The OCEM Journal of
Management, Technology & Social Sciences

Received: Apr 21, 2026 | Revised: May 02, 2026 | Accepted: May 20, 2026 | Published: July 10, 2026

DOI: 10.3126/ocemjmtss.v5i2.1016 **Paper Type: Research Article**

Impact of Storey Number on the Seismic Response of Reinforced Concrete Buildings with Identical Overall Height using NBC 105:2020

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Abstract

Volume 5, Issue 2

ISSN Print:2705-4845

ISSN Online:2705-4845

The structural behaviour of reinforced concrete buildings having equal overall height is remarkably influenced by their storey configuration. This paper examines the how variations in the number of storeys affect the seismic response of reinforced concrete multistorey buildings while maintaining the same overall height. In this paper, five analytical models with 5-storey, 6-storey, 7-storey, 8-storey, and 9-storey building model were developed, considering both square and rectangular plan layouts to ensure representative structural modeling. However, the primary comparison is based on this building model with each other. The developed building models were analysed by help of computer-based software ETABS v22.6.0 using response spectrum analysis method in accordance with the provisions of NBC 105:2020 code. This study focuses on seismic response parameters like base shear, inter-storey drift, fundamental time period, storey stiffness, column axial force, and minimum reinforcement demand for columns and beams.

The results indicate that increasing the number of storeys while keeping the overall height same leads to a longer fundamental time period and a reduction in lateral stiffness, higher inter-storey drift. Also, building experience relatively higher base shear, column axial forces, and influencing the reinforcement requirement. These trends remain consistent across both plan layouts, highlighting the dominant effect of storey configuration on structural behaviour. Overall, the study demonstrates that even when the total building height is same with different number of storeys noticeably affects seismic performance. The findings help professionals to create safer and more effective earthquake-resistant structures by optimising the design of reinforced concrete buildings and guaranteeing adherence to NBC 105:2020 code based seismic design guidelines.

Keywords: *reinforced concrete structure, reinforcement demand, response spectrum analysis, seismic response, storey configuration*

How to cite this paper:
Adhikari, B. (2026). Impact of storey Number on the Seismic Response of Reinforced Concrete Building with Identical Overall Height using NBC 105 : 2020. *The OCEM Journal of Management, Technology & Social Sciences*, *5*(2), 198-214.

Introduction

Nepal is situated in a seismically active zone due to the movement of the Indian plate beneath the Eurasian plate at a rate of approximately 25-40 cm/year (Malla et al., 2024; Wu et al., 2019). Due to this movement, Nepal hit by massive earthquake in 2015 Gorkha earthquake highlighted the vulnerability of buildings to seismic hazards (Poudel, khatiwada & Adhikari, 2025; Dey, 2015; Goda et al., 2015). To reduce these risks, updated Nepal Building Code (NBC) 105:2020 "Seismic Design of Buildings" provides new revised guidelines for earthquake-resistant design. Previously, Indian code IS 1893:2016 (Part 1) was commonly used (Adhikari & Poudel, 2023; Shrestha et al., 2021). The NBC 105:2020 consistently produced higher fundamental time periods across all building models due to its empirical formula that consider building height than base dimensions of building, and consequently produces the highest seismic demand, reflecting a conservative, safety focused approach suitable for Nepal's high-risk zones and construction variability (Khatri et al., 2025). Also, the fundamental time period depends not only on height but also on span length and stiffness distribution (Jamdar et al., 2020).

Storey configuration is a critical architectural and structural parameter that affects both functionality and seismic performance (Dule & Raut, 2025; Tirado-Gutiérrez, González-Drigo & Vargas-Alzate, 2025). The vertical distance from the top of lower floor to the top of upper floor considered as storey height. Height variation generally depends on building function, climate conditions, and local practices. Buildings with equal total height but different storey numbers show different responses such as influencing lateral stiffness, drift distribution, base shear, and axial force. The various numerical studies performs and this study suggested that the buildings having equal overall height with different storey heights shows higher storey displacement and drift due to the mass and stiffness distributions change with storey heights (Haque, Akash & Hasan, 2025).

Although multi-storey RC buildings are widely adopted in Nepal and impact of varying storey numbers on seismic performance under NBC 105:2020 has not been studied. Thus, the main objective of this study is to understanding the seismic response and compare reinforcement demand required by building models. This study fills this gap by comparing building models of 5-storey, 6-storey, 7-storey, 8-storey and 9-storey of the same height and analysing the seismic parameters such as base shear, storey stiffness, drift, column axial force and reinforcement demand using ETABS v22.6.0. The results are intended to contribute to safer and more efficient building design practices in earthquake-prone regions.

Literature Review

Adhikari and Poudel (2023) studied the topic titled "Comparative Study of Building Response on the Adoption of NBC 105: 2020 and IS 1893 (Part 1): 2016." After the study they found that NBC 105:2020 shows higher base shear, higher storey drifts, higher storey displacement. Also, NBC 105:2020 required more reinforcement than IS 1893 (Part 1) 2016.

Chaudhary (2025) researched about "Comparative Study Between NBC 105:2020 and IS 1893:2016 (Part 1) in Torsionally Irregular Structure" and analysis is done in different soil conditions. After the study, they found that NBC 105:2020 have higher base shear and storey drift compared to IS 1893: 2016 (Part 1). Also, they concluded that NBC 1052020 have safe and reliable designing parameteres for torsionally irregular structures in seismic regions like Nepal.

Dule and Raut (2025) studies about effects of RC building with irregular vertical configuration having different storey heights and found that variation in storey drift, displacement and this configuration reduce seismic performance of building. Also, they concluded that uniform floor heights and proper seismic analysis are essential for reducing seismic impacts.

Haque et al. (2025) examine about titled "Numerically predicting influence of storey height on seismic drift of RC buildings" and found that increas in storey height increase the lateral displacement and storey drift. Also,they concluded that maintaining uniform height helps more structural stability during seismic activity.

Jamdar et al. (2020) investigate about "Behaviour of Soft Storey at Different Locations in the Multistory Buildings". After the dynamic analysis of multi-storey building, they found that soft storey afftect building performance leading to increase storey drift, displacement and potential failure. Also, soft storey at lower level is more vulnerable to earthquake.

