Impact of Accidental Eccentricity on Regular Buildings under Seismic Loads: Insights on Nepal National Building Code NBC 105:2020

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Keywords:
Accidental eccentricity, Regular Building, Rigid diaphragm, torsional irregularity, inter- storey drift , seismic design

Received: 9 November 2024
Revised: 26 November 2024
Accepted: 5 January 2025

ISSN: 3102-0763 (Print)
3102-0771 (Online)

Abstract

Accidental eccentricity is one of the most significant factors in the design of buildings against seismic activity as it affects the torsion response of the structure. This study examines the effect of accidental eccentricity on symmetric buildings by analyzing three models: 3, 5, and 7 storey rigid diaphragm models. The analysis is performed for eccentricity values of ±10%, ±5%, and 0%, and considers torsional irregularity (maximum to minimum displacement ratios), maximum drift and overturning moment. The results show that the provision of 10% of eccentricity used by the Nepal Building Code 105:2020 leads to symmetrical buildings classified as torsionally irregular with magnified displacements, drifts, and moments. This suggests potential issues with the soundness of the 10% provision, as regular buildings should not have irregularities to that degree by virtue of their design. This study highlights the necessity of continuing research and revision of the 10% eccentricity requirement to better correlate design with the realistic performance of symmetrical structures and avoid unnecessary design.

Introduction

Problem statement

The eccentricity building plan is called the distance between the center of mass (COM) and the center of stiffness (COS). These can be generalized into two categories. The first of this is the innate eccentricity which results from the theoretical model of the internal structure itself. The second type comes as a result of errors in inhomogeneous mass and stiffness distributions during construction. To cater to this second type, seismic design codes suggest that an additional eccentricity — known as accidental eccentricity to be considered. Accidental eccentricity is treated differently in different seismic design codes. As an example, the Indian seismic code (i.e., IS 1893:2016) recommends a value of 5% and the Canadian National Building Code (NBCC 95) specifies a higher limit of 10%. The recently introduced Nepal National Building Code (NBC 105:2020) also proposes the same 10% accidental eccentricity. Such differences can drastically affect the seismic design of structures.

Objective

To study the effect of accidental eccentricity (+-10%) provision in the NBC 105:2020 and compare with other case (+-5%, 0% (at centroid))

To compare the response of the regular building with different cases of Eccentricity

Methodology

The geometric parameters of these models are listed in the Table 15. All three models share a consistent geometric layout (Figure 18) . In this research, we have considered three regular buildings of 3-stories, 5-stories, and 7-stories. We have considered the same geometric plan for each model. In this study, each building model has two bays of 4.2m in the x direction and three bays of 4.2m in the y direction in order to maintain a geometrically similar arrangement between the models. The length to width ratio of the building is 1.5 which is the most common ratio in low rise residential buildings in Nepal. The some parameters of these models are listed in the Table 15. All three models share a consistent geometric layout (Figure 18)The prevailing size of the column and beam is considered for each model. The typical members of columns and beams are applied, and larger structural members are assigned to buildings that are taller to fulfill the higher demand.

\SAP2000 version 23 was used for the three-dimensional modeling and analyses of the buildings'. Beams and columns in the building were assumed as linear elements while slabs were thin shell elements. Wall loads of 8 KN/m and 4 KN/m were applied to the outer and inner beams respectively. Similarly, standard loading conditions live loads of 2 kN/m² and 1.5 kN/m² have been applied to the intermediate floors and the top roof respectively.

Table 15 Geometric and material parameter of each model

Parameter	Model 1	Model 2	Model 3
Number of storey	3	5	7
Height of the building	3X3m=9m	3X5m=15m	3X7m=21m
Concrete Grade	M20	M25	M25
Size of Column(mm)	350X350	450X450	500X500
Size of Beam (mm)	230X350	230X400	350X500
Time period (sec)	0.48	0.715	0.92

