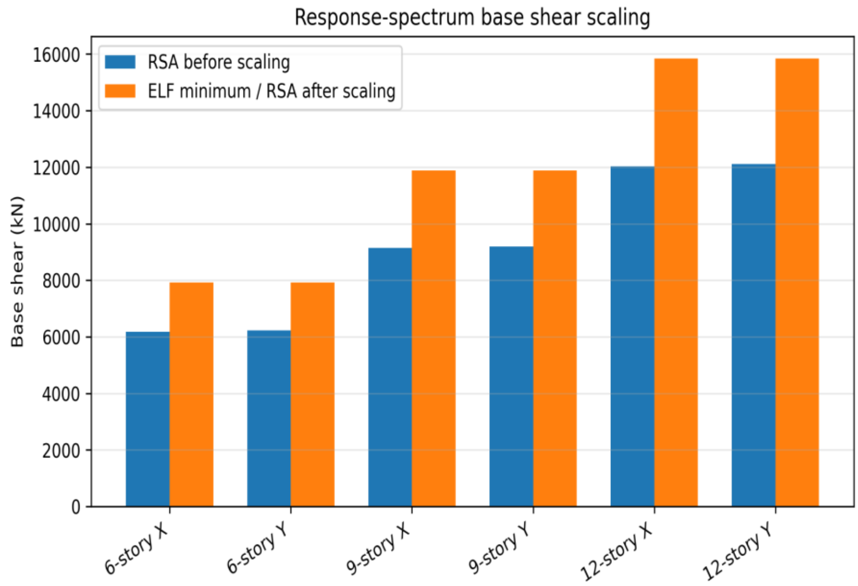

Figure 4. Response-spectrum base shear before and after scaling

The increase in base shear was primarily associated with the increase in total seismic weight. The equivalent-static base shear increased from 7,918.73 kN in the 6-story model to 11,878.09 kN in the 9-story model and 15,837.45 kN in the 12-story model. The nearly proportional increase reflects the constant design coefficient used in the equivalent-static minimum check, while the unscaled response-spectrum values remained lower because the modal response was combined through the response-spectrum procedure.

In addition to the modal and base-shear checks, story-level response profiles illustrate the design response spectrum behavior for the three building-height variations. The controlling story shear, displacement, design inter-story drift, torsion ratio, and P-Delta stability coefficient for the 6-, 9-, and 12-story models are presented in Figure 5. As expected, taller model seismic weight and flexibility increase the narrative shear and lateral displacement. The displacement profiles also exhibit a constant global deformation pattern, without rapid shifts in narrative response as they climb towards the ceiling. As in frame-dominated systems, drift profiles peak on the lower- to mid-floor levels rather than at the roof. The 12-story model has the highest drift demand, but it's still far below the limit. The torsion and P-Delta profiles are also modest across all models, suggesting that the proposed structural design may provide adequate torsional and global lateral stability for the evaluated building heights.