Khatri et al. (2025) studies about topic entitled "Comparison of Seismic Parameter in RC Building using NBC 105:2020, IS 1893:2016 and ASCE 7-22". After the analysis with using different code of provision, they found that NBC generally produce Higher seismic demand comapre to IS 1893:2016 and similar align with ASCE 7-22 in certain cases.

Malla et al. (2024) conduct a study entitled "comparative analysis of apartment building using NBC 105:1994 and revised NBC 105:2020". After the analysis of building using both codes, they found that NBC 105:2020 produces higher seismic demand compared to previous NBC 105:1994.

Poudel et al. (2025) Researched "Seismic Performance Evaluation of Low-Rise Reinforced Concrete Framed Buildings with Ready-to-Use Guidelines (RUD-NBC205:2024) in Nepal" and the building models equivalent static and nonlinear pushover analyses using the displacement coefficient method (FEMA 440) in ETABS software. After the analysis, they found that maximum story drift for the linear static analysis is found to be 0.56% and 0.86% for peak ground acceleration of 0.40 g, for both three and four-storied buildings.

Shrestha et al. (2021) examine the "Impact of Revised Code NBC105 on Assessment and Design of Low Rise Reinforced Concrete Buildings in Nepal". In this study they found that base shear is increased. Also, increase in reinforcement demand.

Thapa (2023) deeply study about "Comparative Analysis of Multistory Reinforced Concrete Buildings designed as per Seismic Provisions of NBC 105-2020 and ASCE 7-22" through analytical modeling and found that huge variation in base shear and storey drift. He suggested that NBC 105:2020 have better seismic response compared to ASCE 7-22 expect reinforcement demand.

Tirado-Gutiérrez et al. (2025) highlight that structural configuration plays a crucial role in seismic performance. After the study, they found that vertical irregularities such as soft storeys and stiffness variations increase storey drift and seismic vulnerability.

Methodology

To achieve the objective of the current study, a set of models with varied storey heights but overall equal height is planned for the square and rectangular plan layout of building models. In this paper, the five models of 5 storey, 6 storey, 7 storey, 8 storey, and 9 storey building models named as SM-A, SM-B, SM-C, SM-D, and SM-E for square plan layout models and RM-A, RM-B, RM-C, RM-D, and RM-E for rectangular plan layout models respectively. All the models of square and rectangular plan layouts will be analysed by response spectrum using ETABS v22.6.0 software using the code of provision of NBC 105:2020 at soil type C and considering the seismic zone factor of Bharatpur Metropolitan City. Comparison is done between five square plan layout models and separately between five rectangular plan layout models in terms of seismic response parameters like base shear, storey stiffness, and storey drift. Also, the comparison is based on the reinforcement demand of columns and beams.

Building Models

The square and rectangular plan-shaped models are illustrated (see Figure 1, and Figure 7). The elevations showing the number of storeys for the square and rectangular plan layouts are presented sequentially (see Figure 2 to 6 for the square model, and Figure 8 to 12 for the rectangular model). A typical elevation layout representing both plan configurations is also provided (see Figure 13).

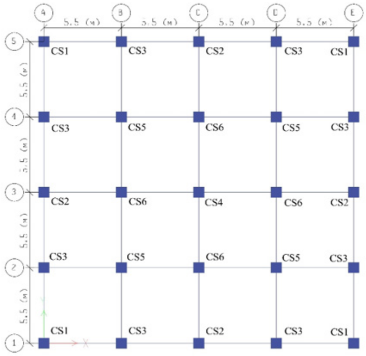


Figure 1: Plan of Square Building Model

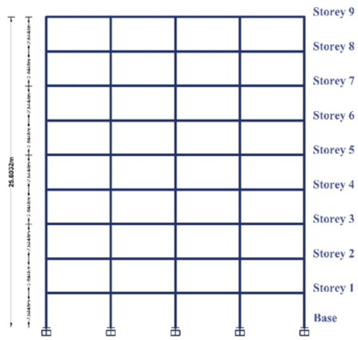


Figure 2: Elevation of Square Model A (SM-A)

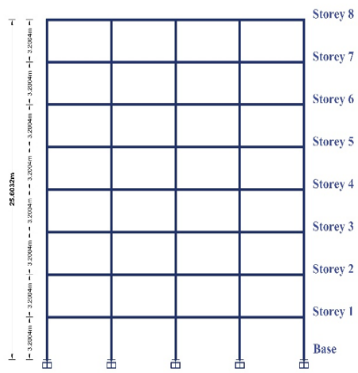


Figure 3: Elevation of Square Model B (SM-B)

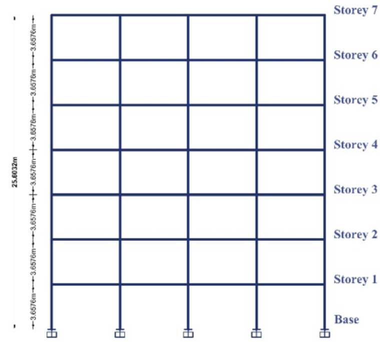


Figure 4: Elevation of Square Model C (SM-C)

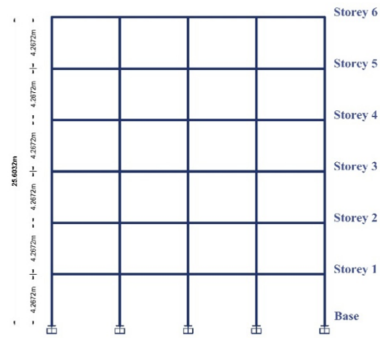


Figure 5: Elevation of Square Model D (SM-D)

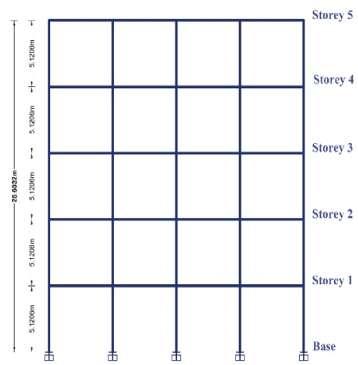


Figure 6: Elevation of Square Model E (SM-E)

Due to the symmetric model in both plan and load conditions, the output response of the building model member also looks symmetric, and it helps to analyse the data in a simplified form. This is the main reason for sampling the members with similar responses. For sampling of the column, it is divided into six categories, CS_1, CS_2, CS_3, CS_4, CS_5, and CS_6 for square and nine categories, CR_1, CR_2, CR_3, CR_4, CR_5, CR_6, CR_7, CR_8, and CR_9 for rectangular-shaped models. Also, Grid E-E and Grid F-F were selected for the beam of square and rectangular plan layout models, respectively.