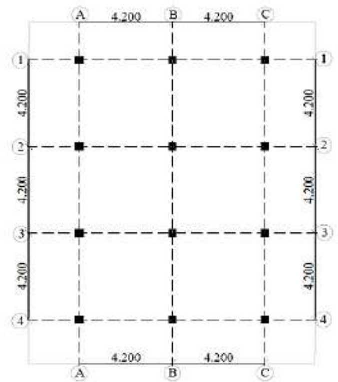

Figure 18 plan of building (dimension are in m)

The seismic demand and required parameters for the analysis were calculated based on the provisions of NBC 105:2020. Using empirical equation and Rayleigh method the natural time period of the buildings was evaluated in terms of year. The natural time period from the empirical equation was multiplied by 1.25, then the results were compared to the period obtained from the Rayleigh method. The analysis utilized the smaller of the two values with the findings given in Table 15. In seismic analysis, a damping factor of 5% was taken. The analysis was conducted considering a zone factor of 0.35 and an importance factor of 1, as stipulated in NBC 105:2020.

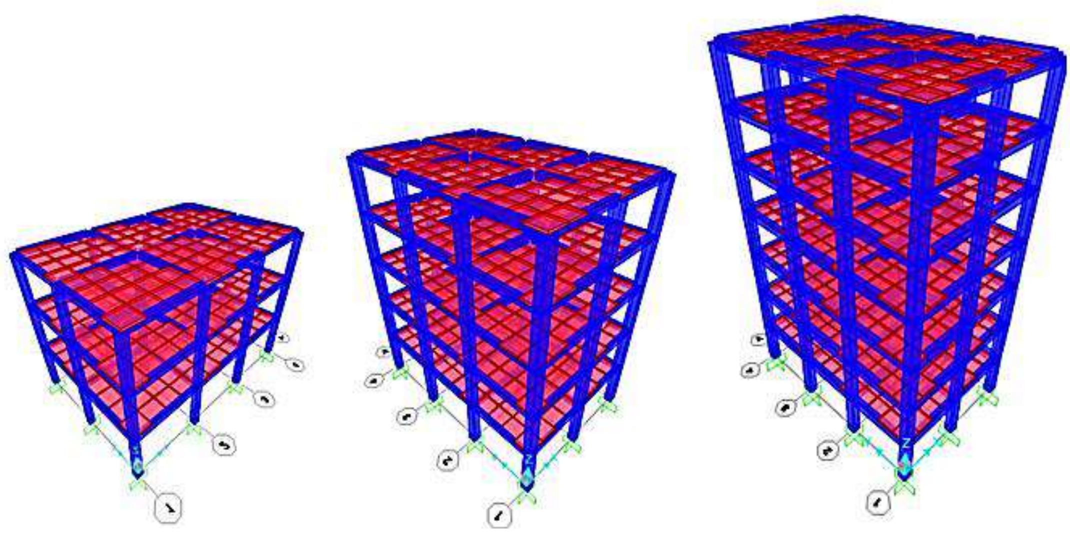

Figure 19 3-D model on SAP 2000 V23 of Model 1,2 and 3

Result and discussion

The building performance check, according to the provided structural design codes, was made in terms of irregularity of torsion, and base shear, overturning moment, inter-storey drift, and maximum torsional moment in critical beams. These parameters were used to evaluate the structural response of and seismic performance of the building models under the applied loads and seismic environment.

Base shear and rotational moment

It was noted that base shear and rotational moment (Mz) considerably affects the overall dynamic behavior of a building. These parameters are evaluated for each model and for all the cases considered in this research and the findings presented in tabular and graphic forms (Table 16 , Figure 20 and Figure 21). This paper reveals that accidental eccentricity has no effect on base shear while a +-5% eccentricity increases rotational moment by +-10%, and a 10% eccentricity raises it by +-20%. It has large dimension in Y direction thus, rotational moment is higher for the earthquake in x direction.