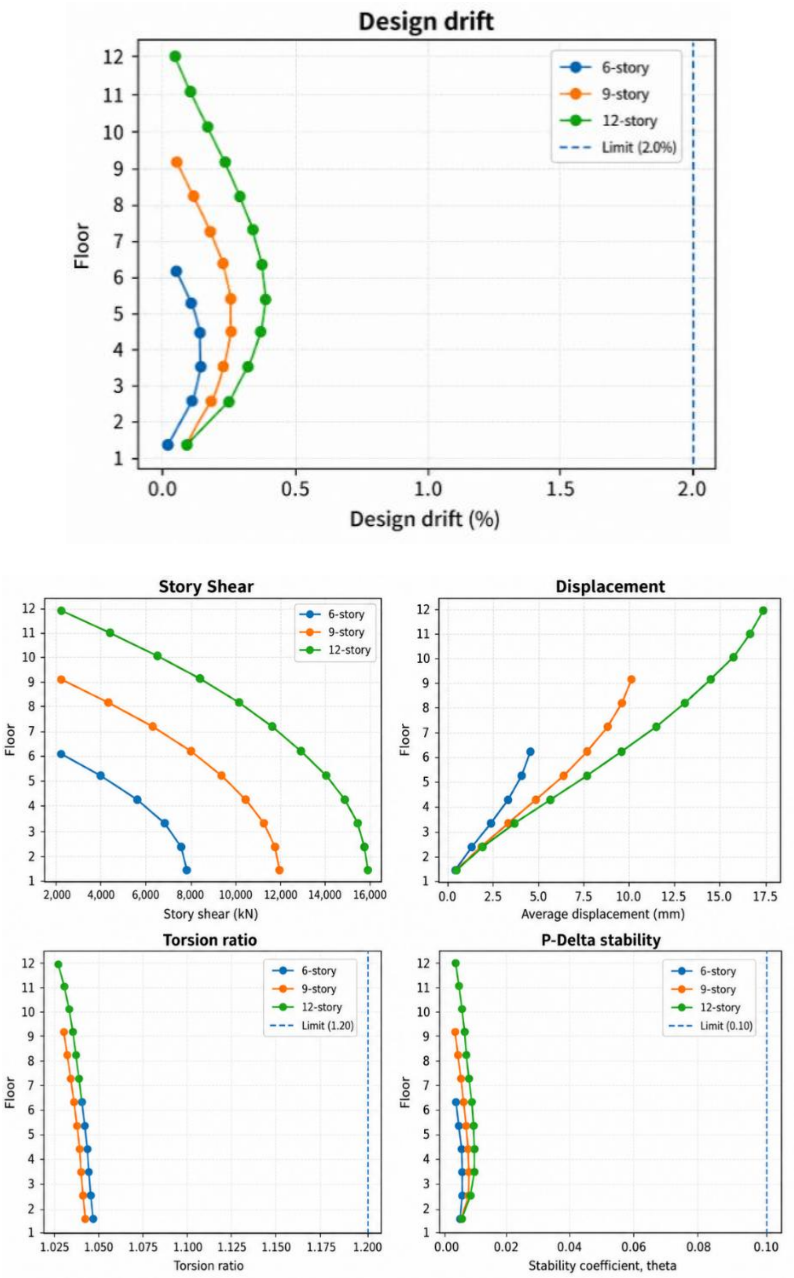

Figure 5. Governing story response profiles for shear, displacement, drift, torsion, and P-Delta stability

From the comparison in Figure 5, the governing story response envelopes of the three models. Story shear increased with building height, while the roof displacement increased from approximately 4.61 mm in the 6-story model to 17.05 mm in the 12-story model. The design drift profile was controlled in all cases. The maximum governing design drift was approximately 0.200% for the 6-story model, 0.297% for the 9-story model, and 0.382% for the 12-story model. These values are far below the 2.0% drift limit used in the screening workflow.

The torsion ratios remained low, with maximum governing values of approximately 1.050, 1.047, and 1.045 for the 6-story, 9-story, and 12-story models, respectively. These values are well below the torsional irregularity screening threshold of 1.20. The P-Delta stability coefficient also remained small. The maximum theta value was about 0.003 for the 6-story model, 0.005 for the 9-story model, and 0.006 for the 12-story model. Therefore, second-order instability did not govern the evaluated models. Although height increased displacement and drift demand, the models remained within the selected code-screening criteria because the member-size schedules were adjusted consistently.

The results show that building height affects displacement, drift, and the scaling demand required to satisfy the minimum equivalent-static base shear. However, increasing height did not produce modal irregularity or excessive torsion in the evaluated models. This indicates that a code-oriented OpenSeesPy workflow can verify the dynamic regularity of parametric RC-SMF models before detailed member design, although final acceptance still requires detailed SNI 2847 checks, including flexural and shear strength, confinement, joint shear, development length, and strong-column weak-beam verification using actual reinforcement layouts. This interpretation is consistent with recent studies showing that seismic assessment should not rely solely on drift, as torsional response and modal characteristics can significantly affect seismic demand even when drift remains acceptable (Blasi et al., 2024; Khosravi Larijani & Tehrani, 2024). Therefore, this study contributes by integrating modal regularity, modal mass participation, base-shear scaling, drift, torsion, and P-Delta checks into a single SNI 1726:2019-based workflow.

CONCLUSION

This study evaluated the effect of building height on global seismic code-compliance indicators for RC special moment frame buildings using an OpenSeesPy-based parametric workflow. Three 6-, 9-, and 12-story models were analyzed with identical plan geometry, span control, Jakarta soft-soil response-spectrum demand, and SNI-oriented screening procedures. The first three modes consistently followed the expected sequence of X translation, Y translation, and torsional rotation. Fundamental periods increased from 0.365 s to 0.689 s as height increased, while modal mass participation remained about 97–98% in both principal directions. Base-shear scaling was required for all models, and taller buildings produced greater shear, displacement, and drift demands. However, all models satisfied the selected drift, torsion, and P-Delta screening limits, with maximum drift below 0.40%, torsion ratios about 1.05 or lower, and stability coefficients below 0.006. The main limitations are that the study was restricted to linear response-spectrum analysis and global checks; nonlinear static analysis, nonlinear time-history analysis, soil-structure interaction, and detailed SNI 2847 member design were not included. Therefore, the findings should be interpreted as preliminary code-compliance screening, not final nonlinear performance or member-design verification. Future work should include detailed SNI 2847 checks and comparison with commercial software or nonlinear benchmark models.

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