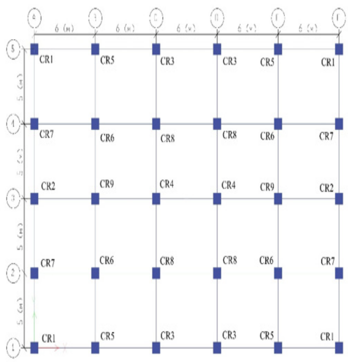


Figure 7: Plan of Rectangular Building Model

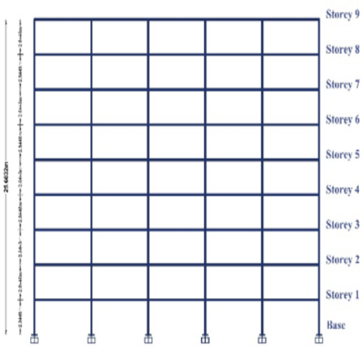


Figure 8: Elevation of Rectangular Model A (RM-A)

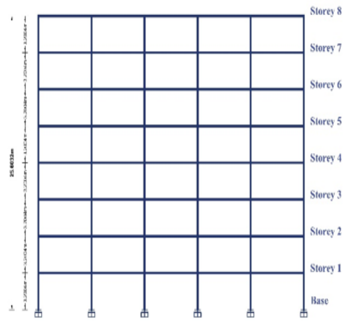


Figure 9: Elevation of Rectangular Model B (RM-B)

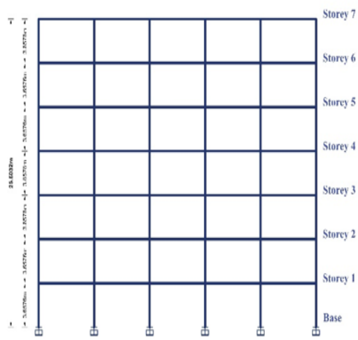


Figure 10: Elevation of Rectangular Model C (RM-C)

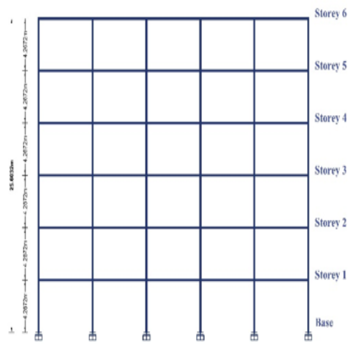
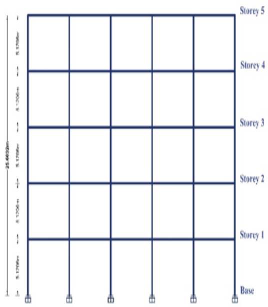


Figure 11: Elevation of Rectangular Model D (RM-D)



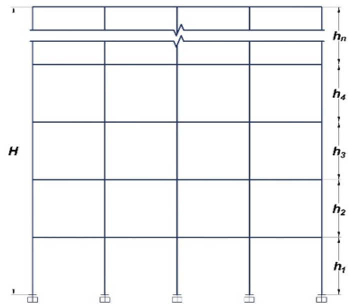


Figure 12: Elevation of Rectangular Model E (RM-E) ***Figure 13: Model Elevation***

Building Configuration

It includes the physical properties of the building, sectional properties, and material properties. The summary of all properties is listed (see Table 1). Sectional design and material properties are based on IS 456 2000 and NBC 105: 2020. The minimum height of rooms selection on the basis of NBC 206:2024 architectural design requirements. According to the NBC 206:2024 CL 3.2.1, minimum height for human habitation should not be less than 2.4m from the surface of the floor to the lowest point of the ceiling.

Table 1: Building Configuration

Description	**Building Models**				
	SM-A/RM-A	**SM-B/RM-B**	**SM-C/RM-C**	**SM-D/RM-D**	**SM-E/RM-E**
			Building Properties:		
Building System			RCC Framed Structure		
Building Type			Commercial/Residential building (Apartment)		
Number of Storeys, *n*	9 Storey	8 Storey	7 Storey	6 Storey	5 Storey
Floor Height, *h*	2.8448 *m*	3.2004 *m*	3.6576 *m*	4.2672 *m*	5.1206 *m*
Building Height, *H*			25.6032 *m*		
Span					
Square Building Models			5.5 *m* in X-direction	5.5 *m* in Y-direction	
Rectangular Building Models			6.0 *m* in X-direction	5.0 *m* in Y-direction	
			Sectional Properties:		
Column Size, *(mm x mm)*					
Square Building Models	750x750	750x750	750x750	750x750	800x800
Rectangular Building Models	750x750	750x750	750x750	750x750	800x800
Beam Size, *(mm x mm)*					
Square Building Models	550x700	550x700	550x700	550x700	550x700
Rectangular Building Models	550x700	600x700	550x700	600x700	600x700
Slab Thickness			150 *mm*		
Brick Wall					
Outer Wall Thickness			230 *mm*		
Partition Wall Thickness			115 *mm*		
			Material Properties:		
Concrete Grade			M30		
Reinforcement Grade			Fe500		

Loads

This building is an RC frame structure, and the load is distributed through the slab, beam, and column. For assigning the loads on the structural components, IS 875 (Part 1) - 1987, and IS: 875 (Part 2) - 1987 are used and these codes are also adopted by the Nepal national building codes as live loads and dead loads. The different types of loads including all self-weight, Wall load, live load, and seismic loads are demonstrated (see Table 2).