Table 16 Variation of Rotational moment (Mz) for different Eccentricity Case , model for EQX and EQY

Eccentricity	Model 1			Model 2			Model 3		
	Base Shear (KN)	Mz ,KN-M		Base Shear (KN)	Mz ,KN-M		Base Shear (KN)	Mz ,KN-M	
		EQX	EQY		EQX	EQY		EQX	EQY
-10%	499.3	2516.5	-1677.7	929.0	4682.2	-3121.5	1515.2	7636.5	-5091.0

-5%	499.3	2831.0	-1887.4	929.0	5267.5	-3511.7	1515.2	8591.1	-5727.4
0%	499.3	3145.6	-2097.1	929.0	5852.8	-3901.9	1515.2	9545.6	-6363.8
5%	499.3	3460.2	-2306.8	929.0	6438.1	-4292.1	1515.2	10500.2	-7000.1
10%	499.3	3774.7	-2516.5	929.0	7023.4	-4682.2	1515.2	11454.8	-7636.5

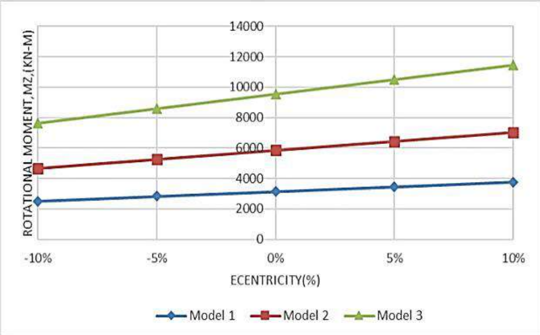

Figure 21 Variation of Rotational Moment due to EQx

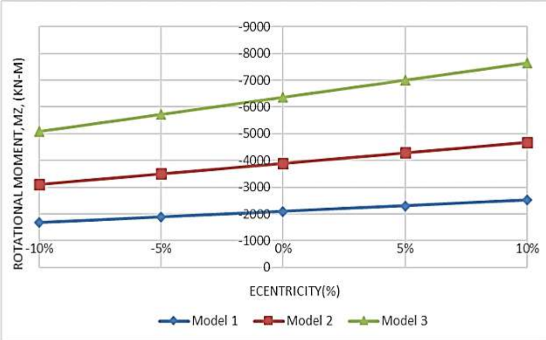

Figure 20 Variation of Rotational Moment due to EQy

Torsional Irregularity

Torsional irregularity in the building is assessed by comparing the maximum displacement to the minimum displacement within each rigid diaphragm, as per NBC 105:2020, whereby it sets a maximum figure of 1.5. The torsional irregularity for each model in terms of the various cases are presented in both tabular and graphical forms (Table 17 and Figure 22). The results show that for a regular building in the third case, with ±10% eccentricity, the limit specified in NBC 105:2020 and with corresponding values of 1.61, 1.56 and 1.54 for models 1,2 & 3 displaying torsional irregularity.

Table 17 Variation of maximum d_{max} /d_{min} for different ecentricity

Eccentricity	Maximum (d_{max} /d_{min})		
	Model 1	Model 2	Model 3
-10%	1.61	1.56	1.54
-5%	1.27	1.25	1.24
0%	1.00	1.00	1.00
5%	1.27	1.25	1.24
10%	1.61	1.56	1.54

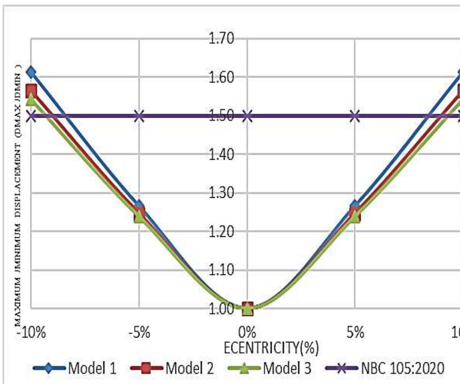

Figure 22 Variation of maximum dmax /dmin for different eccentricity

- Maximum inter-storey drift

  As pointed out in the analysis of this study, accidental eccentricity causes a considerable effect on the maximum Inter-storey drift. Where deflections for each model have been calculated, these were firstly multiplied by the ductility factor (R_m) to arrive at design horizontal deflection and then to assess Inter-storey drift ratio (Inter-storey deflection to storey height) for each model, case. Inter-storey drift ratio (Inter-storey deflection to storey height) was then compared for each model and case. For models 1, 2, and 3, the maximum inter-storey drift occurred in storeys (1-2), (1-2) and (3-4) respectively. In case two (±5% eccentricity), the influence on inter-storey drift was 11.72%, 10.89% and 10.17% for all models 1, 2, and 3, respectively in comparison with case one. In case three (±10% eccentricity), we detected a gain of 23.45%, 21.78% in models 1,2 and 20.34% in model 3 as compared to case one. These results reveal that accidental eccentricity has a major impact on factors affecting inter-storey drift. It has large dimension in Y direction thus, maximum inter-storey drift is higher for the earthquake in x direction.