Table 2: Load Assign

Description	Building Models				
	SM-A/ RM-A	**SM-B/ RM-B**	**SM-C/ RM-C**	**SM-D/ RM-D**	**SM-E/ RM-E**
Dead Loads:					
Wall Loads Masonry Brick Wall with Common Burnt Clay Bricks	19.2 *kN/*				
Outer Wall load, *kN/m*	8.1	9.4	11.0	12.6	15.65
Partition Wall Load, *kN/m*	4.1	4.7	5.5	6.3	7.8
Floor Finished	1.25 *kN/*				
Live Loads:					
Live Load for Rooms	3 *kN/*				
Live load for Roof	2 *kN/*				
Seismic Loads	As per NBC 105:2020				

Code-Based Design Parameters

The response spectrum method is a linear dynamic analysis technique used to determine the peak structural response, such as displacement, velocity, and acceleration during a seismic event, and because it is based on maximum response values, it is generally considered a conservative approach for seismic analysis (Chaudhary, 2025).

The software ETABS do not have any built-in option to select deign code for NBC 105:2020, and it needs to be calculated required design parameters manually. The design parameters are tabulated (see Table 3, Table 4, and Figure 14). They represent the spectral shape factor for the modal response spectrum method.

Formula for Calculation of Spectral Shape Factor,

$C_h(T) = 1+(\alpha-1)(T/T_a)$ If $T<T_a$

$C_h(T) = \alpha$ If $T_a \le T \le T_c$

$C_h(T) = \{\alpha[K+(1-K)(T_C/T)^2](T_C/T)^2\}$ If $T_C \le T \le 6$

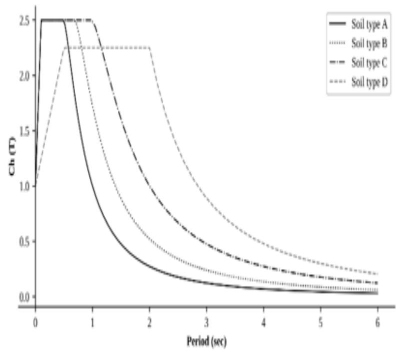


Figure 14: Spectral Shape Factor for Modal Response Spectrum Method

α = Peak spectral acceleration normalized by PGA (2.5)

K = Coefficient that controls the descending branch of the spectrum (1.8)

T_a = lower periods of the flat part of the spectrum

= 0.1 for modal response spectrum method and

= 0.0 for equivalent static method

T_C = upper periods of the flat part of the spectrum (1.0)

T = Approximate fundamental period of vibration

Table 3: Design Parameters for Square Building according to NBC 105 : 2020

Description	Formula	Models Name				
		SM-A	SM-B	SM-C	SM-D	SM-E
		Time Period				
Time Period, *NBC 105:2020 CL 5.1.2*, *NBC 105:2020 CL 5.1.3*	1.25xx	1.067 *sec*				
Rayleigh Method, *NBC 105:2020 CL 5.1.1*		1.062	1.086	1.115	1.150	1.162
Time Taken, *T* *NBC 105:2020 CL 5.1*	Take a Small Value	1.062	1.067	1.067	1.067	1.067
Seismic Zone Factor, *Z* *NBC 105:2020 CL 4.1.4*		0.4				
Soil Type *NBC 105:2020 CL 4.1.3.3*		C				
Importance Factor, *I* *NBC 105:2020 CL 4.1.5, Table 4-6*		1.25				
Base Shear Distribution Factor, *k* *NBC 105:2020 CL 6.3*		1.281	1.284	1.284	1.284	1.284
Spectra Shape Factor, *NBC 105:2020 CL 4.1.2*		2.4176	2.4094	2.4094	2.4094	2.4094
		Elastic Site Spectra, C				
Ultimate Limit State (ULS), *NBC 105:2020 CL 4.1.1*	*xZxI*	1.2088	1.2047	1.2047	1.2047	1.2047
Serviceability Limit State (SLS), *NBC 105:2020 CL 4.2*	0.2x	0.2417	0.2409	0.2409	0.2409	0.2409
		Base Shear Coefficient,				
Ultimate Limit State (ULS) *NBC 105:2020 CL 6.1.1*		0.2015	0.2008	0.2008	0.2008	0.2008
Serviceability Limit State (SLS) *NBC 105:2020 CL 6.1.2*		0.1934	0.1927	0.1927	0.1927	0.1927
Eccentricity Ratio		10%				

Table 4: Design Parameters for Rectangular Building according to NBC 105 : 2020

Description	Formula	Models Name				
		RM-A	RM-B	RM-C	RM-D	RM-E
		Time Period				
Time Period, *NBC 105:2020 CL 5.1.2*, *NBC 105:2020 CL 5.1.3*	1.25xx	1.067 *sec*				
Rayleigh Method, *NBC 105:2020 CL 5.1.1*		1.056	1.062	1.108	1.126	1.138
Time Taken, *T* *NBC 105:2020 CL 5.1*	Take a Small Value	1.056	1.062	1.067	1.067	1.067
Seismic Zone Factor, *Z* *NBC 105:2020 CL 4.1.4*		0.4				
Soil Type *NBC 105:2020 CL 4.1.3.3*		C				
Importance Factor, *I* *NBC 105:2020 CL 4.1.5, Table 4-6*		1.25				

Base Shear Distribution Factor, *k* *NBC 105:2020 CL 6.3*		1.278	1.281	1.284	1.284	1.284
Spectra Shape Factor, *NBC 105:2020 CL 4.1.2*		2.4270	2.4176	2.4094	2.4094	2.4094
		Elastic Site Spectra, *C*				
Ultimate Limit State (ULS), *NBC 105:2020 CL 4.1.1*	*xZxI*	1.2088	1.2047	1.2047	1.2047	1.2047
Serviceability Limit State (SLS), *NBC 105:2020 CL 4.2*	0.2x	0.2417	0.2409	0.2409	0.2409	0.2409
		Base Shear Coefficient,				
Ultimate Limit State (ULS) *NBC 105:2020 CL 6.1.1*		0.2023	0.2015	0.2008	0.2008	0.2008
Serviceability Limit State (SLS) *NBC 105:2020 CL 6.1.2*		0.1942	0.1934	0.1927	0.1927	0.1927
Eccentricity Ratio				10%		

Where,

R_(μ) = Ductility Factor for Ultimate Limit State (4)

Ω_u = Over-strength Factor for Ultimate Limit State (1.5)

Ω_s = Over-strength Factor for Serviceability Limit State (1.25)

K = an exponent related to the structural period as follows

$T \leq 0.5$ sec, k = 1

$T \geq 0.5$ sec, k = 2

For a structure having a period between 0.5 sec and 2.5 sec, k shall be determined by linear interpolation between 1 and 2.

Research and Discussion

The results of the seismic analysis have been compared across building models with identical elevations but varying numbers of storeys. The buildings were analysed according to NBC 105:2020, using the Response Spectrum Analysis method. Five models SM-A, SM-B, SM-C, SM-D, and SM-E for square and another five models RM-A, RM-B, RM-C, RM-D and RM-E for rectangular plan layout were examined to evaluate their structural responses under seismic loading.

Base Shear

The illustrated chart (see Figure 15) presents the base shear values for all models at both the Serviceability Limit State (SLS) and the Ultimate Limit State (ULS). For ULS, it is observed that the SM-A and RM-A Model exhibits the highest base shear about 12197.8 kN and 14996.60 kN , while the SM-E and RM-E model shows the lowest base shear which is about 8436.9 kN and 10492.8 kN for square and rectangular plan layout models respectively. Also, similar patterns seen for SLS where base shear of SM-A and RM-A model is about 11707.4 kN and 14395.6 kN for square model and rectangular model respectively. Again, the SM-E and RM-Emodel have lowest base shear for SLS about 8096.6 kN and 10068.8 kN for square and rectangular model respectively. For square models, the base shear of SM-B, SM-C, SM-D, and SM-E models is approximately 8.01%, 15.80%, 22.44%, and 30.84% lower than SM-A model, respectively. Similarly, for rectangular models, the reductions are 5.93%, 16.28%, 23.30%, and 30.06% relative to the RM-A model. The tabulated Data shows that the base shear is increases with increase in number of stories.

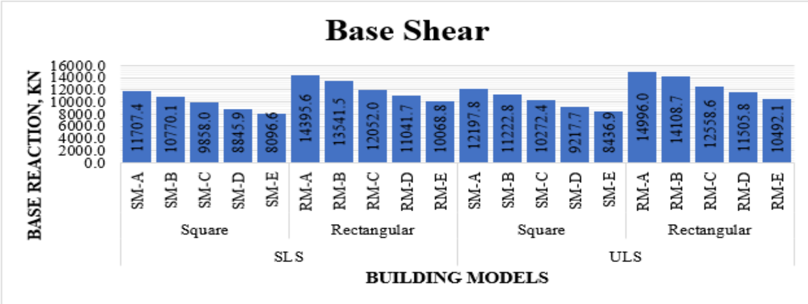


Figure 15: Base Shear

Storey Drift

Storey drift represents the relative lateral displacement between consecutive floors. According to NBC 105:2020, the inter-storey drift ratio shall not exceed 0.025 at ULS and 0.006 at SLS. The maximum storey drifts for square and rectangular models at Serviceability Limit State (SLS) are presented (see Table 6) and the maximum storey drifts for square and rectangular models at Ultimate Limit State (ULS) are presented (see Table 7).

Table 6: Maximum Storey Drifts at Serviceability Limit State (SLS)

Storey	Square Model					Rectangular Model				
	SM-A	SM-B	SM-C	SM-D	SM-E	RM-A	RM-B	RM-C	RM-D	RM-E
Storey 9	0.00126					0.00130				
Storey 8	0.00210	0.00140				0.00216	0.00137			
Storey 7	0.00299	0.00238	0.00159			0.00308	0.00236	0.00162		
Storey 6	0.00382	0.00341	0.00278	0.00185		0.00392	0.00338	0.00284	0.00180	
Storey 5	0.00452	0.00433	0.00398	0.00332	0.00226	0.00463	0.00428	0.00407	0.00327	0.00218
Storey 4	0.00504	0.00504	0.00498	0.00472	0.00400	0.00517	0.00499	0.00509	0.00466	0.00393
Storey 3	0.00527	0.00543	0.00562	0.00572	0.00549	0.00542	0.00540	0.00575	0.00567	0.00543
Storey 2	0.00487	0.00514	0.00549	0.00587	0.00596	0.00504	0.00518	0.00566	0.00589	0.00597
Storey 1	0.00265	0.00286	0.00315	0.00350	0.00361	0.00278	0.00297	0.00330	0.00362	0.00371
Base	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000

For Square Plan Layout Models, it can be seen in table that SM-E model exhibits the maximum storey drift while SM-A model shows the minimum storey drift compared to other models. The maximum storey drift is seen at the storey 3 for SM-A, SM-B and SM-C models while for SM-D and SM-E models maximum storey drift seen at storey 2. The storey drift of SM-A model is about 3.07%, 6.52%, 11.27%, and 13.09% less compared to SM-B, SM-C, SM-D and SM-E model respectively.

Similarly, the rectangular plan layout models follow similar trends as square plan layout models. the maximum storey drift can be seen in RM-E model while RM-A model shows the minimum storey drift compared to other models. The maximum storey drift is seen at the storey 3 for RM-A, RM-B and RM-C models while for RM-D and RM-E models maximum storey drift seen at storey 2. Also, storey drift of RM-A model of rectangular plan layout model is about 0.36%, 6.08 %, 8.59 %, and 10.07 % less compared to RM-B, RM-C, RM-D and RM-E model respectively.

Table 7: Maximum Storey Drifts at Ultimate Limit State (ULS)

Storey	Square Models					Rectangular Models				
	SM-A	SM-B	SM-C	SM-D	SM-E	RM-A	RM-B	RM-C	RM-D	RM-E
Storey 9	0.00526					0.00540				
Storey 8	0.00874	0.00583				0.00900	0.00571			
Storey 7	0.01248	0.00993	0.00663			0.01283	0.00983	0.00674		
Storey 6	0.01591	0.01423	0.01159	0.00772		0.01633	0.01408	0.01184	0.00752	
Storey 5	0.01882	0.01803	0.01661	0.01382	0.00943	0.01929	0.01782	0.01697	0.01363	0.00908
Storey 4	0.02100	0.02101	0.02076	0.01967	0.01669	0.02153	0.02078	0.02122	0.01944	0.01637
Storey 3	0.02197	0.02265	0.02341	0.02384	0.02290	0.02259	0.02251	0.02397	0.02364	0.02263
Storey 2	0.02028	0.02143	0.02289	0.02445	0.02485	0.02101	0.02158	0.02360	0.02454	0.02487
Storey 1	0.01103	0.01193	0.01313	0.01460	0.01502	0.01160	0.01236	0.01375	0.01509	0.01548
Base	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000

Storey Stiffness

Storey stiffness is a critical parameter to avoid soft-storey failures. NBC 105:2020 defines a soft storey based on the stiffness ratio of adjacent storeys. The analysis shows that all models satisfy the stiffness criteria, with no soft-storey formation.