Table 18 Maximum interstorey drift for different case and model

Storey	Maximum inter - storey drift ratio Model 1		
	Case1	Case 2	Case3
1	0.013	0.014	0.016
2	0.017	0.019	0.021
3	0.011	0.012	0.013

Storey	Maximum inter - storey drift ratio Model 3		
	Case1	Case 2	Case3
1	0.011	0.012	0.013
2	0.011	0.012	0.013
3	0.018	0.020	0.021
4	0.018	0.020	0.022
5	0.017	0.018	0.020
6	0.014	0.015	0.016
7	0.010	0.011	0.012

Storey	Maximum inter - storey drift ratio Model 2		
	Case1	Case 2	Case3
1	0.012	0.014	0.015
2	0.021	0.023	0.025
3	0.020	0.022	0.024
4	0.015	0.017	0.019
5	0.010	0.011	0.012

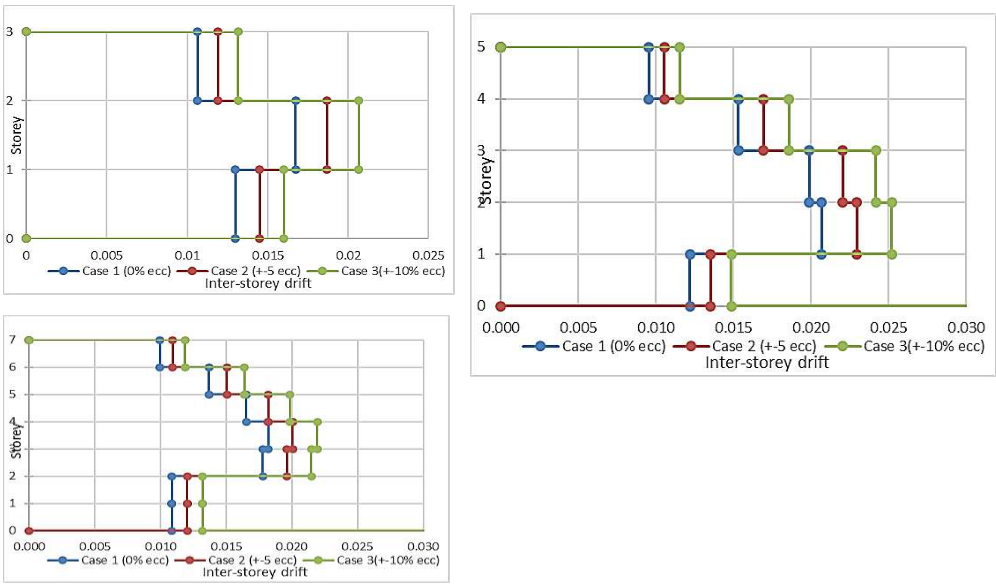

Figure 23 Variation of inter-storey drift for different cases (model 1, model 2 and model 3 respectively)

Conclusion and recommendation

- Base shear is unaffected by accidental eccentricity, while rotational moment increases by 10% for 5% eccentricity and 20% for 10% eccentricity.
- Accidental eccentricity of ±10% causes torsional irregularity in regular buildings, exceeding the NBC 105:2020 limit of 1.5.
- Accidental eccentricity increases inter-storey drift ratios by 20.34% to 23.45% for case 3 (+-10% eccentricity) and 10.17% to 11.72% for case 2 (+-5% eccentricity) comparing with case 1 (earthquake load applied at centroid), with significant impacts on structural behavior.
- This suggests potential issues with the soundness of the 10% provision, as regular (mass and geometry) buildings should not have irregularities to that degree by virtue of their design.

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