Table 8: Storey Stiffness of Square Models in kN/m

Storey	SM-A	SM-B	SM-C	SM-D	SM-E
Storey 9	524628.3	-	-	-	-
Storey 8	702919.1	423526.2	-	-	-
Storey 7	735761.9	558570.6	330269.5	-	-
Storey 6	745306.6	580608.1	428522.5	246765.4	-
Storey 5	751760.3	587395.6	442658.1	314025.2	177372.1
Storey 4	762750.4	595122.0	448723.6	323083.9	230495.7
Storey 3	792702.4	615846.5	462332.3	331750.9	241425.9
Storey 2	902468.9	694353.4	515738.4	365754.1	267845.0
Storey 1	1692138.7	1279686.1	930946.7	643617.8	476319.4
Base	0	0	0	0	0

Table 9: Storey Stiffness of Rectangular Models in kN/m

Storey	RM-A	RM-B	RM-C	RM-D	RM-E	RM-A	RM-B	RM-C	RM-D	RM-E
	x-dir	x-dir	x-dir	x-dir	x-dir	y-dir	y-dir	y-dir	y-dir	y-dir
Storey 9	641149	-	-	-	-	636622	-	-	-	-
Storey 8	851106	555483	-	-	-	848929	551676	-	-	-
Storey 7	886955	718417	400768	-	-	889437	716629	401425	-	-
Storey 6	895934	742446	516462	320271	-	902381	744384	517662	320497	-
Storey 5	902071	749020	531993	400789	228811	911103	753857	534896	401059	231955
Storey 4	914481	757307	538475	410640	292779	924252	763455	542414	411831	294867
Storey 3	950909	781927	554836	420607	305505	958091	786654	557866	421582	306798
Storey 2	1085866	878763	620626	462322	337922	1082773	875652	618152	459571	336285
Storey 1	2050497	1610791	1128584	809139	598020	1998158	1567534	1097657	784895	580769
Base	0	0	0	0	0	0	0	0	0	0

For square models, the SM-A model has the highest stiffness, and the SM-E model has the lowest. Maximum stiffness occurs at the level of storey one, with values of 1.69×10^{6} kN/m for M-A and 4.76×10^{5} kN/m for SM-E (see Table 8). Rectangular models follow the same trend where RM-A model has the highest stiffness about $2.05\text{x}10^{6}$ kN/m and RM-E has the lowest stiffness about 5.98x105 kN/m at the level of storey one (see Table 9). Also, x-direction stiffness consistently higher than y-direction. These results confirm that stiffness decreases with increasing floor height and reduced cross-sectional dimensions, emphasising the influence of structural geometry on lateral resistance.

Longitudinal Reinforcement

Column

Table 10: Column Reinforcement Requirement for Square Models

Column Location	Model Name	Reinforcement Requirement in Percentage (%)								
		Storey 1	Storey 2	Storey 3	Storey 4	Storey 5	Storey 6	Storey 7	Storey 8	Storey 9
CS1	SM-A	2.17	1.11	0.85	0.83	0.80	0.80	0.80	0.80	0.80
	SM-B	2.13	1.05	0.85	0.83	0.80	0.80	0.80	0.80	
	SM-C	2.10	1.00	0.86	0.83	0.80	0.80	0.80		
	SM-D	2.05	0.94	0.86	0.82	0.80	0.80			
	SM-E	1.79	0.86	0.80	0.80	0.80				
CS2	SM-A	1.72	1.38	0.89	0.91	1.29	1.03	0.86	0.80	0.99
	SM-B	1.73	1.45	0.94	1.04	1.25	0.90	0.82	0.99	
	SM-C	1.75	1.13	1.14	1.13	1.15	0.86	1.00		
	SM-D	1.76	1.22	1.28	1.39	0.90	1.02			
	SM-E	1.64	0.97	0.95	0.89	0.86				
CS3	SM-A	1.82	1.45	0.90	1.01	1.27	1.05	0.86	0.80	0.99
	SM-B	1.80	1.41	1.05	1.11	1.25	0.90	0.81	1.00	
	SM-C	1.80	1.50	1.22	1.44	1.18	0.86	1.01		
	SM-D	1.80	1.28	1.34	1.39	0.91	1.01			
	SM-E	1.68	1.03	1.02	0.90	0.86				
CS4	SM-A	1.32	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.89
	SM-B	1.31	0.81	0.80	0.80	0.80	0.80	0.80	0.89	
	SM-C	1.35	0.84	0.80	0.80	0.80	0.80	0.89		
	SM-D	1.39	0.87	0.82	0.81	0.80	0.89			
	SM-E	1.22	0.84	0.80	0.80	0.84				
CS5	SM-A	1.58	0.88	0.80	0.80	0.80	0.80	0.80	0.80	0.90
	SM-B	1.58	0.89	0.80	0.83	0.81	0.80	0.80	0.90	
	SM-C	1.61	0.97	0.85	0.86	1.00	0.80	0.90		
	SM-D	1.62	1.08	0.89	0.87	0.81	0.89			
	SM-E	1.47	1.01	0.96	0.91	0.96				
CS6	SM-A	1.55	0.87	0.80	0.80	0.80	0.80	0.80	0.80	0.90
	SM-B	1.55	0.88	0.80	0.81	0.80	0.80	0.80	0.90	
	SM-C	1.57	0.90	0.83	0.84	0.97	0.80	0.90		
	SM-D	1.58	1.00	0.87	0.86	0.80	0.90			
	SM-E	1.44	1.00	0.94	0.91	0.96				

Table 11: Column Reinforcement Requirement for Rectangular Models

Column Location	Model Name	Reinforcement Requirement in Percentage (%)								
		Storey 1	Storey 2	Storey 3	Storey 4	Storey 5	Storey 6	Storey 7	Storey 8	Storey 9
CR1	**RM-A**	2.49	1.38	0.91	0.88	0.84	0.80	0.80	0.80	0.80
	RM-B	2.43	1.33	0.97	0.88	0.83	0.80	0.80	0.80	
	RM-C	2.38	1.26	0.90	0.87	0.80	0.80	0.80		
	RM-D	2.34	1.20	0.95	0.86	0.80	0.80			
	RM-E	2.00	0.89	0.85	0.80	0.80				
CR2	**RM-A**	1.85	1.49	1.09	1.20	1.43	1.18	0.88	0.81	0.99
	RM-B	1.86	1.61	1.31	1.59	1.43	1.08	0.85	1.15	
	RM-C	1.89	1.63	1.37	1.57	1.28	0.88	1.00		
	RM-D	1.92	1.45	1.52	1.55	1.11	1.17			
	RM-E	1.74	1.22	1.22	1.07	0.89				
CR3	**RM-A**	1.77	1.27	0.85	0.87	0.87	0.90	0.85	0.80	0.99
	RM-B	1.75	0.91	0.89	0.91	0.89	0.89	0.81	1.15	
	RM-C	1.75	0.94	0.92	0.96	1.03	0.84	1.01		
	RM-D	1.74	1.06	1.17	1.06	0.90	1.17			
	RM-E	1.60	0.89	0.89	0.89	0.88				
CR4	**RM-A**	2.10	1.18	0.87	0.89	1.14	0.89	0.85	0.80	1.00
	RM-B	2.05	1.34	0.92	1.00	1.15	0.89	0.80	1.16	
	RM-C	2.02	1.04	1.03	1.03	1.00	0.84	1.01		
	RM-D	1.98	1.15	1.26	1.33	0.90	1.16			
	RM-E	1.76	0.90	0.93	0.89	0.89				
CR5	**RM-A**	1.43	0.85	0.80	0.80	0.80	0.80	0.80	0.80	0.89
	RM-B	1.44	0.87	0.80	0.80	0.80	0.80	0.80	1.03	
	RM-C	1.47	0.88	0.81	0.82	0.80	0.80	0.89		
	RM-D	1.49	0.95	0.87	0.86	0.80	1.03			
	RM-E	1.32	0.87	0.83	0.80	0.87				
CR6	**RM-A**	1.70	1.02	0.84	0.85	0.84	0.81	0.80	0.80	0.90
	RM-B	1.70	1.13	0.88	0.89	0.86	0.82	0.80	1.05	
	RM-C	1.71	1.19	0.89	0.89	0.85	0.80	0.90		
	RM-D	1.72	1.29	1.10	0.98	0.85	1.05			
	RM-E	1.58	1.05	0.89	0.84	0.87				
CR7	**RM-A**	1.95	1.53	1.16	1.26	1.44	1.17	0.88	0.80	0.99
	RM-B	1.96	1.64	1.37	1.61	1.44	1.06	0.84	1.15	
	RM-C	1.98	1.62	1.42	1.56	1.28	0.88	1.01		
	RM-D	2.02	1.50	1.56	1.57	1.10	1.17			
	RM-E	1.78	1.26	1.27	1.08	0.88				
CR8	**RM-A**	1.55	0.86	0.80	0.80	0.80	0.80	0.80	0.80	0.90
	RM-B	1.54	0.88	0.80	0.83	0.81	0.80	0.80	1.05	
	RM-C	1.56	0.89	0.83	0.84	0.80	0.80	0.90		
	RM-D	1.56	1.02	0.88	0.87	0.81	1.04			
	RM-E	1.40	0.88	0.84	0.80	0.87				

CR9	**RM-A**	1.68	1.00	0.84	0.83	0.82	0.80	0.80	0.80	0.90
	RM-B	1.68	1.08	0.87	0.87	0.85	0.81	0.80	1.04	
	RM-C	1.68	1.14	0.88	0.88	0.85	0.80	0.89		
	RM-D	1.69	1.24	1.02	0.91	0.84	1.04			
	RM-E	1.55	0.98	0.88	0.84	0.87				

Table 12: Column Average Reinforcement Requirement

	Column Reinforcement Requirement of Square Models in Percentage (%)								
Model Name	**Storey 1**	**Storey 2**	**Storey 3**	**Storey 4**	**Storey 5**	**Storey 6**	**Storey 7**	**Storey 8**	**Storey 9**
SM-A	1.76	1.18	0.85	0.89	1.03	0.92	0.83	0.80	0.93
SM-B	1.75	1.17	0.91	0.95	1.02	0.85	0.81	0.93	
SM-C	1.75	1.16	1.01	1.08	1.04	0.83	0.94		
SM-D	1.76	1.12	1.09	1.11	0.85	0.94			
SM-E	1.60	0.94	0.91	0.85	0.84				
	Rectangular Column Reinforcement Requirement of Rectangular Models in Percentage (%)								
Model Name	**Storey 1**	**Storey 2**	**Storey 3**	**Storey 4**	**Storey 5**	**Storey 6**	**Storey 7**	**Storey 8**	**Storey 9**
RM-A	1.87	1.19	0.91	0.93	0.99	0.90	0.83	0.80	0.93
RM-B	1.86	1.20	0.98	1.03	1.00	0.88	0.81	1.06	
RM-C	1.86	1.17	1.00	1.04	0.96	0.83	0.94		
RM-D	1.85	1.21	1.15	1.11	0.90	1.07			
RM-E	1.66	0.99	0.95	0.89	0.87				

The tabulated data represents the individual column reinforcement demand percentage of square plan layout models (see Table 10). CS1 is corner column, CS2 and CS3 column is about outer column. CS4 Column is centre column and remaining columns is located near to the centre column. Also, the corner and outer columns required higher reinforcement compared to those columns located near to the centre of building (see Table 10).

For rectangular plan layout models, the tabulated data (see Table 11) show the individual column reinforcement demand in percentage. CS1, CS2, CS3, CS5 and CS6 are outer column, CS4 is centre column and remaining columns located near to the centre column. In this plan layouts, the different pattern seen. The corner column demanding higher reinforcement but centre column also required higher reinforcement as corner column. The CR5 column required less reinforcement compared to other columns. Besides the individual columns, the overall floor wise average reinforcement demands are illustrated (see Table 12).

The average reinforcement requirement of square and rectangular plan layout models. The pattern of overall average reinforcement demand is almost same for both square and rectangular plan layout models. SM-D and RM-D model shows higher average reinforcement demand compared to other models about 1.14 % and 1.21% respectively. For square plan layout models, SM-A and SM-E model required less overall average column reinforce about 1.02% while for rectangular plan layout models, RM-A model required less overall average column reinforce about 1.04%.

Beam

The overall longitudinal reinforcement demand for critical beam from grid E-E and F-F for square and rectangular plan layout models are demonstrated (see Table 13). Also, the beam divided into edge and mid sections (see Figure 20, and Figure 21). The edge section reinforcement represents the top reinforcement of edge portion known as near section of column joints of beam and mid-section represents the bottom reinforcement at mid span of beam.

Table 13: Minimum Reinforcement Requirement of Critical Beam

Model Name	Longitudinal Reinforcement Requirement of Square Models in Percentage (%)											
	Edge	Mid	Edge	Edge	Midw	Edge	Edge	Mid	Edge	Edge	Mid	Edge
	0.00 m	2.75 m	5.50 m	5.50 m	8.25 m	11.00 m	11.00 m	13.75 m	16.50 m	16.25 m	19.25 m	22.00 m
SM-A	1.04	0.53	0.99	1.02	0.51	1.01	1.01	0.51	1.02	0.99	0.53	1.04
SM-B	1.07	0.53	1.01	0.96	0.51	1.03	1.03	0.51	1.04	1.01	0.53	1.07
SM-C	1.11	0.54	1.04	1.06	0.52	1.06	1.06	0.52	1.06	1.04	0.54	1.11
SM-D	1.15	0.56	1.07	1.08	0.52	1.08	1.08	0.52	1.08	1.07	0.56	1.15
SM-E	1.18	0.57	1.10	1.11	0.53	1.10	1.10	0.53	1.11	1.10	0.57	1.18

Model Name	Longitudinal Reinforcement Requirement of Rectangular Models in Percentage (%)											
	Edge	Mid	Edge	Edge	Mid	Edge	Edge	Mid	Edge	Edge	Mid	Edge
	0.00 m	2.50 m	5.00 m	5.00 m	7.50 m	10.00 m	10.00 m	12.50 m	15.00 m	15.00 m	17.50 m	20.00 m
RM-A	1.13	0.55	1.06	1.10	0.53	1.10	1.10	0.53	1.10	1.06	0.55	1.12
RM-B	1.10	0.54	1.03	1.07	0.52	1.06	1.06	0.52	1.07	1.03	0.54	1.07
RM-C	1.20	0.57	1.12	1.15	0.54	1.14	1.14	0.54	1.15	1.12	0.57	1.20
RM-D	1.19	0.57	1.09	1.11	0.53	1.11	1.11	0.53	1.10	1.09	0.57	1.19
RM-E	1.22	0.58	1.13	1.13	0.54	1.13	1.13	0.54	1.13	1.13	0.58	1.22

It can be seen in figures that longitudinal reinforcement demand of all models has similar patterns are illustrated. For square plan layout models, higher reinforcement demand seen in model SM-E and lower reinforcement demand seen in SM-A model. For section used, square plan layout models required same beam section size about 550mm x 700mm. Comparing with rectangular plan layout models, it shows that RM-A model required overall minimum beam reinforcement while RM-C and RM-E model required overall maximum beam reinforcement demand. This variation occurred due to used different beam sectional size. The beam size of RM-B, RM-D and RM-E model is about 600mm x 700mm while RM-A and RM-C model is about 550mm x 700mm.

Conclusion

In this study, the five models of 5-storey, 6-storey, 7-storey, 8-storey, and 9-storey building models named as SM-A, SM-B, SM-C, SM-D, and SM-E for square plan layout models and RM-A, RM-B, RM-C, RM-D, and RM-E for rectangular plan layout models, respectively. All these models are analysed by response spectrum method using the code of provision of NBC 105:2020. The main purpose of this study is analysis and comparison of building models separately for both plan layouts in terms of seismic response parameters like base shear, storey stiffness, storey drift, and reinforcement demand including columns and beams.

After the analysis, all models provide sufficient earthquake resistance. Base shear is highest in the SM-A and RM-A model, lowest in the SM-E and RM-E model. Also, base shear increases with increase in storey number, decrease with decreasing storey numbers adopting same overall height for all square and rectangular plan layout models at both SLS and ULS. Storey drift is maximum in the SM-E and RM-E model and minimum in the SM-A and RM-A model, remaining within NBC 105:2020 limits. Storey stiffness is highest at the ground floor and decreases with increasing floor levels. No soft-storey conditions were observed. For column overall reinforcement, the SM-D and RM-D Model required higher reinforcement, while the SM-A and RM-A Model required minimum reinforcement for both square and rectangular models. For square models, SM-A, SM-B, SM-C, and SM-E models required 10.84%, 8.47%, 2.56%, and 10.18% less reinforcement compared to the SM-D model, respectively. For rectangular models, the RM-A, RM-B, RM-C, and RM-E models required 14.45%, 9.15%, 8.34% and 11.94% less reinforcement compared to the RM-D model. For beam reinforcement, the pattern of reinforcement requirement of beam over the span is almost same for both square and rectangular plan layout models. For square models, the SM-E model requires higher reinforcement while the SM-A model requires overall minimum beam reinforcement. The SM-A, SM-B, SM-C, and SM-D models require 8.68%, 7.59%, 1.38%, 4.38%, and 2.06% less reinforcement compared to the SM-E model, respectively. For rectangular models, the RM-C and RM-E model required overall higher beam reinforcement while the SM-B model required overall minimum beam reinforcement. the RM-A, RM-B, and RM-D models required 4.63%, 7.29%, and 2.23% less reinforcement compared to the RM-E model and RM-C model. For columns section, SM-E and RM-E model required larger columns sectional size about 800mm x800mm while other remaining models for both square and rectangular plan layout models required 750mm x750mm. For beam section, SM-E, RM-B, RM-D and RM-E model required larger sectional size about 600mm x 700 mm while for remaining models required beam sectional size about 550mm x700mm. Overall, SM-A, SM-B, SM-C for square plan layout and RM-A, RM-B, RM-C for rectangular plan layout models exhibit better seismic performance and economical design, while SM-D, SM-E, RM-D and RM-E models show higher response demands and require larger sections.

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